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Review

What drives eco-innovators? A critical review of the empirical literature based on econometric methods

Pablo del Río [a, *], Cristina Peñasco [a, 1], Desiderio Romero-Jordán [b, 2]

[a] CSIC, C/Albasanz 26-28, 28037 Madrid, Spain
[b] Universidad Rey Juan Carlos, Paseo de los Artilleros s/n, 28032 Madrid, Spain

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ABSTRACT

The aim of this paper is to provide a critical review of the literature on the econometric analyses of firm-level determinants to eco-innovation. The review reveals some gaps in knowledge. First, an integrated theoretical framework which merges the insights from different approaches is missing. Second, the influence of some variables is still unsettled (demand-pull and cost-savings), whereas others have hardly been included in previous analyses (internal and international factors). Third, studies on the drivers to eco-innovation versus general innovation are relatively scarce with respect to those on the drivers to eco-innovation in general. Fourth, analyses of the relevance of different determinants to eco-innovation for distinct eco-innovator and eco-innovation types have largely been missing. Fifth, studies on middle-income and developing countries are still scarce. Sixth, the econometric analyses have relied on microeconometric methods based on cross-section data (mostly logit and probit models), whereas the use of panel data is virtually absent. Seventh, detailed econometric analyses on the distinct drivers and barriers to eco-innovation in different sectors and regions have not been performed so far. Finally, whether the position of the firm in the value chain and the market structure influence the propensity to eco-innovate are largely unexplored topics.

Contents

* Corresponding author. Tel.: +34 916022560.
E-mail addresses: pablo.delrio@csic.es (P. del Río), cristina.penasco@csic.es (C. Peñasco), Desiderio.romero@urjc.es (D. Romero-Jordán).
[1] Tel.: +34 916022670.
[2] Tel.: +34 914887825.

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1. Introduction

Transitions to sustainable societies require substantial innovation (Machiba, 2010), both technological and others, as well as changes in consumption patterns. There is a widespread consensus that eco-innovations play a key role in this context.

Defining eco-innovation is not an easy task although several attempts have been made in the literature (see Carrillo-Hermosilla et al., 2010). In general, these definitions emphasize that eco-innovation is innovation that results in a reduction of the environmental impact of consumption and production activities, no matter whether or not that effect is intended (OECD, 2010). Focussing on the actual environmental impact of eco-innovations rather than on their environmental protection intentionality has pros and cons. A clear drawback is deciding which innovations in practice actually reduce the environmental impact of products and production processes. But a definition that focuses on the intention of the innovators has problems as well. The environmental motivation for the innovation may become entangled with other motivations. It may also be difficult to establish the relationship between the dedicated environmental activities of firms and the environmental performance of industry (Carrillo-Hermosilla et al., 2010).

The diversity of eco-innovations is very wide (see OECD, 2011; Carrillo-Hermosilla et al., 2010). Some are certainly systemic, complex and radical, but many are rather incremental. As any other innovation, eco-innovation has to contribute to the general objectives of the firm, including cost reductions and/or revenue increase. Rennings (2000), Oltra (2008) and Del Río (2009) argue that the main specificity of eco-innovation, besides its environmental positive impact, is related to the determining role of regulation and the “double externality” problem. Eco-innovations are generally subject to a double externality (Rennings, 2000). In addition to the negative externality of pollution, innovations have public good features which discourage their development. The later results from the spillovers in the innovation process, which facilitate imitation, in spite of patent protection (Rennings, 2000). While general innovations face the usual knowledge externalities, eco-innovations face both an innovation and an environmental externality. This suggests the need to apply both environmental and innovation policies in order to tackle those externalities and promote eco-innovation.

Since eco-innovations have been argued to play a very relevant role in the quest for more competitive and environmentally sustainable societies in the literature (Machiba, 2010; Carrillo-Hermosilla et al., 2010), identifying the main determinants for those firms either developing or adopting them (i.e., “eco-innovators”) can help policy-makers to implement instruments which are effective and efficient to promote eco-innovation.

The aim of this paper is to review the literature on firm-level determinants of eco-innovation. Our end goal is to provide main lessons for policy-makers and to suggest key avenues for further research for eco-innovation practitioners. While the literature on eco-innovation is voluminous, this review is restricted to those contributions analysing firm-level drivers with econometric methods. Our goal is to show the type of analysis and conclusions that can be drawn from the use of these methods, but also their biases and limitations. Econometric methods are generally used by economists and highly respected in the economics profession. A main advantage of these methods over other alternatives (e.g., case studies) is that they allow us to draw general conclusions on the degree of relationship (and causality) between different variables. Therefore, it is highly likely that economists willing to dedicate their future research efforts to the analysis of eco-innovation drivers will use these methods. Therefore, they may find this review useful. But it may also be interesting for others, because it allows them to get acquainted with the methods used by economists to analyse this topic. Their relevance in the analysis of firm-level drivers to eco-innovation is high. Many of the most cited papers on eco-innovation drivers have used econometric methods (see Section 2).

This article is structured as follows. The following section describes the methodology used in the review and provides details on the existing studies. Section 3 critically discusses their main features. Section 4 concludes.

Table 1
Relevant references in all combinations of selected terms.

	Determinants	Drivers
Eco-innovation	16	11
Environmental innovation	64	64

Source: Own elaboration using Scopus data.

2. Methodology

Three complementary methodologies were used in order to identify the main articles on firm-level drivers to eco-innovation using econometric techniques: a Scopus search, an issue-by-issue search in key eco-innovation journals and references in preselected articles.

2.1. Scopus search

Bibliometric analyses are often based on three information sources: the Web of Science, Scopus and Google Scholar. Each of them has its pros and cons. In this study we base our analysis on the Scopus database because it offers a great flexibility, particularly in terms of citations searches. Scopus is the largest abstract and citation database of peer-reviewed literature and includes scientific journals, books and conference proceedings. Notwithstanding, previous studies have found a notable match between the results from the Web of Science and Scopus (Gavel and Iselid, 2008).

We first selected the key words that would be most useful in the search for relevant articles using Scopus. This was a challenge. Firm-level “drivers” and “determinants” are often used as synonyms and the same occurs with “environmental innovation” and “eco-innovation” (Carrillo-Hermosilla et al., 2010; Karakaya et al., 2014; Schiederig et al., 2012). Those terms were combined in our Scopus search. Table 1 shows the number of relevant references found in each possible combination of the aforementioned terms.

Since some of the 155 references in Table 1 were included in more than one cell, duplications had to be removed. Once they were eliminated, we ended up with 90 references. Not all those contributions used econometric methods to analyse firm-level determinants to eco-innovation, however. While only those using econometric methods make up our final set, articles on firm-level determinants to eco-innovation not using econometric techniques could prove useful as they might include relevant references on econometric studies (see stage 2.3). It is interesting to note that firm-level eco-innovation studies with econometric techniques generally received more citations than those not using econometric techniques. Some of the most cited papers use econometric methods, including Horbach (2008) with 128 cites, Rennings et al. (2006) with 107 cites and Rehfeld et al. (2007) with 99 cites.

2.2. Issue-by-issue search

Since the major contributions to any topic are likely to be in the leading journals, it makes sense to look inside them (Webster and

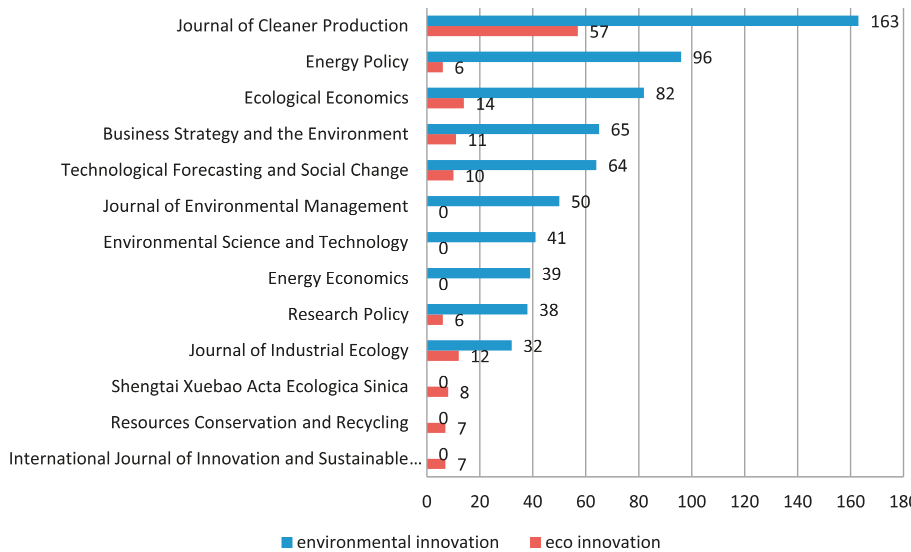

Fig. 1. Journals with articles on environmental innovation and eco-innovation (1986–2015).
Source: Own elaboration using Scopus data.

Watson, 2002). In the realm of eco-innovation, the leading journals include the Journal of Cleaner Production followed at a long distance by Energy Policy, Ecological Economics and Business Strategy and the Environment (Fig. 1). This is generally the case whether the terms "eco-innovation" or "environmental innovation" are used in the search for relevant articles.

The keywords "eco-innovation", "environmental innovation", "drivers" and "determinants" were inserted in the journals' internal engine in order to identify relevant articles. We read their abstract and selected those articles which addressed the drivers to eco-innovation with or without econometric methods. In addition, the tables of contents in the last ten years were checked for possible omissions.

2.3. Relevant references in pre-selected articles

The results of the work carried out in the previous stages (2.1 and 2.2) led to an initial list of pre-selected articles on firm-level drivers to eco-innovation. We looked for potentially relevant references in the articles in that list in order to check whether relevant contributions had been omitted.

2.4. Final selection

As a result of the above three stages, we came up with a long list of articles (150). Only those empirically analysing firm-level drivers to eco-innovation with econometric techniques were included in our final selection (29 papers).[3] We identified the explanatory variables in their models and their statistical significance, and provided details on the econometric method (model) being used, the geographical scope of the article, how the dependent variable was defined, the type of data being used, the sample size and the sample segmentation (Tables 2 and 3). Each study was grouped in two broad categories: studies analysing the drivers of eco-innovation with firm-level data in general and those analysing the drivers to eco-innovation versus general innovation.

[3] We are grateful to an anonymous reviewer for suggesting a couple of relevant contributions.

3. Main features of the literature on the determinants of eco-innovation with firm-level data

3.1. The explanatory variables

The choice of explanatory variables should be rooted on theory. However, a first observation is that an explicit theoretical framework is missing in many of the papers reviewed. When a theoretical underpinning for the empirical analyses exists, it is based on environmental economics, innovation economics, evolutionary economics (systemic perspective), the RBV and the corporate environmental strategy literature. There is not an agreed theoretical framework, and an integrated theoretical framework combining the insights from those approaches has not been built yet.

A distinction is usually made between internal and external drivers to eco-innovation (Del Río, 2009). Factors internal to the firm refer to internal resources, preconditions and features of the firms which facilitate an eco-innovative attitude. In particular, top-level manager commitment with environmental issues, technological competency and financial resources are highly relevant in this regard. Other important variables might include the ownership of the firm, the export-orientation of production and the characteristics of sectors to which the firm belongs (Cainelli and Mazzanti, 2013).

In addition, factors external to the firm have proven highly relevant to explain the decision of firms to eco-innovate, which is a response to the stimulus and incentives stemming from a wide array of actors and factors (Del Río, 2005). This influence can take many forms, including market and non-market pressures, information flows and collaboration partnerships (networking). In addition to environmental regulation, other actors/factors may play a relevant role in this regard, including industrial associations and chambers of commerce, equipment and input suppliers, investors, insurance firms, final consumers/industrial clients, competitors, environmental NGOs, green parties, civil society (influenced by the mass media), public and private research centres, and financial institutions. The external and the internal factors are likely to be interrelated.

Our review shows that the list of determinants used in the econometric studies is very large (Tables 2 and 3), albeit only a few

Table 2
Drivers of eco-innovation with firm-level data.

Main features		Demirel and Kesidou (2011)	Kesidou and Demirel (2012)	Kammerer (2009)	Mazzanti and Zoboli (2009)	Frondel et al. (2007)		Rehfeld et al. (2007)	Rennings et al. (2006)	Wagner (2008)	Wagner (2007)		Veugelers (2012)	Ziegler and Rennings (2004)	Cleff and Rennings (1999)	Borghesi et al. (2012)	Borghesi et al. (2015)	Cainelli et al. (2012)	Triguero et al. (2013)
						End-of-pipe	Clean production				Self-reported env. innov.	Env. patents							
Explanatory variables	Regulation	*		*	*	*	NS	* (exc. process innov.)	(exc. product eco-innov.)				*		Mixed evidence	*ETS	*		* (exc. Product eco-innov.)
	Subsidies				NS	NS	NS						*			* Mixed evidence	* Mixed evidence		NS
	Cost-savings (materials and energy)	*	*			NS	*								NS				NS
	Internal technological capability			* Green capabilities	NS (training)				* (negative sign.)							*	* (training) Mixed evidence	* (training)	* (exc.product eco-innov.)
	R&D			NS		NS	*	* (exc. process innov.)				NS		*		* Mixed evidence	NS	NS	
	Size	NS	*	*	NS	NS	*	*	* (only for process innov.)	NS	*(exc.products)	*	*	*	Mixed evidence	*	* Mixed evidence	NS	*
	Sectoral dummies	NS		NS	*	*	*			*	*	*	*		NS	*	*	*	*
	Demand-pull		NS	* (Customer benefits)	*			* (exc. process innov.)	* (exc. process innov.)				*		NS (exc. product integration)	NS (sales growth)	NS		*
	Main market is internat.							NS						NS		* Exports. Mixed evidence		NS	
	Cooperation				*					*						NS		* (universities, suppliers)	*
	Competitive pressure from established firms					NS	NS												
	Environmental management system (EMS)	* (ISO 14001)				*	*	*	*	* (no effect on product eco-inov.)	*(exc.prodcts)	NS		NS					
	Age							*		NS	* (exc. products)	NS	NS	*(with a negative sign)					
	Other organizational innovation (apart from EMS).		*		NS Organisational flatness:*					*							NS		
	Purchase of equipment/ equipment upgrade	NS	NS																
	Share of demand from final consumers								*(only product innov.)						* (generally)		NS		*
	Productivity	* (small effects)			*											*	*		
	CSR	NS	NS																
	Environmental variables							NS. (exc. disposal)						*					
	Influence of trade unions, NGOs, stakeholders				* (unions)	NS	NS				* (exc. product)	*							
	Internal forces					*	*												
	Image					NS	NS		* (exc. Process innov.)										
										NS	NS	NS				* (4/6)			

(*continued on next page*)

Table 2 (*continued*)

Main features	Demirel and Kesidou (2011)	Kesidou and Demirel (2012)	Kammerer (2009)	Mazzanti and Zoboli (2009)	Frondel et al. (2007)		Rehfeld et al. (2007)	Rennings et al. (2006)	Wagner (2008)	Wagner (2007)		Veugelers (2012)	Ziegler and Rennings (2004)	Cleff and Rennings (1999)	Borghesi et al. (2012)	Borghesi et al. (2015)	Cainelli et al. (2012)	Triguero et al. (2013)
					End-of-pipe	Clean production				Self-reported env. innov.	Env. patents							
Group (subsidiary)																* Mixed evidence	NS (foreign ownership)	
Quality as management system/ ISO9001							NS		NS	NS	*		*in half specifications					
Other		Abatement cots (*)			Financial situation (NS)	Financial situation (NS)		Price as important performance factor (*, exc. process innov.)	Environment as competitive factor (*)				Competitive pressure (Generally NS)	Region (*)	Information from others (mixed evidence)	Information from others (mixed evidence)	Region (*)	Country dummies
Econometric method (model)	Tobit	Heckman selection	Binary logit	Ordinary least squares (OLS)	Multinomial logit		Binary and multinomial logit	Binary probit	Multivariate probit and logit	Multivariate probit	Negative binomial model, binary probit	Bivariate probit	binary probit, and multinomial logit	Multivariate Logit	Probit Model	Probit model	Probit	Multivariate logit
Geographical scope	U.K.	U.K.	Germany	Emilia Romagna (Italy)	Seven OECD countries (none South European)		Germany	Germany	Nine European States (none South European)	Germany	Germany	Germany	Germany	Germany	Italy	Italy	Emilia Romagna (Italy)	UE
Dependent variable	Three binary dependent var.: investments in EOP, integrated cleaner production technologies and env. R&D	Binary. Env. R&D	Binary. Product eco-innovation.	Environmental innovation output	Categorical: End-of-pipe, integrated, no new technology		Dev. of env. product innovation Multinomial logit: env. product-innovation, env. process innovation, no env. Innovation	Binary: Process and product eco-innovations.	Binary.: green design, implementation of cleaner technology.		Whether firms are patenting.	Introduction of eco-innovations in general. Also: eco-innovations introduced in own operations (innovations to reduce CO2 emissions and to reduce energy consumption; development of eco-innovations for users.	Process and product eco-innovation.	Six dependent binary variables	Six binary dependent variables related to environmental issues	Two binary dependent variable related to eco-innovation for CO2 reduction and Energy efficiency	Five binary dependent variables	Three binary dependent variable related to three types of eco-innov.
Types of data	Survey Data. Government survey of environmental protection expenditure by industry		Survey data (online questionnaire).	Survey data	Facility-level dataset derived from a cross-country OECD survey		Dataset collected by a telephone survey.	Telephone survey data	Survey data	Survey data		German CIS	Telephone survey data	Survey data.	Survey data	Survey data	Survey data	Survey data. Flash eurobarometer
Sample size	289 firms	1566 firms	92 firms	140 firms	3699 observations.		371 firms	1277 firms	849	152 observations	248 observations	3896 observations	390 observations	358 firms	6483 firms	6483 firms	555 firms	5222 managers from SME firms
Sample segmentation	End-of −pipe vs. cleaner technologies	–	Use of different subsamples (by env. impact)	–	–		Process vs. product	Process vs. product	Process vs. product	Process vs. product	–	Firms adopting vs. developing clean technologies	Process vs. product	–	–	–	–	–

Note: * indicates statistically significant variable. NS = Not significant. exc means except for. Source: Own elaboration.

variables are common to most of them. The following explanatory variables are included in at least half of the models: regulation, size, sectoral dummies and environmental management systems (EMS).

Regulation, size, cooperation and EMS are generally statistically significant. In contrast, the influence of other variables is not settled. Demand-pull for eco-innovations and cost-savings are two of these variables. The literature on eco-innovation does not support the market demand-pull for eco-innovation. Belin et al. (2011), Rehfeld et al. (2007) and Rennings et al. (2006) for Germany and Veugelers (2012) for Flanders find that the market provides a demand-pull to eco-innovate. However, other authors do not find a statistically significant relationship, i.e., Kesidou and Demirel (2012) for the U.K, Horbach et al. (2012) and Rave et al. (2011) for Germany and Del Río et al. (2013) for Spain. Ziegler (2015), which uses several explanatory variables to proxy the demand-pull factors, finds mixed evidence, with the market-pull factors being relevant for eco-innovation in only a few cases. This may be related to the different definitions of the demand-pull variable in different studies, to the environmental consciousness of consumers in different countries. In fact, data from the European Commission (2011) show that this has traditionally been lower in some South European countries (e.g., Spain and Portugal) than in the centre and north (e.g., Germany). Rave et al. (2011), Albino et al. (2009) and Iles (2008) argue that the environmental consciousness of consumers is an important driver of the demand for product eco-innovations. But, on the other hand, the price of many eco-products is still higher than the alternatives (Rehfeld et al., 2007, Horbach et al., 2012).

The empirical evidence on cost savings is also undetermined. While the influence of this variable is positive and statistically significant in several contributions (Demirel and Kesidou, 2011; Kesidou and Demirel, 2012; Frondel et al., 2007 for clean products; Belin et al., 2011; Horbach, 2008; Horbach et al., 2012), it is negative and statistically significant in Rave et al. (2011) and it is not statistically significant in Frondel et al. (2007) (for end-of-pipe technologies), Cleff and Rennings (1999) and Triguero et al. (2013). Together with an increase in the quality of the product, cost-savings could be a main driver for all innovations, whether eco-innovation or general innovation. Therefore, they should not be a distinctive feature of eco-innovation.

Other variables have been less frequently used, including internal factors to the firm, international drivers, and regional issues. Internal factors to the firm such as resources, competences and dynamic capabilities (RCDCs, see Box 1) have been underrepresented in the empirical literature on eco-innovation, mostly because of the difficulty to include these factors in econometric models due to poor data availability. RCDCs are usually limited to the inclusion of only one variable, normally in the form of adoption of an EMS (Demirel and Kesidou, 2011; Kesidou and Demirel, 2012; Horbach, 2008; Horbach et al., 2012; Wagner, 2008; Rave et al., 2011). Other variables have also been used: ownership of an approved ISO14001 or EMAS certification (Demirel and Kesidou, 2011; Mazzanti and Zoboli, 2009; Testa et al., 2014), relevant changes in organisational structures (Horbach, 2008; Horbach et al.,. 2012), technological capabilities proxied by R&D (Kammerer, 2009; Horbach, 2008; Horbach et al., 2012; Belin et al., 2011; Mazzanti and Zoboli, 2009) and employee qualification (Horbach et al., 2012). Tables 2 and 3 provide details on the use of those proxies. However, the multifaceted influence of those RCDCs and their complex role in the eco-innovation process are not grasped in the studies reviewed. In particular, top-level commitment with environmental protection has not been included in none of the econometric models, in spite of the relevance of this variable as a determinant of eco-innovation, which has been shown by case studies (see, e.g., Carrillo-Hermosilla et al., 2009).

Box 1
Resources, competences and dynamic capabilities.

Resources are firm-specific assets whose value is context dependent. Tangible resources include financial reserves and physical resources, whereas intangible resources encompass reputation, organisational culture, technology, customer relationships and human resources.

Competences (or capabilities) are resources which result from activities that are performed repetitively in a firm. Organisational competences enable economic tasks to be performed that require collective effort, and they are usually underpinned by organisational processes or routines (Nelson and Winter, 1982; Dosi et al. 2000).

Dynamic capabilities are the capacities of an organisation to purposefully create, extend and modify its resource base (Helfat et al. 2007, p.4) to both address and shape rapidly changing business environments (Teece et al. 1997).
Source: Helfat et al. (2007), Cohendet et al. (1999), Katkalo et al. (2010), Nelson and Winter (1982), Dosi et al. (2000), Teece et al. (1997).

This neglect could also be related to the fact that some approaches which have been used to identify relevant drivers to eco-innovation, such as environmental economics, disregard those RCDCs. Environmental economics has mostly and until recently focused on the impact of different policy instruments on innovation. However, eco-innovations are not a systematic response to environmental regulation, but the result of a complex and interactive process, with other factors being involved (Del Río, 2005).

Other theoretical approaches (including the resource-based-view (RBV) of the firm, the systems of innovation (SI) and evolutionary economics (EEv) perspectives) have emphasised the importance of those internal factors in the innovation process but, despite their relevance in this context, they have seldom been used to analyse the determinants of eco-innovation at the firm level, especially the former. This seems to be changing in more recent contributions.

Another set of neglected influences are the international factors. These may include the influence of customers in foreign markets, international regulations, international sources of funding, cooperation with international institutions and the presence of foreign equity in firms. Their inclusion has generally been restricted to the variable "whether the main market is international" for the firm sales in several studies (see Tables 2 and 3). Belin et al. (2011) include three dummies ("local market", "national market" and "European market") in their econometric study of eco-innovation drivers in France and Germany. The variable "foreign ownership" is only included in Cainelli et al. (2012).

To our best knowledge, Cainelli et al. (2012) is currently the most complete study on the international drivers and the only one which specifically focuses on more than one (indeed, two) international factors as a driver of eco-innovation using econometric techniques in a survey of 555 firms in Emilia-Romagna (Italy). In particular, it tests the hypotheses that the multinational ownership and a greater export propensity of local firms positively affect eco-innovation. However, neither export propensity nor foreign ownership of firms are significant drivers of eco-innovation in this study.

Complementarity factors, a research area in general innovation since Monhen and Roller (2005), represent another neglected influence in eco-innovation research, with the exceptions of Antonioli et al. (2013), Gilli et al. (2014) or Hottenrott et al. (2014).

Table 3
Drivers to eco-innovation versus general innovation with firm-level data.

MakMain features		Belin et al. (2011)	Horbach (2008)		Horbach et al. (2012).	Rave et al. (2011)		De Marchi (2012)	Del Río et al. (2013)	Ghisetti et al. (2015)	Cainelli et al. (2015)	Cuerva et al. (2014)	Chassagnon and Haned (2015)	Ziegler (2015)	Horbach (2014)	Del Río et al. (2016)
			Probit	Multinomial logit		Probit	Random-effects probit (New-to market eco-innovations)									
Explanatory variables	Regulation/ subsidies	*	* (subsidies and regulation)		* (only regulation)		* Regulation Sub.: NS	* (only subsidies, env. regul. is not used)	* (subsidies and regulation)	*		NS	*		NS (local taxes) * Social aids received by population	* (subsidies and regulation)
	Cost-savings (material and energy)	*	*		*	* (negative sign)	* (negative sign)						*		NS	*
	Internal technological capability (employer qualification, innovation intensity)		*	NS (* general innovations).	* (with a negative sign)		NS				NS	*			*	NS (except for small companies and new to the firm innov. negative)
	External sources of knowledge	*			* suppliers, others: NS						*				* (proximity to research centers and universities)	NS except for product innov.)
	Internal information	*							*							*
	R&D	*	NS		NS			NS	*	*	*	*		*	*	* (NS for small and big companies, old companies and new to firm innov.)
	Size	*	NS	*	*	*	*	*	*		*	*	*	*	NS	*
	Appropriation (patents)	*			NS				NS							NS (except small companies and old companies and negative)
	Information from institutions	*							*							*
	Sectoral dummies.	NS	* (a few)			*		*		*	*		NS	*	*	*
	Demand-pull.	(only in Germany, not in France)	NS	NS (* for general innovation)	NS	NS (exc in 2 sectors)	NS	* (absence of demand is an obstacle for innovation)	NS: turnover variation NS: market factors, like established firms or uncertainty in the demand, as an obstacle for innovation.			NS	*	Mixed evidence: Sales ratio consumers and Customer important/NS: prices important/NS: quality important (Except non-envir. Process)	*	NS: turnover variation NS: no demand as an obstacle for innovation (except for new companies and negative)
	Main market is international.			*				* (and negative)	* (and negative)	*	*			NS: Main market abroad (except env. Product)/ NS: exportsexcept non-environ. process)		NS (except new firms and negative)
	Cooperation	NS			*	*	*	*	*	*	*	* (only with suppliers and customers			NS	*
	EMS				*	*	*					*		NS (except env. Process)		
	Age		NS		NS	NS	NS		NS			NS		NS	NS	NS
	Other organizational		*	*	*									NS (except envir. Process)		

innovation (other than EMS).															
Other variables	Competitive pressure from established firms (NS)	Region: NS	Profits: NS. Region: NS. Path dependency:*	Region: NS. Patents: NS. Purchase of equipment/ equipment upgrade:* Competition: some NS	Realisation of technology leads: NS.	Realisation of technology leads:*. Social pressure: NS	Purchase of equipment/ equipment upgrade:* Presence of established firms as an obstacle for innovation:* Path dependency:* Belonging to a company group or being a subsidiary: NS. High innovation costs as obstacle for innovation:*	Belonging to a company group or being a subsidiary: NS. Productivity:* Cost factors as an obstacle for innovation:NS Belonging to a high-technology sector:*	Productivity*/ Internal forces*, Group subsidiary*/ Information from others (mixed evidence)	Geographic dummies*/ equipment*/ Reactive innovative strategies(−)*/Training personnel*	Financial constraints (−)*/Product differentiation*/ Label of origin NS/CSR NS	Innovation leadership (*), being part of the group (NS)	Facility dummy (NS) Competition intensity (NS except for non-environmental product) Life cycle (*) Disposal, Environment important, Environmental market (NS except. Env. Product) Geographic dummies (NS)	Attractiveness of location for skilled personnel (*), Regional traffic infrastructure (*); Competition (*); Modernity of the capital stock (NS)	Belonging to a company group or being a subsidiary:* (NS in big companies, process eco-innov. and new to market nor new to the firm eco-innovations; Productivity:* Cost factors as an obstacle for innovation: NS Belonging to a high-technology sector:*.
Econometric Method	Probit	Probit	Multinomial logit	Discrete choice probit	Discrete choice: probit	Random-effects probit	Two-part logit model	Probit model	Negative binomial	Probit model with sample selection	Bivariate probit	Heckman selection	Multivariate (binary) probit model	Two-level mixed effect logistic regression	Probit model with endogenous regressors
Geographical scope	France and Germany (2002−2004)	Germany (2001)	Germany (2001)	Germany (2006−2008)	German manufacturing industries (2004−2006)	German manufacturing industries (2004−2009)	Spanish manufacturing firms (2005−2007)	Spanish manufacturing firms (2007−2009)	11 EU countries	Spanish manufacturing firms (2008−2010)	Castilla-La Mancha (Spain). Food and beverage firms	France, CIS (2002−2004, 2004−2006, 2006−2008)	German manufacturing firms	Germany	Spanish manufacturing firms (2007−2009)
Dependent variable	Binary variable: Environmental innovators-1 Innovation activities of the firmled to high or medium reduction of environmental pollution and/ or health and safety effects and 0 otherwise.	Binary variable: Environmental innovators-1 Innovation activities of the firm led to high or medium reduction of environmental pollution and/ or health and safety effects and 0 otherwise.	Unordered categorical variable: 1 Environmental innovators (realization of innovations with high or medium environmental or health effects) 2 Other innovators 3 Non-innovators	Binary variable: Environmental innovators-1 Innovation activities of the firm led to high or medium reduction of environmental pollution and/ or health and safety effects and 0 otherwise in twelve different areas	Binary variable: 1 = Environmental innovations undertaken in 2004−2006. 0 = other innovations undertaken in 2004−2006	Binary variable1 = Eco-innovations undertaken in 2004−2009 0 = Other innovations undertaken in 2004−2009	Binary variable: 1 = high or medium importance of reduced environmental impacts or improved health and safety as an aim of innovation activity/ 0 = otherwise	Binary variable: Environmental innovators. Importance of lower environmental impact as an aim of innovation activity 1 = high importance 0 = otherwise	Count variable: nº of eco-innovation typologies adopted	Binary variable: 1 = high or medium importance of reduced environmental impacts or improved health and safety as an aim of innovation activity/ 0 = otherwise	Binary variable: 1 = firm conducts green innovation/ 0 = otherwise	Binary variable: 1 = firms have used >2 types of eco-innovations.	4 Binary variables: 1/0 if firm develop environmental product innv; environmental process innov; non-environmental product innov.; non-environmental process innov.	Binary: 1 = suppliers of environmental goods and services with product or process innovations in 2008 (eco-innovators)/ 0 = other innovators	Binary variable: Environmental innovators. Importance of lower environmental impact as an aim of innovation activity 1 = high importance 0 = otherwise
Types of data	Survey Data (CIS)	Survey panel database: Mannheim innovation panel		Survey Data (CIS)	Large scale survey and firm database Amadeus.		Survey data.	Survey data	Survey data (CIS) 2006−2008	Survey data PITEC	Survey data 2010	CIS 2002−2008	Survey data	Survey data: Panel of the Institute for Employment Research in Nuremberg.	Survey data PITEC
Sample size	France:3421 firms, Germany: 1966 firms	1830 observations	1485 observations	3606 observations	625	1332 (1174 groups)	4613 observations	4112 (3272) observations	14366 observations	4829 (849) firms	301 firms	1180 firms	Between 372 and 386 observations depending on the model	13138 observations (3297 innovative firms)	3341 observations
Sample segmentation	–	–		Two different environmental technology fields:	1. New-to-market/new-to-firm eco- innovation 2. Process/Product 3. Energy/non-energy		–	–	–	Product-process innovation	–	EOP vs. certification procedures	Product-process innovation	–	1. Small firms vs. big firms 2. Old firms vs. new firms 3. Process vs. product eco-innovs. 4. New to market vs. New to firm eco-innov.

Note: * indicates statistically significant variable. NS = Not significant. Source: Own elaboration.

Antonioli et al. (2013) analysed the complementarities between strategies of high-performance work practices and human resource management when the firm is willing to adopt an eco-innovation. Gilli et al. (2014) show that the complementarity between the adoption of an eco-innovation and other technological and organizational innovations is a factor influencing environmental productivity. Hottenrott et al. (2014) applied an econometric model to show that complementary organizational innovations affected the adoption of CO2 emissions reduction technologies.

3.2. The analyses of the determinants to eco-innovation versus innovation in general

As mentioned and shown above, the literature on the drivers to eco-innovation can be classified in two main groups, i.e., the literature on the general determinants to eco-innovation, which is relatively abundant (Table 2), and the very recent literature on the specific determinants to eco-innovation versus those of general innovation, which is not (Table 3). Many drivers to general innovation are likely to be shared by eco-innovation. Therefore, policies supporting general innovation would also lead to eco-innovation. However, eco-innovation has distinctive (additional) features, which are mostly related to the double externality problem and the role of public policies as a main driver of these innovations. Therefore, policy makers willing to specifically promote eco-innovation should take these differential drivers into account if they want not only to promote innovation, but to promote eco-innovation. Table 3 shows that some drivers play a more prominent role as specific determinants of eco-innovation: public policies, cooperation and internal capabilities.

First, the findings from the eco-innovation vs. general innovation literature indicate that eco-innovators respond to regulatory stimulus in the form of demand-pull (environmental regulation) and supply-push instruments (subsidies). Horbach et al. (2012) and Rave et al. (2011) for Germany and Del Río et al. (2013) for Spain show that environmental regulation is a main demand-pull driver for eco-innovation compared to general innovation. The relevance of subsidies in eco-innovation is positive and significant in Spain (Del Río et al., 2013), whereas the results are inconclusive in Germany. Horbach et al. (2012) find a positive and statistically significant impact of subsidies on eco-innovation, whereas this variable is not significant in Rave et al. (2011). However, the small magnitude of this marginal effect in Del Río et al. (2013) indicates that, while complementary, demand-pull policies have a greater impact on eco-innovation than supply-push instruments, a finding shared by Veugelers (2012) for Flanders (Belgium). In their studies for Emilia Romagna (Italy) and Germany, respectively, Mazzanti and Zoboli (2009) and Rave et al. (2011) find that regulation is a significant determinant of eco-innovation but subsidies are not significant.

Cooperation between actors and information flows from knowledge institutions to eco-innovators are a crucial driver of eco-innovation. De Marchi (2012) and Del Río et al. (2013) for Spain and Horbach (2008) and Rave et al. (2011) for Germany find a more relevant role of cooperation in eco-innovation compared to general innovation. Cainelli et al. (2012) show that cooperation with universities and suppliers is the most important driver of eco-innovations for most firms in Emilia Romagna. Belin et al. (2011) and Del Río et al. (2013) show that eco-innovative activities require more external sources of knowledge/information than general innovation.

According to a few papers, eco-innovators have higher internal technological capabilities. Horbach (2008) for Germany, Del Río et al. (2013) for Spain and Mazzanti and Zoboli (2009) for the Italian Emilia Romagna region have shown that improvements of technological capabilities by R&D trigger eco-innovation. Company training policies are a main driver of eco-innovation in this later region (Cainelli et al., 2012).

In contrast, the roles of demand-pull and cost-savings are ambiguous, a result in line with the general eco-innovation literature. They are non-significant in one case (market-pull) or significant with a negative sign in half of the studies (cost-savings).

Two important yet largely unexplored issues are whether firms that are consistently innovation leaders are also those more likely to eco-innovate and whether eco-innovative behaviour is path dependent, i.e. whether those eco-innovating in the past are also more likely to eco-innovate in the future. The first issue has recently been addressed by Chassagnon and Haned (2015). Innovation leadership is defined as the dynamic capability of an innovative firm to seize new innovation opportunities due to a proactive investment policy and enhanced innovativeness. The authors conclude that innovation leadership and the propensity to eco-innovate are related. While the issue of "persistence" has received attention in the general innovation literature (Gerosky et al., 1997; Cefis and Orsenigo, 2001; Raymond et al., 2010), testing the hypothesis that "innovation breeds innovation", this has not been the case in the firm-level eco-innovation literature. An exception is Horbach (2008) who include a dummy (innovator in the preceding panel wave) in their model to show that being innovative in the past increases the probability of being eco-innovative in the present or the future. Further research efforts should be devoted to analyse innovation leadership, persistence and path-dependency in eco-innovation.

3.3. Different types of eco-innovation and eco-innovators

We may expect that the determinants to eco-innovation differ across eco-innovation types (for example, process vs. product and new-to-the-firm vs. new-to-the-market eco-innovations) and eco-innovator features (for example, large vs. small and old vs. new firms). If drivers are different per eco-innovation and/or eco-innovator type, and policy-makers want to support specific types of eco-innovations/eco-innovators, then an analysis of those differential determinants is policy-relevant. However, an analysis on the relevance of eco-innovation drivers for distinct types of eco-innovators and eco-innovations has been missing, with the exception of process vs. product eco-innovations.

It is highly likely that the same determinant (size or age) has a distinct influence on firms with different characteristics. Size has generally shown to positively affect the eco-innovative behaviour of firms due to several reasons: a higher public visibility for larger firms and the corresponding pressure from environmental NGOs (Kesidou and Demirel, 2012; Kammerer, 2009), greater financial and human resources (Kammerer, 2009; Walz, 2011; Rave et al., 2011), the existence of a systemized R&D department (Kesidou and Demirel, 2012), the difficulties of smaller firms in facing the complexity of environmental innovations and the investments needed to switch to greener technologies (De Marchi, 2012; Triguero et al., 2013) and economies of scale (Mazzanti and Zoboli, 2009; Ziegler, 2015). Yet, an analysis of the differential barriers and drivers for firms with different sizes has been lacking. This issue can be analysed by segmenting the sample in two subsamples (one for large and another for smaller companies). Del Río et al. (2016) have followed this approach. They find that the eco-innovative behaviour of small firms is more influenced by the lack of internal innovation capabilities (skilled personnel), access to information flows and subsidies.

Firm age can be a double-edged sword. The older the firm, the greater the accumulation of internal capabilities, which could have a positive influence on innovation in general and eco-innovation in particular. But, on the other hand, the internal factors which are needed to eco-innovate might be different from those being accumulated by incumbents. While some authors show a non-significant influence of age on eco-innovation (Del Río et al., 2016; Horbach, 2008; Veugelers, 2012 and Rave et al., 2011), Wagner (2007) reports a weak positive effect.

On the other hand, drivers might also differ for distinct eco-innovation types. For example, process and product eco-innovations are likely to be affected by different factors. Process eco-innovations are primarily developed and adopted in order to reduce energy and resource costs and to comply with environmental regulation, whereas product eco-innovations are driven by demand factors, opportunities in environmental markets and social pressure (Rave et al., 2011; Rehfeld et al., 2007; Rennings et al., 2006; Frondel et al., 2007; Veugelers, 2012). Integrated environmental protection at the level of the process generally confers little additional benefit on the customer and receives comparatively little reward from the market (Cleff and Rennings, 1999). Rehfeld et al. (2007) and Belin et al. (2011) show that product eco-innovations require greater internal innovation capabilities and external knowledge sources.

Another very relevant distinction is between those eco-innovations which are new to the market (NTM) and those which are only new to the firm (NTF). The former have a greater degree of novelty and can be expected to involve more radical changes than the later. The differential determinants of these eco-innovations have not been analysed, with the notable exceptions of Rave et al. (2011), Kammerer (2009) and Del Río et al. (2016). Since the degree of radicality, disruption and complexity is higher for NTM than for NTF eco-innovations, the amount of funds, internal innovation capabilities and degree of cooperation with external actors required to develop or adopt NTM eco-innovations would also be greater. Indeed, Rave et al. (2011) show that NTM eco-innovations typically require more fundamental and often collaborative R&D activities. Similarly, Del Río et al. (2016) show that internal innovation capabilities and involvement in external knowledge flows and cooperation are main drivers of NTM versus NTF eco-innovations. Kammerer (2009) finds that stringent environmental regulation leads to NTF product eco-innovations, but not necessarily to NTM product eco-innovations.

3.4. Geographical scope

Tables 2 and 3 show that the literature is concentrated on Western European countries. More precisely, although several studies in the South of Europe have recently been performed (De Marchi, 2012; Borghesi et al., 2012; Cainelli et al., 2012; Del Río et al., 2013; Del Río et al., 2016), a strong reliance on German data can be observed. To our knowledge, econometric analyses on firm-level eco-innovation drivers have not been performed in other developed country contexts, including the U.S. and Japan. Furthermore, a middle-income and a developing country perspective are clearly missing, probably due to the lack of data. This is unfortunate, since the results of the studies in one particular country should not be extrapolated to other countries, given the differences in national innovation systems, willingness-to-pay for environmental products by consumers and the environmental proactivity of firms.

In addition, there are only a few comparative international studies (Frondel et al., 2007; Wagner, 2008 and Belin et al., 2011). More comparative studies across countries should be performed in order to identify the differential drivers and barriers to eco-innovation in different countries.

3.5. Other features

In addition to the above, our review shows that the contributions to the literature have other characteristics and differ in other respects. First, eco-innovation studies show widely different sample sizes. This can be attributed to data sources, whether researchers' own surveys (usually smaller samples) or official data (greater ones). There is a trade-off between the sample size and the quality of the data. Own surveys are more circumscribed to eco-innovation, rather than to innovation in general. In contrast, official data are generally collected without a focus on eco-innovation. Therefore, proxies for explanatory variables are used (see Tables 2 and 3), and these are not always accurate ones. This can be the case with the dependent variable and RCDCs.

The choice of econometric methods has mostly been restricted to logit and probit models. These models are appropriate if the aim is to calculate the probability that firms eco-innovate and the relative influence of each explanatory variable. In contrast, tobit models would enable us to identify those variables that can affect, both, the probability of investing in eco-innovation and the level of this investment (Del Río, 2009). Tobit models have scarcely been used in the past (only one study in our review).

The available data allow only for cross-section analysis in econometric models. Panel data models are virtually absent. In contrast to analyses with cross-section data, panel data make it possible to analyse long-term relationships between variables and to control for non-observable heterogeneity (including exogenous shocks). However, a major problem with panel data techniques is data availability. If data were available, the generalized method of moments (GMM) estimators, i.e. the DIF-GMM and SYS-GMM estimators proposed by Arellano and Bond (1991) and Arellano and Bover (1995), respectively, would be two alternative techniques. Furthermore, VAR models with panel data would be an appropriate tool to assess the reverse causality relationships between the decision to eco-innovate and the explanatory variables.

Regional issues have largely been a missing theme in the literature, with some exceptions. Idiosyncratic characteristics of the region are specifically analysed by Ghisetti and Quatraro (2013). They find that firms located in highly polluting regions are more likely to eco-innovate. Policy at a local and regional level represents an important driver for eco-innovation. Cainelli et al. (2015b) focus on the influence of local environmental policy and regional features on waste-reducing technologies. Companies located in regions more concerned about recycling issues are more likely to eco-innovate. In general, only one dimension of regional aspects (regional policies) has been considered in the literature. An exception is Horbach (2014). Regional characteristics such as population density, relevance of green parties, unemployment rate or the Herfindahl specialization index are included in this contribution. In addition, the influences of several location dummy factors (proximity to research centers and universities, level of regional wages or trans-regional traffic infrastructure) are analysed. The author finds that regional proximity to research centers and universities are more important for eco-innovations compared to other innovations. Eco-innovations are more likely in regions characterized by high poverty rates and are less dependent on urbanization advantages.

The degree of “eco-innovativeness” can be expected to differ across sectors (Díaz-López, 2008; Montalvo, 2008). The innovativeness of a particular sector depends on factors such as the maturity of the dominant technology, scale, capital intensity, R&D intensity of the industry and competitiveness (Norberg-Bohm, 2000, p.198). Relevant sector-specific features influencing eco-innovation include the existence of technological opportunities, the properties of innovative processes, the market structure, the maturity of the sector, the environmental impact and the exposure to societal pressures (Del Río et al., 2013). Sectoral differences and their influence on eco-innovation have been addressed in a superficial manner, however, only through the inclusion of a sectoral dummy variable. Furthermore, the focus has been on just one dimension of possible sectoral differences (mature and highly pollution-intensive sectors vs. others). This has led to the general conclusion that highly polluting sectors are more likely to eco-innovate (De Marchi, 2012 and Del Río et al., 2013 for Spain and Cainelli et al., 2012, Antonioli et al., 2010 and Mazzanti and Zoboli, 2009 for Italy). However, other possible explanations for sectoral differences (see above) have not been considered. An analysis on the distinct drivers and barriers to eco-innovation in different sectors has not been performed. This might be related to data unavailability problems. When the sample is segmented, there might be few observations (i.e., firms) for one particular sector to perform an appropriate econometric analysis in that sector. If it is found out that the determinants to eco-innovation differ across sectors, then sector-specific policies could more effectively trigger eco-innovation.

On the other hand, most studies have focused on the industrial sector, possibly due to its relatively high environmental impact, large innovation potential and usually greater availability of data. In contrast, the service sector has not received a comparable attention, despite the fact that it accounts for 60–70% of GDP in most OECD countries (Cainelli et al., 2011). An exception is Cainelli and Mazzanti (2013) which explores environmental innovation in services with a dataset of more than 8000 Italian firms, concluding that drivers for eco-innovation differ across sectors.

Finally, another unaddressed issue is the influence of market structure on eco-innovation. Whether competitive or monopolistic structures are more likely to induce eco-innovation remains an open issue. This topic has been addressed in the general innovation literature. According to Pavitt (1984), industry structure is significant in understanding private sector decisions, as some industries are more innovative than others. Market structure may influence the rate of technological change, although the empirical evidence is inconclusive (see Cohen, 1995). In the area of eco-innovation, Montalvo (2008) argues that firms confronting more heterogeneous, hostile and dynamic markets will adopt branding and make efforts to entice consumers to use and gain social legitimacy from more environmentally friendly products. However, for Chassagnon and Haned (2015), the monopoly rents associated with an innovation reduce the risk of failure of innovation projects linked to rivals and provide firms with additional resources to fund innovation projects. To our knowledge, the only empirical contribution dealing with this issue is Brunnermeier and Cohen (2003), which shows that eco-innovations are more likely to be adopted in competitive environments.

4. Conclusions

A critical review of the literature on the econometric analysis of drivers to eco-innovation has been performed in this paper. The identified gaps in knowledge suggest at least ten fruitful avenues for future research.

A first and main opportunity for further research is theoretical. Many of the empirical papers being reviewed lack an explicit theoretical root. Some mention “innovation economics”, others “environmental economics”, “the RBV” and “systems of innovation”. There is not an agreed theoretical framework and different approaches emphasize some drivers, while neglecting others. For example, environmental economics focuses on the influence of public policy (instruments) on innovation. However, context conditions, policy details, the interactions between drivers and between actors and the influence of RDCDs are generally neglected. The firm's internal decision procedures are treated as a black box. The RBV includes RCDCs as a central explanation of the innovation process, but generally downplays the influence of external factors and, in particular, environmental policies. An integrated theoretical framework which coherently merges the insights from different approaches should be built in order to provide a complete picture of the drivers to eco-innovation and their interactions.

Second, the influence of some variables (internal and international factors) has seldom been considered in the empirical literature on eco-innovation with econometric modelling, mostly because of the difficulty to include these factors into econometric models due to poor data availability. When they have been considered, it has been done superficially and in a limited manner through the inclusion of just one variable in econometric models. This fails to account for the multidimensional character of RCDCs, which include in-house knowledge, customer relationships, financial reserves, physical resources, reputation, motivation, attitude (top-management commitment), skillful human resources, personal contacts and networking. Highly imperfect proxies should be avoided. In addition, the influence of the international factors on the eco-innovative behaviour of firms has been a largely unexplored topic. In particular, whether export propensity and foreign ownership drive eco-innovation deserves further research efforts.

Third, since the influence of demand-pull and cost-savings is not settled, further research is needed. Country differences (e.g., environmental awareness) might be part of the explanation and, thus, comparative studies for different countries should be undertaken. Furthermore, since the influence of both factors is likely to differ across distinct eco-innovation types, an analysis per type of technology is recommendable. For instance, demand-pull could be relevant for product eco-innovations, but not for process eco-innovations. Cost-savings are likely to be a driver for incremental eco-innovations whereas more radical eco-innovations are driven by several (interrelated) factors.

Fourth, related to the previous point, but more generally, we may expect that the determinants to eco-innovation differ across eco-innovation types (process vs. product and new-to-the-firm vs. new-to-the-market eco-innovations) and eco-innovator features (large vs. small and old vs. new firms). Therefore, more research on the determinants of different eco-innovation and eco-innovator types is recommendable. This could be done by segmenting the samples and estimating different equations.

Fifth, studies analysing the drivers to eco-innovation vs. general innovation are still relatively scarce with respect to those focussing on the drivers to eco-innovation in general. Policy makers willing to specifically promote eco-innovation should take these differential drivers into account. More research efforts are needed. In particular, the set of countries being analysed should be extended.

Sixth, and related to the previous point, the literature is concentrated on Western European countries, mostly on Germany and, more recently, on Spain. Analyses in other developed country contexts and in middle-income and developing countries are missing. In addition, only a few comparative international studies have been published. Therefore, more studies in other countries and more international comparative studies should be carried out.

Seventh, as mentioned above, the range of microeconometric methods being used should be expanded beyond logit and probit models. Tobit models represent an alternative in this context. In addition, while cross-section analyses dominate, panel data models are virtually absent. Further analyses with panel data models are recommendable because these enable us to analyse long-term relationships between variables and to control for non-observable heterogeneity.

Eight, the position of the firm in the value chain may influence the propensity to adopt an eco-innovation. For example, firms closer to end-consumers might be more affected by the willingness to pay of consumers for cleaner products than firms selling intermediate products. This has been an under-researched topic.

Ninth, although path dependency and innovation persistence have been main topics in the general innovation literature and even in the eco-innovation literature at landscape and regime level (Rip and Kemp, 1998; Unruh, 2000), they remain largely unaddressed topics in the literature on firm-level drivers to eco-innovation with econometric methods. Therefore, future research efforts should be devoted to their influence on the decision of firms to eco-innovate.

Finally, the degree of "eco-innovativeness" can be expected to partly depend on sectoral and regional features. A sector dummy is included sometimes in the econometric models in order to account for differences across sectors. Unfortunately, to our knowledge, no econometric analysis on the distinct drivers and barriers to eco-innovation in different sectors has been performed so far. The influence of market (industry) structure on eco-innovation remains an interesting topic for further research. Finally, we recommend carrying out analyses on the impact of regional and location factors, so far a neglected issue (Horbach, 2014).

Although, compared to other alternatives (e.g. case studies), econometric methods allow for generalizations, basing policy recommendations on econometric studies may be limited due to biases. These limitations, which suggest the need to combine different methods, can be grouped in four categories:

1) Treatment of the policy influence. The impact of policy on eco-innovation is too often simplistically represented through the inclusion of a dummy variable, which captures the effect of a particular instrument (regulation or subsidies). However, the influence of policy does not only depend on the existence of one instrument or another. Design elements within specific instruments, context conditions, regulatory stability, the level of stringency and the enforcement of the regulation are relevant aspects in this regard. However, they are never included in the models, probably because they are very hard to measure. In addition, the interaction between different policies and political economy aspects (which influence the stability and effectiveness of a particular policy) are difficult to address with these methods.
2) The capacity of econometric models to capture the systemic and dynamic aspects of eco-innovation processes is unclear. The dynamic interaction among multiple stakeholders is a distinctive feature of eco-innovation (Carrillo-Hermosilla et al., 2009). In addition, the drivers may interact between each other in complex ways. Both types of interactions are not considered in the econometric models reviewed in this article. On the other hand, the time dimension can be critical in the analysis of eco-innovation drivers. This can refer to the eco-innovator (its history, accumulation of internal capabilities over time which led it to be an eco-innovator …) and to the eco-innovation itself (e.g. its improvements over time). The unavailability of proper data makes it difficult to capture these dynamic aspects.
3) The relevance of the local institutional and socioeconomic context is challenging to include in econometric models. What local circumstances and institutional features of countries influence the propensity of firms to eco-innovate? These have not been addressed with econometric methods and, probably, they could only be properly tackled with in-depth case studies. In general, many subtleties and details which are likely to make a difference in the analysis are not captured well by econometric methods.
4) Econometric methods may be less suitable to analyse the drivers to disruptive eco-innovations (compared to incremental eco-innovations). For Ashford and Hall (2011), major technological, organizational, institutional, and social changes, not just incremental advances, are necessary to achieve sustainability. These changes need to be more systemic, multidimensional and disruptive. Therefore, the drivers to radical eco-innovations are more multifaceted compared to incremental eco-innovations. In principle, distinctive drivers could be identified by segmenting the sample and estimating two equations, one for radical and another for incremental eco-innovations. However, disruptive eco-innovations are necessarily few in number. This results in too few observations, making it difficult to apply econometric methods.

This paper has two main limitations. First, it provides a review of the literature on firm-level eco-innovation drivers based on the method being used. This is arguably a subjective and uncommon manner to organise a review. Second, it focuses on technological eco-innovation and not on organizational innovation. To our knowledge, the literature on firm-level determinants to organizational eco-innovations is emerging, thin and not yet consolidated. But it might be as relevant as technological eco-innovation in the quest for sustainable societies (Ashford and Hall, 2011). Identifying the drivers for organizational eco-innovation as well as the direction of causality between organizational and technological eco-innovations represent fruitful avenues for future research.

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