

# Inbound Open Innovative Strategies and Eco-Innovation in the Spanish Food and Beverage Industry

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**Abstract:** The main purpose of this paper is to analyse the influence of open innovation strategies on eco-innovation by accounting for type of innovation (product vs. process) and novelty degree (radical vs. incremental) in the context of the Spanish food and beverage manufacturing industry over the period 2008-2014. We find that the breadth of external knowledge sources has a positive effect on firms' adoption of most eco-innovations. However, the depth of these sources is only significant for process, product, and incremental eco-innovations related to a more efficient use of materials and energy, but not for radical ones. Moreover, our analysis confirms the presence of path dependence and the influence of both market demand and regulatory factors on adoption in general. Nevertheless, important differences with respect to the influence of embodied R&D, non-embodied R&D, training, external R&D, and cooperation on each type of eco-innovation are highlighted while controlling for past eco-innovation behaviour, size, and age of the firm.

**Keywords:** Low-tech industries; Food industry; Open innovation; Eco-innovation

**JEL classification:** O3, L66

## 1. Introduction

In Schumpeter's theory, economic development is driven by the discontinuous emergence of new combinations (innovations) that are economically more viable than the old way of doing things (Schumpeter, 1934). In this sense, firms depend on their ability to be innovative for achieving and sustaining competitive advantage. Innovation is acknowledged as one of the main factors of organizational success and survival of a company, regardless its size and the industry where it operates (Bigliardi and Galati, 2013). Literature on innovation is quite vast and some of the most popular definitions were proposed by Utterback (1994), OECD's Oslo Manual (2005) and Urabe et al (1998), among others. The latter indicates that "innovation consists of the generation of a new idea and its implementation into a new product, process or service..." (Urabe et al, 1998, p. 3). However, most companies do not have the necessary resources to innovate on their own and need to cooperate with different agents. Partnerships are among the fastest and sometimes cheapest ways to innovate (Hagedoorn and Schakenraad, 1994). Through cooperation, firms can improve their efficiency and increase their profits by securing a wider range of resources and more diversified sources (Kranenburg et al., 2004). This idea of cooperation is an essential part of the open innovation concept, which has recently received increasing attention in the fields of business management and innovation economics (Chesbrough, 2006). This can be described as a shift from the traditional or "closed" innovation model, with a main focus on internal research and development (R&D), toward an "open innovation" approach where firms actively utilize and exploit inward and outward transfer of knowledge and technologies (Chesbrough, Vanhaverbeke, and West 2006).

Open innovation can be defined as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation, respectively" (Chesbrough, 2003, p. 9). According to this paradigm, the use of external knowledge makes innovation easier and faster for firms. Open innovation is commonly associated with fast-growing, technology-intensive industries, such as the information and communication technology sector and the pharmaceutical industry (Sarkar and Costa, 2008), as well as with large and multinational corporations (Chesbrough, 2006). However, the analysis of the consequences of the use of open innovative strategies in traditional industries is under-researched. The literature on open-innovation is traditionally focused on high-tech industries (Del R o et al., 2016), and almost neglects low-tech ones. To the best of our knowledge, only a few studies focus on the open innovation process in the food and beverage industry using large samples (Knudsen, 2007; Pellegrini et al., 2014; Kastelli et al., 2016; Seyfettinođlu, 2016), and even the empirical evidence from case studies is very limited (Sarkar and Costa, 2008; Omta et al., 2014).

Recently, environmental responsibility has attracted increasing attention of both practitioners and academics in recent years, and policy makers are making efforts to set it as a priority in their agenda. Environmental concerns are driven by external pressures from stakeholders or regulators (Cuerva et al., 2014), and/or by the recognition that this behaviour can lead to competitive advantages (Díaz-García et al., 2015). Most of these practices lead to the development of environmental friendly products or manufacturing processes, often called environmental innovations, green innovations or eco-innovations. Kemp and Pearson (2007, p. 8) define eco-innovation as “the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives”.

In the last decade, the number of theoretical and empirical contributions on the drivers of green- or eco-innovation has been increasing (Horbach, 2008; Lanoie et al., 2011; Triguero et al., 2013; Díaz-García et al., 2015). Nevertheless, the empirical research on eco-innovation in traditional sectors such as food and beverage industry- typically characterised as low-tech- is still relatively scarce (Blasi et al., 2014; Cuerva et al., 2014; Bossle et al., 2016). Moreover, longitudinal studies analysing the influence of open innovation on the development of eco-innovations are lacking, especially in traditional sectors.

This paper fills this gap by studying the influence of open innovative strategies on the adoption of eco-innovation by firms in a traditional industry -the food and beverage industry in Spain. Using multivariate probit models, our main purpose is to identify the influence of open innovative strategies on the adoption of three different types of eco-innovation (material-efficiency, energy-efficiency, and environment-responsiveness) in agro-food firms distinguishing between product and process eco-innovators and between incremental and radical eco-innovators. Thus, we expect to increase our understanding about the drivers enhancing the adoption of eco-innovation in a sector traditionally considered as a mature and low-tech industry. Particularly, this paper aims to shed light on the dynamism of the innovation processes in the food industry by considering the relationships with partners that contribute to complement firms' internal knowledge base that leads them to develop eco-innovations.

The main contributions of this work are threefold. First, instead of cross-sectional survey data, we use longitudinal data for a representative sample of Spanish food firms over the period 2008-2014. Such data enable us to study whether eco-innovation in the food sector over time is the

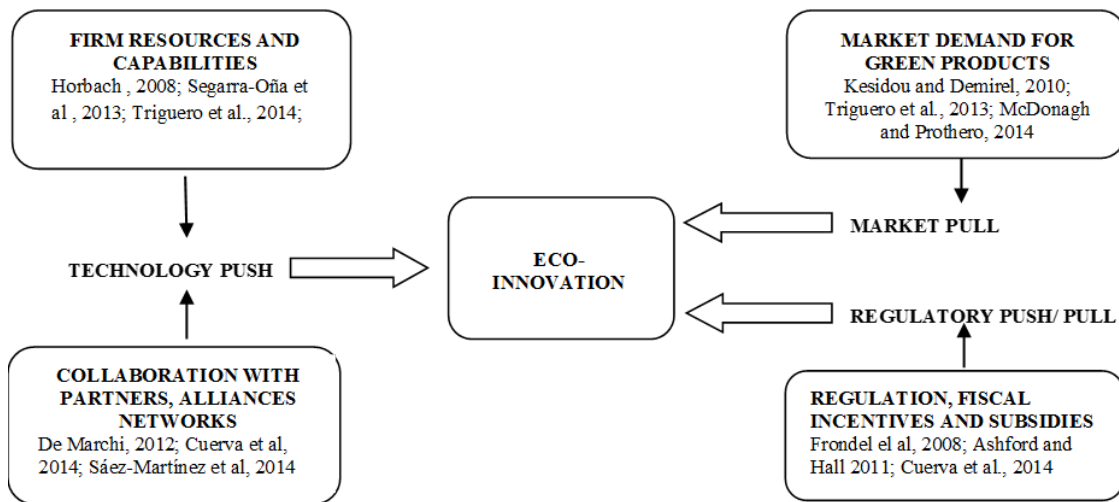
result of previous experience. In this regard, we introduce potential influence of past behaviour towards eco-innovation on current eco-innovation. To the best of our knowledge, there are no studies considering the persistence in eco-innovative activities. Second, we attempt to examine the influence of different factors on three types of eco-innovations closely related and not mutually exclusive. To address this issue, we use a multivariate econometric methodology. Finally, we distinguish between product and process eco-innovators and between radical and incremental eco-innovators to determine whether open inbound innovation flows have a different or a similar influence on the adoption of innovation with environmental benefits.

The outline of the paper is as follows. Section 2 reviews the literature on open innovation and eco-innovation with a special attention to food industry, and proposes the benchmark conceptual model. Section 3 describes the data and the econometric methodology. Section 4 presents the main results, while Section 5 concludes.

## **2. Theoretical framework and hypotheses**

The interest in the drivers of environmental innovation has been usually focused on high-tech, polluting, or energy-intensive industries, overlooking low-tech sectors such as the food industry. Nevertheless, the increase of competition in globalised markets has forced to introduce new, improved products and processes even in sectors traditionally characterised as low-tech (Bender, 2004; Von Tunzelmann and Acha, 2005; Hirsch-Kreinsen, 2009; Robertson et al., 2012). Among these innovations, we specifically refer to environmental ones under the assumption that the drivers of innovations reducing the negative impact of human activities on the environment can be different from those of other kinds of innovation. However, to the best of our knowledge, only few studies investigate the specific drivers of environmental innovations in the food industry using firm-level data (Cuerva et al., 2014; Bossle et al., 2016). In this regard, Cuerva et al. (2014) show that there are differences between the factors influencing “environmental” and “non-environmental” innovations in low-tech sectors. Specifically, using survey data of 301 food and beverage Spanish firms, the authors find that technology push, market pull, and regulatory push-pull factors exert a different influence on eco-product (i.e. ecological products) and eco-process innovations (e.g. recycling of waste or waste disposal, sustainable use of natural resources and environmental technologies and energy efficiency) as compared to non-environmental ones. On the other hand, by considering 581 Brazilian food companies, Bossle et al. (2016) show that both internal factors (e.g. human resources) and external ones (e.g. collaboration) are the most important drivers of environmental innovation. On the same line, Tanguy (2016) theoretically analyses the influence of open innovation on the French food industry and finds that some agro-food companies adopt radical innovations by cooperating with different partners.

**Figure 1. Drivers of eco-innovation**



Source: Own Elaboration

Following Horbach (2008), we assume there are three main types of determining factors of eco-innovation adoption (Figure 1). Among these drivers, the influence of consumer demand for greener products and services has been identified as a market pull towards environmental responsibility (Kesidou and Demirel, 2010; Triguero et al., 2013), and recent studies show that customers are currently more willing to pay for products or services produced in a more environmentally-conscious way (McDonagh and Prothero, 2014). Regulation and fiscal incentives have also been highlighted as effective drivers of companies' environmental responsibility, because benefits of adoption of environmental technologies are higher than costs of paying fines to governments for non-compliance. The Porter hypothesis (Porter and Van der Linde, 1995) suggests that environmental regulation leads to a double “win-win” situation, because firms achieve to accomplish environmental regulation and improve their competitive advantage. Some studies confirm this hypothesis by showing the increase in productivity of companies that implemented environmental-friendly practices (Frondelet al., 2008; Ashford and Hall, 2011; Cuerva et al., 2014). Additionally, technology push has been identified as another driver affecting environmental innovation (Sáez-Martínez et al., 2016a). Then, firm's resources and capabilities enable to develop the necessary knowledge base to promote eco-innovations (Segarra-Oña et al., 2013; Triguero et al., 2014). The role of technology push also generates from the creation of technological alliances (De Marchi, 2012) with different stakeholders, including suppliers, business partners, universities, and research centres (Sáez-Martínez et al., 2014). Therefore, firms' openness and their knowledge networks constitute other elements promoting eco-innovation (Cuerva et al., 2014).

Based on the Resource-based View (RBV) of the firm (Barney, 1991), we will analyse the influence of openness on the adoption of different types of environmental innovation by taking into

account their object and degree of novelty. Innovation includes both major and minor changes. Extremely major change is called a “radical innovation” (Urabe et al, 1988, p.3). Radical innovations are fundamental changes that represent revolutionary changes in technology. They represent clear departures from existing practice (Ettlie, 1983). Minor changes are called Incremental innovations. The OECD's Oslo Manual (OECD 2005) classifies incremental innovation as other changes in products and processes like changes which are “insignificant,” minor, or do not involve a sufficient degree of novelty. Novelty refers to the aesthetic or other subjective qualities of the product.

Thus, our main goal is to test if the adoption of an open model in the food industry enhances eco-innovation. In this regard, we expect that openness, measured as the breadth and depth of external knowledge sources, enhances all types of eco-innovations. Such openness enables to complement firm knowledge base to foster even a specific and idiosyncratic type of innovation (environmental or green). Nonetheless, we distinguish different types of environmental innovation to establish whether different drivers influence each type of eco-innovation. Material efficiency eco-innovations refer to those changes in product or process that involves a decrease in the consumption of inputs (materials). Similarly, energy-efficiency eco-innovations refer to those changes that reduce energy consumption. Finally, environment-responsiveness refers to those changes in product or process that reduce environmental damage of the firm’s activity.

Differences between eco-product and eco-process innovations in the food industry must be also remarked. In this regard, the first type of eco-innovations contributes to increase the consumption demand of novel foodstuffs while the second reduces the consumption of material and energy improving the firm’s productivity and competitiveness. Thus, organic production and the production of food with a high nutritional content are considered eco-product innovations while water pollution abatement, waste management, solid waste collection, material recycling or incineration and energy recovery in food industries are good examples of eco-process innovations. On the other hand, incremental innovations in the food industry are related to minor modifications of existing processes or products while radical innovations involve a break with old technologies. In this sense, some applications of biotechnology advances could be considered as incremental eco-innovations. For example, the use of not less enzymes<sup>1</sup> with the aim to synthesize products that requires less resources (such as water and energy) and create less waste. Regarding radical innovations, the use of novel protein foods replacing animal meat products, food additives based on

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<sup>1</sup> Although enzymes are used since the late 19th century food manufacturers can choose from numerous specially designed enzymes and enzyme blends to improve the texture of bread, add flavors to cheese, and clarify vegetable juices, to name just a few functions. <http://www.ift.org/food-technology/past-issues/2018/march/columns/ingredients-enzymes-used-in-food-beverage-manufacturing.aspx>

nanomaterials and genetic engineering that diminish the use of natural resource and environmental damage are good examples of radical eco-innovations in the food industry.

Since the adoption of eco-innovations depends on internal technological firms' resources and capabilities, our starting point is the influence of internal knowledge base. Although R&D is seldom considered as an essential driver in the food industry (Galizzi and Venturini, 1996), some authors recognise its role on the leadership in food firms after controlling for the increasing competition in the globalised market (Menrad, 2004; Hirsch-Kreinsen et al., 2006). For this reason, a significant relationship between R&D and firms' likelihood to innovate is predicted only for product and radical eco-innovations, and not for process and incremental eco-innovations. In this regard, Traill and Meulenbergh (2002), by using a sample of nearly 500 European food firms, confirm that R&D expenditures are more closely correlated with product innovation than with process innovation. As for eco-innovation, most empirical evidence shows that R&D is essential for all types of eco-innovation (Rehfeld et al., 2007; Horbach, 2008; Marzucchi and Montresor, 2017). However, the results are inconclusive when considering food firms. In this regard, Cuerva et al. (2014) find that R&D does not have a significant influence on eco-innovation in Spanish food firms as compared to conventional innovation. Based on these arguments, we formulate the following hypotheses.

*Hypothesis 1 (H1): In food firms, R&D influence is more associated with product and radical eco-innovations than with process and incremental eco-innovations.*

The technology embodied in new machinery has also been showed as an important technological driver in the innovative performance in the food industry. The acquisition of new machinery, software, and hardware enables to increase the technological capabilities in low-tech industries without high R&D expenditures (Santamaría et al., 2009; Hervas-Oliver et al., 2011). The embodied technology has also been included in open innovation studies. In this regard, Teirlinck and Spithoven (2008) analyse the spatial organisation of innovation by taking into account open innovation and external knowledge relations in a sample of nearly 1,300 Belgium manufacturing firms. Specifically, they show that the acquisition of new machinery enhances innovative performance, although their significance decreases when type of innovation and degree of novelty are introduced. Similar results are found by Santamaría et al. (2009). In a sample of Spanish manufacturing firms over the period 1998-2002, they also confirm that non-R&D activities such as the use of advanced machinery are crucial to product and process innovation in low-tech industries. Finally, Marzucchi and Montresor (2017) also consider the influence of expenditure in embodied technology per employee on the adoption of different types of eco-innovation. They find that the acquisition of embodied technologies only is crucial to explain a high likelihood to adopt energy and material eco-innovations (i.e. process eco-innovations), but not end-of-pipe technologies or

green products. Since the intensive use of embodied technology is one of the main characteristics of food industry, we claim that:

*Hypothesis 2 (H2): In food firms, the acquisition of embodied technology is more associated to process and incremental eco-innovations than to product and radical eco-innovations.*

Compared to other sectors, in the food industry, an innovative behaviour in the food industry cannot be assessed only through R&D expenditure or embodied technology. In this context, innovativeness involves investments in R&D and market-oriented activities to increase the success of launching products (Capitanio et al., 2010). To ensure the introduction of a product innovation that satisfies customer demand, firms have to balance and integrate their R&D and marketing competencies (Traill and Meulenbergh, 2002; Grunert et al., 2014). Therefore, an open innovation model can help achieve valuable information on product design, consumer preferences, and packaging to reduce innovation failures or avoid costly marketing research (Bigliardi and Galati, 2013; Pellegrini et al., 2014). Although the empirical evidence on the effect of this non-R&D disembodied knowledge on eco-innovation is scarce, Marzucchi and Montresor (2017) find that innovation expenditures to strengthen the firm's downstream value chain produce a significant effect on downstream innovations only (end-of-pipe technologies and green products). Therefore, we hypothesise that:

*Hypothesis 3 (H3): In food firms, non-R&D disembodied activities are more associated with product and radical eco-innovations than with process and incremental eco-innovations.*

Technological capabilities also depend on human resources. In this sense, the positive relationship between skills and innovation has been showed in the economics of innovation literature (Freel, 2005). In the same way, workforce high qualification has been highlighted as crucial for the innovative success of food firms (Avermaete et al., 2004). However, Cuerva et al. (2014) find a significant influence of education on general innovation, but not on eco-innovation. Capitanio et al. (2010) point out that the higher the human capital, the more frequent the product innovation in food firms. As for open innovation contexts, Santamaría et al. (2009) also confirm that training is a key factor for product and process innovations in low-tech industries. Firms spending more on training have a higher probability to success in eco-innovation projects, especially regarding sustainable innovation (Green et al., 1994; Ketata et al., 2014; Cainelli et al., 2015). The existing empirical evidence does not enable to determine the expected results on human capital. However, we believe that training is likely related to some types of eco-innovation. Hence, we hypothesise that:

*Hypothesis 4 (H4): In food firms, training is more associated with process and incremental eco-innovations than with product and radical eco-innovations.*

The role of external R&D acquisition in the innovative performance has also been largely addressed in the literature (Cassiman and Veugelers, 2006). Accordingly, external R&D complements the internal knowledge base to increase the absorptive capacity and innovative success of the firm. As expected, the acquisition of external (pecuniary) knowledge has been considered in the open innovation literature, in low- and medium-tech industries, as well as in the food industry (Christensen, 2008; Santamaría et al., 2009; Gassman et al., 2010; Berchicci, 2013). As empirical evidence highlights that external R&D seems more relevant for product innovations, we hypothesise the following:

*Hypothesis 5 (H5): In food firms, external R&D is more linked to product and radical eco-innovations than to process and incremental eco-innovations.*

It has been showed that another important tool to engage in environmental innovation is formal cooperation through R&D collaboration agreements (Horbach, 2008; De Marchi, 2012; Triguero et al., 2013; Cainelli et al., 2015; Del Río et al., 2017). Using Spanish CIS-2009, Del Río et al. (2017) show that cooperation influences product and process eco-innovations, while does not affect radical and incremental eco-innovations. However, some studies on manufacturing firms show that cooperation only affects process eco-innovations (Marzucchi and Montresor, 2017 for Spain), or do not find any significant effect (Borghesi et al., 2015 for Italy). Since eco-innovation requires the introduction of complex and radical technologies, cooperation enables easier access to the external knowledge needed to implement eco-innovation in food companies. Given these premises, we state the following hypothesis:

*Hypothesis 6 (H6): In food firms, technological collaborative agreements increase all types of eco-innovation.*

Regarding openness, the interaction with clients, customers, competitors, and institutions as universities or research centres is crucial in the food sector. In this context, knowledge networks have been found to be very important (Gellynck et al., 2007), and similar results have been obtained for eco-innovation (Carrillo-Hermosilla et al., 2010). External knowledge from customers, competitors, and suppliers is relevant for environmental innovation (Green et al., 1994; Buttol et al., 2012). Knowledge from institutional sources specialised in basic research (e.g. universities) seems also to be essential to enhance eco-innovation (Cainelli et al., 2012). Despite the limited number of studies on the influence of open innovative modes on eco-innovation in food firms, some interesting research shows that the use of a variety of external knowledge sources exerts a positive influence on

eco-innovation in the manufacturing sector (Cai and Zhou, 2014; Ketata et al., 2014; Ghisetti et al., 2015; Marzucchi and Montresor, 2017). Specifically, by measuring the external network strength through a Likert response scale, Cai and Zhou (2014) find a positive relationship between more efficient external networks and eco-innovative activity of Chinese firms. Focusing on a developed economy, Germany, Ketata et al. (2014) show that both breadth and depth of innovation sources positively affect eco-innovation carried out by innovative firms. Analogous results are found by Ghisetti et al. (2015) in a multi-country analysis on 11 European countries. In other words, they confirm that open innovation influences all types of eco-innovations, independently of whether they generate direct profits in terms of energy or material reduction (cost savings) or not. Finally, Marzucchi and Montresor (2017) analyse the influence of synthetic and analytical knowledge modes. They find that the former affects all types of eco-innovation, while the latter has a significant influence on material and energy efficient eco-innovations only, not on end-of-pipe technologies and green products. Following previous findings, we hypothesise that:

*Hypothesis 7: External knowledge networks positively influence all types of eco-innovation in food firms.*

*Hypothesis 7 (H7a): The influence of the external knowledge breadth is positive for all types of eco-innovation in food firms.*

*Hypothesis 7 (H7b): The influence of the external knowledge depth is positive for all types of eco-innovation in food firms.*

As for demand factors, customer and stakeholder pressure must be considered. Consequently, consumer demand for high standards of food quality and safety involves technological advances in the production processes and the development of new products (Capitanio et al., 2010). This is particularly important in the food industry because consumers' environmental awareness is higher than for other products. Furthermore, the increasing market demand for eco-products enhances the adoption of product and process eco-innovations by food companies (Cleff and Rennings, 1999; Kammerer, 2009). Cuerva et al. (2014) show that product differentiation is a key factor for eco-innovation by food firms, but not for general innovation in which origin labelling is essential. In this respect, consumer motivation enhances the use of sustainability labels by food firms (Grunert et al., 2014). Taking into account consumer preferences and the need for environmental concerns in production processes to guarantee sustainability in food supply chains (Hamprecht et al., 2005), we propose that:

*Hypothesis 8 (H8): Demand factors foster the adoption of all types of eco-innovation in food firms.*

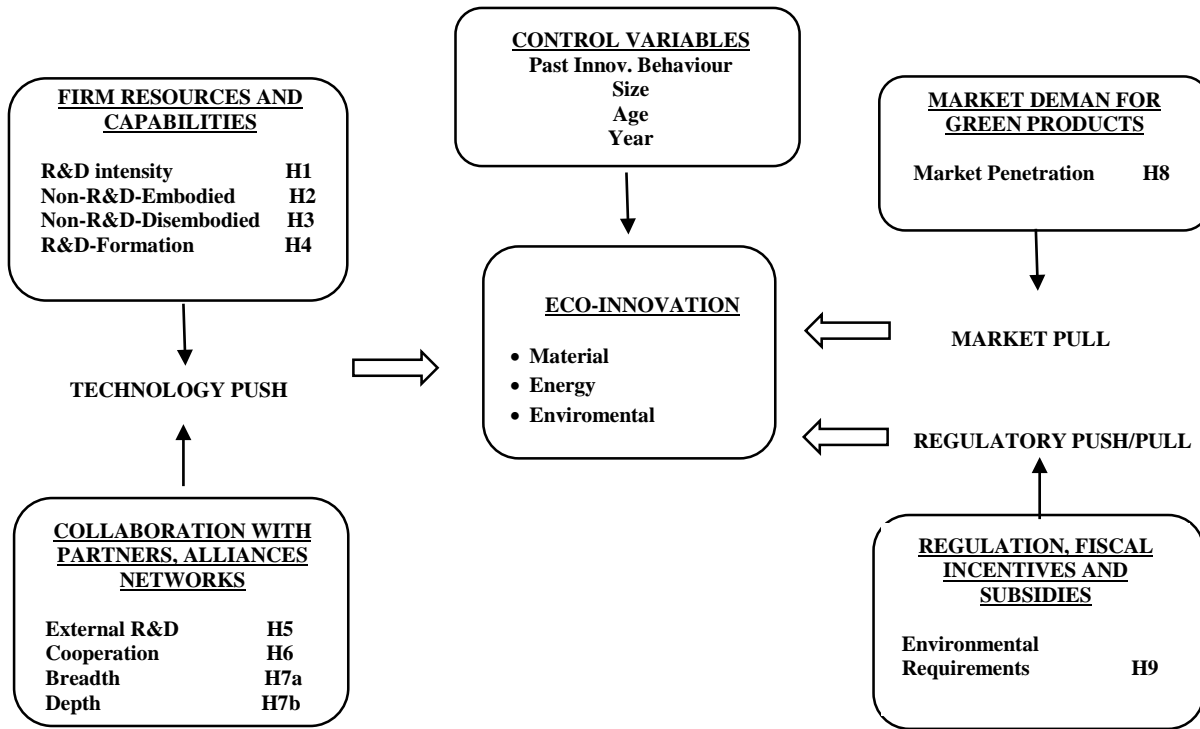
Moreover, regulatory measures have also been contemplated as drivers of eco-innovation. In this regard, most empirical studies support the positive influence of regulatory push-pull factors (Horbach, 2008; Belin et al., 2011; De Marchi, 2012). Ketata et al. (2014) find that high regulatory pressure on innovation activities positively influences environmental innovation. Similarly, the existence of public support to firm's innovation activities positively affects all types of eco-innovation (Ghisetti et al., 2015; Marzucchi and Montresor, 2017). Thus, we claim that:

*Hypothesis 9 (H9): The existing regulatory framework enhances all types of eco-innovation in the food industry.*

Apart from technological push factors, market-driven factors, and regulatory framework, in our work we also consider firm's past behaviour of eco-innovation, age, and size. The persistence in innovative activities has been confirmed in a number of studies (Geroski et al., 1997; Raymond et al., 2010; Triguero and Córcoles, 2013), but not analysed in eco-innovation research. Regarding size, empirical results show that larger firms are more eco-innovative than smaller ones (Demirel and Kesidou, 2011; De Marchi, 2012). However, there are also studies suggesting that size has no influence (Horbach, 2008). However, the effect of size seems to follow the same pattern in food as in other industries, with larger firms being more innovative than smaller ones (Galizzi and Venturini, 1996). Contrary to other studies, Cabral and Traill (2001) empirically show that younger firms in the food sector present a higher likelihood to innovate (Cabral and Traill, 2001). Hence, looking at the relationship with eco-innovation, we expect a negative sign for age and a positive one for size when considering open innovative modes. We do not translate these relationships into hypotheses because they go beyond our main research objectives.

Based on the theoretical model presented previously in figure 1, figure 2 provides a graphical representation of our research model.

**Figure 2. The research model**



### 3. Data and methods

#### 3.1 Data and descriptive statistics

The empirical analysis is based on firm-level data from the last available Spanish Community Innovation Survey, the Technological Innovation Panel (PITEC). PITEC is an adequate statistical database to investigate the main drivers of eco-innovation adoption by food and beverage firms in the country. Following the Oslo Manual guidelines (OECD, 2005), this dataset contains information about diverse firms' innovation objectives and strategies, enabling to identify different types of eco-innovation and the use of inbound open innovative strategies by Spanish food firms over the period 2008-2014. The PITEC contains an average sample around 12,800 innovative firms and provide information about the innovative activity by firms operating in all sectors in Spanish economy but only firms operating in the Food, Beverage and Tobacco industry (NACE 10, 11 and 12) are included. Thus, our final sample includes 650 firms in the agro-food sector, amounting to approximately 3,500 observations. Among all Spanish firms, it is showed a decrease of ratio of eco-innovators during the period 2008-2014 (from 35.7% to 23.86%) while the share of eco-innovative firms in the food industry is more stable and higher than in the whole economy because is from 40.85% to 50.34% during the same period –see table 1-.

**Table 1. Number of eco-innovators in all sectors and in the Food Industry in Spain.**

	PITEC	Eco-PITEC	% of Eco-innovators	Food	Eco-Food firms	% of eco-innovators
2008	12,813	4,574	35.70	743	374	50.34
2009	12,817	4,543	35.45	731	383	52.39
2010	12,821	4,427	34.53	715	369	51.61
2011	12,828	3,842	29.95	698	340	48.71
2012	12,838	3,556	27.70	669	287	42.90
2013	12,839	3,327	25.91	639	261	40.85
2014	12,842	3,064	23.86	509	256	50.29

Unfortunately, PITEC do not provide more disaggregated sectoral data but we have tried to show the heterogeneity in the Food and Beverage Industry distinguishing the eco-innovative behaviour by size. In this regard, large firms are more prone to adopt any type of eco-innovation (product/process; incremental/radical) than smaller firms during all the period (See Table A.1 in the Appendix).

Firstly, dependent variables are defined using two different information sets. On the one hand, we have four innovation variables that take the value 1 if firms do product, process, incremental, or radical innovation and 0 otherwise (*PROD*, *PROC*, *INCRE*, *RADI*). According to PITEC, a product innovation (*PROD*) is the market introduction of a new or significantly improved good or service with respect to its capabilities, user friendliness, components or sub-systems. A process innovation (*PROC*) is the implementation of a new or significantly improved production process, distribution method, or supporting activity.

Regarding the novelty of the innovation, PITEC questionnaire distinguishes between radical and incremental innovations in the following way. Radical innovation (*RADI*) is when the enterprise introduced a new or significantly improved product or service onto its market before its competitors (it may have already been available in other markets). Incremental innovation (*INCRE*) is when the product or service is only new to the firm, that is, when the enterprise introduced a new or significantly improved product or service that was already available from other competitors in the market.

On the other hand, three dummies on the importance (high or medium) of the innovation objective are also used with reference to material efficiency, energy use or environmental damage reduction (*MATER*, *ENERGY*, *ENVIR*). Then, these sets of variables are combined, resulting in twelve dependent variables. Material efficiency innovations (*MATER*) refer to those changes in product or process that involves a decrease in the consumption of inputs (materials). Similarly, energy-efficiency innovations (*ENERGY*) refer to those changes that reduce energy consumption.

Finally, environment-responsiveness (*ENVIR*) refers to those changes in product or process that reduce environmental damage of the firm's activity.

As for independent variables, we use five proxies to measure firm's knowledge resources and capabilities. First, *R&D intensity* is measured by the total R&D expenditure over the number of employees. The second variable tries to capture the embedded non-R&D based knowledge using the acquisition of machinery, equipment, and advanced hardware or software for the production of new or significantly improved products or processes over the number of employees (*Non-R&D-EMB*). Moreover, the third variable, *Non-R&D-DISEMB*, refers to internal knowledge non-R&D based that is not produced or diffused directly through embodied mechanisms. To proxy this variable, we use the expenditure in activities aimed to introduce improved products or services (including market prospecting and advertising) in the market, as well as the related expenditure on procedures and technical preparations for implementation. These three variables have been built following Marzucchi and Montesor (2017).<sup>2</sup> Additionally, a variable taking into account the training expenditure per employee to develop or introduce new or improved products or services within the firm (*R&D-FORM*) is also used. Finally, *EXTERNAL-R&D*, which refers to the expenditure for the acquisition of external knowledge (patents, licenses, know-how, and so on), is considered. All these variables are measured per employee and used in logarithmic form after adding up one to the argument in order to avoid dropping the zeros.

The second set of explanatory variables focuses on firms' cooperation and external knowledge sources. *COOP* is a dummy highlighting whether the firm reports a technological cooperation agreement with other partners. Following Laursen and Salter (2006), two additional variables, *BREADTH* and *DEPTH* of knowledge sources, are built using 11 sources (firms of the group, suppliers, customers, competitors, laboratories or private research centres, universities, public research organisms, technological centres, conferences, research journals, and professional or industrial associations). For *BREADTH*, each of the 11 sources is coded as a binary variable (1 if firm uses it and 0 otherwise). Then, these knowledge sources are added resulting in a variable that varies between 0 and 11. *DEPTH* is built in the same way, but sources take value 1 if the firm reports that uses the knowledge source at a high degree.

To complete the theoretical framework, we define two additional dummies: *MARKET-PULL* that takes the value 1 when the firm considers of high or medium importance to increase its market

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<sup>2</sup> However, our measures differ from Marzucchi and Montesor (2017). They use a three-year period average R&D expenditure (intramural and extramural), embodied R&D, non-embodied R&D, and other external R&D acquisition divided by the average number of employees over the same period. Differently, we calculate these variables for each year because we use five waves of Spanish CIS instead of two. Furthermore, we consider training expenditures per employee to enhance innovation as an additional explanatory factor.

penetration and 0 otherwise. *REGULATORY-PUSH*, it takes the value 1 when the firm considers of high or medium importance the accomplishment of regulatory environmental requirements and 0 otherwise. In addition, lagged dependent variables for each type of eco-innovation were introduced, as well as *SIZE*, *AGE* of the firm, and *YEAR-DUMMIES* are used as control variables.

Furthermore, a variable of capital stock is included as robustness check. Capital stock is measured as the net tangible assets at current replacement values (in euros) deflated by the annual mean of the capital goods price index (in thousands of euros). To estimate this variable, the value of stock capital in the initial moment and the rates of depreciation and annual investments in capital goods in the Spanish food industry is taken into account<sup>3</sup>.

Variable definitions are summarized in Table A.2 in the appendix. Similarly, Table A.3 and Table A.4 illustrates descriptive statistics and the correlation matrix. Since *BREADTH* and *DEPTH* are correlated, a VIF<sup>4</sup> test has been carried out to exclude that such correlation invalidates results.

The Food Industry is one of the most important branches of the national economy in Spain and the European Union, with high relevance for employment and economic output. As it can be seen in Table 2, Spanish Food firms are mainly process-innovation oriented. This is consistent with previous literature that argues that in this industry, the use of new technologies is developed by upstream industries and that innovation occurs through equipment and capital goods investments (Capitanio et al, 2010). Additionally, our findings show that most innovations are incremental rather than radical. This may be related to the so-called consumer inertia. There is a conservative consumer behaviour and aversion to new food products that may be guiding innovation in the food industry (Galizzi and Venturini, 2008). Similar findings regarding the nature of innovations and its degree of novelty were obtained in previous studies in different countries such as Germany (Menrad, 2004). Analogous pattern is observed using the distinction among material efficiency, energy use or environmental responsiveness eco-innovations (*MATER*, *ENERGY*, *ENVIR*). All these types of eco-innovations are more process-oriented and more-radical.

The dynamics of evolution of the different eco-innovations in the Spanish Food industry according to the frequency of each type of eco-innovation is showed in Figures 3 and 4. In general terms, the number of eco-innovators in the food industry economic recession of 2007 did not decrease at the beginning of the economic recession but diminish from 2010 to 2012. On contrary address, the number of eco-innovators has increased in the last two years as consequence of economic recovery.

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<sup>3</sup> The construction method of the capital stock is similar to the procedure used by Triguero et al. (2013).

<sup>4</sup> VIF test results available upon request.

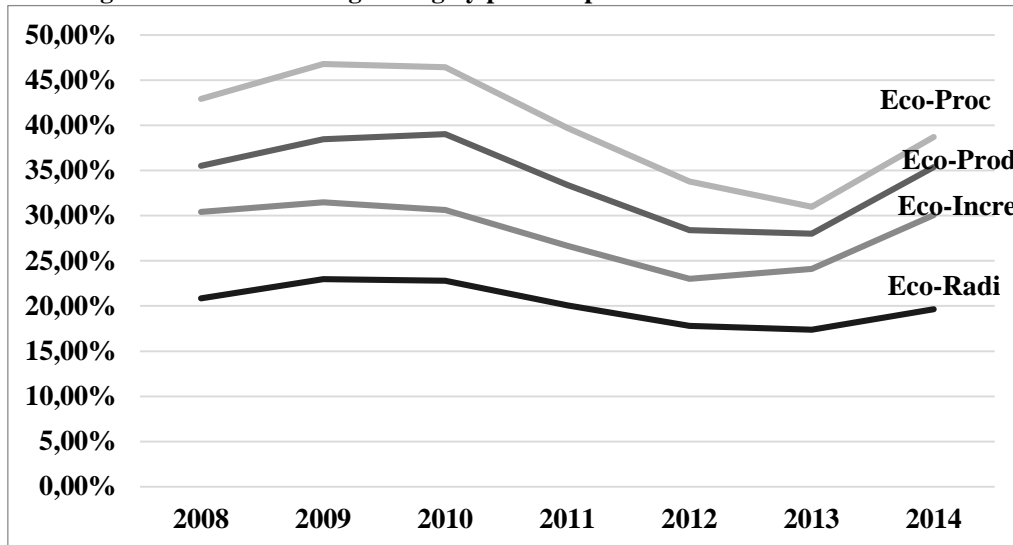
**Table 2. Types of Eco-Innovation in the Spanish Food Industry.**

Product versus Process					
Types of PROD-EI	#Firms	#Obs (%)	Types of PROC-EI	#Firms	#Obs (%)
<b>PROD-MATER</b>	160	1,119 (23.81%)	<b>PROC-MATER</b>	187	1,307 (27.83%)
<b>PROD-ENERGY</b>	167	1,167 (24.85%)	<b>PROC-ENERGY</b>	197	1,376 (29.32%)
<b>PROD-ENVIR</b>	192	1,338 (28.57%)	<b>PROC-ENVIR</b>	224	1,566 (33.33%)
Incremental versus Radical					
Types of INCRE-EI	#Firms	#Obs (%)	Types of RADI-EI	#Firms	#Obs (%)
<b>INCRE-MATER</b>	133	932 (19.79%)	<b>RADI-MATER</b>	94	661 (13.99%)
<b>INCRE-ENERGY</b>	138	964 (20.54%)	<b>RADI-ENERGY</b>	99	695 (14.73%)
<b>INCRE-ENVIR</b>	158	1,107 (23.51%)	<b>RADI-ENVIR</b>	117	821 (17.41%)

Source: Own Elaboration

If we distinguish among types of eco-innovation, the share of firms adopting process eco-innovations in the food industry is higher than the number of firms adopting product eco-innovation (39.9% versus 34.02% on average terms). In the same way, the percentage of firms with incremental eco-innovations is higher than firms with radical eco-innovations (28.05% versus 20.21%) (See Figure 3).

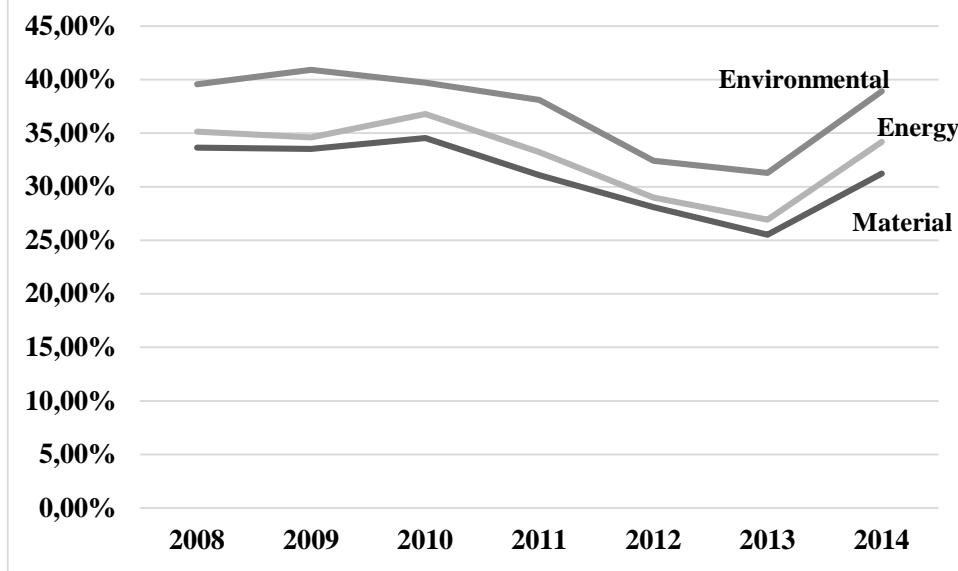
**Figure 3. Percentage of food firms distinguishing by product/process and incremental/radical eco-innovations.**



Source: Own Elaboration

Regarding material, energy and environmental eco-innovators in the food industry, the most frequent type of firms in the sector corresponds to environmental responsiveness while the percentage of firms adopting energy and material efficiency technologies is less important (Figure 4).

Figure 4. Percentage of food firms distinguishing by material, energy and environmental eco-innovations



Source: Own Elaboration

### 3.2 Econometric strategy

We estimate four multivariate probit models (*PROD*, *PROC*, *INCRE*, *RADI*) distinguishing among three different eco-innovative strategies (*MATER*, *ENERGY*, *ENVIR*). The multivariate probit model allows a simultaneous estimation of four types of firms while taking into account three different types of eco-innovation behaviour. Since unobserved firms' characteristics simultaneously influence the adoption of each decision, the multivariate model provides the pairwise correlation across the error terms of the three equations in each of the four models. These coefficients enable us to detect potential complementarities or substitution effects among the three alternatives. Thus, this technique is adequate to simultaneously address the factors influencing the diversity of eco-innovation.

Multivariate probits are implemented using the *mvprobit* command in STATA, allowing the joint estimation of the corresponding correlated binary outcomes and error terms. Following Cappellari and Jenkins (2006), the multivariate probit model is based on three variables, namely  $MATER_{it}^*$ ,  $ENERGY_{it}^*$ , and  $ENVIR_{it}^*$ :

$$\text{For } j = \begin{cases} PROD_{it} = 1 \text{ and } 0 \text{ otherwise} \\ PROC_{it} = 1 \text{ and } 0 \text{ otherwise} \\ INCRE_{it} = 1 \text{ and } 0 \text{ otherwise} \\ RADI_{it} = 1 \text{ and } 0 \text{ otherwise} \end{cases} \begin{cases} MATER_{ijt}^* = \theta_m + \phi_m MATER_{ijt-1} + \varphi_m X_{im,t-1} + \varepsilon_{im,t} & (1) \\ ENERGY_{ijt}^* = \theta_m + \phi_m ENERGY_{ijt-1} + \varphi_m X_{im,t-1} + \varepsilon_{im,t} & (2) \\ ENVIR_{ijt}^* = \theta_m + \phi_m ENVIR_{ijt-1} + \varphi_m X_{im,t-1} + \varepsilon_{im,t} & (3) \end{cases}$$

where

$MATER_{ijt} = 1$  if  $MATER_{ijt}^* = > 0$  and 0 otherwise;  
 $ENERGY_{ijt} = 1$  if  $ENERGY_{ijt}^* = > 0$  and 0 otherwise;  
 $ENVIR_{ijt} = 1$  if  $ENVIR_{ijt}^* = > 0$  and 0 otherwise.

The error terms  $\varepsilon_{im}$  are distributed as a multivariate normal, with zero mean and variance-covariance matrix  $V$ , where  $V$  takes value 1 on the leading diagonal, and correlations  $\rho_{jk} = \rho_{kj}$  are the off-diagonal elements. The model allows for the estimation of  $\rho_{32}$ ,  $\rho_{31}$ , and  $\rho_{21}$  to reflect the correlation across the errors of the four equations following the simulation of a multivariate distribution function based on the Geweke-Hajuvassilow-Keane (GHK) method (Cappellari and Jenkins, 2006).

#### 4. Results and discussion

Table 3 shows the results of the probit models. First, our findings show a persistence effect of eco-innovations over time. All lagged dependent variables are positive and significant, highlighting a clear inertia-effect on eco-innovation. Persistence of innovative activities has been confirmed in a large number of studies (Geroski et al., 1997; Raymond et al., 2010; Triguero and Córcoles, 2013), and our findings demonstrate that this is true also for eco-innovations. Moreover, we control for firm SIZE, as it is considered an essential factor to explain the adoption of eco-innovations (Demirel and Kesidou, 2011; De Marchi, 2012; Sáez-Martínez et al., 2016b). Our findings confirm that larger firms eco-innovate more than SMEs, probably due to the lack of financial resources and market power of the latter (with the exception of incremental and radical environmental friendly eco-innovations).

Overall, our findings point out the expected positive influence of market factors, regulatory framework, and technology push on the propensity to develop eco-innovations. However, their effect varies with the nature (product or process) and the degree of novelty (radical or incremental) of eco-innovations.

Regarding firm's resources and capabilities, our results show that R&D capabilities are positively and significantly related to product and radical eco-innovations, suggesting that R&D intensity (R&D) promotes the development of eco-innovations aimed at material-efficiency, energy-efficiency, and environmental-responsiveness (coefficients .029, .032, and .049, respectively). Additionally, radical material-efficiency and environmental-responsible eco-innovations are fostered when firms exhibit high R&D intensity (coefficient .030). These findings are consistent with previous literature on innovation in this industry, stating a positive relationship between R&D intensity and product innovation, not confirmed when it turns to process innovation (Trail and Meulenbergh, 2002). Regarding eco-innovation, previous results are inconclusive about the influence of R&D on adoption by food firms. Our findings highlight that R&D intensity fosters

the development of more radical eco-innovations when they are aimed to reduce the materials employed and the environmental harm of firms' activities. This finding supports H1 claiming that R&D influence is more associated with product and radical eco-innovations than with process and incremental eco-innovations in food firms. R&D plays a key role in the leadership among food firms (Hirsch-Kreinsen et al., 2006).

**Table 3. Influence of Open Innovation on Eco-Innovation in the Agro-food Sector**

	PROD			PROC			INCRE			RADI		
	MATER	ENERGY	ENVIR	MATER	ENERGY	ENVIR	MATER	ENERGY	ENVIR	MATER	ENERGY	ENVIR
<i>MATER<sub>i,t-1</sub></i>	1.497*** (0.063)			1.455*** (0.057)			1.427*** (0.069)			1.327*** (0.074)		
<i>ENERGY<sub>i,t-1</sub></i>		1.469*** (0.061)			1.507*** (0.056)			1.353*** (0.066)			1.330*** (0.071)	
<i>ENVIR<sub>i,t-1</sub></i>			1.540*** (0.066)			1.444*** (0.064)			1.485*** (0.073)			1.471*** (0.076)
<i>R&amp;D intensity<sub>i,t</sub></i>	0.029*** (0.011)	0.032*** (0.010)	0.049*** (0.011)	-0.007 (0.010)	-0.009 (0.009)	0.010 (0.010)	0.003 (0.013)	0.015 (0.013)	0.010 (0.014)	0.030** (0.015)	0.020 (0.014)	0.030** (0.014)
<i>Non-R&amp;D-EMB<sub>i,t</sub></i>	0.009 (0.011)	-0.017 (0.011)	0.009 (0.011)	0.052*** (0.010)	0.037*** (0.010)	0.068*** (0.011)	0.013 (0.012)	-0.003 (0.012)	0.018 (0.013)	0.024* (0.013)	0.015 (0.012)	0.008 (0.013)
<i>Non-R&amp;D-DISEM<sub>i,t</sub></i>	0.070*** (0.012)	0.073*** (0.011)	0.093*** (0.012)	0.007 (0.011)	0.016 (0.011)	0.024** (0.012)	0.006 (0.014)	0.004 (0.013)	0.011 (0.014)	0.037*** (0.014)	0.030** (0.013)	0.028** (0.014)
<i>R&amp;D-FORM<sub>i,t</sub></i>	-0.058*** (0.022)	0.013 (0.021)	0.019 (0.024)	-0.021 (0.020)	0.043** (0.020)	0.051** (0.023)	-0.047* (0.024)	0.021 (0.024)	0.056** (0.026)	-0.040 (0.026)	0.008 (0.023)	-0.009 (0.025)
<i>OTHER-EXT<sub>i,t</sub></i>	0.032 (0.031)	0.014 (0.030)	0.022 (0.032)	0.030 (0.032)	0.005 (0.029)	0.049 (0.035)	0.043 (0.034)	0.037 (0.031)	0.030 (0.034)	0.040 (0.034)	0.006 (0.032)	0.017 (0.034)
<i>COOP<sub>i,t</sub></i>	0.028 (0.070)	0.115* (0.067)	0.118 (0.072)	0.012 (0.067)	0.057 (0.065)	0.102 (0.070)	-0.001 (0.081)	0.090 (0.077)	0.035 (0.082)	0.122 (0.086)	0.168** (0.083)	0.184** (0.086)
<i>BREADTH<sub>i,t</sub></i>	0.020* (0.012)	0.032*** (0.012)	0.019 (0.012)	0.038*** (0.011)	0.044*** (0.010)	0.046*** (0.011)	0.028** (0.014)	0.030** (0.014)	0.027* (0.015)	0.038** (0.016)	0.050*** (0.015)	0.050*** (0.016)
<i>DEPTH<sub>i,t</sub></i>	0.059*** (0.019)	0.065*** (0.019)	0.031 (0.020)	0.078*** (0.019)	0.086*** (0.018)	0.046** (0.020)	0.068*** (0.022)	0.048** (0.021)	0.031 (0.022)	0.035 (0.022)	0.026 (0.021)	0.006 (0.022)
<i>MARK-PULL<sub>i,t</sub></i>	0.497*** (0.080)	0.470*** (0.078)	0.462*** (0.081)	0.173** (0.072)	0.197*** (0.070)	0.066 (0.075)	0.352*** (0.097)	0.395*** (0.094)	0.280*** (0.100)	0.260** (0.109)	0.439*** (0.106)	0.287*** (0.106)
<i>REGU-PUSH<sub>i,t</sub></i>	0.508*** (0.071)	0.577*** (0.068)	1.160*** (0.074)	0.563*** (0.066)	0.625*** (0.064)	1.335*** (0.070)	0.485*** (0.083)	0.562*** (0.079)	1.139*** (0.085)	0.490*** (0.091)	0.530*** (0.084)	0.939*** (0.091)
<i>SIZE<sub>i,t</sub></i>	0.152*** (0.026)	0.129*** (0.025)	0.069*** (0.027)	0.128*** (0.024)	0.102*** (0.023)	0.044* (0.025)	0.114*** (0.031)	0.104*** (0.029)	0.043 (0.032)	0.124*** (0.033)	0.086*** (0.031)	0.030 (0.032)
<i>AGE<sub>i,t</sub></i>	-0.002 (0.001)	0.001 (0.001)	0.001 (0.002)	-0.001 (0.001)	0.001 (0.001)	0.001 (0.001)	-0.002 (0.002)	0.001 (0.002)	0.001 (0.002)	0.001 (0.002)	0.003* (0.002)	0.005*** (0.002)
<i>YEAR</i>	YES			YES			YES			YES		
<i>Observations</i>	2,732			2,732			1,680			1,680		
<i>χ<sup>2</sup></i>	1,961***			2,102***			1,179***			974.7***		
<i>Log Likelihood</i>	-2,339.255			-2,669.663			-1,759.619			-1,465.784		
<i>ρ<sub>32</sub></i>	0.605*** (0.029)			0.548*** (0.029)			0.694*** (0.028)			0.757*** (0.024)		
<i>ρ<sub>31</sub></i>	0.538*** (0.032)			0.520*** (0.032)			0.612*** (0.033)			0.724*** (0.027)		
<i>ρ<sub>21</sub></i>	0.832*** (0.017)			0.837*** (0.029)			0.858*** (0.017)			0.906*** (0.015)		

\*p < 0.10; \*\*p < 0.05; \*\*\* p < 0.01. Control variables omitted from the table: TIME2009-TIME2014.

Acquisition of machinery, software, and hardware enables to increase the technological capabilities in low-tech industries without high R&D expenditure (Santamaría et al., 2009; Hervás-Oliver et al., 2011). As per our findings, embodied technology from such acquisitions (Non-R&D-EMB) positively and significantly promotes process eco-innovations, regardless of their type (coeff. .052 for MATER, .037 for ENERGY, and .068 for ENVIR). However, we find no significant effect on incremental eco-innovations. This partially supports H2, stating that the acquisition of embodied technology is more linked to process and incremental eco-innovations than to product and radical eco-innovations. This result is consistent with previous empirical evidence by Teirlinck and Spithoven (2008) on 1,274 Belgium manufacturing innovative firms over the period 1998-2000. Their findings show that the acquisition of new machinery enhances innovative performance,

although the significance decreases when the degree of novelty and the types of innovation are introduced. Similarly to our results, Marzucchi and Montresor (2017) confirm that the embodied technology in new machinery, software, and hardware explains a high likelihood to adopt energy and material eco-innovations (process), but not end-of-pipe technologies or green products.

Additionally, our results point out that Non-R&D-DISEMB increases the firm propensity to develop product (coeff. .070, .073, and .093) and radical eco-innovations (coeff. .037, .030, and .028), as well as process innovations with the objective to reduce environmental damage (coeff. .024). This result is in line with recent literature. Marzucchi and Montresor (2017) find that innovation expenditures to strengthen firm's downstream value chain only exert a significant effect on both downstream innovations (end-of-pipe) and green products. Our findings show that product and radical eco-innovations in food firms involve investments in R&D as well as in market-oriented activities (non-R&D disembodied activities). Therefore, although we find that these activities also foster process innovations reducing environmental damage, we can confirm H3 and state that Non-R&D disembodied activities are more associated with product and radical eco-innovations than with process and incremental eco-innovations in food firms.

Furthermore, R&D technological capabilities also depend on human resources. The variable R&D-FORM measures the firm's training expenditure per employee to develop or introduce new or improved products or services. With respect to the hypothesis (H4) that training for R&D personnel is more linked to process and incremental than to product and radical eco-innovations, our findings are not conclusive. While we find a positive relationship with process eco-innovation for energy-efficiency (coeff. .043) and environmental-responsiveness (coeff. .051), as well as for incremental environmental-responsiveness eco-innovation (coeff. .056), Table 2 shows that R&D-FORM negatively promotes product and incremental material-efficiency eco-innovation (coeff. -.058 and -.047, respectively). In other words, training for R&D personnel has a different effect on eco-innovations depending on their type. This could explain why previous literature (e.g. Cuerva et al., 2014) finds no significant influence of formation on eco-innovation in food firms. Training for R&D personnel increases employees' consciousness about the importance of reducing the environmental impact of firm's activities. This training leads them to propose incremental innovations to reduce such an impact, which also fosters a more efficient behaviour regarding energy use. However, the development of incremental innovations in products that suppose a reduction in materials' use is negatively correlated with these training expenses. Given the difficulties in explaining this relationship, deep case studies could shed light on the reasons why more qualified and trained R&D personnel negatively influences the propensity to develop material-efficient eco-innovations in the food industry.

Finally, firms can acquire knowledge and technology by purchasing patents and licences. External R&D complements the internal knowledge base to increase firm's absorptive capacity and innovative success (Cassiman and Veugelers, 2006). Contrary to expectations, we find no significant relationship between pecuniary acquisition of external knowledge (EXT-R&D) and any type of eco-innovation. Therefore, we cannot corroborate that external R&D is more associated with product and radical eco-innovations than with process and incremental eco-innovations (H5).

Regarding the effect of knowledge networks on eco-innovation propensity, we considered formal cooperation agreements and the structure of the network the firm uses as a knowledge source. We hypothesised (H6) that formal technological collaborative agreements increase all types of eco-innovation in food firms. Our findings show that these cooperation agreements (COOP) positively and significantly increase firms' propensity to develop radical eco-innovations aimed at energy saving (coeff. .168) and environmental responsiveness (coeff. .184). While the literature generally claims that formal cooperation through R&D collaboration agreement is an important tool to engage in environmental innovation (Horbach, 2008; De Marchi, 2012; Triguero et al., 2013; Cainelli et al., 2015; Del Río et al., 2017), empirical research is not conclusive. Recently, Del Río et al. (2017) show that cooperation has a positive influence on product and process eco-innovations; however, this does not seem to hold for radical and incremental eco-innovations. On the other hand, Marzucchi and Montresor (2017) point out that cooperation positively affects process eco-innovations only, while Borghesi et al. (2015) find no significant influence. Our findings, focused on the food industry and controlling for inertia effects, are different in this respect. Radical eco-innovation requires the introduction of complex and radical technologies, and cooperation enables the firm to get the external knowledge needed to implement this type of eco-innovations, especially energy savings.

Additionally, regarding the effect of the structure of the firms' knowledge sources network, we show that the greater the number of sources of external knowledge (BREADTH), the greater the propensity to develop eco-innovations. This positive and significant effect is present for all types of eco-innovations, except for product innovations whose objective is to reduce or minimise environmental damage. Therefore, we can conclude that the breadth of external knowledge sources increases all types of eco-innovations in our context (H7a). Our finding is consistent with previous literature demonstrating that, in the food industry, the interaction with clients, customers, competitors, and institutions like universities or research centres is crucial for the development of eco-innovations (Green et al., 1994; Carrillo-Hermosilla et al., 2010; Buttol et al., 2012).

Furthermore, as for the DEPTH of the firm's relationships with its knowledge network, we proposed its positive influence on all types of eco-innovations (H7b). However, our findings

highlight a positive relationship with process and product eco-innovations (with the exception of environmental-responsiveness product innovations), and no significant relationship with either radical or environmental-responsiveness incremental innovations. This result, shedding light on a different effect of DEPTH depending on the nature of eco-innovations (product vs. process), is similar to those obtained by Cai and Zhou (2014) and by Ketata et al. (2014) for Chinese and German manufacturing firms, respectively.

As far as demand factors (MARKET-PULL) are concerned, our findings corroborate the hypothesis (H8) of a positive influence on the adoption of all types of eco-innovation. Customer and stakeholder pressure fosters high standards requirements related to food quality and safety (Capitanio et al., 2010). This increasing demand for eco-products enhances the adoption of product and process eco-innovations (Cleff and Rennings, 1999; Kammerer, 2009). In this respect, our finding is consistent with the existing literature showing how clients force firms in this industry to adopt green labels (Grunert et al., 2014) and even use eco-innovation for product differentiation (Cuerva et al., 2014).

Furthermore, we confirm H9 by showing that regulatory measures (REGULATORY-PUSH) are positive and significant drivers of all types of eco-innovation in the food industry. Similarly to our findings, several empirical studies confirm that regulatory push/pull fosters the development of eco-innovations in several industries (Horbach, 2008; De Marchi, 2012). As an example, Ketata et al. (2014) find that a high regulatory pressure positively influences environmental eco-innovation. Likewise, in Ghisetti et al. (2015), the existence of public support to firm's innovation activities positively affects all types of eco-innovation.

As a robustness check, we include a variable of capital stock in all models. The results are similar to previous estimations confirming the robustness of our conclusions –see Table A.5 in appendix-. Finally, we have summarized the hypotheses and the main results in Table 4:

**Table 4. Summary of hypotheses results**

Hypothesis	Test Result	Observations
<i>H1: In food firms, R&amp;D influence is more associated with product and radical eco-innovations than with process and incremental eco-innovations.</i>	Supported	With the only exception of RADI-ENVIR
<i>H2: In food firms, the acquisition of embodied technology is more associated to process and incremental eco-innovations than to product and radical eco-innovations.</i>	Partially supported	Supported only for all types of process eco-innovation (PROC-MATER PROC-ENERGY PROC-ENVIR)
<i>H3: In food firms, non-R&amp;D disembodied activities are more associated with product and radical eco-innovations than with process and incremental eco-innovations.</i>	Strongly supported	
<i>H4: In food firms, training is more associated with process and incremental eco-innovations than with product and radical eco-innovations.</i>	Partially supported	Supported only for PROC-ENERGY PROC-ENVIR and RADI-ENVIR
<i>H5: In food firms, external R&amp;D is more linked to product and radical eco-innovations than to process and incremental eco-innovations.</i>	Not supported	
<i>H6: In food firms, technological collaborative agreements increase all types of eco-innovation.</i>	Partially supported	Supported only for RADI-ENERGY and RADI-ENVIR
<i>H7a: The influence of the external knowledge breadth is positive for all types of eco-innovation in food firms.</i>	Strongly supported	
<i>H7b: The influence of the external knowledge depth is positive for all types of eco-innovation in food firms.</i>	Supported	With the exception of PROD-ENVIR and all types of radical (RADI-MATER, RADI-ENERGY, RADI-ENVIR)
<i>H8: Demand factors foster the adoption of all types of eco-innovation in food firms.</i>	Supported	With the only exception of PROC-ENVIR
<i>H9: The existing regulatory framework enhances all types of eco-innovation in the food industry.</i>	Strongly supported	

## 5. Conclusions

Using data on Spanish firms over the period 2008-2014, this paper studies the influence of open innovation on the adoption of eco-innovation by firms belonging to a traditional industry, the food and beverage industry. Through multivariate probit models, we find that both the innovation strategy and the acquisition of external knowledge information sources must be taken into consideration to understand the adoption of distinct types of eco-innovation in a context of increasing and rapid competitiveness and globalisation.

While distinguishing different objectives and novelty degrees of eco-innovations, we confirm that disembodied R&D and non-R&D intensities increase the probability of product and

radical eco-innovations, while the acquisition of embodied technologies only affects the adoption of incremental eco-innovations. We show that external R&D is not an influencing factor for the adoption of eco-innovations in food firms. Contrary to the studies arguing that innovative collaboration and human resources are key factors to eco-innovation in the food industry (Cuerva et al., 2014; Bossle et al., 2016), our results indicate that cooperation only has a positive effect on the adoption of two types of radical eco-innovations: energy-efficiency and environment-responsiveness.

The fact that cooperation does not seem to affect incremental eco-innovations while it influences radical eco-innovations may be due to our measurement model. Our database only consider formal cooperation agreements and not informal cooperation mechanisms. Usually, formal cooperation agreements are settled to develop more risky, uncertain and radical innovations, while other informal agreements and collaboration mechanisms are used to develop less uncertain and incremental innovations. Unfortunately, we do not have information on informal collaboration. It could be that for incremental eco-innovations in the food sector, face-to-face and other informal cooperation mechanism would be more adequate and could lead to a positive effect on incremental eco-innovations. Several studies point out that European food companies do involve, at least on an informal basis, retailers and suppliers in their product development processes (Costa and Jongen, 2006), therefore, we could expect that this informal cooperation would also lead to the development of eco-innovations. Future research should include informal collaboration mechanisms as a driver of this type of eco-innovations.

Nonetheless, we find a higher influence of extensive (breadth) and intensive use (depth) of external knowledge sources on the majority of eco-innovations. Specifically, the breadth of external sources of information exerts a positive influence on all eco-innovations with the exception of environmental friendly product eco-innovations. A similar influence is found for the depth of external sources of information. Furthermore, the depth of knowledge sources does not influence any type of radical eco-innovation. This result is reasonable, as most food firms declare environmental concerns in their innovation process, and undertaking radical innovations in the food industry probably depends on other factors. Moreover, we point out the complementarity among all types of eco-innovation (material, energy, and environmentally-responsiveness) in the multivariate models. Moreover, in line with previous empirical research, the influence of regulatory push and market pull factors is also confirmed. Finally, size emerges as an essential factor to explain the adoption of eco-innovations (with only the exception of incremental and radical environmentally eco-innovations), confirming that larger firms eco-innovate more than SMEs, probably due to the lack of financial resources and market power of the latter. Learning economies measured through

past eco-innovative behaviour are also highlighted, while the age of the firm is only significant to explain a high probability to adopt environmentally-responsiveness radical eco-innovations.

Based upon our findings, we conclude that the food industry benefits from open innovative strategies (depth and breadth) in the introduction of all types of eco-innovation. However, only high R&D per employee, the introduction of product eco-innovations in the market (market research and launch advertising), and the adoption of eco-processes within the firm (testing, routine software development) increase the probability of introducing product and radical eco-innovations. Regarding process and incremental eco-innovations, embodied technology and external R&D seem to exert the same influence as for general innovation in food firms. Therefore, breadth and depth of external knowledge sources lead to a clear orientation towards adopting eco-friendly products, process, and incremental and radical eco-innovations by Spanish agro-food firms. However, a more integrated and comprehensive strategy through more extensive collaborative networks and technological agreements may probably bring to a more open innovation context, enhancing high adoption of eco-innovations in this traditional low-tech sector. Hence, open innovative strategies could be a recommendable corporate strategy for food companies that face important barriers to innovation in general (financial restraints, technological lock-ins, lack of qualified employees, etc.) and particularly to eco-innovation due to high complexity and uncertainty. From a practical perspective, it is even more important for SMEs firms. Since majority of Spanish Food and Beverage companies are SMEs, OI offers to small and medium firms a tool to move towards more eco-innovate strategies and high competitiveness. Thus, SMEs must adopt the 'Sharing Is Winning' model purposed by Saguy and Sirotinskaya (2014) to get the lack of knowledge or financial resources to stimulate eco-innovation in this low-tech sector. Policy-makers can also develop strategies and programs aimed at improving the open schemes in the adoption of environmental responsible innovations.

In this situation, food firms could decide to go beyond formal legal requirements of environmental policy and take a pro-environmental strategy, adopting eco-innovation as a tool to create a competitive advantage. In this regard, more open firms could increase their internal knowledge base by exploiting external knowledge while taking into account market demand dynamics (Bigliardi and Galati, 2013). Furthermore, policy makers should consider that low-tech sectors as food industry are a fundamental part of the national innovation ecosystem, because they are adopting radical and incremental technological changes generated in other sectors such as biotechnology, nutrition, health-care, or IT to improve the success of their innovation in the integrated food markets value chain (Kastelli et al., 2016).

Despite food industry traditionally being considered a low-tech sector, new industrial processing and packaging technologies, as well as the launching of new products, show how food firms are building up valuable knowledge related to non-R&D activities, while simultaneously adopting new processes and developing new products to compete in the global food markets. In this context, the adoption of eco-innovations by firms operating in a traditional sector in which some sustainability problems related to safety and energy issues in food processing are present should be considered. Furthermore, aspects related to open innovation practices, technological collaborative agreements, and customer demand should be taken into account by food firms' managers if they wish to achieve the “*win-win*” Porter effect implicit in innovations with environmental benefits. Thus, to achieve success and competitiveness in the current food industry, companies should consider environmental consumer awareness, new lifestyles, and higher incomes to adapt their production to customer demands through the adoption of environmental-friendly process and innovative eco-products.

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