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RESEARCH ARTICLE

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External stakeholder engagement: Complementary and substitutive effects on firms' eco-innovation

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Abstract

In this paper, we investigate whether firms' engagements in collaboration agreements with different types of external stakeholders produce complementary effects on the likelihood of eco-innovation. Although collaboration network and open eco-innovation theories affirm that the combination of external partners such as scientific partners, suppliers and customers produces complementary effects on the firm's likelihood of eco-innovation, several empirical studies found the existence of substitutive effects between them. To bridge this gap in the literature, we shape the nature of the interaction between different external partners, analysing an unbalanced panel sample of 10,918 innovative Spanish firms, covering the period 2008–2016. Consequently, we can show how firms benefit the most from collaboration with external partners. Our results show that firms that simultaneously collaborate with scientific partners, suppliers and customers generate partial complementary effects, which increase the firm's likelihood to eco-innovate the most, and that the combination of customer-collaboration with scientific partners, or supplier-collaboration, produces partial substitutive effects. Taking this in account, our results also confirm that engaging with scientific partners, suppliers or customers, independent of one another, increases firms' likelihood of eco-innovation more than noncollaboration. These results have important implications for managers, researchers and policy designers. For managers, this study provides a correct understanding of the benefits that they can expect to obtain from multi-partner external collaboration. For researchers, it introduces the marginal analysis to estimate interaction on nonlinear models. Finally, for policy designers, it shows the need for sponsored R&D collaboration to encourage coordinated ecosystems in which sustainability goals are pursued together.

KEYWORDS
collaboration agreements, complementarity, eco-innovation, external partners, stakeholder engagement

1 | INTRODUCTION

Environmental responsibility and sustainability are issues impossible to be ignored by the management of companies. External stakeholders are increasingly demanding firms to introduce environmental products and to reduce CO_2 emissions as well as materials and energy waste (Jové-Llopis & Segarra-Blasco, 2018). Top managers can see these pressures as threats to their core business but also as an opportunity to obtain a competitive advantage exploiting these demands (Ghisetti et al., 2015; Goodman et al., 2017; Zubeltzu-Jaka et al., 2018). Collaboration agreements with external stakeholders let firms convert them into key partners in eco-innovation—to introduce new products, processes or services which generate value and significantly decrease environmental impacts (Fussler & James, 1996, p. 303; OECD, 2009).

Collaboration with external partners is regarded as a critical determinant for firms' standard innovation (Belderbos et al., 2015; Jensen et al., 2007; Lundvall, 1992) and also for eco-innovation (Foray & Grübler, 1996; Hofman et al., 2020; Lee & Kim, 2011). For example, collaboration with scientific partners minimises the cost of internalising new technologies and materials (Cainelli et al., 2012; Cassiman & Veugelers, 2006; Horbach, 2016); collaboration with suppliers reduces CO_2 emission or energy waste (Dangelico, 2016; Hofman et al., 2020; Vachon, 2007); and collaboration with customers explores sustainable market demands (Cohen & Vandenbergh, 2012; Hofman et al., 2020; Melander, 2019). Each type of external partner offers access to different key resources for firms' eco-innovation; several scholars have claimed that multiple collaboration agreements with external stakeholders can generate complementary effects and increase the firms' likelihood to eco-innovate (De Marchi, 2012; Mårtensson & Westerberg, 2016; Melander, 2017).

However, these theories have collided with a stream of empirical literature, which claims that rather than be complementary, collaboration with multiple partners produces substitutive effects and diminishing returns (Fu, 2012; Laursen & Salter, 2006; Leiponen & Helfat, 2010). These scholars argue that an excessive number of collaborators introduce an amount of information and complexity impossible to be handled by the firm's managers; this situation produces a direct negative effect on firms' eco-innovation performance (Christensen, 2011; Ghisetti et al., 2015; Ketata et al., 2015). Thus, since the existence of the diminishing results has been checked empirically, the analysis of multi-partner collaboration effects has advanced to consider other attributes, which can moderate the complementary effects on firms' likelihood to eco-innovate. For example, the level of trust (e.g., González-Moreno et al., 2019) or the existence of interactive effects in the combination of different types of external collaborations (e.g., Bönte & Dienes, 2013; Hofman et al., 2020; Kobarg et al., 2020; Marzucchi & Montresor, 2017).

Eco-innovation studies that consider interactive effects among different external partners on firms' eco-innovation outcomes have been few and far between. Moreover, their results are contradictory; some studies found 'suppliers and customers' as complementary stakeholders (Du et al., 2018; Melander, 2020; Rauter et al., 2019), while others regarded them as substitutive ones (Hofman et al., 2020; Wei et al., 2020). This lack of consensus can also be addressed in other combinations such as 'suppliers and scientific partners' (Bönte & Dienes, 2013; Marzucchi & Montresor, 2017; Mothe et al., 2018) or 'customer and scientific partners' (Mothe et al., 2018; Rauter et al., 2019). Therefore, as revealed in several literature reviews, the impact of combining multiple external stakeholders on firms' eco-innovation needs to be analysed in depth to connect theory with managerial implications for collaboration networks and open eco-innovation strategies (Dangelico, 2016, p. 573; Del Río et al., 2016, p. 2169; Ehls et al., 2020, p. 420; Johnsen, 2009, p. 197).

Consequently, the aim of this paper is to analyse the existence of interactive effects between collaboration agreements with different types of external stakeholders. Specifically, we focus on those which the literature point to as having a bigger effect on firms' likelihood to eco-innovate: scientific partners, suppliers and customers. Based on these previous studies (e.g., Bönte & Dienes, 2013; Du et al., 2018; Hofman et al., 2020; Kobarg et al., 2020; Marzucchi & Montresor, 2017; Melander & Pazirandeh, 2019), we suggest that the contradictory effects reported in the literature are caused by complex interactive effects resulting from the type of external partners combined.

To answer this research question, we conducted our analysis of an unbalanced panel sample of 10,918 Spanish firms during the period 2008–2016. The panel is constructed with data from the Spanish version of the Community Innovation Survey (CIS) (Panel de Innovación Tecnológica, PITEC). Using a marginal effect analysis, we estimate the effect of every possible combination of external partner collaboration on a firms' likelihood to eco-innovate. This research represents the first time that this technique has been applied to analyse the interactive effects between external partners on a firm's likelihood to eco-innovate. The results show that simultaneous collaboration with 'scientific partners, suppliers and customers' is what increases the firms' likelihood to eco-innovate the most. The combination of 'scientific partners and suppliers' shows partial complementary effects, while the combination of 'scientific partners and customers' and 'suppliers and customers' shows partial substitutive effects. Finally, our result confirms the literature background that engaging with scientific partners, suppliers or customer independently from one another increases firms' likelihood to eco-innovate more. Mainly, this study provides practitioners with a correct understanding of the benefits that they can expect to obtain from multi-partner external collaboration.

This paper is organised as follows. In the next section, we review pertinent literature on the role of eco-innovation of different external stakeholders. In Section 3, we present the sample and the methodology used to analyse the data. In Section 4, we present the results from the empirical analysis. In Section 5, we discuss the result. The main conclusions and the future lines are presented in the final section.

2 | LITERATURE BACKGROUND

2.1 | Collaboration agreements with external stakeholders

Practitioners and innovation management scholars regard collaboration agreements with firms' external stakeholders as a critical determinant for firms' innovation (van Beers & Zand, 2014). Making them key partners lets firms access resources and infrastructures, which have a significant impact on firms' innovative performance (Belderbos et al., 2004, 2015). One of the most widely used mechanisms to formalise cooperative relationships with external stakeholder is 'collaboration agreements' (Martínez-Noya & Narula, 2018). Collaboration agreements can be defined as formal partnership agreements among different organisations to pursue an innovative assignment (Arranz & Fernandez de Arroyabe, 2008). This mechanism reduces transactional costs and generates mutual benefits (Hagedoorn et al., 2000). Although they can be formalised with all types of stakeholders, firms prefer to establish collaborative agreements with non-competitors such as scientific partners, suppliers and customers because they are perceived as partners with fewer options to develop an opportunistic behaviour (Martínez-Noya & Narula, 2018; Nieto & Santamaría, 2007; Rauter et al., 2019).

Collaboration agreements with scientific partners—universities, research institutes and other research organisations—let firms access advanced R&D activities, infrastructures and human capital, reducing the cost of internalising them (Cassiman & Veugelers, 2002; Perkmann & Walsh, 2007). During the last decade, these scientific actors have increased their engagement in collaborative projects with private organisations to transform their basic knowledge into applied knowledge, creating value for society through market-oriented projects (Barge-Gil & Modrego, 2011). As recent literature reviews pointed out, (Mascarenhas et al., 2018; Vivas & Barge-Gil, 2015), collaboration with scientific partners is a key determinant of firms' innovation.

Eco-innovation scholars share this point of view (Foster & Green, 2000; Steward & Conway, 1998). Moreover, they claim that as scientific partners have been engaging in collaboration agreements with firms, they have done it focusing on sustainable environmental challenges. Specially, their collaboration has been orientated to develop new technologies capable of reducing CO_2 emissions and using new, less environmentally damaging materials (Demirel & Kesidou, 2019; Fabrizi, Guarini, & Meliciani, 2018; Ghisetti & Pontoni, 2015). Several studies have shown the importance of firms' collaborating with scientific partners (Triguero et al., 2013), and the positive impact that this collaboration has on firms' eco-innovation (Cainelli et al., 2012; De Marchi & Grandinetti, 2013; Horbach, 2016).

For example, Cainelli et al. (2012) analysed a sample of 555 Italian manufacturing firms and showed how a university positively affects the introduction of eco-innovations more than any other collaboration agreement. De Marchi and Grandinetti (2013) also showed in a sample of 1831 Italian firms how collaboration with universities, research institutes and consultants is an essential driver of firms' eco-innovation. Additionally, Horbach (2016) showed how important it is for firms to collaborate with public research institutes to introduce eco-innovation related to new materials in a sample of western European firms and to introduce eco-innovations related to CO_2 emissions in a sample of eastern European firms. Based on this empirical and theoretical literature, we expect to find that scientific partner-collaboration positively affects firms' likelihood of eco-innovating. This first hypothesis can be summarized as follows:

H1. Firms that collaborate with scientific partners are more likely to introduce eco-innovation than those that do not.

Upstream collaboration agreements with suppliers contribute to firms' innovation, sharpening its focus on core competencies, bettering design processes and securing vital inputs (Belderbos et al., 2015). Supplier collaboration can also create additional opportunities for firms to add value, for example, steering their innovation efforts in the firms' interest (Ragatz et al., 1997). The effective integration of suppliers into firms' innovations can help them achieve a competitive advantage in terms of cost, technologies and time (Chung & Kim, 2003; Nieto & Santamaría, 2007; Un & Asakawa, 2015).

Due to its orientation towards introducing efficient technologies, supplier collaboration is significantly related to reducing CO_2 emissions, energy and materials waste (Foster & Green, 2000; Green et al., 1994; Johnsen, 2009). Thus, eco-innovation literature has regarded this type of collaboration as an essential source of firms' eco-innovation (Dangelico, 2016; Johnsen, 2009). This type of collaboration could be accomplished by pursuing a productivity goal, but it also positively impacts the environment (Sarkis et al., 2011; Vachon, 2007). Recently, this type of eco-innovation also pursued satisfying market demands related to environmental standards of quality such as ISO 14001 or eco-labelling (Melander, 2018; Papagiannakis et al., 2019). Scholars have widely demonstrated how collaboration with suppliers is a critical factor of eco-innovation (Bos-Brouwers, 2010; Lee & Kim, 2011; Pujari et al., 2003).

For example, Pujari et al. (2003) show in a sample of 151 UK manufacturing firms that a higher degree of supplier involvement positively influences eco-innovation performance. Bos-Brouwers (2010) found similar results in a qualitative study of Austrian firms. They found that supplier collaboration is focused on introducing new materials or technologies which increases the firms' likelihood of eco-innovating. Lee and Kim (2011) studied the Korean semiconductor industry and showed how collaboration with suppliers is a strategic relationship to develop successful eco-innovation, bringing environmental and commercial success together. Based on this empirical and theoretical literature, we suggest that collaboration with suppliers positively affects a firms' likelihood of eco-innovating. This second hypothesis can be summarized as follows:

H2. Firms that collaborate with suppliers are more likely to eco-innovate than those that do not.

Last but not least, downstream collaboration agreements with customers are also vital for firms' standard innovation (Von Hippel, 1978, 2005). Customer collaborations have been used to reduce the risks associated with the introduction of new products in a heterogeneous market where the cost of internalising the customer demands is high (Sánchez-González et al., 2009; Von Hippel, 2005). Customer collaboration is also used to improve firms' products and services, thereby introducing incremental innovations (Belderbos et al., 2004, 2015). Although innovation literature has been focused on the role played by customer collaboration in the commercialisation of product innovations (He & Wang, 2016; Stockstrom et al., 2016), several studies have also shown the relevance of this relationship to firms' process-innovation (Chen & Tsou, 2012).

From an eco-innovation perspective, customer collaboration is the determinant partner for firms to introduce eco-innovations. Through their purchasing decision, customers can reward firms, which satisfy their environmental consciousness and punish firms which do not (Campbell, 2007). Making these decisions is comfortable, talking about product innovation for which environmental specifications are easily verifiable (e.g., related to materials or packaging). Nevertheless, as Kobarg et al. (2020) point out, making this decision when the ecological innovation is related to processes implies trusting what is defined as a 'credence feature' (Rex & Baumann, 2007). The environmental impact developed previously in the back-door process is hard for the customer to recognise (De Marchi & Grandinetti, 2013). Despite the existence of this psychological disincentive (Dulleck et al., 2011), several studies have shown that this problem is becoming less and less relevant thanks to more information that customers have because of successful environmental labelling policies. These have increased the ecological perspective of society (Baksi et al., 2017; Cohen & Vandenbergh, 2012) and have a positive impact on firms' likelihood to eco-innovate (Kammerer, 2009; Liao & Tsai, 2019; Melander, 2018).

For example, Kammerer (2009) showed how customers play a crucial role in the introduction of eco-innovations in a sample of 92 German manufacturers. They found that firms that attributed a considerable potential for customer benefit to an environmental issue were significantly more likely to implement eco-innovations orientated towards solving this issue than others. Melander (2018) qualitatively studied 10 different eco-innovations with data from five large industrial firms. Her work explained how customers contribute positively in the early phase by generating ideas and providing knowledge about the market, customers' requests and environmental requirements. In the end phase, customers contribute positively by participating in testing the product as pilot users. Finally, Liao and Tsai (2019) checked, in a sample of 1717 Taiwanese service firms, how customer demand influences firms to adopt eco-innovation and how their achievement is directly related to firms' performance. Based on this empirical and theoretical literature, we expect to find that customer collaboration positively affects firms' likelihood to eco-innovate. This third hypothesis can be formulated as follows:

H3. Firms that collaborate with customers are more likely to introduce eco-innovations than those which do not.

2.2 | Complementarity between different external stakeholders

The competition in the market has forced organisations to formalise collaboration agreements with more than one external stakeholder to increase firms' opportunities to explore and exploit their resources (Belderbos et al., 2015; West & Bogers, 2014). Innovation management theory widely supports the contention that simultaneous collaboration with different external stakeholders can generate complementary effects on firms' innovation (Faems et al., 2005; Jensen et al., 2007; Tether, 2002). However, empirical studies that have analysed multi-partner collaboration have found that beyond an optimal level, firms that rely on an increasing number of external partners suffer from decreasing returns in terms of innovation performance (Laursen & Salter, 2006). These studies claim that as the number of external collaborations increases, the complexity and the challenge of dealing with them increases as well (Fu, 2012; Stuermer et al., 2009).

Thus, firms must confront this trade-off between the benefits and costs of collaboration by aligning search breadth and depth with other factors, allowing them to overcome the impediments of relying on different external stakeholders (Powell et al., 1996; Tödtling et al., 2009). That is why many scholars have suggested that complementary effects depend not on their number but rather on their type (Belderbos et al., 2015; González-Pernía et al., 2015; Haus-Reve et al., 2019; Jensen et al., 2007). From this perspective, collaborating only with suppliers could be less effective regarding firm innovation than combining collaboration with supplier and scientific partner. The few studies that have analysed the existence of these interactive effects on standard innovation have shown contradictory results. González-Pernía et al. (2015) found positive results in firms' simultaneous collaboration with supply-chain partners and scientific ones in a sample of 4969 innovative Spanish firms covering the period 2003–2011, while Haus-Reve et al. (2019) found the opposite results in a sample of 4534 Norwegian firms covering the period 2006–2010.

From an eco-innovation perspective, the existence of complementary effects between external partners has been more accepted by theory and practice than in standard innovation (Dangelico, 2016; Del Río et al., 2016; Foster & Green, 2000). For example, De Marchi (2012) and Triguero et al. (2013) demonstrated how eco-innovations benefit more from collaboration agreements than standard innovation, although other studies have also found the existence of dismissing results as the number of partners grows (Bönte & Dienes, 2013; Christensen, 2011; Ghisetti et al., 2015; Ketata et al., 2015). Due to the importance of collaboration for firms and society, scholars reaffirm the undeniable benefits of broader collaboration agreements with external stakeholders. Theoretically, this point has been addressed from two important streams of literature: the collaborative networks perspective and the ecosystem approach.

The collaborative network perspective relies on social capital theory (Cainelli et al., 2007; Cainelli et al., 2012), interfirm agreements and knowledge spillovers in industrial areas (Geffen & Rothenberg, 2000; Steward & Conway, 1998). From this perspective, the network can partially substitute economies of scale in an environment characterised by small and medium firms (Mazzanti & Zoboli, 2009) and generate positive impacts on the firms and aggregated levels (Fritsch, 2001; Fritsch & Schwirten, 1999). Collaboration agreements in this network can save raw materials, improve waste disposal, limit polluting emissions or reduce energy consumption, packaging and transportation (Cantono & Silverberg, 2009; Manzini & Vezzoli, 2003). Moreover, it has been proven that being part of the network encourages firms to change their behaviours and values to become more environmentally friendly (Marcon et al., 2017).

Empirical studies that have studied collaborative networks and firms' eco-innovation have found a positive relationship between them (Inigo et al., 2020; Ma et al., 2017; Melander & Pazirandeh, 2019; Melane-Lavado & Álvarez-Herranz, 2020; Pellegrini et al., 2019). For instance, Ma et al. (2017), who analysed Chinese joint-filing patents over the period 2006–2015, found that external collaborations have moved towards a higher level of multidisciplinary and larger technological distance, positively influencing the introduction of eco-innovations related to waste-of-energy reductions. Melander and Pazirandeh (2019) interviewed 30 top managers from the high-technological sector and found that firms which collaborate with inter-industry and intra-industry partners eco-innovate more. Inigo et al. (2020) analysed a sample of 170 firms in Spain's Basque Country region—which has a highly collaborative regional innovation system—and found that collaboration proactiveness is positively related to firms' eco-innovation.

The ecosystem approach focuses on the complex social–ecological nature of the sustainability challenge (Dietz et al., 2003, p. 1908) and tries to analyse the nonlinear interactions of the economic, social and environmental spheres, as well as the necessity of societal cross-sector collaboration in support of sustainability and conservation efforts (Costanza et al., 2007). In this approach, the firms and other organisations are part of the ecosystem and cannot be separated from it (Slocombe, 1993). Thus, all the ecosystem members have a common goal of sustainability development and are coordinated by the institutional agents (Bengtsson & Kock, 2000; Dahl, 2014; Folke, 2006).

Empirically, this ecosystem approach has found that multiple types of well-established relationships between different partners are needed in order to achieve firms' higher level of eco-innovation (Behnam et al., 2018; Planko et al., 2019; Wei et al., 2020). For example, Planko et al. (2019) have shown the importance of trust and shared goals in the Dutch smart grid industry, and Wei et al. (2020) found similar results studying three different cases from the platform service industry. And Behnam et al. (2018) found that networking, competence mapping and relational capabilities with other agents strongly depend on the eco-innovation outcome characteristics.

Both theoretical frameworks have been combined in open eco-innovation studies, which have analysed whether the combination of multiple collaborative agreements with external partners generates a positive effect or not (e.g., Cuerva et al., 2014; Ghisetti et al., 2015; Horbach et al., 2012; Horbach et al., 2013). For example, Cuerva et al. (2014) found that supply-chain partners positively affect eco-innovation in a sample of 205 Spanish small and medium-sized enterprises (SMEs) from low-tech sectors, as did Horbach et al. (2012) in an analysis of 1294 German firms. However, few studies have analysed the existence of complementary or substitutive effects between different types of external stakeholders, and those which have, show contradictory results (Hofman et al., 2020; Kobarg et al., 2020; Rauter et al., 2019; Wei et al., 2020). Some of them found suppliers and customers as complementary partners (Melander, 2019; Rauter et al., 2019), while others regarded them as substitutive ones (Hofman et al., 2020; Wei et al., 2020). This contradiction can also be addressed in other combinations such as suppliers and scientific partners (Kobarg et al., 2020; Mothe et al., 2018). Recently, Kobarg et al. (2020) have quantitatively analysed the combination of scientific partners, suppliers and customers. These authors studied 546 German firms and found mixed effects: a positive effect on the combination of scientific partners, suppliers and customer, but neutral effects between scientific partners and customers, and adverse ones between suppliers and customers.

Theoretically, based on the benefits that extended collaborative network and interactive environments have on firms' eco-innovations for all of society, we expect that the combination of different types of partners has a positive effect on the firms' likelihood to eco-innovate to higher levels than those which only cooperate with one type of partner. This fourth hypothesis can be formulated as follows: (Melander & Pazirandeh, 2019; Pellegrini et al., 2019; Planko et al., 2019; Wei et al., 2020). However, due to other empirical literature, which has pointed out the existence of substitute effects, we do not disregard the adverse effects on specific external partner combinations (Hofman et al., 2020; Kobarg et al., 2020; Wei et al., 2020).

H4. Firms that collaborate with scientific partners, suppliers and customers are more likely to eco-innovate than those with only one partner.

3 | METHODOLOGY

3.1 | Dataset

We tested the hypotheses presented above using data from the Spanish Technological Innovation Panel (PITEC). This panel survey is based on the CIS and is one of the most used datasets in innovation studies (e.g., Cainelli et al., 2015; De Marchi, 2012; Del Río et al., 2016; Jové-Llopis & Segarra-Blasco, 2018, 2020; Marzucchi & Montresor, 2017). Since 2008, PITEC includes variables related to environmental innovation objectives in each survey series following the Oslo Manual. These variables have been used in both cross-sectional (Arranz et al., 2019; De Marchi, 2012) and panel analyses (Jové-Llopis & Segarra-Blasco, 2020; Marzucchi & Montresor, 2017). Nowadays, the main advantage of the PITEC database is its time dimension, which allows us to deal with unobserved heterogeneity and simultaneity problems.

In our analysis, we use an unbalanced panel of innovative firms from the time-period 2008–2016. As in previous literature (González-Pernía et al., 2015; Haus-Reve et al., 2019), we excluded earlier observations from firms that have suffered sudden employment changes resulting from a merger or acquisition process, high labour turnover or layoffs. The resulting sample is composed of 10,918 firms, during an average period of 7.1 years, yielding a total sample of 67,982 observations. In 2016, almost a third of the firms eco-innovated, indicating an increasing trend among innovative Spanish firms.

3.2 | Variables

As the dependent variable, we analyse firms' engagement in *eco-innovation*, based on their ex-post self-assessment. For that, we utilise a PITEC question of asks (on a 4-point scale) to what degree the firm has introduced any innovation pursuing an environmental objective. We coded this question as a binary variable (positive values if the firm responds 'strong or medium', negative otherwise). This dependent variable offers the best approach to determining a firms' likelihood of eco-innovating as previous studies have shown (e.g., Cainelli et al., 2015; De Marchi, 2012; Del Río et al., 2016; Horbach, 2008; Marzucchi & Montresor, 2017). In this sample, 53.68% of firms have declared to have introduced eco-innovations during the period analysed at least once.

As independent variables, we use questions about the existence of collaboration agreements with firms' external stakeholders. Although the specification of the type of external partners is a common practice in innovation studies (e.g., Faems et al., 2005; Fitjar & Rodríguez-Pose, 2013; Haus-Reve et al., 2019), eco-innovation studies tend to treat firms' external collaboration as a single binary variable (e.g., De Marchi, 2012; Marzucchi & Montresor, 2017; Triguero et al., 2013), but this codification could bias the result, mixing and hiding interactive effects. That is why notable exceptions in this field have tried to analyse what the specific effect produced by different partner combinations is (e.g., Bönte & Dienes, 2013; Cuerva et al., 2014; Del Río et al., 2016; Kiefer et al., 2019; Kobarg et al., 2020; Sáez-Martínez et al., 2016). Following their approach, we use the binary questions of PITEC about collaboration agreements to construct our independent variables. First, we coded collaboration with *scientific partners (STI)* as a positive value if the firm responded affirmatively to collaboration with universities or research institutes (Cainelli et al., 2012; Horbach, 2016). Second, we coded upstream collaboration with *suppliers* positively when the firm responded affirmatively to have engaged collaboration agreements with this partner (Dangelico, 2016; Melander, 2017). Third, we coded downstream collaboration with *customers* positively if the firm responded affirmatively (Kobarg et al., 2020; Melander, 2020).

As control variables, we used several factors at firm, sectoral and regional levels, which may influence firms' eco-innovation and have been taken into account in previous studies (Del Río et al., 2016): collaboration with *competitors*, *subsidies*, *firms' R&D internal expenditure*, *share of exports in turnover*, *size*, *age*, *sector* and *region*. The correlation estimation between them tends to be low, suggesting that severe multicollinearity is not a problem (VIF = 1.36). See correlation matrix in Table A.

At the firm level, we controlled for collaboration with *competitors*. Although empirical studies have found that coopetition has a positive effect on a firm's likelihood to eco-innovate (Bouncken et al., 2015; Ritala & Hurmelinna-Laukkanen, 2013), firms prefer to establish collaborative agreements with noncompetitive partners because the latter are perceived as partners with fewer options to develop an opportunistic behaviour (Martínez-Noya & Narula, 2018; Nieto & Santamaría, 2007; Rauter et al., 2019). Based on this literature, we expect collaboration with competitors to have a neutral or small positive effect on firms' likelihood to eco-innovate. We employ the dummy variable, *subsidies*, referring to the firms' reception of funds to innovate from a public institution, although data constraints do not enable us to relate this policy to eco-innovation (Jové-Llopis & Segarra-Blasco, 2018; Triguero et al., 2013; Veugelers, 2012). Because of that, we expect that this variable and the firms' likelihood to innovate remain neutral. In addition, we controlled for firm's internal R&D expenditure and *share of exports in turnover*. Although previous literature has shown contradictory conclusions about whether R&D investment increases firms' likelihood to eco-innovate (Cainelli et al., 2015, 2012; Marzucchi & Montresor, 2017), we expect that higher levels of internal R&D expenditure will have a positive effect. Otherwise, previous studies have not found a strong relationship between firm's exports and eco-innovation. That is why we expect to find a neutral effect (Cainelli et al., 2012; Marzucchi & Montresor, 2017). Finally, we use the firm's *size* (total number of employees) and *age* (number of years since founding) to control firms' internal characteristics such as experience, management capabilities and ability to obtain resources. We accept that older and big firms may benefit from building on previous routines and capabilities to increase their likelihood to eco-innovate (Del Río et al., 2016).

At the sectoral level, based on previous literature (Del Río et al., 2016; Jové-Llopis & Segarra-Blasco, 2018; Segarra-Oña et al., 2016), we point out the existence of differences between service and manufacturing firms and their technological levels. To control these differences, we classify firms as belonging to a high or medium–high technology level in the manufacturing or services sector. We assign a group of three dummy variables based on NACE Rev.2 classification (Eurostat, 2018)—See Table 1 for further description—*high technology manufacturing*, *medium–high technology manufacturing and high technology services*. We accept that medium–high technology manufacturers are more likely to eco-innovate than any other firm (Segarra-Oña et al., 2016). Finally, regional characteristics were coded as a dummy variable: *innovative region*—taking the positive value if the firm is established in the Spanish regions of Madrid, Basque Country or Catalonia, negative otherwise. These regions are considered the most innovative Spain regions (Barajas & Huergo, 2010; Herrera & Nieto, 2008; Inigo et al., 2020). According to previous literature, we expect that being settled in these regions increases the firms' likelihood of eco-innovating due to being part of an ecosystem with broader collaborative networks (Inigo et al., 2020).

3.3 | Methods

To test our hypotheses, we established the following panel regression model.

$$logit(P(EI_{i,t})) = \beta_0 + \beta_1 EI_{i,t-1} + \beta_2 (Collab_{i,t}) + \beta_3 Z_{i,t} + \varepsilon_{i,t} + \alpha_i$$

TABLE 1 Summary statistics of the variables used in the estimations

Variables	Description	Mean (σ)
Eco-innovation	Dummy variable taking the value 1 if firm introduced any innovation with a medium or strong environmental-objective in the preceding 3 years; 0 if not	0.323 (0.468)
Scientific partners (STI)	Dummy variable taking the value 1 if firm collaborated with universities, research institutes or consultancy firms in the preceding 3 years; 0 if not	0.197 (0.398)
Suppliers	Dummy variable taking the value 1 if firm collaborated with suppliers in the preceding 3 years; 0 if not	0.123 (0.328)
Customers	Dummy variable taking the value 1 if firm collaborated with customers in the preceding 3 years; 0 if not	0.100 (0.300)
Competitors	Dummy variable taking the value 1 if firm collaborated with competitors in the preceding 3 years; 0 if not	0.067 (0.251)
R&D expenditure (log)	Log of total expenditure on research and development activities in the preceding 3 years	6.716 (6.382)
Firm age (log)	Log of number of years since firm foundation up to year of the survey	2.752 (1.224)
Firm size (log)	Log of number of full-time employees in firm in the year of the survey	4.123 (1.748)
Share of exports (%)	Share of firm's sales in non-domestic market in the year of the survey	20.278 (30.21)
Subsidies	Dummy variables taking the value 1 if firm received funds from a public institution to innovate in the preceding 3 years; 0 if not	0.150 (0.358)
Manufacturing high technology	Dummy variable taking the value 1 if firm sector is: Pharmaceutical; computing (hardware), optics or electronics and aeronautics; 0 if not	0.043 (0.202)
Manufacturing medium–high technology	Dummy variable taking the value 1 if firm sector is: Chemistry, metallurgy; electrical equipment and supplies; other machinery; motor vehicles; other transportation or other manufacturing assets; 0 if not	0.235 (0.424)
Service high technology	Dummy variable taking the value 1 if firm sector is: Computing (software) or R&D services; 0 if not	0.047 (0.202)
Innovative region	Dummy variable taking the value 1 if firm is settled in Madrid, Basque Country or Catalonia; 0 if not	0.249 (0.432)

$P(EI_{i,t})$ is the likelihood of eco-innovation for firm *i* at time *t*. We decided to deal with unobserved heterogeneity, controlling for firms' eco-innovation in the last period ($EI_{i,t-1}$). The vector $Collab_{i,t} = (STI_{i,t}, Suppliers_{i,t}, Customers_{i,t})$ captured firm *i* collaboration at time *t*. The $Z_{i,t}$ vector refers to a firm's control variables, including industrial and regional ones. This econometric approach is consistent with previous studies of firms' innovation modes (Faems et al., 2005; Fitjar & Rodríguez-Pose, 2013; González-Pernía et al., 2015; Haus-Reve et al., 2019; Jensen et al., 2007) and eco-innovation studies (Frondel et al., 2007; Marzucchi & Montresor, 2017; Veugelers, 2012; Wagner, 2007, 2008). As in previous literature (De Marchi, 2012; Haus-Reve et al., 2019; Marzucchi & Montresor, 2017), because of the unobservable influences of endogeneity, we validate our results using a fixed-effects model (also known as a 'within panel data' model).

4 | RESULTS

Table 2 shows the estimates for eco-innovation following a general-to-specific model approach. In column 1, firms' likelihood to eco-innovate is a function of itself in the previous period as well as control variables. In the next columns, several combinations of external partners are shown until the final model in which all possible combinations are analysed. As expected, innovating in the preceding period makes firms significantly more likely to eco-innovate in the analysed period. In column 2, the estimates confirm that collaborating with scientific partners, suppliers or customers independently of one another increases a firms' likelihood to eco-innovate more than firms, which do not collaborate with any partner. This result confirms our Hypotheses H1–H3, the existence of a positive effect derived from what

TABLE 2 Random-effect model, eco-innovation; unbalanced panel

Variables	(1) Coef. (SE)	(2) Coef. (SE)	(3) Coef. (SE)	(4) Coef. (SE)	(5) Coef. (SE)	(6) Coef. (SE)	(7) Coef. (SE)
Eco-innovation$_{t-1}$	2.998*** (0.031)	2.945*** (0.032)	2.945*** (0.032)	2.945*** (0.032)	2.971*** (0.314)	2.945*** (0.032)	2.950*** (0.032)
Scientific partner (STI)		0.440*** (0.040)	0.519*** (0.043)	0.580*** (0.042)		0.548*** (0.046)	0.578*** (0.047)
Suppliers		0.230*** (0.044)	0.365*** (0.063)		0.360*** (0.050)	0.196*** (0.067)	0.265*** (0.071)
Customers		0.282*** (0.050)		0.810*** (0.084)	0.450*** (0.061)	0.692*** (0.094)	0.854*** (0.109)
STI×Suppliers			−0.125 (0.083)			−0.023 (0.090)	−0.171* (0.103)
STI×Customers				−0.670*** (0.099)		−0.664*** (0.104)	−0.910*** (0.133)
Suppliers×Customers					−0.100 (0.090)	0.115 (0.097)	−0.323* (0.177)
STI×Suppliers×Customers							0.621*** (0.210)
Competitors	0.303*** (0.050)	−0.030 (0.055)	0.024 (0.054)	0.013 (0.054)	0.084 (0.054)	−0.015 (0.055)	−0.019 (0.055)
Subsidies	0.061 (0.038)	−0.087** (0.040)	−0.071* (0.040)	−0.090** (0.040)	−0.007 (0.039)	−0.085** (0.040)	−0.087** (0.040)
R&D expenditures (log)	0.189*** (0.003)	0.183*** (0.003)	0.182*** (0.003)	0.182*** (0.003)	0.185*** (0.003)	0.181*** (0.003)	0.181*** (0.003)
Share of exports (%)	0.002*** (0.001)	0.002*** (0.001)	0.002*** (0.001)	0.002*** (0.001)	0.002*** (0.001)	0.002*** (0.001)	0.002*** (0.001)
Firm size (log)	−0.004 (0.010)	−0.012 (0.010)	−0.012 (0.010)	−0.004 (0.010)	−0.013 (0.010)	−0.009 (0.010)	−0.009 (0.010)
Firm age (log)	0.142*** (0.026)	0.154*** (0.027)	0.148*** (0.027)	0.158*** (0.027)	0.148*** (0.027)	0.155*** (0.027)	0.155*** (0.027)
Manuf. (high technology)	−0.024 (0.068)	−0.178 (0.070)	−0.132 (0.071)	−0.019 (0.070)	−0.020 (0.069)	−0.017 (0.067)	−0.016 (0.070)
Manuf. (medium–high tech.)	0.221*** (0.036)	0.243*** (0.037)	0.248*** (0.037)	0.244*** (0.037)	0.226*** (0.036)	0.245*** (0.037)	0.246*** (0.037)
Service (high technology)	−0.294*** (0.069)	−0.342*** (0.071)	−0.316*** (0.071)	−0.333*** (0.071)	−0.337*** (0.070)	−0.329*** (0.071)	−0.331*** (0.070)
Innovative region	−0.178*** (0.035)	−0.171*** (0.035)	−0.164*** (0.035)	−0.175*** (0.035)	−0.181*** (0.035)	−0.173*** (0.036)	−0.173*** (0.036)
Constant	−4.061*** (0.088)	−4.010*** (0.091)	−4.087*** (0.091)	−4.150*** (0.091)	−4.056*** (0.089)	−4.121*** (0.091)	−4.130*** (0.091)
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−22264.922	−22102.469	−22117.488	−22093.201	−22164.017	−22080.19	−22075.82
Wald χ^2	17881.15 (18)	17423.94 (21)	17453.23 (21)	17449.70 (21)	17651.70 (21)	17426.82 (24)	17409.52 (25)
Observations	67,982	67,982	67,982	67,982	67,982	67,982	67,982
Firms	10,918	10,918	10,918	10,918	10,918	10,918	10,918

Abbreviation: SE, standard error.
*Significance level of 10%.
**Significance level of 5%.
***Significance level of 1%.

eco-innovation literature defines as firm's collaboration or cooperation (De Marchi, 2012; Del Río et al., 2016; Melander, 2017).

In all the model specifications, the estimated coefficients for the control variables are in line with expectations. Collaboration with *competitors* is only relevant if firms do not collaborate with any other partner. If collaboration with noncompetitive partners is taken into account, horizontal collaboration does not have a significant effect on firms' eco-innovation. Innovation *subsidies* have a negative small-size effect on firms' likelihood of eco-innovation. *R&D expenditure* has a positive effect on eco-innovation, as do firms' exports, but this last one has only a small effect size. A firm's *age* and *size* produce different results, the former having a positive impact on the firms' likelihood to innovate, and the latter not showing a significant effect. Regarding sectorial variables, *medium–high technology* manufactures are more likely to introduce eco-innovations than those of any other sector. Moreover, being a *high-tech services* firm has a negative effect on the likelihood to eco-innovate. Finally, at regional level, the results show that firms from more *innovative* Spanish *regions* do not eco-innovate more than firms from other regions.

4.1 | Estimating complementarity

To answer the main question of this research—whether or not there exist complementary effects between different types of external partners on the firms' likelihood to eco-innovate—we have to study the interactions between them. As Ai and Norton (2003) state, interactions cannot be evaluated simply by looking at the sign, magnitude or statistical significance of the coefficient on the interaction term when the model, as here, is nonlinear. Instead, the interaction effect requires computing the cross-derivative or cross-difference effects (Corneließen & Sonderhof, 2009). Thus, we have to regard with caution the estimated effect of the panel model and following that analyse the different marginal effects of each type of collaboration to provide the correct estimated interaction (Buis, 2010; Haus-Reve et al., 2019).

The estimated coefficients of the interaction terms among different types of collaboration (columns 3–6) show that the combination of two partners can have a negative ('scientific partners and customers') or nonsignificant effect ('scientific partners and suppliers' and 'suppliers and customers') on firms' likelihood to eco-innovative in comparison to a no-collaboration situation. In the final model (column 7), the collaboration with all types of partners ('STI, suppliers and customers') reflect a positive effect, while the combinations of two partners keep their negative sense but increase their statistical significance. The estimated coefficient of the collaboration with the three partners shows the second biggest impact on the likelihood of eco-innovate after customer collaboration. However, as we discuss before, the existence of an interactive between different types of external partners in this nonlinear model requires an analysis of the marginal differences (Ai & Norton, 2003; Mitchell, 2012).

The marginal difference analysis, also known as marginal analysis, computes the difference between the expected probability of eco-innovation of each partner combination rather than the derivative of the effect expected probability with respect to no-collaboration. The reason for computing the marginal effect this way is that our independent variables are categorical ones, so the discrete difference corresponds more closely with what would actually be observed in reality. Table 3 shows the marginal effects on the probability of firms' eco-innovation in different types of collaboration at average levels of the control variable. The results show that firms that do not collaborate with any partner are those that have the least likelihood to eco-innovate—only an 18% chance. Firms that only collaborate with scientific partners, suppliers or customers have a probability of 28%, 22.1% and 34%, respectively. Firms which collaborate with 'scientific partners and suppliers' increase the probability to 30% and those that collaborate with 'scientific partners and customers' and 'suppliers and customers' reduce the likelihood to innovate to 27% and 32,7%, respectively. Finally, the biggest effect on the probability of eco-innovation results from the simultaneous collaboration with the three types of partner, 35.3% chance. These estimations can be illustrated more clearly by examining them in a graphical representation. The marginal effects of different types of collaboration on the firms' likelihood to eco-innovation are shown in Figure 1.

TABLE 3 Marginal effects of different types of collaboration on eco-innovation

	Scientific partners = 0	Scientific partners = 1
Suppliers = 0, Customers = 0	0.180*** (0.003)	0.280*** (0.009)
Suppliers = 1, Customers = 0	0.222*** (0.012)	0.300*** (0.014)
Suppliers = 0, Customers = 1	0.340*** (0.024)	0.270*** (0.014)
Suppliers = 1, Customers = 1	0.327*** (0.027)	0.353*** (0.015)

*Significance level of 10%.
**Significance level of 5%.
***Significance level of 1%.

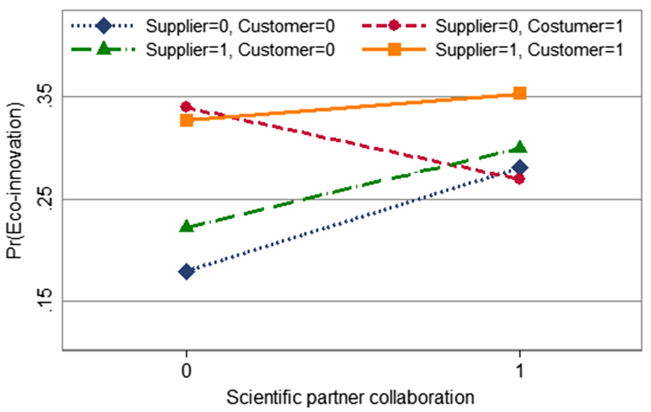

FIGURE 1 Collaboration with scientific partners, suppliers and customers and the firms' likelihood to eco-innovate [Colour figure can be viewed at wileyonlinelibrary.com]

4.2 | Robust analysis

In addition to the common test for quality of fit and performance, which support the acceptability of the estimates, we performed the robustness analysis of our principal panel random-effects regression: specifically, by running a fixed-effect panel estimation model. This model allowed us to monitor for biased firm-level heterogeneity (De Marchi, 2012; Haus-Reve et al., 2019; Marzucchi & Montresor, 2017). Table 4 shows the coefficients of using a balanced panel data set in all specifications. Although the sample was reduced

TABLE 4 Fixed effect model, eco-innovation; balanced panel

Variables	(1) Coef. (SE)	(2) Coef. (SE)	(3) Coef. (SE)	(4) Coef. (SE)	(5) Coef. (SE)	(6) Coef. (SE)	(7) Coef. (SE)
Eco-innovation$_{t-1}$	1.028*** (0.029)	1.021*** (0.030)	1.018*** (0.030)	1.023*** (0.030)	1.027*** (0.296)	1.021*** (0.030)	1.021*** (0.030)
Scientific partner (STI)		0.540*** (0.052)	0.647*** (0.056)	0.669*** (0.540)		0.659*** (0.060)	0.696*** (0.061)
Suppliers		0.239*** (0.057)	0.455*** (0.0783)		0.507*** (0.083)	0.319*** (0.084)	0.402*** (0.089)
Customers		0.282*** (0.067)		0.753*** (0.106)	0.415*** (0.065)	0.626*** (0.121)	0.832*** (0.140)
STI×Suppliers			−0.287*** (0.105)			−0.184 (0.113)	−0.366*** (0.128)
STI×Customers				−0.601*** (0.128)		−0.524*** (0.131)	−0.843*** (0.170)
Suppliers×Customers					−0.213* (0.119)	0.021 (0.125)	−0.504** (0.216)
STI×Suppliers×Customers							0.771*** (0.258)
Competitors	0.368*** (0.069)	0.084 (0.072)	0.120* (0.072)	0.111 (0.072)	0.215*** (0.071)	0.093 (0.072)	0.089 (0.072)
Subsidies	0.037 (0.055)	−0.041 (0.055)	−0.043 (0.055)	−0.043 (0.055)	0.008 (0.055)	−0.046 (0.056)	−0.049 (0.056)
R&D expenditures (log)	0.153*** (0.004)	0.147*** (0.004)	0.147*** (0.004)	0.148*** (0.004)	0.150*** (0.004)	0.146*** (0.004)	0.146*** (0.004)
Share of exports (%)	0.002** (0.001)	0.002** (0.001)	0.002** (0.001)	0.002** (0.001)	0.002** (0.001)	0.002** (0.001)	0.002** (0.001)
Firm size (log)	0.330*** (0.056)	0.300*** (0.056)	0.299*** (0.056)	0.303*** (0.056)	0.316*** (0.056)	0.300*** (0.056)	0.299*** (0.056)
Firm age (log)	0.091 (0.222)	0.163 (0.223)	0.169* (0.223)	0.169 (0.223)	0.108*** (0.022)	0.170 (0.223)	0.169 (0.223)
Manuf. (high technology)	0.140 (0.266)	0.072 (0.267)	0.086 (0.267)	0.073 (0.266)	0.106 (0.266)	0.073 (0.267)	0.059 (0.266)
Manuf. (medium–high tech.)	0.190 (0.186)	0.213 (0.187)	0.204 (0.187)	0.216 (0.187)	0.209 (0.186)	0.215 (0.187)	0.215 (0.187)
Service (high technology)	−0.162 (0.207)	−0.154 (0.208)	−0.157 (0.208)	−0.146 (0.208)	−0.147 (0.207)	−0.147 (0. 207)	−0.150 (0.208)
Innovative region	0.247*** (0.072)	0.235*** (0.073)	0.244*** (0.073)	0.227*** (0.073)	0.234*** (0.073)	0.232*** (0.073)	0.233*** (0.073)
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−10122.719	−10007.328	−10012.528	−10004.502	−10061.192	−9995.288	−9990.826
Wald χ^2	4228.34 (18)	4459.12 (21)	4448.72 (21)	4464.77 (21)	4351.39 (21)	4483.20 (24)	4492.12 (25)
Observations	30,199	30,199	30,199	30,199	30,199	30,199	30,199
Firms	4,238	4,238	4,238	4,238	4,238	4,238	4,238

Abbreviation: SE, standard error.
*Significance level of 10%.
**Significance level of 5%.
***Significance level of 1%.

from 10,918 to 4,238 firms, the effects of each type of individual collaboration are positive and significant, so H1–H3 are accepted. As in the random-effect model, single customer collaboration is the one that has the highest coefficient. The interaction term of the cooperation with two types of partners is negatively statistically significant, and only the cooperation with scientific partners, suppliers and customers is statistically positive, confirming the results for H4 obtained in the random model.

5 | DISCUSSION

We used data on 10,918 innovative Spanish firms to study how the collaboration agreements with external stakeholders impact the firms' likelihood to eco-innovate. Collaboration with external partners plays a crucial role in increasing firms' likelihood to eco-innovate because it is done either to pursue sustainable goals together (Behnam et al., 2018; Planko et al., 2019; Wei et al., 2020), to generate economies of scale orientated to reduced environmental impact (Melander & Pazirandeh, 2019; Melane-Lavado & Álvarez-Herranz, 2020; Pellegrini et al., 2019) or to increase the creation of value for society and itself (Cuerva et al., 2014; Ghisetti et al., 2015; Horbach et al., 2013). However, several empirical works have found contradictory results about the complementariness of specific combinations of external partners (Hofman et al., 2020; Kobarg et al., 2020; Melander, 2020; Rauter et al., 2019; Wei et al., 2020). To address this debate, we analysed all possible combinations of collaborations with 'scientific partners, suppliers and customers' to examine whether the interaction between them generates complementary effects on firms' likelihood to eco-innovate or not. We analysed the data using a marginal effects approach and this analysis suggested important results for eco-innovation literature.

First, collaboration with any type of noncompetitive partner—scientific partner, supplier or customer—increases the firms' likelihood to eco-innovate. This result confirms an extended point of view in eco-innovation literature, namely, that collaboration is a key determinant of eco-innovation (De Marchi, 2012; Horbach, 2008; Mazzanti & Zoboli, 2009). In addition, our results show that customers are the most important partner for increasing firms' likelihood to eco-innovate. Firms' could orientate their eco-innovation activities to introduce ecofriendly products that the customer can easily verify (De Marchi & Grandinetti, 2013). This orientation generates a lot of benefits, such as the changing of customers' mentality and improving the firms' image, but this could also limit other types of eco-innovations which would have a more critical impact on the environment before the product reaches the customer (Melander, 2018).

Second, multi-partner collaboration does not always generate complementary effects. The simultaneous existence of partial-complementary and substitute effect can explain why the previous literature contains contradictory results (Hofman et al., 2020; Melander, 2020; Rauter et al., 2019; Wei et al., 2020). Our marginal analysis shows that 'scientific partners and suppliers' increases firm's likelihood to eco-innovate to a higher level than collaborate with only one of them. This positive effect supports studies, which find positive effects (Bönte & Dienes, 2013; Kobarg et al., 2020; Melander, 2020), either because of a firm's increase in access to external resources or because the reduction of the transaction costs when tangible resources or new technologies are shared (Cainelli et al., 2012; Foster & Green, 2000; Johnsen, 2009; Steward & Conway, 1998). Although it is true that the combination of both does not have a multiplicative or additive effect, only a partial complement effect from a marginal perspective, this can be the explanation for the negative results shown by several studies (Hofman et al., 2020; Marzucchi & Montresor, 2017; Mothe et al., 2018). A partial substitutive effect can be caused by the cost of coordination between the partners (Albort-Morant et al., 2018; Ghisetti et al., 2015), trust issues (González-Moreno et al., 2019; Melander & Pazirandeh, 2019) or the difficulty in aligning their interest (Ketata et al., 2015). The substitutive effects are clearer when we studied the combinations of customer collaboration with scientific partners (Kobarg et al., 2020; Mothe et al., 2018; Rauter et al., 2019) or suppliers (Hofman et al., 2020; Wei et al., 2020). In these cases, the firms' likelihood of eco-innovation is reduced in comparison with collaboration with customers alone.

Finally, only firms that collaborate with the three external partners can reach the maximum likelihood of eco-innovation. It is a partial complementary effect, but it is the only combination, which can overcome the effect of collaboration with customers. This result is in line with studies, which have addressed the complementary effect from collaboration network and environment approaches. In these situations, the firms live in a community and are not seen as individuals but rather members of a network, which have sustainability goals in common (Dahl, 2014; Folke, 2006). Planko et al. (2019) and Wei et al. (2020) showed that there are some industries in which this perspective is more relevant and could increase the likelihood of eco-innovation together. Moreover, being part of this network or environment could encourage firms to change their behaviour and values to become more environmentally friendly as a way of creating value for the community where the firms are located (Marcon et al., 2017).

6 | CONCLUSIONS

Building on collaborative networks and open-eco innovation theory, this research set out to understand how collaboration agreements with different stakeholders such as scientific partners, suppliers and customers increase the firms' likelihood of eco-innovation and whether their combination produces a complementary or substitute effect. We examine the question empirically by steering the nature of the interaction between different combinations. Because of that we were able to show how firms' eco-innovation could benefit the most from external collaboration.

Our results offer a point of view, which is able to unite both sides of the discussion about the complementary or substitutivity effect of external collaboration. We contribute to open eco-innovation and collaboration network theories by extending prior analyses and moving beyond the dichotomic debate by using a marginal analysis approach.

This approach allows us to analyse the interactions, opening a window to discover mixed and partial interactive effects. Thus, we discovered that customer collaboration is what marginally increases a firm's likelihood of eco-innovating the most and that the combination of this important partner with others, such as scientific partners or suppliers, generates partial substitutive effects. We also found that simultaneous collaboration with scientific partners and suppliers increases their individual impacts, generating a partial complementary effect, and that collaboration with all external partners can reach the highest level of firms' likelihood to eco-innovate. In this way, we respond to recent calls which emerged in several eco-innovation literature reviews about the necessity of analysing the complementarity effect between external partners in depth (Dangelico, 2016; Del Río et al., 2016; Ehls et al., 2020; Johnsen, 2009).

These findings have important implications for firm managers but also for researchers and policy designers. First, business strategy and open innovation theory always point out the benefit of engagement in collaboration agreements with multiple external stakeholders on firms' likelihood to eco-innovate (Melander & Pazirandeh, 2019; Pellegrini et al., 2019; Planko et al., 2019; Wei et al., 2020). Our results suggest that firms must consider carefully their partner selection, based on their business strategy (Ma et al., 2017). For example, simultaneous collaboration with scientific partners, suppliers and customers increases the firms' likelihood to eco-innovate, while customer collaboration is what will marginally increase the firms' likelihood of eco-innovating. We suppose that it is very likely that collaboration with customers will orientate firms' activities to introduce eco-innovations that markets can easily recognise. Hence, knowing that firms' resources are limited, we believe that this eco-innovation could break others, which would have a more critical impact on the environment, such as on those related to the supply-chain efficiency or new technologies obtained from the collaboration with scientific partners and suppliers (De Marchi & Grandinetti, 2013). Based on this, we suggest that managers should align their collaborative agreements with those external stakeholders who better complement their objectives rather than establish a 'catch-all' partnership strategy.

Second, methodologically our findings suggest the importance of introducing marginal difference analysis to estimate interaction terms between independent variables on nonlinear models. Although interaction terms are used widely in applied econometrics, and many researchers know the correct way to interpret them, most applied researchers misinterpret the interaction term's coefficient (Ai & Norton, 2003; Buis, 2010). Thus, our work and that of others like the Kobarg et al.'s (2020) research, open a window in eco-innovation literature to expand and make more robust the studies about how determinants of firms' eco-innovation interact between them.

Third, our results suggest that public institutions need to create specific instruments such as public-supported R&D collaboration, subsidies or tax incentives to encourage firms to eco-innovate. As we report in our results, the standard innovation subsidies programme could not achieve this objective, so they have to be redefined. Moreover, public sponsored R&D collaboration could be the best way for institutions to develop an ecosystem in which sustainability goals are coordinately pursued together between different types of agents (Bengtsson & Kock, 2000; Dahl, 2014; Folke, 2006).

This study is not without limitations, and addressing them may open new research avenues. First, although this study focuses on the impact of external stakeholder engagement, we do not examine its interaction with internal dimensions—such as absorptive capacity, social capital or corporate social responsibility (CSR) strategy (Du et al., 2018; Hagedoorn & Wang, 2012; Ketata et al., 2015; Melander, 2018). It is undeniable that these dimensions would moderate the effect of multi-partner collaboration on firm's likelihood to eco-innovate and that is why we encourage tracking research to try to follow this lead to joint internal and external dimensions. Second, our data show how external collaboration interacts in a developed country over a long period, but further analyses need to be done with samples from different countries and with more recent observations. Specifically, we need to focus on firms from nondeveloped regions to be able to draw universally applicable conclusions (Hofman et al., 2020; Sanni, 2018). More recent observations could offer a new perspective of how firms' external collaboration is evolving as society is becoming aware of the importance of pursuing sustainable goals. Finally, the binary structure of our dependent variable limits our understanding of the quality and complexity of eco-innovations. Further investigations need to be done using, for example, the patents' relevance as a proxy or the quality of the eco-innovation, or other innovation surveys, which analyse in-depth eco-innovation like the Mannheim Innovation Panel (Kobarg et al., 2020).

Taking these caveats into account, the results, nevertheless, provide considerable food for thought about the scope of external collaboration needed for firms to eco-innovate. Overall, the results supply new ideas about what types of external stakeholders are needed in order to maximise eco-innovation outputs and about whether firms need to consider different combinations of partners based on what their business and environmental strategies are.

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APPENDIX A

TABLE A Correlation matrix

	Eco-Inno.	STI	Supplier	Customer	Competitors	Size	Age	Export	R&D expenditure	Subsidies	Innovative region	Manuf. High	Manuf. M-H	Service H-T
Eco-innovation	1.000													
STI	0.317	1.000												
Supplier	0.250	0.474	1.000											
Customer	0.240	0.503	0.477	1.000										
Competitors	0.174	0.424	0.340	0.402	1.000									
Firm size (log)	0.113	0.096	0.170	0.065	0.086	1.000								
Firm age (log)	0.029	−0.002	0.034	0.004	−0.002	0.126	1.000							
Export (%)	0.171	0.111	0.087	0.093	0.037	0.075	0.082	1.000						
R&D expenditure (log)	0.510	0.440	0.337	0.323	0.268	0.176	−0.015	0.242	1.000					
Subsidies	0.246	0.436	0.251	0.331	0.297	0.048	−0.058	0.096	0.443	1.000				
Innovative region	0.268	0.240	0.178	0.209	0.170	0.061	0.007	0.190	0.561	0.285	1.000			
Manufacturing high technology	0.076	0.065	0.039	0.047	0.041	−0.014	0.003	0.097	0.147	0.061	0.159	1.000		
Manufacturing medium–high technology	0.134	0.009	0.014	0.023	−0.044	−0.069	0.045	0.259	0.133	0.011	0.114	−0.117	1.000	
Service high technology	0.020	0.117	0.059	0.135	0.118	−0.068	−0.067	−0.054	0.120	0.184	0.068	−0.047	−0.123	1.000