Journal of Cleaner Production 384 (2023) 135479

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Cooperation with the Triple Helix and corporate environmental innovation

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A R T I C L E I N F O

Handling Editor: Dr. Govindan Kannan

Keywords:
Cooperation
Triple helix
Environmental innovation
Synergic effect
Panel data

A B S T R A C T

This paper investigates the possible synergic effect of the cooperation between firms and the main agents of the Triple Helix approach (academia, industry and government) on corporate environmental innovation. The results of analysing a broad sample of Spanish firms from various sectors (38,269 observations) over a 9-year period show that cooperation between firms and Triple Helix agents, both individually and jointly, increases the likelihood of corporate environmental innovation. Indeed, the more Triple Helix agents involved in cooperation with firms, the greater the likelihood of corporate environmental innovation. In addition, for the same number of Triple Helix agents involved, the influence of cooperation on corporate environmental innovation depends on the type of agents. Consequently, the paper provides empirical evidence of the existence of a synergic effect of cooperation on environmental innovation.

1. Introduction

The pressure exerted by different stakeholder groups for firms to decrease the impact of their activities upon the environment is increasing. In this context, firms are taking environmental factors into consideration in their strategic and innovation decision-making processes (De Marchi et al., 2022).

Environmental innovation or eco-innovation (EI) is a crucial element to improve the environmental performance of organisations (Carrillo-Hermosilla et al., 2010; Del Río et al., 2016; He et al., 2018), but it requires technological capabilities (Hart, 1995; Horbach, 2008; Triguero et al., 2013), which turns R&D into a key factor. However, as with R&D in general, environmental R&D comes with high risk and costs (García Martínez et al., 2014; Lin, 2019). Indeed, uncertainty is an especially relevant factor when it comes to EI, to the point of the recognition of the higher level of complexity associated with EI, compared to other types of innovation (Niesten et al., 2017; Awan and Sroufe, 2020).

The adoption of an open innovation approach, such as R&D cooperation strategies and networking with external collaborators, can help overcome the barriers associated with EI (Wiesmeth, 2020; Chistov et al., 2021a; De Marchi et al., 2022), by facilitating knowledge transfer for the development of EI. Interaction promotes the exchange of knowledge and the access to complementary resources and capabilities, as well as contributing to the advancement of knowledge overall (Faucheux and Nicolaï, 2011; Xie and Wang, 2020). Close cooperation between public and private agents can act as a powerful catalyst to address environmental issues, while giving firms the opportunity to reduce risks or costs and enhance their competitive advantage (Mirata and Emtairah, 2005; Niesten and Jolink, 2020).

Cooperation for EI in firms is receiving considerable attention in recent decades (Pereira et al., 2020). This is shown in the comprehensive bibliometric study by Chistov et al. (2021a), which illustrates the growing interest in the use of open innovation in the process of EI, exploring the wide variety of synonyms that have been used in the theoretical literature to name this phenomenon, especially since 2010: “Open eco-innovation” (OEI) (Ghisetti et al., 2015; González-Moreno et al., 2019; Garcia et al., 2019), “open environmental innovation” (De Marchi and Grandinetti, 2013; Spena and Di Paola, 2020), or “inter-organizational collaboration (cooperation) in eco-innovation” (Melander, 2017; Fernández, 2019; Pereira et al., 2020), among others. Also, the terms "sustainable open innovation" or "open innovation for sustainable innovation" (Perl-Vorbach et al., 2014; Rauter et al., 2017; Bogers et al., 2020), which are often used interchangeably, although it should be noted that they refer to a broader concept. Sustainability encompasses three dimensions: economic, social and environmental (Elkington, 2018), so these terms would include not only the development of environmental innovation, but also economic and social innovations. The latter is beyond the scope of our work, which focuses exclusively on the environmental dimension of sustainability.

Despite the interest in the topic, academic research on OEI is still in

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https://doi.org/10.1016/j.jclepro.2022.135479
Received 10 May 2022; Received in revised form 30 November 2022; Accepted 1 December 2022
Available online 6 December 2022

its early stages (Chistov et al., 2021a), without even a clear definition of the concept of OEI (González-Moreno et al., 2019), nor a precise delineation of the boundaries of this line of research. For this reason, it is encouraged to deepen the knowledge achieved to date and to provide additional empirical evidence. Pereira et al. (2020) point out that empirical studies are still scarce and propose future research on corporate environmental innovation from an integrated perspective, with the participation of different actors.

In this context, Etzkowitz and Leydesdorff's (1995) Triple Helix theoretical approach can be very useful for advancing this line of research. This approach stresses the importance of cooperation between various key agents, both public and private, for the development of innovation systems. Authors such as Hernández-Trasobares and Murillo-Luna (2020) provide empirical evidence of the synergic effect of cooperation with the Triple Helix agents on business innovation, in general.

Cooperation for environmental innovation from the Triple Helix approach has already been studied in previous research. However, the empirical evidence offered to date is limited. Case studies clearly predominate (Yang et al., 2012; Tamayo-Orbegozo et al., 2017; Yang et al., 2019; Rowan and Casey, 2021, among others) and, to a much lesser extent, we find eminently theoretical papers (Anttonen et al., 2018; Gkoumas and Christou, 2020; Quartey and Oguntoye, 2021), descriptive analyses (Janahi et al., 2022), or cross-sectional studies (Anttonen et al., 2018; Cassetta et al., 2022).

Thus, the objective of this study is to analyse the potential synergic effect of the cooperation of firms and the key Triple Helix agents on EI, providing ample empirical evidence, based on an extensive sample of Spanish firms from various sectors over a period of several years, through the application of the panel data analysis methodology. The aim is to replicate Hernández-Trasobares and Murillo-Luna's study (2020), focusing on environmental innovation, in particular. It should be noted that Hernández-Trasobares and Murillo-Luna's study (2020) had a more generalist approach, taking product and process innovation as a reference, without considering in any case the environmental factor, which is the subject of study in this work.

The contribution of this study to the existing literature lies precisely in the methodology of analysis used, which, based on the large number of observations available, provides ample empirical evidence about the topic. The methodology of panel data analysis has been used to study EI issues, such as Silva Rabêlo and de Azevedo Melo's (2019) paper on the drivers of multidimensional corporate environmental innovation, which provides empirical evidence from the Brazilian industry. However, as far as our search has been able to reach, we have not found a previous study dedicated to the analysis of the possible synergic effect of cooperation for environmental innovation in the firm from the theoretical approach of the Triple Helix, in which such extensive empirical evidence is provided through panel data analysis.

We conclude this section by clarifying that in this paper the study of the synergic effect is addressed at the meso level, i.e. the focus is on the analysis of cooperation between various actors and the choice of partners (Chistov et al., 2021a,b). From the prism of the multilevel approach (micro, meso y macro), Garcia et al. (2019) highlight the complexity associated with environmental innovation, in particular because of value creation and value capture in the multilevel open environmental innovation process. Value is created at the level of the individual firm (micro) and co-created among stakeholders (meso), but the main value capture targets are expected to reach the natural environment and society (macro level).

Finally, the study is structured as follows: first, we present the theoretical framework. The following section presents and describes the methodology used, followed by the results of the analysis. Finally, we present the discussion of the results and the main conclusions, limitations and future lines of research.

2. Theoretical framework

Firms have been forced to adapt their strategies, incorporating environmental aspects into the strategic management process to reduce the environmental impact of their activity (Martín-de Castro et al., 2020). In this context, the importance of EI is indisputable (Pan et al., 2020).

Beise and Rennings (2005, p.6) define the environmental innovation concept as "*new or modified processes, techniques, practices, systems and products to avoid or reduce environmental harms*". Two years later, Kemp and Pearson (2007, p.7) propose another definition, as "*the production, assimilation or exploitation of a product, production process, service or management or business methods that is novel to (firms) and which results, through-out its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives*". This is an intentionally broad definition, which includes changes to both products and/or business processes, in order to achieve environmentally sustainable objectives (Cainelli et al., 2015).

In 1995, Hart proposed the Natural-Resource-Based View of the firm, which highlights the importance of knowledge, resources and capabilities for environmental innovation. According to Cainelli et al. (2015), the resources and capabilities necessary for EI can be acquired or developed by firms internally (internal R&D activities, human resources training), or externally (inter-organizational relationships, alliances and networks).

However, many companies face major barriers to EI, including unfavourable internal company conditions due to lack of financial resources or low technological competence (Del Río et al., 2010). There are firms that do not have the resources and capacities required for EI and others for which, although they do not have this difficulty, it is too expensive or time-intensive to develop internally (Kazadi et al., 2016). In these cases, cooperation strategies have become a key determinant to cope with EI barriers (De Marchi, 2012). It is an alternative that makes available external resources and capabilities that would otherwise not be accessible to the firm, as well as diversifying risks (Cainelli et al., 2015). This is demonstrated by studies developed over the last decade, which conclude that cooperation is a very important factor, even more so than in other types of innovation, because of the complex and systemic nature of EI (Chistov et al., 2021a).

Consequently, open environmental innovation is a widespread practice among firms. The term open innovation (OI) was coined by Chesbrough (2003), although collaborative strategies for seeking external resources for the development of environmental innovation in organisations go back much further (Chistov et al., 2021a). The concept of open environmental innovation is more recent, with one of the first approaches being found in Winston (2010).

Chistov et al. (2021a, p.3) define the concept of "open eco-innovation" (OEI) as "*the use of purposive inflows and outflows of knowledge, resources and commercialization paths to develop and/or adopt innovations improving the environmental performance of firms*". They also identify what the main features of the OEI are: the main objective of reducing the environmental impact of the organisations' activity; the focus on two-way information and knowledge flows, which may also include access to external physical and financial resources; the help to overcome internal constraints, favouring the acceleration of innovation in organisations; knowledge and information gain through cooperation with external partners, R&D acquisition and interaction in environmental innovation ecosystems; and finally, the scalability of the benefits of environmental innovation, as the intellectual capital generated can be patented, registered and shared (licensed) outside the organisation, which multiplies the positive impact on society and the environment.

The Triple Helix model, proposed by Etzkowitz and Leydesdorff (1995), has been used for the theoretical foundation of cooperation for EI between firms and external actors, in the context of the OEI (recently, Gkoumas and Christou, 2020; Rowan and Casey, 2021; Quartey and Oguntoye, 2021; Cassetta et al., 2022; Janahi et al., 2022, for example).

It describes innovation, in general, as a cooperative creative effort in which the involvement of three key agents – academia, industry and governments – plays a crucial role. The interaction of these agents facilitates the exchange of resources, capabilities and know-how (Badillo et al., 2017) and helps to generate synergies that favour innovation (Leydesdorff and Etzkowitz, 1996; Etzkowitz and Leydesdorff, 2000).

Concerning cooperation with universities and research centres and agencies, authors such as Galliano and Nadel (2015), Triguero et al. (2016), Hroncova Vicianova et al. (2017), Zubeltzu-Jaka et al. (2018) and Pereira et al. (2020) highlight the positive contribution of these partners to the development of environmental innovation. De Marchi et al. (2022) explain that each actor provides different capabilities and contributes differently to environmental innovation (Watson et al., 2018). Universities and research centres provide complementary expertise for the development of advanced environmental innovations (De Marchi and Grandinetti, 2013; Di Maria et al., 2019; Triguero et al., 2013). The ability to develop new and advanced knowledge, which transcends traditional business boundaries, is a specific capacity of these partners, which can be particularly useful for corporate environmental innovation (De Marchi and Grandinetti, 2013; Triguero et al., 2013; Di Maria et al., 2019). Universities are specialised knowledge suppliers (Cainelli et al., 2015). Scarpellini et al. (2017) argue that this collaboration allows firms to upgrade their internal technological capabilities, while reducing the risk inherent in environmental innovation activities. Triguero et al. (2013, 2015) agree that this type of cooperation allows access to external knowledge and the development of networking technological capabilities. Given the complexity of this type of innovation, this cooperation is particularly important for environmental innovation (De Marchi, 2012). It can be beneficial for eco-product innovation (Triguero et al., 2013) and is essential for the development of radical environmental innovation (Del Río et al., 2015). Consequently, Fabrizi et al. (2018) recommend the involvement of scientific profiles that collaborate in this type of projects.

Despite this, Durán-Romero and Urraca-Ruiz (2015) point out the scarce participation of universities in the development of environmental innovation. This is something that draws attention, especially when innovation-related studies have highlighted the increasing degree of cooperation between firms and universities, among other external agents, in the development of new products and processes (Belderbos et al., 2004). One possible explanation is the drawback of the divergence that may occur between the two partners' motivations for collaboration (research and economic performance, i.e. scientific publications for academics and environmental innovations that contribute to reducing environmental impact for firms), which could limit the application or exploitation of the knowledge generated at the firm level (Di Maria et al., 2019). In any case, De Jesus Pacheco et al. (2017) understand that cooperation for environmental innovation is one of the great challenges for the future, an opportunity to establish links between universities and research centres and companies.

These arguments lead us to put forward the following hypothesis:

Hypothesis 1a. Cooperation with academia increases the likelihood of corporate environmental innovation.

Regarding cooperation with industry, Díaz-García et al. (2015) highlight the importance of networking with other companies for environmental innovation, because it facilitates the search for environmentally sustainable technological solutions.

Firms can cooperate to eco-innovate with value chain partners (such as customers and suppliers) and with other market partners such as competitors (Pereira et al., 2020). With regard to value chain partners, firms cooperate with suppliers and business clients to ensure the supply of eco-friendly inputs or components, promote recycling in productive processes and innovate green products (Seuring and Müller, 2008; De Marchi, 2012; Melander, 2018). Suppliers can help firms better understand the life cycle of new environmental technologies and improve the outcome of environmental innovation. As for customers, they can contribute to improve the firm's knowledge and propose solutions to new demands, including the challenge of achieving more sustainable economies (Fabrizi et al., 2018; Melander, 2018; De Stefano and Montes-Sancho, 2018; Kiefer et al., 2019). This type of collaboration with value chain partners contributes, in particular, to the promotion of environmental innovation in SMEs (Triguero et al., 2015). Regarding other partners such as competitors, Mirata and Emtairah (2005) also stress the potential of collaboration between firms with shared interests for the development of innovation activities aimed at facing industry's multiple and varied environmental challenges. For this reason, they emphasise the benefits of inter-organisational and inter-sectoral cooperation.

Cooperation between firms generates a feeling of trust which encourages the dissemination and adoption of external knowledge and promotes product (Dangelico, 2016), process and management environmental innovation (He et al., 2018). Firms thus gain access to new environmental expertise, knowledge or technology and overcome barriers of access to information that could potentially lead to environmental gains.

On the basis of the above arguments, the following hypothesis is proposed:

Hypothesis 1b. Cooperation with industry increases the likelihood of corporate environmental innovation.

As regards governments, public-private collaboration in R&D can contribute to improving firms' internal technological capabilities for the development of environmental innovation (Horbach et al., 2013; Del Río et al., 2015). Through cooperation, both parties share resources and risks, but also the benefits of environmental innovation (Lin, 2019).

Public policies can be very useful to promote environmentally friendly technologies. This is the conclusion reached by Aldieri et al. (2019), after analysing the public policy strategies introduced to support diffusion of this type of technologies. Therefore, they recommend the implementation of a coherent policy mix to achieve sustainable economic growth, ensuring that it particularly contains a supportive cooperation strategy.

Government cooperation for clean technology development can be carried out through direct and indirect public instruments (Lin, 2019). Existing and future environmental regulation definitely play a key role in environmental innovation (Horbach et al., 2012; Blundel et al., 2013). However, market-based instruments for environmental protection have an even greater effect than command-and-control approaches (Jaffe et al., 2005), hence the importance of public policies based on supportive cooperation strategies that favour environmental innovation.

Public support can consist of funding or the development of structures to provide consultancy or advisory services, favouring the dissemination of environmental innovation (Freitas and Von Tunzelmann, 2008). In relation to subsidies, Horbach (2008) explains that they are more important to environmental innovation than to other types of innovation, and have a positive effect on environmental product innovation.

Therefore, the third hypothesis is set out below:

Hypothesis 1c. Cooperation with government increases the likelihood of corporate environmental innovation.

According to the above arguments, cooperation for innovation with the three main Triple Helix agents can favour EI. But what if firms join forces with more than one Triple Helix partner for environmental innovation cooperation activities? Melander (2018), for instance, explains that inter-firm cooperation rarely happens in isolation, but generally takes place in a network context. Industrial ecosystems or industrial symbiosis facilitate the promotion of forums for the research and development of new ideas aimed at finding solutions to environmental problems connected with business activities (Chertow, 2000; Puente et al., 2015; Tseng and Bui, 2017). On the other hand, Christensen et al. (2019) highlight the power of public policy to improve collaboration between firms and other partners. Authors such as Arranz and Arroyabe (2008) and Busom and Fernández-Ribas (2008) claim that capturing R&D public subsidies increases the chances of establishing cooperation agreements with other agents.

Markovic and Bagherzadeh (2018) argue that, the larger the number of partners involved, the greater the positive impact on innovation. Carrillo-Hermosilla et al. (2010) explain that the success of environmental innovations depends, to a large extent, on the participation and involvement of different stakeholders in their development, being very likely to be obtained as a result of cooperation between the public sector, academia and industry. Therefore, it can be understood that the more Triple Helix agents involved in cooperation with firms, the greater the positive effect on environmental innovation.

These arguments lead us to propose the following hypothesis, to be empirically tested (Fig. 1):

Hypothesis 2. The greater the number of Triple Helix agents involved, the greater the likelihood of corporate environmental innovation.

3. Materials and methods

3.1. Sample

In this research, we have based our analysis on data from the Spanish Technological Innovation Panel (PITEC), an unbalanced database published by the Spanish National Statistical Institute (INE) and the Spanish Foundation for Science and Technology (FECYT). This database includes information about technological and environmental innovation activities of Spanish firms, being one of the most widely used in the literature related to innovation (Laursen and Salter, 2006; De Marchi, 2012; Hernández-Trasobares and Murillo-Luna, 2020). Further information is available at: https://icono.fecyt.es/PITEC. In our case, we have gathered information of more than 12,000 firms from different industries during the period 2003–2016. However, it should be noted that the sample was limited to 2008–2016, as some of the variables used are not available in previous years.

Firms for which some data are missing owing to special circumstances (absorption, merge, temporary closures, final closures, sleeping firms, untraceable firms, etc.), firms for which information concerning all the variables considered in the model is not available and outliers have been removed from the sample. Finally, in order to keep the sample homogeneous, only firms for which data is available for a period of at least four consecutive years have been included in the sample. The final sample is thus an unbalanced panel including 5,489 firms from different industries (38,269 observations), which will allow the application of econometric panel data techniques.

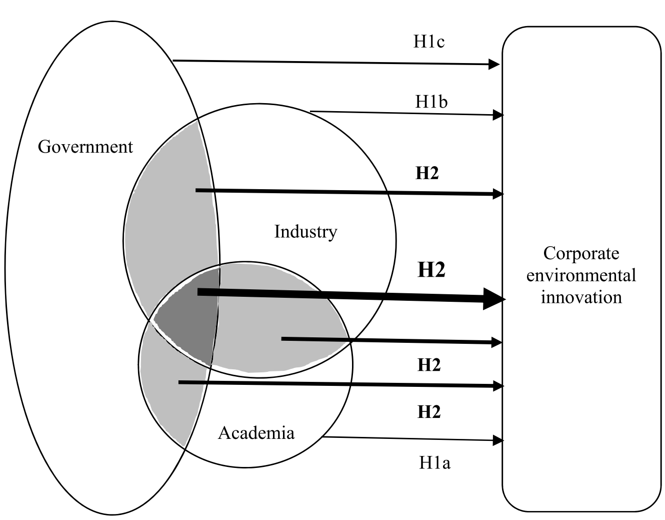

Fig. 1. Hypotheses of the study
Source: Prepared by the authors.

3.2. Variables

Following our hypotheses, corporate environmental innovation is the dependent variable (ENV_INN). It is a variable based on a question of PITEC database asking about the “importance of reducing environmental impact”. Respondents could choose among four possibilities, reporting if this effect was null, low, medium or high. The dependent variable ENV_INN takes the value 1 if the company reported high or medium importance of this effect and 0 otherwise. This variable has been previously used by other authors as a proxy for environmental innovation (Horbach, 2008; De Marchi, 2012; Cainelli et al., 2015; Marzucchi and Montresor, 2017).

PITEC defines cooperation for innovation as the active participation with other companies or non-commercial entities in activities of innovation. It is not necessary for both parties to extract a commercial benefit. The outsourcing of work is excluded without active cooperation. The model’s explanatory variables are defined from the cooperation for innovation variables available in PITEC, which consider each of the main Triple Helix agents separately. The following three PITEC codes have been used: a) Code COOP (period 2008–2011); b) Code COOPNEW (period 2012–2015); c) Code NEWCOOP (year 2016). These categorical variables are used to determine the type of partner the firm cooperates with: other firms within the same group; hardware and software suppliers; customers (public or private); competitors and other firms in the sector; consultants; commercial laboratories; private R&D institutes; universities and other higher education institutions; research centres or agencies (public or private); and technological centres.

Based on the PITEC variables codes above, following the Triple Helix approach, and taking as reference Hernández-Trasobares and Murillo-Luna’s (2020) work, three kinds of cooperation are considered: a) Industry (Helix 1): when cooperation takes place with another agent in the market which operates with the firm, in this case firms in the same group; hardware and software suppliers; customers; competitors; other firms in the same sector; consultants; and commercial laboratories; b) University (Helix 2): when cooperation takes place with universities and other higher education centres; c) Governments (Helix 3): when cooperation takes place with governments. In PITEC this cooperation includes the provision of subsidies (regional, national and international subsidies) as well as the cooperation through public institutions.

PITEC also includes cooperation with research centres and agencies (public and private) and technological centres, which often involve the interaction of more than one helix. For instance, technological centres frequently involve the cooperation of governments, universities and private firms (three helices). This has been taken into consideration for the analysis of the type of cooperation undertaken by each firm.

In this paper, all cooperation variables considered are binary variables, which have a value of 1 when the firm cooperates in the way described. The Cooperation (COOP) variable indicates whether the firm cooperates, regardless of the specific partner. The Industry Cooperation (H_IND), University Cooperation (H_UNI) and Government Cooperation (H_GOV) variables have a value of 1 if the firm cooperates with industrial agents, universities and governments, respectively, and 0 otherwise. Also considered are Three-Helix Cooperation (COOP_3H), Two-Helix Cooperation (COOP_2H) and One-Helix Cooperation (COOP_1H) variables, which have a value of 1 when the firm cooperates with three, two or one helices respectively, and 0 otherwise. Finally, the following dummy variables have been considered (Hernández-Trasobares and Murillo-Luna, 2020): cooperation with academia-government-industry (COOP_UNI_GOV_IND), cooperation with academia-government (COOP_UNI_GOV), cooperation with academia-industry (COOP_UNI_IND), cooperation with government-industry (COOP_GOV_IND), cooperation only with academia (COOP_UNI), cooperation only with industry (COOP_IND) and cooperation only with government (COOP_GOV).

These variables have a value of 1 if the firm cooperates with the agents involved in each case, and 0 otherwise.

Some of the usual control variables are also used (Horbach, 2008; De Marchi, 2012; Fitjar and Rodríguez-Pose, 2013; González-Pernía et al., 2015; Triguero et al., 2017; Marzucchi and Montresor, 2017; García-Pozo et al., 2018; Hernández-Trasobares and Murillo-Luna, 2020). With regards to the binary control variables, the Innovation variable (INN) is a variable whose value is 1 when the firm innovates in products or processes and 0 otherwise (De Marchi, 2012; González-Pernía et al., 2015; García-Pozo et al., 2018). PITEC provides data in both cases, considering that a firm innovates in product if it has introduced significant product (goods or services) improvements in the last three years (from t-2 to t); similarly, it is considered that the firm innovates in processes if it has introduced significant process improvements (manufacturing or production systems; logistics systems; or process support activities) in the last three years (from t-2 to t). The Export (EXPORT) variable is a binary variable to reflect whether the firm exports (De Marchi, 2012; González-Pernía et al., 2015; Marzucchi and Montresor, 2017). The Public Enterprise (PUBLIC) variable is a binary variable to reflect whether the firm is publicly owned (De Marchi, 2012; Triguero et al., 2017). The Group (GROUP) binary variable reflects whether the company is part of a holding (Triguero et al., 2017; Marzucchi and Montresor, 2017). The R&D External Costs (IDEX) and Internal Costs (IDIN) variables have a value of 1 if the firm incurs internal/external costs in technological innovation and 0 otherwise (González-Pernía et al., 2015).

Finally, four other control variables are used. R&D Personnel (RD_P) is the ratio between the firm's R&D-related workforce and the total workforce (Triguero et al., 2017; Marzucchi and Montresor, 2017). Age (LN_AGE) reflects the age of the company expressed logarithmically (Marzucchi and Montresor, 2017; García-Pozo et al., 2018). Size (LN_SIZE) reflects the size of the workforce expressed logarithmically (Marzucchi and Montresor, 2017; García-Pozo et al., 2018). Productivity (LN_PRODUCT) is the coefficient between sales and workforce, expressed logarithmically (González-Pernía et al., 2015; García-Pozo et al., 2018). Finally, temporal and sectoral dummy variables are used in order to correct possible year- and industry-specific effects on econometric results. More specifically, and according to the information provided by PITEC database, eight industry control variables (SECTOR) and nine temporal control variables (YEAR) have been used (period 2008–2016). Although they are not included in the results, they enable a better formulation of the econometric models.

In more detail, Table 1 summarises the variables used in the study.

Table 1
Description of the variables.

Dependent variables	
ENV_INN	Dummy, 1 if the reduction of the environmental impact through innovation is a highly or moderately important target for the firm.
Explanatory variables	
COOP	Dummy, 1 if the firm cooperates with industry, academia or the government
H_IND	Dummy, 1 if the firm cooperates with industry
H_UNI	Dummy, 1 if the firm cooperates with academia
H_GOV	Dummy, 1 if the firm cooperates with government
COOP_3H	Dummy, 1 if the firm cooperates with all three helices (industry-academia-government)
COOP_2H	Dummy, 1 if the firm cooperates with two helices (industry-academia, industry-government or academia-government)
COOP_1H	Dummy, 1 if the firm cooperates with a single helix (industry, academia or government)
COOP_UNI_GOV_IND	Dummy, 1 if the firm cooperates jointly with the three helices
COOP_UNI_GOV	Dummy, 1 if the firm cooperates jointly with academia and government
COOP_UNI_IND	Dummy, 1 if the firm cooperates jointly with academia and industry
COOP_GOV_IND	Dummy, 1 if the firm cooperates jointly with government and industry
COOP_UNI	Dummy, 1 if the firm cooperates only with academia
COOP_IND	Dummy, 1 if the firm cooperates only with industry
COOP_GOV	Dummy, 1 if the firm cooperates only with government
Control variables	
INN	Dummy, 1 if the firm innovates in products or processes
EXPORT	Dummy, 1 if the firm exports
PUBLIC	Dummy, 1 if the firm is publicly-owned
GROUP	Dummy, 1 if the firm is a subsidiary of another company
IDIN	Dummy, 1 if the firm incurs in internal costs in technological innovation
IDEX	Dummy, 1 if the firm incurs in external costs in technological innovation
RD_P	Firm's R&D-related workforce/total workforce
LN_AGE	Log(age of the company)
LN_SIZE	Log (total number of employees)
LN_PRODUCT	Log (Revenue/total number of employees)
SECTOR	Dummy, 1 if the firm belong to the established industry; eight industries have been considered.
YEAR	Dummy, 1 if the firm belong to the established year (Period, 2008–2016)

All variables are obtained from PITEC database.

3.3. Econometric techniques

The study uses panel data, specifically random logistic regression, in order to control unobserved heterogeneity (Wooldridge, 2002). The choice of this technique is due to the qualitative nature of the dependent variable and the characteristics of the sample (Larsen et al., 2000). Given that the explanatory variables and some control variables are binary, when they do not vary over time they are eliminated from the analysis (Faraway, 2005). Consequently, the possible use of fixed effect models would not appropriately identify the effect of these variables on the dependent variable, also reducing degrees of freedom (Wooldridge, 2002; Faraway, 2005). Indeed, the persistence of cooperation throughout the time period under consideration, and its elimination from the study models if fixed effect models are used, makes the use of random effect models advisable (Vijayamohanan, 2016).

The following model was devised to test the hypotheses:

$$\text{Environmental innovation}_{i,t} = \alpha + \beta_1 \text{ Cooperation Variables}_{i,t-1} + \beta_2 \text{ Control Variables}_{i,t-1} + \beta_3 \text{ Sector Variables}_{i,t} + \beta_4 \text{ Year Variables}_{i,t} + \varepsilon_{it}$$

Where i is the firm (i = 1, …n) and t is time (t = 1, …,t); Environmental innovation is the dependent variable; Cooperation Variables are the explanatory variables of cooperation with Triple Helix agents; and Control variables are the control variables used in the study. The model includes both sectoral and time variables.

4. Results

Table 2 shows the descriptive statistics of the sample variables. On the one hand, 52.5% of the firms regard reducing environmental impact through innovation (environmental innovation) as highly or moderately important. Just over half of the firms in the sample (50.7%) cooperate with other agents, cooperation with the industrial sector being the preferred option (41.1%) followed by, to a lesser extent, cooperation with governments (35.9%) and universities (30.0%). Concerning the number of helices involved in cooperation, cooperation with three helices is the preferred option (24.7%) followed by cooperation with one helix (19.4%) and with two (6.6%). In more detail, joined cooperation with Triple Helix agents is the most common scenario (24.8%), followed by cooperation with industry only (11.0%) and cooperation with government only (7.0%).

Regarding the control variables, 87.1% of the firms in the sample innovate in products or processes, 76.2% export, 2.4% are publicly owned and 48.3% are part of holdings. As for the R&D control variables, 73.1% incur internal R&D costs and 33.5% incur external R&D costs. Finally, 17.2% of the workforce is involved in R&D-related activities on

Table 2
Descriptive statistics of the study variables.

Variable	Mean	Standard deviation	Min	Max
ENV_INN	0.525	0.499	0	1
COOP	0.509	0.500	0	1
H_IND	0.411	0.492	0	1
H_UNI	0.300	0.459	0	1
H_GOV	0.359	0.480	0	1
COOP_3H	0.247	0.432	0	1
COOP_2H	0.066	0.249	0	1
COOP_1H	0.194	0.396	0	1
COOP_UNI_GOV_IND	0.248	0.432	0	1
COOP_UNI_GOV	0.013	0.115	0	1
COOP_UNI_IND	0.024	0.154	0	1
COOP_GOV_IND	0.028	0.166	0	1
COOP_UNI	0.015	0.121	0	1
COOP_IND	0.110	0.313	0	1
COOP_GOV	0.070	0.254	0	1
INN	0.871	0.335	0	1
EXPORT	0.762	0.426	0	1
PUBLIC	0.024	0.155	0	1
GROUP	0.483	0.499	0	1
IDEX	0.335	0.472	0	1
IDIN	0.731	0.443	0	1
RD_P	0.172	0.283	0	1
LN_AGE	3.382	0.519	1.386	5.849
LN_SIZE	4.289	1.615	0	10.619
LN_PRODUCT	11.891	0.999	3.193	19.19

average.

Table 3 shows the relationship between corporate environmental innovation and cooperation, considering the type and number of helices involved in this cooperation. The results show that cooperation and corporate environmental innovation are positively related. When the firm cooperates, 60.6% of firms consider that reducing environmental impact is important. In this regard, firms that cooperate with the university helix take first place (65.7%), but they are not far ahead from those cooperating with the government helix (63.7%) and those cooperating with industry (62.4%). In more detail, there is triple cooperation in 68% of cases, followed by two-helix cooperation (55.9%), with academia-industry cooperation being the most used (58.80%).

When considering the number of helices involved, a reduction in the number involved in cooperation reduces the number of firms that see environmental impact reduction as important or moderately important in their innovation strategies (68% three-helix cooperation, 55.9% two-helix cooperation and 52.9% one-helix cooperation). Also, the differences in corporate environmental innovation, depending on whether the firm cooperates or not (regardless of type of cooperation), are significant in all cases, except for firms that cooperate with only one helix.

Appendix A presents the correlations between the model's variables.

Table 3
Relationship between corporate environmental innovation and cooperation according to the Triple Helix approach (percentage and difference of means).

	Corporate environmental innovation			
	Yes	No	Student's T	Mann-Whitney U
COOP	60.6%	39.4%	32.744***	−32.300***
H_IND	62.4%	37.6%	32.638***	−32.091***
H_UNI	65.7%	34.3%	34.616***	−33.819***
H_GOV	63.7%	36.6%	33.424***	−32.776***
COOP_3H	68.0%	32%	35.714***	−34.745***
COOP_2H	55.9%	44.1%	3.480***	−3.468***
COOP_1H	52.9%	47.1%	0.698	−0.698
COOP_UNI_GOV_IND	68.0%	32%	35.714***	−34.745***
COOP_UNI_GOV	52,6%	47,4%	0,033	−0,033
COOP_UNI_IND	58,8%	41,2%	3,923***	−3,897***
COOP_GOV_IND	54,9%	45,1%	1,552	−1,552
COOP_UNI	50,8%	49,2%	0,852	−0,852
COOP_IND	52,4%	47,6%	0,247	−0,247
COOP_GOV	54,2%	45,8%	1,801*	−1,798*

Environmental innovation is positively related with cooperation of any kind (except one helix), innovation, exporting, being part of holding, R&D internal and external costs and personnel, age, size and productivity, and negatively related to public ownership. Cooperation is positively correlated with exporting, public ownership, membership of holding, R&D costs and personnel and negatively related with age. These results are seldom affected by the types of cooperation under consideration.

Table 4 presents the results of the logistic estimations of random effects, where the explanatory variables correspond to the industry, university and government helices. These models enable us to evaluate the impact of cooperation with each of the three helices on the likelihood of corporate environmental innovation, enabling us to test hypotheses H1a, H1b and H1c. In order to achieve this, each variable is individually (models 1, 2 and 3) and jointly tested (model 4). The results show that cooperation increases the likelihood of environmental innovation being given greater weight in the firm's decision-making processes, regardless of the helix involved. These results confirm hypotheses H1a, H1b and H1c, and support the arguments provided by De Marchi (2012) and Cainelli et al. (2015), which suggest that environmental innovative firms or green innovators cooperate for innovation with external partners to a greater extent than other innovative firms or, in other words, that they are characterised by more intensive external relationships. This evidence is also consistent with Pereira et al.'s (2020) arguments, which highlight the positive effect on environmental innovation of business cooperation with governments and

Table 4
Impact of type of cooperation on corporate environmental innovation according to the Triple Helix approach (random-effect logit estimations).

	ENV_INN			
	(1)	(2)	(3)	(4)
H_IND	0.587*** (0.042)			0.346*** (0.059)
H_UNI		0.698*** (0.048)		0.397*** (0.064)
H_GOV			0.523*** (0.048)	0.165*** (0.057)
INN	0.357*** (0.055)	0.357*** (0.055)	0.405*** (0.055)	0.357*** (0.055)
EXPORT	0.125** (0.063)	0.128** (0.063)	0.118* (0.063)	0.124* (0.063)
PUBLIC	−0.245 (0.202)	−0.234 (0.202)	−0.219 (0.201)	−0.257 (0.202)
GROUP	0.058 (0.064)	0.085 (0.064)	0.087 (0.064)	0.065 (0.064)
IDEX	0.267*** (0.045)	0.251*** (0.045)	0.268*** (0.045)	0.220*** (0.045)
IDIN	1.137*** (0.053)	1.120*** (0.053)	1.082*** (0.053)	1.085*** (0.053)
RD_P	0.297*** (0.097)	0.300*** (0.098)	0.289*** (0.098)	0.256*** (0.098)
LN_AGE	0.118 (0.080)	0.129 (0.080)	0.124 (0.080)	0.135* (0.080)
LN_SIZE	0.223*** (0.026)	0.223*** (0.026)	0.228*** (0.026)	0.215*** (0.026)
LN_PRODUCT	0.223*** (0.032)	0.231*** (0.032)	0.234*** (0.032)	0.230*** (0.032)
CONSTANT	−5.491*** (0.577)	−5.697*** (0.577)	−5.658*** (0.577)	−5.684*** (0.577)
Number of observations	38,254	38,254	38,254	38,254
Number of groups	5,489	5,489	5,489	5,489
Wald X^2	1849.36***	1861.74***	1793.51***	1907.26***
McFadden's Pseudo R-squared	0.0521	0.052	0.050	0.054

Robust standard errors (clustered by firm) in brackets.
***, **, * denote 1%, 5% and 10% levels of significance, respectively.
Sector and year dummies included.

universities or research centres, in particular. Governments can support cooperation for environmental innovation between different actors and stimulate the flow of information from knowledge centres to firms (Del Río et al., 2015). Finally, these results are also consistent with previous general studies on cooperation for innovation, which stress the strategic advantage of cooperation with other firms (Un and Rodríguez, 2018), universities (Monjon and Waelbroeck, 2003) and governments (Busom and Fernández-Ribas, 2008).

With regards to the control variables, innovation (products and processes) has a positive effect on corporate environmental innovation. Similarly, exporting, R&D costs (internal and external), R&D personnel, size and productivity increase the likelihood of environmental innovation.

Finally, Table 5 presents the results of the random effect logistic estimations, in which the explanatory variables express how many helices are involved, three (COOP_3H), two (COOP_2H) or one (COOP_1H). These models are able to verify possible differences in the likelihood of corporate environmental innovation according to the number of helices involved in cooperation, as a way to test hypothesis H2. The variables are tested individually (models 1, 2 and 3) and jointly (model 4).

When considering the impact of type of cooperation on environmental innovation, the results confirm the positive effect of cooperation with all three helices (industry-academia-government) simultaneously for all the estimated models.

When analysing cooperation with two helices or one, the results seem to indicate that this type of cooperation has no effect on environmental innovation. However, the complete model (4) also confirms the positive relationship between cooperation and a greater concern for reducing the firm's environmental footprint in its innovation strategy. These results can be explained by the different reference groups considered in each model. In the regressions that analyse the individual effects, the reference groups are both firms that do not cooperate and firms that cooperate in a way other than the one referred to in the explanatory variable, including those that cooperate with all three helices, which are firms with a greater weight in corporate environmental innovation than the rest (their coefficients in the complete models are higher than the coefficient of cooperation with a single helix).

It is shown that the coefficient of the COOP_3H variable is higher than that of COOP_2H, which in turn is higher than that of COOP_1H. This means that the more helices involved in cooperation the greater the likelihood of corporate environmental innovation. These results confirm hypothesis H2, supporting Markovic and Bagherzadeh's (2018) claim that the number of partners involved is directly proportional to the positive impact of cooperation on innovation. They are in line with the conclusions provided by Marzucchi and Montresor (2017), Rauter et al. (2019) and Pereira et al. (2020). The results yielded by the control variables are similar to the above.

Table 6 presents the effect of cooperation on corporate environmental innovation, considering all Triple Helix combinations: academia-government-industry, academia-government, academia-industry, government-academia, only academia, only industry and only government. Firstly, results confirm the positive effect of cooperation with Triple Helix agents in all scenarios, being verified that the greatest likelihood of corporate environmental innovation happens when all the Triple Helix agents cooperate. Secondly, although cooperation with two Triple Helix agents has positive effects on corporate environmental innovation, the various combinations yield different coefficients. Academia-industry cooperation yields the better results, followed by academia-government cooperation and finally government-industry cooperation. Finally, concerning collaboration with a single Triple Helix agent, collaboration has a positive effect. According to type of cooperation, industry cooperation yields the best results, followed by academia and

Table 5
Influence of cooperation on the environmental innovation considering the Triple Helix approach (random-effect logit estimations).

	ENV_INN			
	(1)	(2)	(3)	(4)
COOP_3H	0.717*** (0.052)			0.938*** (0.058)
COOP_2H		0.054 (0.070)		0.507*** (0.077)
COOP_1H			−0.044 (0.044)	0.353*** (0.049)
INN	0.383*** (0.054)	0.414*** (0.055)	0.414*** (0.055)	0.363*** (0.055)
EXPORT	0.118* (0.063)	0.127** (0.063)	0.126** (0.063)	0.120* (0.063)
PUBLIC	−0.228 (0.202)	−0.191 (0.202)	−0.190 (0.202)	−0.254 (0.202)
GROUP	0.085 (0.064)	0.096 (0.064)	0.094 (0.064)	0.065 (0.064)
IDEX	0.260*** (0.045)	0.346*** (0.044)	0.346*** (0.044)	0.215*** (0.045)
IDIN	1.131*** (0.052)	1.190*** (0.053)	1.190*** (0.052)	1.069*** (0.053)
RD_P	0.293*** (0.097)	0.381*** (0.098)	0.382*** (0.098)	0.247** (0.098)
LN_AGE	0.129 (0.080)	0.099 (0.081)	0.100 (0.081)	0.138* (0.080)
LN_SIZE	0.222*** (0.026)	0.243*** (0.026)	0.243*** (0.026)	0.214*** (0.026)
LN_PRODUCT	0.229*** (0.032)	0.224*** (0.032)	0.224*** (0.032)	0.232*** (0.032)
CONSTANT	−5.567*** (0.576)	−5.449*** (0.578)	−5.454*** (0.579)	−5.712*** (0.577)
Number of observations	38,254	38,254	38,254	38,254
Number of groups	5,489	5,489	5,489	5,489
Wald X^2	1852.02***	1693.89***	1693.97***	1905.20***
McFadden's Pseudo R-squared	0.052	0.047	0.047	0.054

Robust standard errors (clustered by firm) in brackets.
***, **, * denote 1%, 5% and 10% levels of significance, respectively.
Sector and year dummies included.

Table 6
Influence of cooperation on the environmental innovation considering the different collaboration scenarios in the Triple Helix approach (random-effect logit estimations).

	ENV_INN Coef (s.e.)
COOP_UNI_GOV_IND	0.924*** (0.058)
COOP_UNI_GOV	0.598*** (0.150)
COOP_UNI_IND	0.723*** (0.121)
COOP_GOV_IND	0.262** (0.110)
COOP_UNI	0.310** (0.147)
COOP_GOV	0.246*** (0.075)
COOP_IND	0.414*** (0.061)
INN	0.357*** (0.055)
EXPORT	0.123* (0.063)
PUBLIC	−0.254 (0.202)
GROUP	0.061 (0.065)
IDEX	0.219*** (0.045)
IDIN	1.086*** (0.053)
RD_P	0.257*** (0.098)
LN_AGE	0.136* (0.087)
LN_SIZE	0.224*** (0.026)
LN_PRODUCT	0.231*** (0.032)
CONSTANT	−5.701*** (0.583)
Number of observations	38,254
Number of groups	5,489
Wald X^2	1914,35***
McFadden's Pseudo R-squared	0.054

Robust standard errors (clustered by firm) in brackets.
***, **, * denote 1%, 5% and 10% levels of significance, respectively.
Sector and year dummies included.

government cooperation.

In sum, the results presented in Table 6 corroborate those obtained in Table 5, although it is necessary to consider the type of cooperation with the different Triple Helix agents, as there are differences with the multiple combinations of cooperation. Finally, the behaviour of the control variables does not deviate significantly from the one obtained in previous regressions.

Additionally, we have also conducted complementary analyses to test the robustness of the results (see appendix B). We have considered two different specifications of the dummy dependent variable: Health and Regulation (De Marchi, 2012; Sáez-Martínez et al., 2016; Triguero et al., 2017). Health is based on a question of PITEC database asking about the "importance of improved health and safety"; Regulation is based on a question of PITEC database asking about the "importance of environmental, health or safety compliance". In both cases, respondents could choose among four possibilities, reporting if this effect was null, low, medium or high. The dependent variable takes the value 1 if the company reported high or medium importance of this effect and 0 otherwise.

The results obtained from the robustness tests for the models in Tables 4–6 are the following (see appendix B): First, we find a positive and significant effect of those organisations that cooperate with industry and academia. Although cooperation with the government helix has a positive effect, it is not significant; secondly, the results obtained in Table 5 are confirmed: the greater the number of Triple Helix agents involved, the greater the likelihood of corporate environmental innovation; thirdly, the differences in the various combinations of cooperation between the Triple Helix agents are also verified. The greatest positive effect occurs with the combination of all the Triple Helix agents together, as well as in academia-industry cooperation. When cooperation takes place with only one Triple Helix agent, it is positive and significant in the case of industry. It should be noted that, although the results of the new estimated coefficients show the same trend as in the previous models, they lose significance in some cases. This may be due to the characteristics of the new dependent variables, given that they include other additional aspects such as health or regulations, beyond environmental issues. However, the results obtained previously are ratified.

5. Discussion and conclusions

Businesses have a key role to play in tackling the major environmental challenges facing society today, and are obliged to develop and incorporate environmental innovations to reduce the impact of their activities on the environment (De Marchi et al., 2022). Consequently, EI is becoming increasingly important for many firms (Aldieri et al., 2019).

However, these decisions are surrounded by a high degree of uncertainty and complexity, even greater than in the case of traditional innovation (De Marchi, 2012; Da Silva Rabélo and de Azevedo Melo, 2019). This leads firms to cooperate with external partners in order to reduce costs and risk (Cainelli et al., 2015). Thus, open environmental innovation (OEI) is an emerging research topic in both EI and OI literature that can make valuable contributions to sustainable development (Sanni and Verdolini, 2022). Nevertheless, at the moment research is fragmented, due to a lack of clear nomenclature to unify under one umbrella the different synonyms and perspectives on this subject (Chistov et al., 2021a,b).

Cooperation for the development of environmental innovation activities, as well as the choice of partners whose collaboration contributes to the success of the joint effort, have been identified as key issues of the OEI strategy, with much more literature on the former, while the latter is a field still little studied (De Marchi et al., 2022).

This paper analyses the possible synergic effect of cooperation between firms and the main agents in the Triple Helix approach (university, industry and government) on corporate environmental innovation. This contributes to existing literature on meso-level open environmental innovation, by offering pioneering empirical evidence based on this theoretical approach and by increasing our understanding of the circumstances that facilitate greater corporate environmental innovation.

Our results confirm that cooperation between firms and Triple Helix agents, both individually and jointly, favours corporate environmental innovation, providing support for previous research focused on empirically testing the positive effect of collaboration on EI (Aboelmaged and Hashem, 2019). In fact, not only do they show the valuable contribution of cooperation with any of the actors of the Triple Helix model, but they also confirm that the more different Triple Helix agents involved, the greater the likelihood of corporate environmental innovation. These results provide evidence of the synergic effect of cooperation between firms and Triple Helix agents on corporate environmental innovation, which is directly proportional to the number of different agents involved in cooperation. This is consistent with the results obtained previously by Hernández-Trasobares and Murillo-Luna (2020), in relation to innovation in general; it shows the importance of an appropriate choice of collaboration partners (Melander, 2017), and may provide some guidance for answering one of the fundamental research questions on cooperation for environmental innovation: With whom should firms cooperate to develop environmental innovation? (Pereira et al., 2020).

Nevertheless, it should be noted that it is also necessary to consider the type of cooperation with the different Triple Helix agents, as there are differences with the multiple combinations of cooperation. For the same number of Triple Helix agents involved, the influence depends on the type of agents, being greater when industry collaborates.

This analysis is a novel contribution to EOI literature. While there are studies on cooperation between the different agents, they do not usually consider the Triple Helix agents as a whole (Kobarg et al., 2020; De Marchi et al., 2022), or they adopt a more theoretical point of view (Quartey and Oguntoye, 2021; Rowan and Casey, 2021). On the other hand, other studies specialise in analysing the effect of cooperation with a single helix (Spena and Di Paola, 2020; Acebo et al., 2021). In this study, from a methodological point of view, the size of the sample of firms considered, as well as the long time period, allow the use of more complex econometric techniques (Gkoumas and Christou, 2020; Rauter et al., 2019; Janahi et al., 2022). With respect to Hernández-Trasobares and Murillo-Luna's study (2020), in this paper not only has environmental innovation been considered as a key variable, but also a larger database has been used and robustness tests have been provided, which corroborate to a greater extent the results obtained.

The results obtained have interesting implications. Nowadays, there are multiple stakeholders who are exerting increasing pressure on firms to reduce the impact of their activities on the environment. The consideration of the environmental variable by firms is no longer an option but an obligation. In view of these results, it seems appropriate for firms to design cooperative innovation strategies that contribute to the development and adoption of environmental innovations. To this end, it is advisable to establish cooperative relations with universities, industry and governments, in order to develop their environmental innovation strategies, as it seems more likely that this type of cooperative strategy will favour the development of corporate environmental innovations (Acebo et al., 2021; De Marchi et al., 2022). A joint and full collaboration of Triple Helix agents facilitates corporate environmental innovation.

In addition, industry stands out as the agent with the greatest positive influence on corporate environmental innovation. In this respect, it is noteworthy that most firms committed to environmental innovation do not cooperate or share resources or infrastructures with other firms (Ormazabal et al., 2018). Nevertheless, the contribution of the different partners in industry can be diverse (De Marchi et al., 2022), which requires a deeper analysis. On the other hand, it is reaffirmed that the transfer to enterprises represents a fundamental contribution of universities, besides education and research, since their role in the cooperative strategies of firms is key to achieving corporate environmental innovations. Finally, it should be noted that public policies aimed at fostering the competitiveness of firms by promoting innovation should give priority to supporting cooperation initiatives for innovation involving at least two of the agents considered in this study, and the more the better, given that the results of this research show that corporate environmental innovation is directly proportional to the number of agents involved in cooperation. Carrillo-Hermosilla et al. (2010) highlight the important role that governments can play in designing public policies that promote collaboration among multiple actors.

However, this study is subject to various limitations that could guide future lines of research in this field. First, in relation to cooperation between firms and the industry, it would be interesting to characterise the relationship between cooperating firms in more detail. De Marchi (2012), for instance, argues that cooperation with suppliers is more important for environmental innovation than innovation in general; but this does not apply to cooperation with customers. It is therefore necessary to investigate further the possible differences in cooperation between the different partners in industry, given that different behaviours are observed between clients, suppliers, customers, competitors, etc. (De Marchi et al., 2022). Additionally, cooperation with governments can take place through multiple options, subsidies being just one of them.

Second, the approach presented by Etzkowitz and Leydesdorff in 1995 was later expanded to include other stakeholder groups, such as society at large (McAdam and Debackere, 2018) or the environment (Carayannis et al., 2012). The limitations of the database have restricted the number of helices considered in this study. However, future research should contemplate cooperation with these new stakeholder groups to better adjust to recent trends that point towards increasingly open cooperation processes.

De Marchi et al. (2022) adopt a configurational approach to address the study of collaboration for environmental innovation as a complex causal phenomenon, which allows considering multiple explanatory factors that lead to one outcome (conjunction), which can be achieved by different paths (equifinality). Consequently, cooperation with the agents of the Triple Helix (university, industry and government) is only one possible combination of collaboration with external partners that can result in a positive effect on EI, while other combinations with new external stakeholders can also lead to positive results for corporate environmental innovation. In these possible alternative combinations, Yang et al. (2012), for example, call for recognition of the role of civil society groups in environmental innovation, equating their importance to that of universities, industry and governments; Carayannis and Campbell (2010) propose incorporating the natural environment as another fundamental actor. However, Acebo et al. (2021) point out that not all combinations of collaboration with external partners are necessarily conducive to environmental innovation, and that there may be substitutive effects between them. Hence the importance of the nature of the interaction between the different external partners, which is very relevant to consider in cooperation strategies for environmental innovation.

Third, it would be interesting to analyse the differences in terms of environmental innovation, between product and process innovation, following the Olso Manual (OECD/Eurostat, 2019). Rennings (2000), Mirata and Emtairah (2005) and Horbach et al. (2012) even consider an additional option, organisational innovation. By applying this greater level of detail, we shall be able to analyse whether cooperation with different agents has a greater or a lesser impact on the different areas of environmental innovation. For instance, Horbach et al. (2012) conclude that cooperation with universities and research institutes has a positive effect on eco-process innovations related to materials and energy, but not so with eco-product innovations.

Fourth, the synergic effect of cooperation on environmental innovation has been analysed at the meso level. As explained by Garcia et al. (2019), this issue can also be analysed at other levels, specifically at the micro level (in terms of the creation and capture of value by firms cooperating on EI with Triple Helix actors) or at the macro level (benefits for society and the natural environment). It would also be very interesting to continue deepening the analysis at the micro level, to try to identify the influence of certain aspects (such as company traits, strategic orientation, or the availability or access to specific internal resources, capacities and competences), in the adoption of open environmental innovation strategies in collaboration with the agents of the Triple Helix.

Decidimos entonces situarlo en el nivel micro, dado que se pretende analizar el posible efecto positivo de la cooperación con los actores de la Triple Hélice para la innovación medioambiental empresarial. Sin embargo, estamos de acuerdo con usted en que el documento explora la cooperación entre varios actores y la elección de los socios, sin entrar en los determinantes internos de la cooperación.

Finally, with respect to the database used, some of the existing variables are binary, which makes it difficult to measure the intensity of cooperation between firms and other organisations. Therefore, it is necessary to make progress in introducing new quantitative variables that allow the measurement of the intensity of cooperation between the different Triple Helix agents.

CRediT authorship contribution statement

Josefina L. Murillo-Luna: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Funding acquisition. **Alejandro Hernández-Trasobares:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Acknowledgments

This work was supported by the Spanish Ministry of Science and Innovation, MCIN/AEI/10.13039/501100011033 [PID2020-113338RB-I00]; and the Department of Science, University and Knowledge Society of the Regional Government of Aragon [S42_20R: CREVALOR].

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.135479.

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