

**CORPORATE ENVIRONMENTAL R&D:
DOES ORGANISATIONAL INNOVATION MATTER?**

Del Río, Pablo. Consejo Superior de Investigaciones Científicas. Email: pablo.delrio@csic.es

García-Quevedo, Jose. Department of Economics, Chair of Energy Sustainability and Barcelona Institute of Economics, Universitat de Barcelona. E-mail: jgarciaq@ub.edu

Martínez-Ros, Ester. Departamento de Economía de la Empresa, Universidad Carlos III. E-mail: emros@emp.uc3m.es

Abstract

Investments in environmental research and development (R&D) are a crucial element for firms to make superior environmental performance compatible with financial performance. This relevance of environmental R&D suggests a need to identify its drivers. However, the literature on environmental R&D has given a prominent focus to external drivers to the firm, with a limited focus on factors internal to the firm. In contrast, the impact of crucial organisational changes in firms, in the form of organisational innovation, has not been addressed. We argue that organisational innovation drives environmental R&D expenditures. Using data on manufacturing firms from the Spanish Technological Innovation Panel survey during 2008–2016, we find support for this idea. Further analysis suggests that it is particularly the introduction of new methods of organising workplaces that is positively associated with environmental R&D. This suggests that a regulatory environment that facilitates workplace flexibility may promote environmental R&D investments.

Keywords: organisational innovation, R&D, environment, panel data

1.- INTRODUCTION

Eco-innovations are innovations which reduce the environmental impact of production and consumption activities. However, these innovations do not fall like a manna from heaven, but are partly the result of previous investments in environmental research and development (R&D) by firms and the public sector (Marzucchi and Montresor 2017). In order to remain competitive and address environmental concerns, companies need to invest in environmental R&D, which enhances their technological capabilities and skills and results in new and eco-innovative solutions (Triguero et al. 2017, Bataineh et al. 2023, Lee and Min 2015)¹. This allows them to respond to the environmental demands of different stakeholders (Shuwaikh et al. 2023, Tian and Wang 2020, Cakrabarty and Wang 2012).

The aforementioned importance of environmental R&D suggests a need to identify its drivers and, particularly, those which are internal to the firm, i.e., its organisational resources, capabilities and organisational changes.

There are few contributions on the quantitative analysis of the drivers of environmental R&D by firms (Johnstone and Labonne 2007, Arimura et al. 2007, Demirel and Kesidou 2011, Kesidou and Demirel 2012, Costa-Campi et al. 2017, van Leeuwen and Mohnen 2017). Factors external to the firm (i.e., policies) have played a dominant role in this literature. In contrast, although some internal factors have been included in empirical analyses, crucial organisational changes in the form of organisational innovation (OI) or “the implementation of new organisational methods” (OECD 2005), have been disregarded.

¹ Environmental R&D expenditures by firms, as used in this paper, are regarded as an input measure of eco-innovation (Lee and Min 2015, Kemp and Foxon 2007).

OIs provide a new or improved organisation of firm resources (Ramadani et al. 2019). They include modifications in the structure and processes of a firm and are related to the implementation of new managerial and working concepts and practices (Damanpour 1987). According to the Oslo Manual (OECD 2005, 51), there are three OI types: innovations in *business practices* (which involve the implementation of new methods for organising routines and procedures for the conduct of work), innovations in *workplace organisation* (new methods for distributing responsibilities and decision making among employees for the division of work within and between firm units and new concepts for the structuring of activities) and new organisational methods in a firm's *external relations* (new ways of organising relations with other firms or public institutions). The distinguishing feature of an OI compared to other organisational changes is the implementation of an organisational method that has not been used before in the firm and is a result of strategic decisions taken by management (OECD 2005, 51).

The innovation economics literature has shown that OI is an important driver of technological innovations since it boosts creativity and flexibility (Mothe and Nguyen 2010, Haned et al. 2014, Lam 2004, Le Bas et al. 2015). It maintains competitive advantage in a rapidly changing environment (Piva and Vivarelli 2002) through the adaptation of organisational managerial decisions to global changes. OI is also a particularly relevant component when connecting environmental practices to environmental capabilities (Amui et al. 2017). Since they provide companies with more flexibility in the decision-making process and a greater efficiency in the production process, OIs could help firms to transit to greener innovation activities by encouraging them to spend on environmental R&D. Horbach (2008) argues that eco-innovations are not realised because of incomplete information, organisational and coordination problems, and OIs can contribute to solve these within-firm problems.

Indeed, OIs have been found to drive technological innovation and also environmental practices. Therefore, their impact on environmental R&D, which has not been the focus of previous research, is worth researching. Environmental regulations would oblige firms to redesign the way they work (Rave et al. 2011). As argued by Antonioli et al. (2013, 976) “more stringent environmental standards might foster firms’ adoption of training and OI, which in turn could lead to further environmental innovation”. Thus, companies are encouraged to be innovative through changes in their organisational practices in response to regulatory requirements. Investing in environmental R&D in order to develop green technologies would facilitate meeting those requirements (Bataineh et al. 2023b).

Some contributions have included organisational eco-innovations as a driver of the adoption of technological eco-innovations (see section 2.1.1). Organisational eco-innovations, which are a specific subtype of eco-innovation (Rodríguez-Rebés et al. 2021), “involve the implementation of several management activities aimed at reducing environmental impact” (Triguero et al. 2013, 27), with environmental management systems (EMS) being the clearest example. However, the impact of general OIs (i.e., not only “organisational eco-innovations”) on environmental R&D expenditures by firms has received scant attention. In general, knowledge about the role that OI plays in environmental initiatives by firms remains limited (Gabler et al. 2015). Furthermore, the impact of different types of OIs on environmental R&D expenditures as well as the differential impact of OI on general R&D vs. environmental R&D have not been the focus of previous research. Although many papers have analysed the determinants of the adoption of eco-innovations (see, e.g., Xavier et al. (2017) and del Río et al. (2021) for reviews of the literature), the initial stages in the environmental technological change process (i.e., innovation) have received much less attention (Marin 2014; D’Amato et al. 2021).

Thus, the aim of this paper is to cover the aforementioned gaps in the literature. It tries to answer the following research questions: Does OI affect environmental R&D expenditures by manufacturing firms? What types of OIs have a greater influence in this regard? Do OIs impact environmental R&D expenditures by firms in a different way than overall R&D expenditures?

Using data from the Spanish Technological Innovation Panel survey during 2008–2016, our paper specifically focuses on the relationship between general OIs and environmental R&D expenditures. This is in contrast to the literature on eco-innovation, which has analysed the impact of organisational capabilities (resources, competences and dynamic capabilities) on eco-innovation (del Río et al. 2015), organisational eco-innovation (i.e., not general OI) as a driver of technological eco-innovation (e.g., Wagner 2008, Ziegler and Rennings 2004, Frondel et al. 2007) or general OI as a determinant of the adoption of eco-innovations (Bataineh et al. 2023, Galliano and Nadel 2015, Horbach 2008, Horbach et al. 2012). Whereas those contributions on OI have paid attention to eco-innovation adoption, this paper focuses on environmental R&D expenditures, which has received much less attention than other eco-innovation indicators, probably due to the unavailability of firm-level data (Alam et al. 2019). It considers several aspects and dimensions of OI in general, whereas OI is often included in a very limited manner in the literature on eco-innovation², and measures how the introduction of OI impacts the environmental R&D efforts made by firms. The relationship of different OI types and green innovations is a topic which has not been addressed in the past (Bataineh et al. 2023). We close this gap by analysing the relationship between different OIs and

² That is, in the form of organisational eco-innovation as proxied by the adoption of an EMS, an environmental accounting system or a corporate social responsibility (CSR) policy in the firm.

environmental R&D expenditures, since the managerial implications of those OIs are likely to differ.

Section 2 provides the theoretical background. Section 3 describes the data and the model used in the empirical analysis. The results are provided and discussed in section 4. The article closes with some conclusions.

2.- THEORETICAL FRAMEWORK

2.1. Environmental R&D and organisational innovation.

As mentioned before, investments in environmental R&D are a crucial element for firms to make superior environmental performance compatible with financial performance, allowing them to meet the environmental demands of different types of stakeholders. As argued by Blomquist (2004, 366), a firm's green efforts are made evident in its R&D work, which is the ultimate test of whether or not greening is rhetorical or manifested in the firm.

This relevance of environmental R&D suggests a need to identify its drivers. To the best of our knowledge, only six papers have analysed the determinants of corporate environmental R&D expenditures (see Table 1 for details of these studies), which are modelled using firm-level and policy variables (country and sector variables are also used in some papers).

INSERT TABLE 1 HERE

The literature on environmental R&D has given a prominent focus to external drivers to the firm, with a limited focus on the factors which are internal to companies. Within firm-level variables, apart from company size or productivity, environmentally-related OIs are

included (EMS, ISO 14001 certifications, CSR policy, an environmental accounting system or an environment training programme).

In contrast, the impact of crucial organisational changes in firms, in the form of organisational innovation, on environmental R&D has not been addressed. Indeed, management factors or organisational capabilities are seldom included and, when they are, it is done in a rather limited manner, i.e., personnel in R&D as a share of total personnel (as in Costa-Campi et al. 2017) or whether the firm has a quality management, full-cost accounting, management accounting system, process control system and inventory requirement planning (as in Arimura et al. 2007).

This is unfortunate, given that organisational innovativeness drives eco-innovation (e.g., Gabler et al. 2015, Amui et al. 2017). As further explained in 2.1, OI mediates the relationship between the pressures on firms from environmental regulation or key stakeholders and their environmental innovation activities as indicated by their corporate R&D expenditures. OIs have an influence on the capacity and willingness of firms to engage in environmental practices such as environmental R&D. Thus, substantial organisational changes in the form of OIs as a result of environmental pressures can be expected to influence eco-innovation in general and environmental R&D in particular. The distinctive features of environmental R&D with respect to overall R&D (more complex, knowledge-intensive, uncertain and peripheral) suggest that OIs would have a different impact on each R&D type.

Indeed, the literature has shown that general OI can have significant effects on eco-innovation, although the empirical analysis has been restricted to adoption, i.e., not to environmental innovation measured with environmental R&D expenditures. Some contributions have analysed the influence of single OIs (i.e., not the three OI types) on

eco-innovation, highlighting the influence of changes in work organisation and management on eco-innovations, including the role of the manager (Wagner and Llerena 2011), new organisational arrangements (Hottenrott et al. 2016), employee training (Horbach 2008, Cainelli et al. 2012) and the involvement of the workforce (Delmas and Pekovic 2013, Nadel 2013)³.

Other articles have assessed the influence of the three OI types on eco-innovation adoption. Horbach (2008) found a positive and statistically significant relationship between general organisational changes and eco-innovation. Horbach et al. (2012) and Galliano and Nadel (2015) showed that the three OI types were significantly related to eco-innovation adoption. Arranz et al. (2020) found that OI affects technological eco-innovation, although a disaggregated analysis per OI type was not provided. The three OI types influenced technological eco-innovation in Galliano and Nadel (2018), with changes in work organisation having the greatest impact.

Finally, Bataineh et al. (2023) have analysed the relationship between general OI and eco-innovations, also in Spanish firms. However, our paper is clearly different to Bataineh et al. (2023) in several respects: 1) Those authors focus on adoption, not the previous stage (i.e. innovation, measured with environmental R&D)⁴; 2) Their dependent variable identifies green innovation based on self-reported data by the firm on the goal pursued to introduce the innovations (i.e., a lower environmental impact). Therefore, it is based on the views and opinions of the respondents about such goals. In contrast, we use

³ One stream of the literature has assessed the impact of organisational eco-innovation (i.e., not general OI) on the adoption of technological eco-innovations, including the influence of an EMS (e.g., Wagner 2008, Frondel et al. 2007, Mazzanti and Zoboli 2008), an environmental accounting system (Arimura et al. 2007) or a CSR policy (Demirel and Kesidou 2011). EMSs have been an important firm internal capacity to continuously generate/adopt eco-innovations (Wagner 2008, Frondel et al. 2007, Mazzanti and Zoboli 2008).

⁴ As argued by the authors themselves, their data do not include “certain aspects of green activities, primarily environmental managerial matters such as supply chain administration, human resource management, and green R&D” (Bataineh et al. 2023, 10).

hard data on corporate environmental and non-environmental R&D expenditures; 3) In contrast to Bataineh et al. (2023), we analyse and compare the relationship between OI and, both, environmental and overall R&D expenditures.

2.2. Analytical framework.

A link between OI and environmental R&D is built based on both theoretical and empirical arguments. Several streams of the literature have been used in the past to assess the impact of different drivers on firms' involvement in environmental practices and, particularly, in eco-innovation. These approaches can be regarded as complementary to explain the drivers to environmental R&D and, thus, they are included in our integrated theoretical framework⁵.

The factors external to the firm have been emphasised by some approaches (i.e., institutional theory, the systems of innovation and stakeholder theory), suggesting that the institutional context and different stakeholders influence the decision of firms to improve their environmental performance (Kiefer et al. 2024), including their decision to invest in environmental R&D. However, institutional and stakeholder theories tend to assume that external factors lead to similar responses by different firms (Darnall et al. 2008). The reality is that firm-level characteristics and internal resources and capabilities are crucial in explaining the eco-innovativeness of firms (Kiefer et al. 2024).

Thus, other theoretical approaches focus on the firm internal factors. One of these approaches is the dynamic capabilities (DCs) approach. Another is the highly influential resource-based-view of the firm (RBV), according to which the internal factors which influence innovation processes include the resources, capabilities and competences

⁵ A detailed discussion of these approaches and their relevance for this paper is beyond its length restrictions. See Kiefer et al. (2024) for further details.

(RCCs) of the firm. Since the RBV has been criticised for not fully taking into account the institutional context of firms (Peng et al. 2008, Xiao et al. 2013), the RBV and the DCs on the one hand, and institutional and stakeholder theories on the other, are deemed complementary (Kiefer et al. 2024). The natural RBV (NRBV) and evolutionary approaches follow a balanced view which takes into account the interactions between external and internal factors.

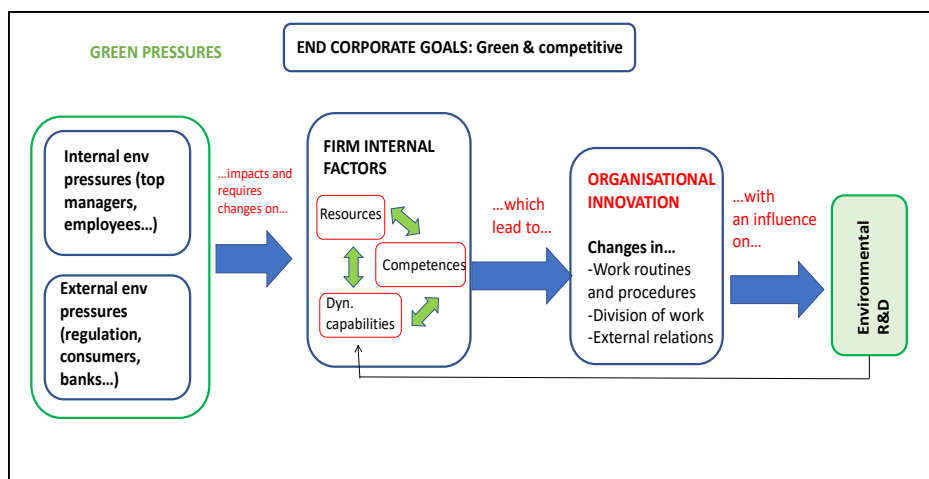
Therefore, the insights provided by those approaches are included in our integrated theoretical framework (Figure 1). Our basic idea is that OIs, partly influenced by environmental concerns and demands, both incentivise and enable environmental improvements in the firm, and particularly its environmental innovation capability, measured with environmental R&D expenditures. Furthermore, some empirical streams of the literature are based on those theoretical approaches and allow us to provide a specific link between OI and environmental R&D expenditures: The literatures on the relationship between OI and technological innovation (e.g., Armbruster et al. 2008, Mothe and Nguyen 2010, Damanpour 2017, Le Bas et al. 2015), on the impact of OI on R&D (Chen et al. 2019, Anzola-Román et al. 2018), on the link between organisational eco-innovation and (technological) eco-innovation (see 2.1.1) and on the analysis of the drivers of environmental R&D (see 2.1.2).

It is assumed that external and internal pressures influence firms to improve their environmental performance without reducing their financial performance. As postulated by the NRBV, “a firm can achieve sustainable competitive advantages through the allocation of its resources and capabilities in environmental-friendly business activities” (Alam et al. 2019, 401). Thus, R&D investments play a crucial role in reducing environmental impacts while achieving economic returns (Alam et al. 2019).

However, the factors which are internal to the firm (its RCCs) mediate the relation between external pressures and the improvement of environmental performance by firms (Kiefer et al. 2024), including its decision to spend on environmental R&D. Following Laughlin (1991), the organisation is a social system with a resistance to change. Green strategic issues are shocks influencing the organisation. Changes in organisational structure (organisational change and OI) are a response to unexpected changes in the circumstances (Blomquist 2004). But the success of OI also depends on the availability of different resources which are critical to its execution (Zhang et al. 2020).

Therefore, internal and external pressures lead firms to change their RCCs to improve their environmental performance while maintaining their competitiveness, eventually resulting in organisational changes and OIs (Kiefer et al. 2024). In turn, OIs have an influence on the capacity and willingness of firms to engage in environmental practices such as environmental R&D. OIs are closely related to education, training and human capital formation within firms, but also to changes in external relations (Antonioli et al. 2013). They all allow firms to increase their skill base and access external knowledge, which is particularly important with complex technologies such as environmental ones (see 2.2.1). This facilitates the involvement of firms in environmental R&D.

Figure 1. Depicting our theoretical framework.



Source: Own elaboration.

Therefore, the adoption of OIs is influenced by the environmental context, the organisational context and internal change agents (Birkinshaw et al. 2008, Alänge and Steiber 2011, Steibert et al. 2015)⁶. Several authors note that environmental concerns trigger OIs. Everywhere, firms are facing the urgency of balancing productive consumption and ecological conservation, which requires OI (Zhang et al. 2020). More stringent environmental standards might foster firms' adoption of training and OI, which lead to environmental innovation (Antonioli et al. 2013). According to Ganter and Hecker (2014), many attempts to adapt to external change are related to OI, including sustainability demands. For Wagner and Llerena (2011), firms develop organisational skills "that improve responsiveness to sustainability challenges". Therefore, company involvement in environmental innovations goes in tandem "with changes in routines and skills involving environmental issues, which leads to the transformation of the firm's organisation" (Galliano and Nadel 2018, 41). Moreover, in order to adapt to the constant changes in their environment, firms need to adopt new methods of decision-making such as flexibility, work teams and quality systems to improve their performance. Hence, OI can be regarded as a dynamic capability. The capabilities of a firm become dynamic when they interact with the business environment and/or change over time to accommodate the needs of stakeholders. Thus, a firm must persistently be innovative by upgrading its capabilities in order to be competitive.

Previous studies depict OI as a capability that positively influences other capabilities (e.g., collaboration, technology, and learning) as well as performance (Gabler et al. 2015). Eco-innovation places specific demands on the internal capacities and resources of firms

⁶ For example, Buchanan et al. (2005) identified seven organisational factors (managerial, leadership, cultural, organisational, individual, political, and financial) that influence organisational change.

and how these are developed (Kleef and Roome 2007). Amui et al. (2017) and Gabler et al. (2015) emphasise organisational innovativeness as a central construct in their company sustainability models. The managerial capabilities and organisational structures of a company may be inadequate to materialise existing opportunities and can even hinder the development of eco-innovations (del Río et al. 2017). Improved environmental performance requires a fundamental shift in a firm's resources and the organisational capabilities required to manage them (Russo and Fouts 1997).

2.2.1. OI triggers environmental R&D

Thus, deep organisational changes (i.e., OIs), partly as a result of the aforementioned environmental pressures, can be expected to lead to changes in the technological innovation routines of firms and improvements in their environmental performance and, thus, to investments in environmental R&D. This is in line with the finding that OI influences the generation of technological innovation by activating different mechanisms (Anzola-Román et al. 2018, Tohidi et al. 2012, Mothe and Nguyen 2010, Haned et al. 2014)⁷. There is a strong complementarity between OI and technological innovation (Sapprasert and Clausen 2012) and firms are likely to be engaged in these innovation modes simultaneously (Carboni and Rusu 2017). However, the role of OI as a determinant of R&D has not received the same attention. Chen et al. (2019) find that OI influences technological innovation capabilities, one of which is R&D. A synergistic effect of OI and R&D on TI is found in Anzola-Román et al. (2018).

⁷ That is, by enhancing flexibility and creativity and changing the factors (e.g. R&D investments) that determine technological innovation (Mothe and Nguyen 2010), by allowing firms to adapt to environmental changes and achieve strategic goals for sustaining and improving performance (Damanpour 2017), by creating a proper internal environment for technological innovations and for business to succeed (Carboni and Rusu 2017), by changing the structure and processes of enterprises that result from a new understanding of the adequate organisation for the current market situation (Armbruster et al. 2008) and by enhancing flexibility and creativity (Le Bas et al. 2015).

OIs could act as prerequisites and facilitators of environmental R&D decisions. The question is, then, why would general OIs rather than only environmental OIs trigger environmental R&D?

In general, OIs could be expected to encourage technological innovation and also the integration of environmental objectives in the company. Organisational structure and management support are key factors in incorporating environmental policy as an integral part of a company's strategy. Several practices related to OI (i.e. teamwork, employee participation, decentralisation in decision making) and training for innovation are key human capital management factors to achieve environmental objectives (Garcia-Marco et al. 2020, Rodríguez-Rebés et al. 2021). Innovation strongly depends on organisational ability (Aboelmaged and Hashem 2019). Thus, an inadequate organisational structure may be a barrier to innovation in general and eco-innovation (environmental R&D) in particular. As Bataineh et al. (2023, 2) argue, "internal barriers to innovation that prevent companies from actively undertaking changes may be attributed to a lack of expertise, insufficient resources, or an ineffective organisational structure".

More specifically, several authors have proposed that organisational innovativeness is an essential driver of eco-innovation, arguing that general OIs would improve the environmental performance of the firm through the uptake of environmental practices. For example, Antonioli et al. (2013, 979) observe that OIs allow capturing "the within firms' strategic decisions belonging to the organisational sphere capable of increasing the absorptive capacity of the firm towards eco-innovations". Cassetta et al. (2023) note that eco-innovation requires deeper changes in organisational structures. García-Marco et al. (2020) argue that OI increases firms' capacities to implement environmental practices that improve their productivity and flexibility, but also their responsiveness to the views of external stakeholders. For Marzucchi and Montresor (2017) and Ghisetti et al. (2015),

eco-innovations require firms to have multidisciplinary competencies and not only environmental ones. Gabler et al. (2015) argue that, since OI seeks creative solutions to problems or needs, it connects environmental practices to environmental capabilities and it is particularly important for green innovation, which is quite radical because it has several inherent risks. Furthermore, they observe that, since organisational innovativeness enhances the effectiveness of a firm's market orientation, “organisational innovativeness should interact with environmental orientation to enhance a firm's eco-capability” (Gabler et al. 2015, 154). Zhou et al. (2019) also showed that OIs help firms to adopt new ecological approaches by increasing the efficiency of administrative and operating procedures, and improving the environmental performance of the firm. Bataineh et al. (2023, 3) argue that the adoption of new organisational methods “contributes to apply green innovations by following innovative strategies for organising routines and procedures for work productivity” and that “firms seek to refine their strategies, resource management, and organisational structures to deal with uncertainty, including stringent environmental regulation, and adopt practices within their organisation aimed at gaining competitive advantages, and at achieving environmental sustainability” (Bataineh et al. 2023, 3).

2.2.2. Environmental R&D is affected differently by different OI types

In line with the literature on the impact of different OI types on technological innovation (Armbruster et al. 2008, Mothe and Nguyen 2010, Sappasett and Clausen 2008), not all OIs can be expected to have the same effect on environmental R&D expenditures.

The literature suggests that a strong influence on total (and, thus, environmental) R&D investments can be expected by the first and second OI types, particularly by workplace

innovation. New work practices are related to lean and just-in-time production, decentralised decision making, team work and shared rewards (OECD 2005)⁸. Although the organisational literature already indicates that organisational encouragement supports employee creativity and innovation, the more specific “work environment literature” is relevant in this context (Amabile et al. 1996, Amabile 2012, Willey et al. 2018). It has been found that workplace innovation encourages the creative potential of groups in organisations, i.e., it fosters creativity and R&D investments (Amabile et al. 1996, 1997, Isaksen et al. 2001, Beblavy et al. 2012). Some authors have identified a direct link between workplace innovation (flexible work schedules) and attraction of talented workers (Dervojeda et al. 2013, Willey et al. 2018).

The eco-innovation literature has also emphasised the importance for eco-innovation of training activities or work practices (Antonioli et al. 2013) or the human factor more generally (Garcia Marco et al. 2020, del Brio and Junquera 2003, Rodríguez-Rebés et al. 2021)⁹.

Some authors have found that eco-innovation is driven by cooperation (which is related to the third OI type) (see, e.g., de Marchi 2012, del Río et al. 2015, Cainelli et al. 2015, Kobarg et al. 2020). Eco-innovations necessarily involve multiple stakeholders and their systemic nature may force firms to integrate elements beyond their frontiers (van Kleef and Roome 2007). For Galliano and Nadel (2018), the development of eco-innovations is related to changes in firm external relations. Arfi et al. (2018) argue that achieving a green product is complex and often requires information and skills that are different from

⁸ According to Dervojeda et al. (2013, 3), “workplace innovation is the underlying trend and is a generic term to cover – notably but not only – innovations in the way enterprises are structured, the way they manage their human resources, the way internal decision-making and innovation processes are devised, the way relationships with clients or suppliers are organised or the way the work environment and the internal support systems are designed”.

⁹ As Rodríguez-Rebés et al. (2021, 857) point out, “OI acts as an enabler or catalyst for the adoption of eco-innovations through changes in the firm’s work responsibilities and decision making”.

the traditional knowledge base of the industry¹⁰. Cassetta et al. (2023) stress the importance of collaborations with stakeholders in eco-innovation, i.e., with public institutions (process eco-innovations) and civil society (product eco-innovations).

However, some contributions have found a less relevant role of cooperation. For example, Jové-Llopis and Segarra-Blasco (2018) showed that eco-innovation is not driven by cooperation. In Cuerva et al. (2014), firms that followed an in-house strategy were more eco-innovative. These authors did not find that an open innovation strategy and eco-innovation were positively related. de Paulo et al. (2020) and Dimakopoulou (2022) found that internal firm drivers and cooperation were both relevant drivers of eco-innovation. R&D collaboration does not affect the probability of a firm's decision to eco-innovate in Dimakopoulou (2022)¹¹. Fear of imitation may prevent some firms from cooperating with external partners, as shown in de Paulo et al. (2020). Furthermore, engagement with externally sourced innovation practices may be challenging, as it increases complexity (Anzola-Román et al. 2018). Rodriguez-Rebés et al. (2021, 856) emphasise “the true importance of management (decision making, leadership) in promoting eco-innovative activities”, whereas a lower impact of external relationships is expected. Similarly, Marzucchi and Montresor (2017, 219) argue that “eco-innovators are expected to be like ‘heroes of two worlds’, with competencies of both the world of science (and research) and the world of business. Still, the two modes appear in need of separate management, as there seem to emerge problems in combining the relative competences and sources of knowledge across the firm's boundaries”¹².

¹⁰ “Green innovations represent a technological frontier on which companies are still inexperienced and market and technological uncertainties increase, as there are no widespread-accepted standards” (Arfi et al. 2018, 212).

¹¹ “The group of variables which refers to the internal knowledge generation is a more prominent block compared to the one that refers to the external knowledge generation” (Dimakopoulou 2022, 22).

¹² According to Marzucchi and Montresor (2017, 219), “this contrasts with the complementarity between internal and external knowledge found for standard innovations”.

2.2.3. OI affects environmental R&D expenditures by firms in a different way than overall R&D expenditures

Obviously, organisational eco-innovation would likely have more influence on environmental R&D expenditures than overall R&D expenditures, as shown by Johnstone and Labonne (2007). However, the impact of general OIs is a priori less clear.

General OIs can be expected to affect corporate environmental R&D expenditures in a different manner than overall R&D expenditures because eco-innovation and environmental R&D have some distinctive features with respect to normal innovations and overall R&D, apart from their obvious different focus. Compared to normal innovations, eco-innovations are considered more complex (de Marchi 2012, Cassetta et al. 2023, Dewick and Foster 2018, Jacobsen and Clausen 2016, Ghisetti et al. 2015), knowledge-intensive (Dimakopoulou 2022, Horbach et al. 2013, Arfi et al. 2018), uncertain (de Marchi 2012, Boutry and Nadel 2021) and peripheral (Ramus 2003, Demirel and Kesidou 2019)¹³.

Demirel and Kesidou (2019) argue that environmental R&D is outside the company's core activities. For them, generic R&D refers to R&D activities that are closely related to the core business of the firm, whereas environmental R&D is more outward-looking "exploration", i.e., peripheral and in the domain of "distant search" for many firms. They expect that at least one OI (workplace innovation) encourages total R&D and environmental R&D more specifically, since workplace innovation attracts talent (higher-level human resources) to the firm (Dervojeđa et al. 2013, Beblavy et al. 2012, Willey et

¹³ For example, Dimakopoulou (2022, 3) state that "eco-innovation activities are related to R&D synergetic schemes as they are considered as complex projects which require significant knowledge modularity".

al. 2018). These high-talented workers are more needed to carry out environmental R&D, given its aforementioned more complex, knowledge-intensive, uncertain and peripheral nature compared to general R&D. Antonioli et al. (2013) link this higher complexity with OI and argue that increasing workforce involvement and the skill base through OIs facilitates the absorption and exploitation of more complex eco-innovations. Similarly, Consoli et al. (2016) observe that, compared to non-green jobs, green jobs demand higher educational levels, work knowledge, cognitive talents, interpersonal abilities and training. Furthermore, environmental protection provides an additional motivation for employees (Beblavy et al. 2012), requires a cross-cutting perspective across the company and spurs creativity and innovation than it is the case with non-environmental innovation¹⁴. This emphasises the relevance of workplace innovation, empowering different departments, adopting an interdisciplinary vision, facilitating team work (of employees with different backgrounds), putting more emphasis on training systems and allowing more decision-making power among employees.

Nevertheless, the literature does not provide a clear framework to postulate well-grounded hypotheses regarding potential differences on the role of OI on environmental R&D expenditures compared to overall R&D expenditures.

3. DATA AND EMPIRICAL ANALYSIS

The data are taken from the Spanish Technological Innovation Panel (PITEC) survey for the period 2008–2016. The survey is conducted annually by the National Statistical Institute (INE) in collaboration with the Spanish Science and Technology Foundation

¹⁴ As argued by Willey et al. (2018, 281), innovation is “closely related to the environment and requires new ideas to be developed and transformed into products, services or processes in the company”. Ramus (2003) found out that employees who felt strong signals of organisational and supervisory encouragement were more likely to have developed and implemented creative ideas that positively affected the natural environment.

(FECYT) and the Foundation for Technological Innovation (COTEC). With this information, the INE built this dataset as a panel of data. We have merged these data with information on environmental R&D provided by INE.

The justification for the choice for PITEC is multifold. First, PITEC is one of the few large-scale surveys that provides data on green innovation and is rich on the characteristics of firms and innovative activities. It has been used by several scholars to analyse the determinants of eco-innovation in the past (see, e.g., de Marchi 2012, del Río et al. 2015). Second, PITEC is based on the Community Innovation Survey (CIS) framework, which is one of the most commonly used datasets for studying innovation (Laursen & Salter 2004, 2006). This allows for direct comparisons with previous and future research using similar datasets. Third, it is possible to estimate models using panel data techniques since this database allows us to control for individual specific characteristics. Firms are followed along the period 2008-2016, although 2008 and 2009 are skipped due to problems with key variables. Therefore, we work with 4542 firms in 7 years. 46% of these firms are present during the whole period and thus, we have an unbalanced panel of 31794 observations. However, the sample used for the estimations is smaller (22141 observations), since some information is lost for some variables due to the existence of missing values¹⁵.

Firms are distributed across 24 manufacturing sectors, based on the 2009 Clasificación Nacional de Actividades Económicas (CNAE). 19% are large firms and 81% are SMEs. 70% of firms carry out internal R&D but only 9% invest in environmental R&D¹⁶.

¹⁵ For a more detailed description, see Table 2 in Appendix 1.

¹⁶ These data are similar to other surveys. For example, in the study of seven OECD countries (Norway, Germany, France, Canada, Hungary, Japan and the United States) by Arimura et al. (2007), only 9.3% of facilities had invested in environmental R&D.

Environmental R&D investments decreased until 2012 and increased later, being 1% higher in 2016 than in 2010.

38% of firms engaged in cooperation, around 20% had “reductions in material and energy” as a corporate goal, 32% considered compliance with environmental requirements in their strategy and 27% included a lower environmental impact as a goal. In terms of OIs, around 42% of firms have introduced new organisational forms (delegation of power), 40% have implemented workplace innovations and only 16% of firms have introduced new external and institutional relationships. The highest correlation among the three OIs is between practices and workplace (0.684), with correlations between other OIs being much lower (around 0.4). The main statistics are shown in table 2. Appendix 1 provides the correlation matrix¹⁷.

INSERT TABLE 2 HERE

3.1. VARIABLES

3.1.1. Dependent variables

Since 2008, firms have been asked to classify their internal R&D expenditures according to their socio-economic objective (SEO) in the Spanish version of the CIS, following the Frascati Manual (OECD 2002). Specifically, firms are required to distribute their R&D expenditures between fourteen socio-economic objectives, according to the purpose of the R&D programme or project. One of these objectives is the control and care of the environment (SEO 3) that allows us to know the amount of expenditures in environmental R&D (Env exp) with the information provided by INE¹⁸. According to the Frascati

¹⁷ In addition to the correlation matrix, which suggests that multicollinearity is not present, we have conducted the variance inflation factor (VIF) test, which confirms this conclusion.

¹⁸ This objective does not include research on the efficiency of energy production and distribution and the study of energy conservation covered in SEO 5.

Manual, this SEO covers research on pollution control aimed at the identification and analysis of the sources of pollution, their causes and the effects on humans, species (fauna, flora, micro-organisms) and the biosphere. The development of monitoring facilities for the measurement of all kinds of pollution is also included. The same is valid for the elimination and prevention of all forms of pollution.

We also use internal R&D expenditure in the estimations to analyse the relationship between OI and overall R&D expenditures and compare the results with those for environmental R&D.

3.1.2. Independent variables

Organisational innovation and its different types are measured using the definition of the Oslo Manual (2005) (see Appendix 2), which is in line with other contributions to the literature (e.g., Le Bas et al. 2015, Van de Ven and Poole 2005).

We use two types of measures for OI. First, we have the dummy variables “Practices” (that takes the value “1” when the firm introduces new business practices of work, and “0” otherwise), “Workplace” (“1” when the firm engages in new methods of organising the workforce, as decentralisation, restructuring departments and team management, among others) and “Relation” (“1” when the firm develops new methods of managing external relations with other companies or public institutions). Second, to account for an overall relationship, OI is built as a synthetic index that measures the introduction of the three OI types. It takes “0” when firms do not introduce any OI and “0.33”, “0.66” and “1” when firms introduce one, two or three OIs, respectively. “Practices” and “Workplace” are the most commonly introduced OI.

Environmental aims. We assume that the environmental objectives of the companies are a crucial component of their strategic plan. In practice, we measure those aims as four

dummy variables which take the value “1” if the firm attaches a high importance to the reductions of raw materials (*material*), energy (*energy*) and the environment impact (*impact*) and compliance with environmental requirements (*comply*), and 0 otherwise.

Controls

We include controls commonly used in this type of models, which account for internal and external determinants of environmental R&D expenditures (Horbach et al. 2012, Galliano and Nadel 2018). Facility size is potentially an important factor affecting decisions on R&D, since there may be a minimum efficient scale for undertaking R&D and small firms may not have enough staff to conduct environmental R&D in an efficient manner (Arimura et al. 2007). Size is captured by the log of firm’s sales (*lsal*) and the experience of the firm is measured using the firm’s age in logs (*lage*). Innovation is an activity that often requires cooperation among different actors (e.g., other firms, suppliers and clients). Thus, cooperation in general (*coopera*) is included as a dummy variable. Public incentives to innovation are a relevant driver of R&D expenditures by firms in the literature. Hence, we include two variables to capture this effect: having contracts with the central administration (*lcontrat*) and subsidies from the central administration (*lsuv*). Both variables are measured in euros. Moreover, belonging to an industrial group (*group*) is included to control for the higher opportunities to share the uncertainty derived from innovation activity. Human resources are crucial for any type of innovation and, thus, the percentage of high skilled workers (*highskills*) is included. Finally, time and sectoral dummy variables are also specified in order to control for economic and conjunctural shocks. Appendix 2 summarises the construction of variables.

3.2. Estimation strategy

We estimate our model following recent contributions in the literature (Raymond et al. 2010; García-Quevedo et al. 2014). In particular, we nest both decisions, following the seminal work by Crepon et al. (1998), by splitting the decision process in two: whether the firm engages in R&D in general and the amount of investment which is devoted to environmental R&D. To account for this, we use a two-step Heckman selection model that allows us to deal with sample selection bias. More specifically, following Raymond et al. (2010), we use a dynamic type 2 tobit model with an unbalanced panel of firm data accounting for unobserved heterogeneity through individual effects. We reflect on why companies decide to integrate both decisions and, looking at the data, we observe that only 12.7% of companies engage in both investments at the same time. We also have checked whether all R&D investments are devoted totally to environmental R&D, and this happens in only 148 observations. Therefore, we infer that firms decide to undertake the two investments in different ways and maybe in different moments. Our data also show that both decisions (investing in R&D and environmental R&D) are highly persistent. Accordingly, the following two equations are estimated:

$$D R\&D\ exp_{it} = 1[\alpha_{1i} + \tau DR\&D\ exp_{it-1} + \beta OI_{it} + \delta' ZControls_{it} + \epsilon_{it}] > 0 \quad [1]$$

$$\log ENV\ exp_{it} =$$

$$\begin{cases} \alpha_{2i} + \log ENV\ exp_{it-1} + \beta OI_{it} + \gamma ENV\ aims_{it-1} + \delta XControls + \epsilon_{2it} & \text{if } DR\&D\ exp_{it} = 1 \\ 0, & \text{if } DR\&D\ exp_{it} = 0 \end{cases} \quad [2]$$

Eq. [1] is the selection equation and measures the long-run firm's decision to invest in R&D considering past R&D investment decisions, OI and several exogeneous controls which are specific to this equation, time invariant individual effects and the error term.

Eq. [2] represents our main equation and the short-run decision to invest a given amount of environmental R&D once the decision to invest in R&D has been taken¹⁹. Such amount

¹⁹ We estimate two models, one for environmental R&D and another one for internal R&D in general. In the estimation for R&D in general, the first equation represents the decision to engage in R&D. In the second equation, contingent

is determined by the company's previous investments in environmental R&D, OI, the strategic environmental aims of the firm, specific control characteristics, time-invariant fixed effects and the error term. We also split the OI variable in its three types: "Practices", "Workplace" and "Relation".

This simultaneous model entails several methodological concerns which should be considered: 1) A sample selection bias in equation [2], since only the firm's environmental behaviour is observed; 2) The presence of unobserved individual effects; 3) The correlation between the initial conditions and the individual effects. We follow the approaches in Raymond et al. (2010) and Garcia-Quevedo et al. (2014) to solve all those concerns. Hence, we estimate our model using a dynamic panel data type-2 tobit model reporting the parameters of the initial conditions ($DR\&D_{exp_{i0}}$ and $\log EnvR\&D_{i0}$), the cross-equation correlations ($\ln\rho_{a1-a2}$, $\ln\rho_{e1-e2}$) and the standard deviations of the error terms (Lns_{a1} , Lns_{a2} , Lns_{e2}).

As an empirical pre-test, we have conducted several interviews with managers from different firms and industries that helped us to understand how they organise and manage the resources and capabilities of the firm when they decide to invest in environmental R&D. They noted that strategic decisions should adapt the organisation and adopt organisational changes to succeed in their goals, whatever they were.

4. RESULTS AND DISCUSSION

upon this decision, the amount invested in R&D is included (in logarithms). Therefore, in the second equation, only the observations with a positive value are used. Similarly, in the estimation for environmental R&D, the first equation considers the decision to engage in R&D and, in the second equation, contingent upon this decision, the amount invested in environmental R&D is included (in logarithms). In this case, the environmental R&D investment variable is transformed by $\text{envR\&D} + 1$ when the values are zero. This is a similar solution to the one used by Raymond et al. (2010) to deal with the observations with zeros in the variable of the second equation. In addition, following the suggestion of a referee, we have used an inverse hyperbolic sine transformation to deal with the zeros of the variable on the amount invested in environmental R&D. The results for the relationship of OI (and the different types of OI) and environmental R&D expenditure are very similar (Table 3, Appendix 1).

As mentioned above, this paper aims to answer the following research questions: Has OI an effect on environmental R&D expenditures by firms? What types of OI have a greater influence in this regard? Does OI affect environmental R&D expenditures by firms in a different way than overall R&D expenditures?

In our estimations (Table 3), we examine the amount invested in environmental R&D considering the previous decision to engage in R&D in general. The results of the selection equation show that OI is positively and significantly associated with the decision to invest in R&D expenditures by firms (Table 3, column 3), which confirms the findings in the previous literature (Chen et al. 2019, Anzola-Román et al. 2018). In this equation, we have included the lag of the dependent variable to control for potential persistence in these decisions, as well as the control variables that may explain the decision to invest in R&D expenditures (public support (subsidies and public contracts), size, age, cooperation in innovation, belonging to a group and human capital). The results show the importance of the persistence of these decisions and the positive effect of size and human capital, as highlighted in the economics of innovation literature (e.g., Arimura et al. 2007).

The results of the main equation show that OI is positively and significantly associated with the amount invested in environmental R&D by firms (Table 3, column 3). In these estimations, together with the lag of the dependent variable and the control variables, we have included the innovation objectives related to environmental issues as explanatory variables. Firms engage in innovation for different reasons and setting up innovation goals is the starting point of the innovation process (Jakobsen and Clausen 2016). Our results show that there is a positive relationship between reducing environmental impacts and environmental R&D, whereas the parameter is not significant for the rest of the variables (reducing material costs, reducing energy costs and meeting environmental regulatory requirements).

Therefore, these estimations show the importance of introducing OIs to explain corporate environmental R&D behaviour. This confirms the findings of other authors that show that organisational innovativeness drives eco-innovation (e.g., Gabler et al. 2015, Amui et al. 2017). It suggests that, by following innovative strategies for organising routines and procedures for work productivity and increasing the efficiency of administrative and operating procedures, OIs increase firms' capacities to engage in environmental practices that improve their productivity and flexibility, but also their responsiveness to the views of external stakeholders (García-Marco et al. 2020, Zhou et al 2019, Bataineh et al. 2023).

In both equations, we have included the lag of the dependent variable and the initial conditions, several exogenous variables and time invariant individual effects. In addition, OI is measured for the period $t-2$ to t whereas the dependent variables, the decision to invest in R&D and the amount of environmental R&D expenditures, refer to t . There is a lag between the implementation of new methods to organise departments, establishing external relations and new procedures for the delegation of decisions and their tangible effects. The results suggest that implementing new organisational methods is positively associated with technical change and could encourage firms to engage in environmental protection and invest in R&D²⁰.

INSERT TABLE 3 HERE

The results show that significant differences exist regarding the relationship of specific OI types and the decision to invest a given amount of money in environmental R&D, once the decision to engage in R&D has been taken (Table 3, column 4). While the parameters are not significant for two types of OIs (new business practices and new methods of

²⁰ We have also carried out the estimations aligning the period of the environmental R&D variable (using the average of the period $t-2$ to t) with the organisational innovation variable which has been measured (as most qualitative variables in innovation surveys) for a three-year period. The results hold. They are available upon request.

managing external relations), the parameter is positive and highly significant for new methods of organising workplaces. This result suggests that an increasing involvement of the employees in the strategies and organisation of the firms encourages them to move to green technologies. This is aligned with the human resources literature that pointed out the need to increase the participation of employees, since this improves the performance of the firm. Furthermore, this result confirms our interpretation in section 2.2.2. As mentioned there, eco-innovation and environmental R&D may have differential features with respect to normal innovation and non-environmental R&D. If they are both more complex, knowledge-intensive, uncertain and peripheral than normal innovation, then workplace innovation, which attracts more talented employees to the firm, may be a particularly relevant driver of environmental R&D. Following the “work environment” literature (Amabile 2012) and the general organisation literature, which indicate that organisational encouragement supports employee creativity and innovation (Beblavy et al. 2012), and given the specific nature of environmental innovation, appropriate work practices (i.e., new methods of organising workplaces) are particularly important for eco-innovation and, thus, to encourage environmental R&D investments. OI, particularly in the form of workplace innovation, promotes employees who are innovative (Dervojeda et al. 2013), which is essential to encourage the creative potential for innovation in general (Willey et al. 2018, Martin 2017), but even more so for knowledge-intensive, complex, uncertain and peripheral (eco)innovations, the ones that investing in environmental R&D are expected to result.

Our result is also in line with the empirical analyses by Rodríguez-Rebés et al. (2021), who found that the type of OI most linked to eco-innovation is innovating in work responsibility and decision-making methods compared to other OI types, Galliano and Nadel (2018), who found that different types of technological eco-innovation are more

influenced by different OI types but that, compared to changes in production organisation and in external relations, changes in work organisation have the greatest impact, and Antonioli et al. (2013), who argued that changing the organisational system to increase workforce involvement and the skill base facilitates the absorption and exploitation of complex innovations, such as eco-innovations. Environmental R&D expenditures may be undertaken as part of work changes and the reorganisation or rationalisation of relations between firms' units, as suggested by Galliano and Nadel (2018) for France and Horbach et al. (2012) for Germany.

On the other hand, the lack of relevance of new ways of organising relations with other firms and public institutions may seem surprising. However, although initial papers on eco-innovation drivers stressed the importance of cooperation (e.g. de Marchi 2012, del Río et al. 2015, Cainelli et al. 2015), recent contributions have shown that factors which are internal to the firm could play a more relevant role in driving eco-innovation development (de Paulo et al. 2020, Dimakopoulou 2022) (see 2.1). Dimakopoulou (2022, 11) argue that “the internal generation process allows the minimisation of knowledge leaking to competitors and ensures the non-imitability of green technologies developed, strengthening the firm’s competitiveness”. Similarly, de Paulo et al. (2020) note that organisations may not collaborate with external partners to protect their technologies and avoid imitation. Rodriguez-Rebés et al. (2021, 856) emphasise “the true importance of management (decision making, leadership) in promoting eco-innovative activities”, with a lower role being played by external relationships in this context.

An interesting finding is that the first OI (new business practices) is not significant. This suggests that not all internal changes may be effective to encourage firms to eco-innovate. Changes in business practices may imply fewer substantial changes in the workforce and

the firm compared to workplace innovation. If a creative and talented workforce is what has an effect on R&D, then this can be considered a logical result.

Third, the results of the estimations presented in table 3 show that there are notable differences regarding the relationship between the different OI types and the amounts invested in environmental R&D compared to overall R&D. They confirm the importance of implementing new methods of organising workplaces. While this OI is positively associated with environmental R&D expenditures, the corresponding parameter is not significant for general R&D investments.

As mentioned above, eco-innovation and environmental R&D have differential features with respect to normal innovation and non-environmental R&D and, thus, workplace innovation is a more relevant driver for environmental R&D than for general R&D.

Instead, the implementation of new business practices and the introduction of new methods of managing external relations is positively associated with overall R&D but not with environmental R&D. To check the robustness of these differences, two equality of means tests have been carried out, one for OI and another for the three different OI types. The results show that the differences are clearly significant, highlighting the importance that OI and, in particular, new methods of organising workplaces have on the environmental behaviour of firms.

5. CONCLUSIONS

The relationship between organisational innovation and environmental R&D has been analysed in this paper. Based on data from the Spanish Technological Innovation Panel (PITEC) for the period 2008 to 2016, an empirical analysis has been performed. The results of the estimations support the idea that OI drives environmental R&D

expenditures. Further analysis suggests that it is particularly the introduction of new methods of organising workplaces that is positively associated with environmental R&D. Therefore, our findings suggest that a policy-mix with instruments that promote organisational changes and incentivise investments in environmental R&D would be more effective than policies only devoted to foster private environmental expenditures on R&D. In addition, the results show that encouraging OIs in firms would trigger a greater environmental expenditure on R&D but this would happen for some OIs only. In particular, a regulatory environment that facilitates workplace innovation (such as addressing regulatory challenges which hamper workplace innovation and facilitating workplace flexibility) may promote environmental R&D investments. In contrast, the effectiveness of promoting new business practices and new ways of organising relations with third parties would be limited to encourage environmental R&D investments.

This last result is in contrast to traditional findings in the eco-innovation literature and indicates that supporting cooperation between firms may not be so effective to encourage environmental R&D. If environmental innovations often go beyond firms' core competences (Jakobsen and Clausen 2016) and do not build on a continuous and successive improvement of the firms' existing knowledge (Hemmelskamp 1997), and firms undertaking eco-innovations might have to search for completely new knowledge and solutions in their innovation process (De Marchi and Grandinetti 2013), then the firm may need to search for this knowledge elsewhere, i.e. outside its boundaries. However, our results suggest that firms may not do so through changes in external relationships which facilitate access to external knowledge sources, but by implementing OIs which attract workers with the necessary expertise. This is in contrast to the literature, which supports the idea that the reliance on external R&D is higher for eco-innovators compared

to firms which innovate, but do not eco-innovate (Cainelli et al. 2015, Horbach et al. 2012, De Marchi and Grandinetti 2013, Ghisetti et al. 2015).

The first result (new business practices are not positively associated with environmental R&D) may indicate that changes in business practices imply fewer substantial changes in the workforce and the firm compared to workplace innovation and suggests that managers should focus less on innovation in business practices in order to encourage environmental R&D.

If environmental R&D investments may improve both the environmental performance of the firm and its competitiveness (King and Lenox 2002, Lee and Min 2015, Alam et al. 2019), our results suggest that company managers should devote resources and build technological and organisational human skills within the company. Firms should thus be encouraged to engage in a diverse set of innovation practices, paying attention to the often disregarded non-technological aspects of the innovation phenomenon. Indeed, the results of this research clearly highlight the positive effects of implementing OIs on the generation of eco-innovations (environmental R&D). Managers should not focus exclusively on generating and implementing technological innovation, but on combining these efforts with new ways of organising the workplace and with new methods of coordinating activities. More generally, an important implication of our results is that managers should accommodate the organisation's resources to fit the environmental strategies. This implies that the specific and idiosyncratic decisions on engagement in environmental investments require a flexible company structure that allows the flow of information and communication to create an atmosphere where creativity and innovation circulate in a more open way.

Some limitations of our work are worth mentioning. First, similarly to what it is argued by Lee and Min (2015), this article focuses on environmental R&D, which limits the

study's sample to manufacturing industries in which green R&D represents a significant share of total R&D. Therefore, the study's findings may not apply to non-manufacturing industries that have modest green R&D activity. Future research should examine differences between manufacturing and services firms. Furthermore, the focus has been on a single country. Some features of Spain make it a relevant country to investigate. It is the fourth largest EU economy and greenhouse gas (GHG) emitter, it has experienced a significant push toward innovative and sustainable practices (Bataineh et al. 2023b), and it is advanced regarding eco-innovation (Kunapatarawong and Martínez-Ros 2016). However, compared to other EU countries, it is a moderate innovation country, with a unique innovation system (de Marchi 2012, Jove-Llopis and Segarra-Blasco 2018), low environmental regulation stringency and low willingness to pay “green” price premiums by consumers (Kiefer et al. 2019). Its economic structure contrasts sharply with northern/central European economies (i.e., del Río et al. 2021, Horbach et al. 2022). Therefore, comparative studies across countries should be conducted in order to increase the validity of the analysis, although data availability will probably be a substantial constraint in this regard.

There are other potential extensions of our work. First, the Spanish business community is not uniform and it is mainly made up of SMEs. Therefore, it would also be interesting to investigate differences in the size and age of the firms. Second, the assessment of the impacts of OI on eco-innovation can benefit from analyses being performed in the general OI literature. One of them is related to reverse causality, a possible limitation of this paper. Whereas the effects of OI and OI types on technological eco-innovation (measured with environmental R&D expenditures) have been analysed in this paper, future research

could be devoted to assess the other direction of causality²¹, i.e., how environmental R&D investments may lead to OI changes, particularly in work and production organisation²². In fact, OI scholars have found that there is strong complementarity between OI and technological innovation (Sapprasert and Clausen 2012, Carboni and Rusu 2017). These complementarities should be explored for the case of eco-innovation. Further research should also identify the existence of a potential substitution effect in firms which may occur when combining environmental R&D and OI activities for the generation of innovations, an issue observed in the literature on OI and technological innovation (Anzola-Roman et al. 2018)²³. Recent work on new e-business technologies (i.e. industry 4.0) provides strong evidence that technological changes closely interact with organisational changes in the firm (Najmaei and Sadeghinejad 2023, Cassetta et al. 2020, Khan et al 2020). OIs and technological changes are complementary and their relationship is bidirectional: OIs may favour technological changes, but technological changes (e.g., Industry 4.0) may facilitate the organisational and management changes needed for the adoption of green business models. This points out that the interaction between environmental R&D expenditures and OI improves firm performance (e.g., sales, benefits....) with respect to their single influence (i.e., “environmental R&D” effects isolated from “OI effects”), suggesting a fruitful line of further research. Finally, the non-significance of innovation in business practices deserves more attention in the future.

Acknowledgements: Previous versions of this paper were presented at the Workshop: “New technologies, eco-innovation, and productivity: Does innovation efficiency

²¹ This potential reverse causality may still raise endogeneity concerns, although we have tried to minimise these concerns by using, as explained above, a dynamic type 2 tobit model with an unbalanced panel of firm data accounting for unobserved heterogeneity through individual effects. Endogeneity may still be an issue for some variables.

²² For example, within the general R&D literature, Carboni and Rusu (2017) strongly suggest that a firm’s R&D commitment strongly impacts production and process innovation, but also OI.

²³ For example, Anzola-Roman et al. (2018) empirically show that dedicating time and effort to the implementation of OIs might be draining resources away from effectively profiting from the internal R&D activities.

matter?”, University of Patras, Athens, Greece, 18-19 October 2022; at the VII KIIS Workshop, University of Valencia, Valencia, Spain, 17-18 November 2022; at the Workshop on “Eco-innovation, circular economy and firm performance”, University of Barcelona and University Rovira i Virgili, Barcelona, Spain, 21 April 2023; at the annual SEEDS Workshop, Ferrara, Italy, 4-6 May 2023; and at the ALLIES Workshop on environmental economics and innovation, CSIC, Madrid, Spain, 16-17 May 2023. We would like to thank the participants at these meetings for their helpful comments. We acknowledge financial support from the Chair of Energy Sustainability (IEB, University of Barcelona) and from funds of the Ministry of Science and Innovation provided for projects nº PID2021-126153NB-I00. Jose Garcia-Quevedo acknowledges support from the project PID2022-140546OB-I00 funded by MCIU/AEI/10.13039/501100011033 and ERDF, EU. This work has been supported by the Madrid Government (Comunidad de Madrid-Spain) under the multiannual Agreement with UC3M in the line of Excellence of University Professors (EPUC3M12) in the context of the VPRICIT (Regional Programme of Research and Technological Innovation) and CSIC intramural project PIE 202010E134 on the “Circular Transition: Identification of barriers to the Circular Economy in the energy and industrial sectors”.

REFERENCES

- Aboelmaged, M., Hashem, G. (2019). Absorptive capacity and green innovation adoption in SMEs: The mediating effects of sustainable organisational capabilities. *Journal of Cleaner Production* 220, 853–863.
- Alam S., Atif, M., Chien-Chi, C., Soytaş, U. (2019). Does corporate R&D investment affect firm environmental performance? Evidence from G-6 countries. *Energy Economics* 78, 401–411.
- Amabile, T. M., Conti, R., Coon, H., Lazenby, J. & Herron, M. (1996). Assessing the work environment for creativity. *Academy of Management Journal* 39(5), 1154-1184.
- Amabile, T.M. (1997), “Motivating creativity in organizations: on doing what you love and loving what you do”, *California Management Review* 40(1), 39-58.
- Amabile, T.M. (2012), *Componential Theory of Creativity*, Harvard Business School, Boston.
- Amui, L., Jabbour, C., Jabbour, A., Kannan D. (2017). Sustainability as a dynamic organizational capability: a systematic review and a future agenda toward a sustainable transition. *Journal of Cleaner Production* 142, 308-322
- Antonioli, D., Mancinelli, S., & Mazzanti, M. (2013). Is environmental innovation embedded within high-performance organisational changes? The role of human resource management and complementarity in green business strategies. *Research Policy* 42(4), 975–988.
- Arimura, T., Hibiki, A., Johnstone, N. (2007). An empirical study of environmental R&D: what encourages facilities to be environmentally innovative. *Environmental policy and corporate behaviour*, 142-173
- Anzola-Román, P., Bayona-Sáez, C., García-Marco, T. (2018) Organizational innovation, internal R&D and externally sourced innovation practices: Effects on technological innovation outcomes. *Journal of Business Research* 91, 233–247
- Arfi, W. B., Hikkerova, L., Sahut, J. M. (2018). External knowledge sources, green innovation and performance. *Technological Forecasting and Social Change* 129, 210–220.
- Armbruster, H., Bikfalvib, A., Kinkela, S., Lay, G. (2008). Organizational innovation: The challenge of measuring non-technical innovation in large-scale surveys. *Technovation* 28, 644–657
- Arranz, N., Arroyabe, M. Li; J., Fernandez de Arroyabe, J.C (2020). Innovation as a driver of eco-innovation in the firm: An approach from the dynamic capabilities theory. *Bus Strat Env.* 29, 1494–1503.
- Bataineh, M.J., Sánchez-Sellero, P., Ayad, F. (2023). The role of organizational innovation in the development of green innovations in Spanish firms. *European Management Journal*.
- Beblavý, M., Maselli, I. Martellucci, E. (2012). *Workplace Innovation and Technological Change*. CEPS Special Report.
- Birkinshaw, J., Hamel, G., Mol, M.J. (2008). Management innovation. *Acad Manage Rev* 33(4), 825–845
- Blomquist, T., Sandström, J. (2004). From issues to checkpoints and back: managing green issues in R&D. *Bus. Strat. Env.* 13, 363–373.
- Boutry, O., Nadel, S. (2021). Institutional Drivers of Environmental Innovation: Evidence from French Industrial Firms. *0 34*, 135-167

- Buchanan, D., Fitzgerald, L., Ketley, D., Gollop, R., Jones, J.L., Lamont, S.S., Neath, A., Whitby, E. (2005). No going back: a review of the literature on sustaining organizational change. *Int J Manage Rev* 7(3), 189–205
- Chakrabarty S., Wang, L. (2012). The long-term sustenance of sustainability practices in MNCs: A dynamic capabilities perspective of the role of R&D and internationalization. *Journal of Business Ethics* 110(2), 205-217.
- Cainelli, G., Mazzanti, M., Montresor, S. (2012). Environmental innovations, local networks and internationalization. *Ind. Innov.* 9 (8), 697-734
- Cainelli G, De Marchi V, Grandinetti R. (2015) Does the development of environmental innovation require different resources? Evidence from Spanish manufacturing firms, *Journal of Cleaner Production* 94, 211-220
- Carayannis, E.G. and Gonzalez, E. (2003), “Creativity and innovation = competitiveness? When, how, and why”. In: Shavinina, L.V. (Ed.), *The International Handbook on Innovation*, Elsevier, Oxford, pp. 587-606.
- Carboni, O., Russu, P. (2017). Complementarity in product, process, and organizational innovation decisions: evidence from European firms. *R&D Management* 48(2), 210-222
- Cassetta E., Monarca U., Dileo I., Di Berardino C., Pini M. (2020), The relationship between digital technologies and internationalisation. Evidence from Italian SMEs. *Industry and Innovation*, 27(4), 311-339.
- Cassetta E., Dileo I., Pini M. (2023), Linking external collaborations, eco-innovation and sustainable growth. An empirical analysis on the Italian manufacturing firms. *Industry and Innovation* 30(4), 452-479
- Chen, Q., Wang, C., Huang, S. (2019). Effects of organizational innovation and technological innovation capabilities on firm performance: evidence from firms in China’s Pearl River Delta, *Asia Pacific Business Review*.
- Costa-Campi, M.T., García-Quevedo, J. Martínez-Ros, E. (2017). What are the determinants of investment in environmental R&D? *Energy Policy* 104, 455-465.
- Consoli, D., Marin, G., Marzucchie, A., Vona, F. (2016). Do green jobs differ from non-green jobs in terms of skills, human capital? *Res. Pol.* 45, 1046-1060.
- Crepon, B., Duguet, E., Mairesse, J., (1998). Research, innovation and productivity: an econometric analysis at the firm level. *Economics of Innovation and New Technology* 7, 115-158.
- Cuerva, M. C., Triguero-Cano, Á., & Córcoles, D. (2014). Drivers of green and non-green innovation: Empirical evidence in Low-Tech SMEs. *Journal of Cleaner Production* 68, 104–113.
- Damanpour, F. (1987). The adoption of technological, administrative and ancillary innovations: impact of organizational factors. *Journal of Management* 13, 675–688.
- Damanpour, F. (2017) *Organizational Innovation*. Oxford Research Encyclopedia of Business and Management.
- D’Amato, A., Mazzanti, M., & Nicolli, F. (2021). Green technologies and environmental policies for sustainable development: Testing direct and indirect impacts. *Journal of Cleaner Production*, 309, 127060.
- Darnall, N., Henriques, I., Sadorsky, P. (2008). Do environmental management systems improve business performance in an international setting? *J. Int. Manag.* 14 (4), 364–376.

- Delmas M., Pekovic, D. (2013). Environmental standards and labor productivity: Understanding the mechanisms that sustain sustainability. *Journal of Organizational Behavior, J. Organiz. Behav.* 34, 230–252.
- De Marchi, V. (2012). Environmental innovation and R&D cooperation: empirical evidence from Spanish manufacturing companies. *Res. Pol.* 41, 614–623.
- De Marchi, V., Grandinetti, R. (2013). Knowledge strategies for environmental innovations: the case of Italian manufacturing firms. *J. Knowl. Manag.* 17 (4), 569–582.
- De Paulo, A. F., Nunes, B., & Porto, G. (2020). Emerging green technologies for vehicle propulsion systems. *Technological Forecasting and Social Change* 159, 120054.
- Del Brío, J.A., Junquera, B. (2003). A review of the literature on environmental innovation management in SMEs: implications for public policies. *Technovation* 23(12), 939-948.
- Del Río, P., Peñasco, C., Romero-Jordán, D. (2015). Distinctive features of environmental innovators. An econometric analysis. *Business Strategy and the Environment* 24(6), 361–385
- Del Río, P., Peñasco, C., Romero-Jordán, D. (2016). What drives eco-innovators? A critical review of the empirical literature based on econometric methods. *Journal of Cleaner Production* 112, 2158-2170.
- Del Río, P., Kiefer, C., Carrillo, J., Könnöla, T. (2021). *The Circular Economy: Economic, managerial and policy implications.* Springer International. Nueva York 10.1007/978-3-030-74792-3
- Demirel, P., Kesidou, F. (2011). Stimulating different types of eco-innovation in the UK: Government policies and firm motivations. *Ecological Economics* 70, 1546-1557.
- Demirel, P., Kesidou, F. (2019). Sustainability-oriented capabilities for eco-innovation: Meeting the regulatory, technology, and market demands. *Business Strategy and the Environment* 28, 847–857.
- Dervojeđa, K et al (2013). *Workplace Innovation Solutions for enhancing workplace productivity.* Business Innovation Observatory. European Commission.
- Dewick, P., Foster, C. (2018). Focal Organisations and Eco-innovation in Consumption and Production Systems. *Ecological Economics* 143, 161–169
- Díaz-García, C., González-Moreno, Á. & Sáez-Martínez, F.J. (2015). Eco-innovation: insights from a literature review. *Innovation* 17, 6-23.
- Dimakopoulou, A., Chatzistamoulou, N., Kounetas, K., Tsekoura (2022). Environmental innovation and R&D collaborations: Firm decisions in the innovation efficiency context. *The Journal of Technology Transfer.*
- Frondeľ, M., Horbach, J., Rennings, K. (2007). End-of-pipe or cleaner production? An empirical comparison of environmental innovation decisions across OECD countries. *Business Strategy and the Environment* 16, pp. 571-584.
- Gabler, C., Richey, R.C., Rapp, A. (2015). Developing an eco-capability through environmental orientation and organizational innovativeness. *Industrial Marketing Management* 45, 151–161
- Galliano, D., Nadel, S. (2015). Firms' Eco-innovation Intensity and Sectoral System of Innovation: The Case of French Industry. *Industry and Innovation* 22(6), 467-495,
- Galliano, D., Nadel, S. (2018). Environmental innovation and firms' organizational changes. *Revue d'Économie Industrielle* 166, 36-71.

- Ganter, A., Hecker, A. (2014). Configurational paths to organizational innovation: qualitative comparative analyses of antecedents and contingencies. *J Bus Res* 67, 1285–1292
- García-Marco, T., Zouaghi, F., Sánchez, M. (2020). Do firms with different levels of environmental regulatory pressure behave differently regarding complementarity among innovation practices? *Business Strategy and the Environment* 29, 1684-1694.
- García-Quevedo, J., Pellegrino, G., Vivarelli, M. (2014). R&D drivers and age: Are young firms different, *Research Policy* 43, 1544-1566.
- Ghisetti C., Marzucchi A., Montresor, S. (2015). The open eco-innovation mode. An empirical investigation of eleven European countries. *Research Policy* 44, 1080–1093
- Haned, N., Mothe, C. and Nguyen-Thi, T.U. (2014) Firm Persistence in Technological Innovation: The Relevance of Organizational Innovation. *Economics of Innovation and New Technology* 23, 490-516.
- Hemmelkamp, J. (1997). Environmental policy instruments and their effects on innovation. *European Planning Studies* 5(2), 177-194
- Hojnik, J and Ruzzier, M. (2016). What drives eco-innovation? A review of an emerging literature. *Environmental Innovation and Societal Transitions* 19, 31–41
- Horbach, J. (2008). Determinants of environmental innovation—New evidence from German panel data sources. *Research Policy* 37, 163–173.
- Horbach, J., Rammer, C., Rennings, K., (2012). Determinants of eco-innovations by type of environmental impact. The role of regulatory push/pull, technology push and market pull. *Ecol. Econ.* 78, 112-122.
- Horbach, J., Oltra, V., Belin, J. (2013) Determinants and Specificities of Eco-Innovations Compared to Other Innovations—An Econometric Analysis for the French and German Industry Based on the Community Innovation Survey. *Industry and Innovation*, 20(6), 523-543
- Hottenrott, H., Rexhauser, S., Veugelers, R. (2016). Organisational change and the productivity effects of green technology adoption. *Resource and Energy Economics* 43, 172–194.
- IEA (2020). *Clean Technology Innovation*. Paris.
- Isaksen, S.G., Lauer, K.J., Ekvall, G. and Britz, A. (2001). Perceptions of the best and worst climates for creativity: Preliminary validation evidence for the situational outlook questionnaire. *Creativity Research Journal* 13(2), 171-184
- Jakobsen, S., Clausen, T. (2016). Innovating for a greener future: the direct and indirect effect of firms' environmental objectives on the innovation process. *Journal of Cleaner Production* 128, 131-141.
- Johnstone, N., Labonne, J. (2007). *Environmental policy, management and R&D*. OECD Economic Studies, Vol. 2006/1.
- Jové-Llopis, E., Segarra-Blasco, A. 2018. Eco - Innovation Strategies: A Panel Data Analysis of Spanish Manufacturing Firms. *Business Strategy and the Environment* 27(8), 1209–1220
- Kemp, R., Foxon, T. (2007). *Typology of Eco-innovation*. Deliverable 2. EU FP6 funded project 044513: 24. Maastricht.
- Kesidou, F, Demirel, P. (2012). On the drivers of eco-innovation: Empirical evidence from the
- Khan, I., Ahmad, M., Majava, J. (2021). Industry 4.0 and sustainable development: A systematic mapping of triple bottom line, Circular Economy and Sustainable Business Models perspectives, *Journal of Cleaner Production*, Volume 297.

- Kiefer, C., del Río, P., Carrillo-Hermosilla, J. (2024). How does corporate environmental culture enable the ecoinnovation transition of firms towards the circular economy? *Corporate Social Responsibility and Environmental Management (CSREM)* 1-27.
- Kiefer, C. P., Río, P., & Carrillo-Hermosilla, J. (2021). On the contribution of eco-innovation features to a circular economy: A microlevel quantitative approach. *Business Strategy and the Environment* 30(4), 1531-1547.
- Kiefer, C., Del Río, P., Carrillo, C. (2019). Drivers and barriers of eco-innovation types for sustainable transitions: A quantitative perspective. *Business Strategy and the Environment* 28, 155–172.
- King, A., Lenox, M. (2002). Exploring the locus of profitable pollution reduction. *Management Science* 48(2), 289–299.
- Kobarg, S., Stumpf-Wollersheim, J., Schlägel, C., Welp, I. (2020). Green together? The effects of companies' innovation collaboration with different partner types on ecological process and product innovation. *Industry and Innovation* 27(9), 953-990.
- Lam, A. (2004). Organizational innovation. Working Paper, Brunel Research in Enterprise, Innovation, Sustainability & Ethics, available at: <http://mpra.ub.uni-muenchen.de/11539/>
- Laughlin, R.C. (1991). Environmental disturbances and organizational transitions and transformations: some alternative models. *Organization Studies* 12(2), 209–232.
- Laursen, K., Salter, A. (2004). Searching high and low: what types of firms use universities as a source of innovation? *Research Policy* 33, 1201–1215
- Laursen, K., Salter, A. (2006) Open for Innovation: The Role of Openness in Explaining Innovation Performance among UK Manufacturing Firms. *Strategic Management Journal*, 27, 131-150.
- Lee, K., Min, B. (2015). Green R&D for eco-innovation and its impact on carbon emissions and firm performance. *Journal of Cleaner Production* 108, 534-542
- Le Bas, C., Mothe, C. and Nguyen-Thi, T.U. (2015) The Differentiated Impacts of Organizational Innovation Practices on Technological Innovation Persistence. *European Journal of Innovation Management* 18, 110-127.
- Marin, G. (2014). Do eco-innovations harm productivity growth through crowding out? Results of an extended CDM model for Italy. *Research Policy* 43, 310-317.
- Martin. (2017) *The Innovation Process: Definition, Models, Risks & Opportunities*, Tips. Cleverism.
- Marzucchi, A., Montresor, S. (2017). Forms of knowledge and eco-innovation modes: Evidence from Spanish manufacturing firms. *Ecological Economics* 131, 208–221.
- Mazzanti, M., Zoboli, R. (2008). Complementarities, firm strategies and environmental innovations: empirical evidence for a district based manufacturing system. *Environmental Sciences* 5, 17-40.
- Mothe, C. and Nguyen, T. (2010). The Link between Non-Technological Innovations and Technological Innovation. *European Journal of Innovation Management*, 13 313-332.
- Nadel, S., (2013). La responsabilité sociale de l'entreprise comme forme de justification : quels impacts sur le travail ? *Revue Française de Socio-Économie* 11, 165-179.
- Najmaei, A., Sadeghinejad, Z. (2023). Green and sustainable business models: historical roots, growth trajectory, conceptual architecture and an agenda for future research—A bibliometric review of green and sustainable business models. *Scientometrics* 128, 957–999.

- Nanda, T. and Singh, T.P. (2009). Determinants of creativity and innovation in the workplace: a comprehensive review. *International Journal of Technology, Policy and Management*, 9(1), 84-106.
- OECD (2002). *The Measurement of Scientific and Technological Activities. Frascati Manual 2002: Proposed Standard Practice for Surveys on Research and Experimental Development*.
- OECD (2005). *Oslo Manual. The measurement of scientific and technological activities. Proposed guidelines for collecting and interpreting technological innovation data. 3rd Edition*. OECD Publishing.
- Peng, M.W., Wang, D.Y.L., Jiang, Y. (2008). An institution-based view of international business strategy: a focus on emerging economies. *J. Int. Bus. Stud.* 39, 920–936.
- Piva, M., Vivarelli, M. (2002). The Skill Bias: Comparative evidence and an econometric test. *International Review of Applied Economics* 16(3), 347-357
- Ramadani, V., Hisrich, R. D., Abazi-Alili, H., Dana, L. P., Panthi, L., & Abazi-Bexheti, L. (2019). Product innovation and firm performance in transition economies: A multistage estimation approach. *Technological Forecasting and Social Change* 140, 271–280.
- Ramus, C. (2003). *Employee Environmental Innovation in Firms: Organizational and managerial factors*. Routledge, London.
- Raymond, W., Mohnen, P., Palm, F., Schim van der Loeff, S. (2010). Persistence of Innovation in Dutch manufacturing: Is it Spurious? *Review of Economics and Statistics* 92, 495-504.
- Rave, T., Goetzke, F., Larch, M. (2011). The determinants of environmental innovations and patenting: Germany reconsidered. *Ifo Working Paper*, 97
- Rodríguez-Rebes, L., Navío-Marco, J., Ibar-Alonso, R. (2021). Influence of organisational innovation and innovation in general on eco-innovation in European companies. *Journal of Intellectual Capital* 22(5), 840-867.
- Russo, M.V., Fouts, P.A. (1997). A resource-based perspective on corporate environmental performance and profitability. *Acad. Manag. J.* 40 (3), 534–559.
- Salim, N., Rahman M, Wahab, D. (2019). A systematic literature review of internal capabilities for enhancing eco-innovation performance of manufacturing firms. *Journal of Cleaner Production* 209, 1445-1460.
- Sapprasert, K. and Clausen, T. (2012). Organizational innovation and its effects. *Industrial and Corporate Change* 21(5), 1283-1305.
- Shuwaikh, F., Benkraiem, R., Dubocage, E. (2023). Investment in Green Innovation: How does It Contribute to Environmental and Financial Performance? *Journal of Innovation Economics & Management* 41 (2023/2), 107-149.
- Steiber, Annika; Alänge, Sverker (2015). Organizational innovation: a comprehensive model for catalyzing organizational development and change in a rapidly changing world. *Triple Helix* 2(1), 1-25.
- Tian, H., Wang, Z.H. (2020), Chinese Green Process Innovation in Automotive Painting: The Strategic Niche Management Perspective, *International Journal of Environmental Science and Technology* 17, 993-1010.
- Tohidi, H. and Jabbari, M.M. (2012). The Important of Innovation and Its Crucial Role in Growth, Survival and Success of Organizations. *Procedia Technology* 1, 535-538.
- Triguero, A., Cuerva, M. C., Alvarez-Aledo, C. (2017). Environmental innovation and employment: Drivers and synergies. *Sustainability* 9(11)(2057), 1-22.

- Van De Ven, A.H. & Poole, M.S. (2005). Alternative Approaches for Studying Organizational Change. *Organization Studies* 26, 1377-1404.
- van Kleef, J., Roome, N. (2007). Developing capabilities and competence for sustainable business management as innovation: a research agenda. *Journal of cleaner production* 15, 38-51.
- Van Leeuwen, G & Mohnen, P. (2017). Revisiting the Porter hypothesis: an empirical analysis of Green innovation for the Netherlands, *Economics of Innovation and New Technology*, 26(1-2), 63-77.
- Wagner, M. (2008). Empirical influence of environmental management on innovation: evidence from Europe. *Ecol. Econ.* 66 (2-3), 392–402.
- Wagner, M., Llerena, P. (2011). Eco-innovation through integration, regulation and cooperation: Comparative insights from case studies in three manufacturing sectors. *Industry and Innovation* 18(8), 747-764.
- Willey M., Figueiredo, P., Pereira-Guizzo, C. (2018). Antecedents of innovation in industry. The impact of work environment factors on creative performance. *Innovation & Management Review* 15(3), 269-285
- Xavier, A.F., Naveiro, R.M., Aoussat, A. & Reyes, T. (2017). Systematic literature review of ecoinnovation models: Opportunities and recommendations for future research. *Journal of Cleaner Production*, 149, 1278-1302.
- Xiao, S.S., Jeong, I., Moon, J.J., Chung, C.C., Chung, J. (2013). Internationalization and performance of firms in China: moderating effects of governance structure and the degree of centralized control. *J. Int. Manag.* 19, 118–137
- Zhang, Y., Sun, J., Yang, Z., & Wang, Y. (2020). Critical success factors of green innovation: Technology, organization and environment readiness. *Journal of Cleaner Production*, Article 121701
- Ziegler, A., Rennings, K. (2004). Determinants of Environmental Innovations in Germany: Do Organizational Measures Matter? ZEW (Centre for European Economic Research). Discussion Paper No. 04-030.
- Zubeltzu-Jaka, E., Erauskin-Tolosa, A., Heras-Saizarbitoria, I. (2018). Shedding light on the determinants of eco-innovation: A meta-analytic study. *Bus Strat Env* 27, 1093–1103.

TABLES

Table 1. Summarising the literature on the determinants of environmental R&D.

Paper	Geographical and temporal scope	Methodology and sample size	Dependent and explanatory variables	Results
Johnstone and Labonne (2007)	2003 Seven OECD countries (Canada, France, Germany, Hungary, Japan, Norway and United States)	The decision to engage in environmental R&D is modelled as a two-stage process (probit models). Sample size: 2132 facilities.	Dependent variable: Whether firms carry out environmental R&D or not (binary variable). Explanatory variables: Environmental regulation stringency, input ban, technology-based standard, performance-based standard, input taxes, emissions taxes and technical assistance, presence of an environmental management system in the facility, whether the facility has introduced an environmental accounting system and whether the facility has an environmental training programme in place for its employees In the questionnaire, facilities were also asked to describe the institutional location of the person (if any) with explicit responsibility for environmental concerns. The options were: "Senior Management", "Production/Operations", "Specialised Environmental Department".	Whether the facility has introduced an environmental accounting system and whether it has an environment training programme have a significant positive impact on the decision to invest in environmental R&D. However, the presence of an EMS does not.
Arimura et al. (2007)	2003 Seven OECD countries (Canada, France, Germany, Hungary, Japan, Norway and United States)	Tobit and bivariate probit models. Sample size: 4312 facilities	Dependent variable: investments in environmental R&D Explanatory variables: Policy variables (stringent Env Policy, Inspection Frequency, dummies for Technology-based Standards, Performance-based Standards, Input Taxes (including energy), Emission or Effluent Taxes and Technical Assistance), firm/facility characteristics (number of employees, sales increase, bad performance and multi-facilities), market structure (oligopoly), stakeholders (dummies for listed firms and global markets), management practices (EMS, quality management, safety management, full-cost accounting, management accounting system, process control system and inventory requirement planning) and country and sector variables.	Policy stringency has a positive effect on investment in environmental R&D. While the direct effect of the use of flexible policy instruments on environmental R&D is not significant, their application promotes the adoption of an environmental accounting system, which in turn induces investment in environmental R&D. Four management practices (EMS, quality management, full-cost accounting and management accounting system) are statistically significant.
Kesidou and Demirel (2011)	2006 U.K.	Tobit model Sample size: 73 firms.	Dependent variable: Environmental research and development (£) Explanatory variables: External determinants: if the firm invested in environmental protection due to environmental regulation compliance, if the firm invested in environmental protection because of environmental taxes. Internal determinants: Total cost savings resulting from environmental improvements (£), if the firm invested in environmental protection because	The authors show that an EMS in t-1 has a positive and significant effect on driving investments in environmental R&D expenditures. They conclude that EMS and ISO14001 have a positive impact on environmental R&D expenditures, whereas

			of equipment upgrade, if the firm has implemented environmental management Systems, if the firm has and ISO14001 certified environmental management System, if the firm invested in environmental protection because of parent company or owner policy/CSR, number of employees, turnover (£), productivity and Total Capital (£).	corporate social responsibility policies do not.
Kesidou and Demirel (2012)	2006 U.K.	Heckman selection model and quintile regressions. 1566 UK firms, but only 242 undertook environmental R&D	Dependent variable: Environmental research and development (£) Explanatory variables: They include organisational capabilities (investment of environmental protection because of parent company or owner policy/CSR, investment in environmental protection because of customer environmental requirements and implementation of an EMS), abatement costs, if the firm invested in environmental protection because of equipment upgrade, Total cost savings resulting from environmental improvements, Total income obtained from the sale of by-products arising from environmental improvements, company turnover and number of employees.	They find that building organisational capabilities related with the EMS affects investments in environmental R&D. Firms that implement an EMS invest more in environmental R&D, compared to firms without an EMS. Increased investments in eco-innovations are stimulated by cost savings, firms' organisational capabilities, and stricter regulations. Firms that build organisational capabilities accumulate the necessary soft skills that enable them to initiate environmental R&D.
Costa-Campi et al. (2017)	Spain 2008-2013	Random effects panel data model. 22 manufacturing sectors	Dependent variable: Business R & D expenditure on the control and care of the environment. Explanatory variables: Annual Turnover, Personnel in R & D as % of total personnel, Number of firms with more than 50% of foreign capital as % of total firms, Public subsidies to R & D activities of the firms, Investment in environmental protection (integrated equipment and facilities), Investment in environmental protection (independent equipment and facilities), Expenditure on acquisition of energy products (electricity, gas and other fuels), Firms that consider of high importance the innovation objective "Reduce environmental impact" (as % of total firms), Taxes on energy, Taxes on pollution and resources, Carbon dioxide emissions into the atmosphere of (thousands of tonnes of equivalent CO2) and Number of ISO 14001 certifications per industry.	A positive relationship between investment to prevent pollution and environmental R&D and a positive relationship between the greater use of energy products as an intermediate input in the production process and environmental R&D are found. Second, instruments of innovation policy (R&D subsidies) as well of environmental policy (environmental taxes) have a positive impact on environmental R&D. However, this is not the case for general energy taxes. The stringency of regulations positively affects environmental R&D.
van Leeuwen and Mohnen (2017)	The Netherlands 2003-2008	Probit models. 5989 observations.	Dependent variable: environmental R&D Explanatory variables: employment, environmental regulation dummy, investment/labor, energy cost share in t – 1, Eco subsidies received, Industry dummies and Time dummies.	They show that energy cost share, environmental levies and environmental regulation foster investment in eco-R&D. Large firms are more likely to invest in eco-R&D although the intensity decreases with size.

Table 2. Descriptive Statistics

	N	Mean	SD	Min	Max
R&D exp	22141	828610.69	4982284.518	0	1.895e+08
DR&D	22141	.701	0.458	0	1
Env exp	22141	29259.333	775074.207	0	66524128
sales	22141	76966658	477004412.96	0	1.861e+10
age	22141	33.182	19.328	2	181
subv	22141	43980.625	459662.709	0	39335904
contrat	22141	22105.061	885414.834	0	73167912
coopera	22141	.385	0.487	0	1
grupo	22141	.487	0.500	0	1
highsills	22141	22.002	19.792	0	100
energy	22141	.202	0.401	0	1
material	22141	.196	0.397	0	1
comply	22141	.32	0.467	0	1
impact	22141	.273	0.446	0	1
oi	22141	.326	0.373	0	1
practices	22141	.419	0.493	0	1
workplace	22141	.401	0.490	0	1
relation	22141	.158	0.365	0	1

Table 3. Dynamic Panel Data type-2 Tobit Results: effect of OI on environmental R&D expenditures and R&D expenditures.

	LEnv Expenditure		LR&D Expenditure	
Main equation	OI	Types of OI	OI	Types of OI
LR&D exp _{t-1}			0.072*** (0.003)	0.072*** (0.003)
LR&D exp _{t0}			0.048*** (0.002)	0.048*** (0.002)
LEnv exp _{t-1}	0.403*** (0.007)	0.401*** (0.008)		
LEnv exp _{t0}	0.075*** (0.006)	0.074*** (0.007)		
OI	0.189*** (0.047)		0.094*** (0.021)	
Practices		-0.016 (0.043)		0.047** (0.019)
Workplace		0.191*** (0.046)		-0.010 (0.019)
Relation		-0.019 (0.049)		0.072*** (0.020)
Material	0.018 (0.053)	0.022 (0.053)	0.027 (0.022)	0.026 (0.022)
Energy	0.016 (0.030)	0.017 (0.054)	0.015 (0.023)	0.014 (0.023)
Impact	0.183*** (0.050)	0.186*** (0.046)	0.053*** (0.020)	0.053*** (0.020)
Comply	0.047 (0.043)	0.041 (0.043)	-0.005 (0.019)	-0.005 (0.019)
Lage	-0.033 (0.097)	-0.031 (0.034)	0.014 (0.018)	0.014 (0.018)
Lsales	0.035*** (0.016)	0.029*** (0.014)	0.439*** (0.007)	0.441*** (0.007)
Coopera	0.092*** (0.011)	0.095*** (0.036)	0.275*** (0.016)	0.272*** (0.016)
Group	-0.054 (0.196)	-0.051 (0.042)	0.201*** (0.021)	0.202*** (0.021)
High skills	-0.096 (0.311)	-0.103 (0.095)	0.609*** (0.044)	0.609*** (0.045)
Industry dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Selection equation	OI	Types of OI	OI	Types of OI
DR&D _{t-1}	1.385*** (0.035)	1.385*** (0.035)	1.518*** (0.036)	1.519*** (0.036)
DR&D _{t0}	0.900*** (0.044)	0.901*** (0.044)	0.945*** (0.048)	0.942*** (0.048)
OI	0.491*** (0.045)		0.452*** (0.043)	
Practices		0.224*** (0.043)		0.215*** (0.041)
Workplace		0.107*** (0.043)		0.093*** (0.041)
Relation		0.159*** (0.051)		0.135*** (0.049)
Lsub	0.730	0.836	0.688	0.713

	(0.945)	(3.508)	(0.615)	(0.814)
Lcontract	0.596 (2.634)	0.749 (8.754)	0.530 (1.262)	0.587 (2.882)
Lage	0.042 (0.035)	0.042 (0.035)	0.040 (0.033)	0.040 (0.033)
Lsales	0.178*** (0.013)	0.179*** (0.013)	0.173*** (0.013)	0.174*** (0.013)
Coopera	0.366*** (0.035)	0.367*** (0.035)	0.345*** (0.034)	0.346*** (0.036)
Group	-0.164*** (0.042)	-0.166*** (0.042)	-0.165*** (0.040)	-0.166*** (0.040)
High skills	0.581*** (0.092)	0.584*** (0.092)	0.554*** (0.087)	0.556*** (0.087)
Industry dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
lnrho a1-a2	-0.345*** (0.020)	-0.345*** (0.020)	0.176*** (0.028)	0.177*** (0.028)
lnrho e1-e2	0.084*** (0.031)	0.082*** (0.031)	0.306*** (0.039)	0.307*** (0.039)
Lns a1	-0.354*** (0.035)	-0.354*** (0.035)	-0.531*** (0.045)	-0.531*** (0.050)
Lns a2	0.967*** (0.018)	0.967*** (0.018)	-0.420*** (0.012)	-0.419*** (0.012)
Lns e2	0.690*** (0.006)	0.689*** (0.006)	-0.307*** (0.006)	-0.308*** (0.006)
Observations	22.141	22.141	22.141	22.141
Wald test	3.877,00***	3.924,90***	16.729,17***	16.755,53***
Log Likelihood	-41.586,13	-41.572,43	-25.651,06	-25.644,506

Note: Equality test of coefficients. OI in both equations. t-student = 1,83, significant at the 95% level. Equality test of coefficients. Types of OI in both equations. Chi2 = 25,99, significant at the 99% level. All the estimations include individual effects, time dummies and industry dummies.

APPENDIX 1

Table 1. Distribution of our sample

nfirms	year						Total	
	2010	2011	2012	2013	2014	2015		
1	641	10	12	7	3	0	14	687
2	371	356	21	21	10	21	32	832
3	318	315	328	46	48	43	39	1,137
4	273	253	257	288	94	76	75	1,316
5	284	273	267	276	278	123	109	1,610
6	271	283	271	289	280	286	144	1,824
7	2,105	2,105	2,105	2,105	2,105	2,105	2,105	14,735
Total	4,263	3,595	3,261	3,032	2,818	2,654	2,518	22,141

Table 2. Correlations matrix

Variables	(R&D)	(Env exp)	(sales)	(age)	(subv)	(contrat)	(coopera)	(group)	(High sk)	(energy)	(material)	(comply)	(impact)	(OI)	(Practic.)	(Workpl.)
R&D exp	1.000															
Env exp	0.477*	1.000														
Sales	0.360*	0.205*	1.000													
Age	0.086*	0.026*	0.103*	1.000												
Subv	0.429*	0.282*	0.115*	0.044*	1.000											
Contrat	0.386*	0.028*	0.037*	0.025*	0.097*	1.000										
Coopera	0.127*	0.031*	0.101*	0.082*	0.079*	0.021*	1.000									
Group	0.131*	0.031*	0.136*	0.114*	0.051*	0.023*	0.217*	1.000								
high sk	0.079*	-0.006	0.007	-0.075*	0.025*	0.014*	0.102*	0.012	1.000							
Energy	0.058*	0.032*	0.081*	0.048*	0.026*	0.013*	0.105*	0.098*	-0.033*	1.000						
Material	0.051*	0.042*	0.059*	0.022*	0.018*	-0.010	0.112*	0.116*	-0.020*	0.647*	1.000					
Comply	0.046*	0.006	0.069*	0.043*	0.018*	-0.014*	0.119*	0.066*	0.031*	0.319*	0.279*	1.000				
Impact	0.068*	0.025*	0.095*	0.054*	0.033*	0.010	0.138*	0.080*	-0.002	0.388*	0.289*	0.605*	1.000			
OI	0.111*	0.036*	0.102*	0.069*	0.057*	0.014*	0.210*	0.135*	0.071*	0.153*	0.165*	0.209*	0.174*	1.000		
Practic.	0.086*	0.033*	0.083*	0.062*	0.049*	0.003	0.178*	0.130*	0.057*	0.133*	0.147*	0.173*	0.148*	0.877*	1.000	
Workpl.	0.094*	0.031*	0.075*	0.059*	0.040*	0.019*	0.169*	0.121*	0.055*	0.120*	0.131*	0.185*	0.139*	0.879*	0.684*	1.000
Relation	0.099*	0.023*	0.100*	0.048*	0.055*	0.014*	0.176*	0.076*	0.067*	0.126*	0.130*	0.159*	0.145*	0.697*	0.416*	0.426*

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 3. Dynamic Panel Data type-2 Tobit Results: effect of OI on environmental R&D expenditures and R&D expenditures

	Hyp.Env Expenditure		Hyp. R&D expenditure	
Main equation	OI	Types of OI	OI	Types of OI
HypR&D exp _{t-1}			0.065*** (0.003)	0.066*** (0.003)
HypR&D exp _{t0}			0.044*** (0.002)	0.045*** (0.002)
Hypcontrol _{t-1}	0.469*** (0.008)	0.696*** (0.007)		
Hypcontrol _{t0}	0.087*** (0.006)	0.123*** (0.006)		
OI	0.301*** (0.048)		0.095*** (0.021)	
Management		0.009 (0.055)		0.047** (0.019)
Decision		0.230*** (0.056)		-0.009 (0.019)
Relation		0.050 (0.057)		0.072*** (0.020)
Material	0.060 (0.053)	-0.068 (0.063)	0.027 (0.022)	0.028 (0.022)
Energy	0.008 (0.055)	0.092 (0.064)	0.015 (0.023)	0.012 (0.023)
Impact	0.196*** (0.047)	0.339*** (0.055)	0.054*** (0.020)	0.053*** (0.021)
Comply	0.123*** (0.044)	0.100** (0.051)	-0.004 (0.019)	-0.005 (0.019)
Lage	0.386*** (0.037)	-0.095*** (0.040)	0.014 (0.018)	0.013 (0.018)
Lsales	-0.041 (0.026)	-0.047*** (0.014)	0.444*** (0.007)	0.443*** (0.007)
Coopera	0.181*** (0.037)	0.129*** (0.043)	0.275*** (0.016)	0.274*** (0.016)
Group	0.078 (0.054)	0.078* (0.049)	0.204*** (0.021)	0.205*** (0.021)
High skills	-0.002 (0.103)	-0.278*** (0.111)	0.615*** (0.044)	0.606*** (0.045)
Ind dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Selection equation	OI	Types of OI	OI	Types of OI
DR&D _{t-1}	1.108*** (0.029)	0.961*** (0.036)	1.508*** (0.036)	1.504*** (0.036)
DR&D _{t0}	0.680*** (0.033)	1.626*** (0.057)	0.949*** (0.048)	0.987*** (0.049)
OI	0.418*** (0.037)		0.454*** (0.044)	
Management		-0.484*** (0.044)		0.214*** (0.041)
Decision		0.771*** (0.046)		0.097*** (0.041)
Relation		-0.163*** (0.053)		0.140*** (0.049)
Lsub	0.132*** (0.006)	0.351*** (0.351)	0.697 (0.668)	0.425*** (0.054)

Lcontract	0.093*** (0.019)	0.238*** (0.049)	0.540 (1.393)	0.357*** (0.163)
Lage	0.022 (0.026)	0.704*** (0.041)	0.040 (0.033)	0.035 (0.033)
Lsales	0.284*** (0.007)	0.036*** (0.014)	0.173*** (0.013)	0.174*** (0.013)
Coopera	0.270*** (0.029)	0.643*** (0.037)	0.344*** (0.034)	0.348*** (0.033)
Group	-0.397*** (0.030)	0.450*** (0.046)	-0.165*** (0.040)	-0.170*** (0.040)
High skills	0.504*** (0.074)	-0.872*** (0.096)	0.553*** (0.087)	0.556*** (0.088)
Industry dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
lnrho a1-a2	-0.495*** (0.016)	0.269*** (0.024)	0.176*** (0.028)	0.179*** (0.028)
lnrho e1-e2	0.166*** (0.039)	0.032 (0.024)	0.281*** (0.040)	0.292*** (0.040)
Lns a1	-0.701*** (0.035)	0.022 (0.040)	-0.522*** (0.045)	-0.491*** (0.043)
Lns a2	0.895*** (0.025)	-0.923*** (0.074)	-0.412*** (0.012)	-0.408*** (0.012)
Lns e2	0.718*** (0.006)	0.858*** (0.006)	-0.306*** (0.006)	-0.303*** (0.006)
Observations	22.141	22.141	22.141	22.141
Wald test	4614,42***	21034,85***	16.494,96***	16.253,79***
Log Likelihood	-43.275,05	-43.956,236	-25.698,79	-25.696,25

Note: Inverse hyperbolic sine transformation for the variables environmental expenditure and R&D expenditure.

APPENDIX 2

Measurement of Variables

Names	Description
LR&D exp	Level of internal R&D expenditure in logs
DR&D	Dummy variable takes value 1 whether expenditure in internal R&D is positive, 0 otherwise
LEnv exp	Level of environmental internal R&D in logs
lsales	Level of sales in logs
lage	Years of firm from foundation in logs
lsubv	Firm expenditure in subsidies in logs
lcontrat	Firm expenditure in contracts with Government in logs
coopera	Dummy variable equals to 1 if firm cooperates with others, 0 otherwise
group	Dummy variable equals to 1 if firm belongs to a group, 0 otherwise
highskills	Average salary of high skill workers
material	Dummy variable equals to 1 when firm consider material reduction of high importance, 0 otherwise
energy	Dummy variable equals to 1 when firm consider energy reduction of high importance, 0 otherwise
impact	Dummy variable equals to 1 when firm consider environmental impact of high importance, 0 otherwise
comply	Dummy variable equals to 1 when firm consider compliance with standards of high importance, 0 otherwise
OI	Index of organisational innovation which takes value 0,33 when firm only develop 1 organisational innovation, 0,66 when develops 2 OI, and 1 when develops the 3 OI, 0 otherwise
Practices	Dummy variable equals 1 if firm engages in new business practices in the organisation of work or company procedures (e.g., supply chain management, knowledge management systems, business re-engineering, efficient production, quality management, education and training systems...)
Workplace	Dummy variable equals 1 if firm engages in new methods of organising workplaces in your company with the objective of better sharing of responsibilities and decision making (e.g. first time use of a new system of sharing responsibilities among employees, team management, decentralisation, restructuring of departments, education/training systems...)
Relation	Dummy variable equals 1 if firm engages in new methods of managing external relations with other companies or public institutions (e.g. first-time creation of alliances, partnerships, outsourcing or subcontracting...).