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**INNOVATION VS. STANDARDIZATION:
THE CONJOINT EFFECTS OF ECO-INNOVATION AND ENVIRONMENTAL
MANAGEMENT SYSTEMS ON ENVIRONMENTAL PERFORMANCE**

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ABSTRACT

In this study, we first analyze whether firms' eco-innovation, manifested through green patents, improves environmental performance. Then, we assess whether adopting environmental management systems (EMS) that follow standardized guidelines enhances the potential of eco-innovation to improve environmental performance. To test our predictions, we build a unique firm-level dataset that combines global data on green patents, EMS adoption, and performance from five different data sources. The data support the positive effect of eco-innovation on environmental performance. However, our results show that adopting EMS, rather than strengthening the positive impact of eco-innovation on environmental performance, generates organizational rigidities that weaken the eco-innovation–environmental performance link. After conducting a set of qualitative post hoc interviews with elite informants, our surprising findings became more meaningful. Furthermore, we conducted a set of additional tests to validate our results in different scenarios where organizational rigidities could be a pivotal factor in explaining environmental performance differences connected to eco-innovation. This study has relevant theoretical and practical implications for the design and adoption of EMS and the conjoint dynamics between innovation and standardization practices to improve performance.

Keywords: eco-innovation; green patents; environmental performance; environmental management systems; resource-based view; organizational rigidities

JEL code: Q550, O310.

1. INTRODUCTION

Solving grand challenges such as climate change, biodiversity loss, and natural resource depletion and achieving sustainable development will not be a successful quest without an increase in firms' eco-innovation (Sachs et al., 2019; Scherer and Voegtlin, 2020). Eco-innovation is the firm's capacity to generate technological knowledge and develop innovative solutions for reducing environmental impact (Barbieri et al., 2016; Nagaoka et al., 2010). Eco-innovators can reduce their environmental footprint by, for example, delivering new or improved products and services and implementing renewed processes, practices, and systems that, in comparison to conventional alternatives, save resources such as energy, water, and raw materials and reduce emissions to air, soil, and water (Rennings, 2000).

However, eco-innovation needs to be embedded within an organizational context that provides favorable conditions for the evolution of the environmental capacities that are able to generate solutions for facing sustainability challenges (Antonioli et al., 2013; Barbieri et al., 2016; De Marchi, 2012; Horbach, 2008; Rennings et al., 2006; Wagner, 2007). This study proposes that adopting environmental management systems that follow standardized guidelines—EMS henceforth—may propitiate one such enabling context. One EMS example is the International Organization for Standardization (ISO) 14001: the most widespread certifiable standard guiding firms on how to adopt EMS to reduce their environmental impact (Orcos et al., 2018). Through its influence on the knowledge processes—experience accumulation, knowledge articulation, and knowledge codification—involved in the creation and evolution of dynamic capabilities (Zollo and Winter, 2002), we claim that the ISO 14001 introduces a supporting structure that allows eco-innovators to develop their capacities to generate green knowledge-based solutions to environmental challenges (Amores-Salvadó et al., 2015; Horbach, 2008; Kesidou and Demirel, 2012; Wagner, 2007).

Based on these considerations, our study examines whether the adoption of EMS,

such as the ISO 14001 standard, allows firms to improve the environmental output of their eco-innovation. We hypothesize that the positive influence of eco-innovation on environmental performance will be strengthened when firms adopt EMS. Building on the natural resource-based view and dynamic capabilities arguments, we argue that EMS allow the development of new green technological knowledge that nurtures the firm's eco-innovation capacity to develop solutions that will reduce environmental impact. Specifically, the EMS adoption generates routines that help develop green tacit knowledge through an experiential learning process (Amores-Salvadó et al., 2015; Manders et al., 2016). Also, EMS adoption encourages firms to take a more systematic approach to the articulation and sharing of this green experiential knowledge (Darnall and Edwards Jr., 2006; Rondinelli and Vastag, 2000). Finally, EMS include guidelines, models, and an extensive list of documentation requirements that illustrate how firms can codify their knowledge (Bénézech et al., 2001) to increase the effectiveness with which the firm's green knowledge base can generate solutions to reduce the firm's environmental impact.

To test our predictions, we assembled a unique data set that brings together firm-level data from five different sources: eco-innovation data from EPO-PATSTAT, EMS and environmental performance data from Thomson Reuters ASSET4 ESG, Sustainalytics ESG Research and Bloomberg ESG, and financial data from COMPUSTAT. The resulting dataset has some advantages over past studies in terms of accessibility of information (i.e., all are secondary sources); comparability across firms, industries, countries, and periods; and objectivity (i.e., we use data and measures that have already been validated in the literature). Our results illustrate the complex relationship between eco-innovation, EMS, and environmental performance. Specifically, even though our findings support that eco-innovation positively impacts firms' environmental performance, we do not find support for our moderation hypothesis that EMS adoption enhances the positive effect of eco-innovation

on environmental performance. Even more intriguing is the sign of such an unexpected effect. The negative moderation effect disputes the idea that EMS always foster the development of environmental knowledge and technological capabilities. Instead, our results suggest that EMS may introduce organizational rigidities that limit the generation of environmental knowledge and evolution of technological capabilities. These findings are in accordance with previous studies showing that the relationship between eco-innovation and EMS is more complex than the currently prevailing view (Demirel and Kesidou, 2011; Horbach et al., 2012; Wagner, 2008), and with some critical voices that warned about the negative consequences of establishing standards for innovation, as they may limit firms' capacity to innovate (Darnall, 2006; Demirel and Kesidou, 2019; Könnölä and Unruh, 2007).

To further investigate our counterintuitive findings, we conducted a qualitative analysis in the form of post hoc interviews with elite informants from the environmental management and innovation fields (Aguinis and Solarino, 2019; Bluhm et al., 2011). These interviews supported our unexpected results. Furthermore, we conducted a set of additional tests to validate our results in different scenarios where organizational rigidities could be a pivotal factor in explaining environmental performance differences connected to eco-innovation. In particular, we studied the environmental impact of the eco-innovation–EMS interface in (1) countries with different institutional frameworks, (2) industries with different levels of dynamism, and (3) organizations with different degrees of structural complexity. The results of all these analyses suggest that, under certain micro and macro conditions, EMS adoption may introduce organizational rigidities that influence negatively, rather than positively, the evolution of dynamic capabilities for generating the knowledge needed for eco-innovation to improve environmental performance.

Our theory and findings contribute primarily to developing research on the impact of eco-innovation on environmental performance and the linkages between eco-innovation and

EMS. Based on the natural resource-based view and dynamic capabilities arguments, we show that when firms engage in eco-innovation, they improve their environmental performance. However, if firms have EMS in place, such impact is reduced because of the organizational rigidities generated by the standardization of management practices.

2. CONCEPTUAL FRAMEWORK

To contextualize our contribution to the study of the relationships among eco-innovation, EMS, and environmental performance, we first provide a background review of earlier studies in two research areas: (1) the impact of eco-innovation on environmental performance and (2) the impact of EMS on environmental performance.

2.1. The impact of eco-innovation on environmental performance

Eco-innovation is defined as “the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives” (Kemp and Pearson, 2007, p. 7).

In the early 2020s, two meta-analyses reviewed studies on the relationships between eco-innovation and firm performance, including environmental performance (Hizarci-Payne et al., 2021; Liao et al., 2021). Hizarci-Payne et al. (2021) compiled 70 studies including more than 25,000 firms, while Liao et al. (2021) focused their meta-analysis on 33 studies comprising more than 7,300 firms. Substantial agreement exists in these studies that eco-innovation improves firms’ environmental performance. This result can be found in studies conducted in various research settings, such as Chinese manufacturing firms (e.g., Liao and Zhang, 2020), Japanese manufacturing firms during the 2001-2010 period (e.g., Lee and Min, 2015), small and medium-sized manufacturing firms operating in the United Arab Emirates

(e.g., Singh et al., 2020), Malaysian firms (e.g., Kraus et al., 2020), and manufacturing industries across European Union member countries (e.g., Costantini et al., 2017).

Theory-wise, most of these studies relied on (natural) resource-based view (Barney, 1991; Hart, 1995) arguments to connect eco-innovation with environmental performance, reaching a similar conclusion: *eco-innovation improves environmental performance* because, by devoting resources to eco-innovate, firms develop a set of environmental capabilities and skills that help to improve their environmental performance.

Much less attention has been paid to possible contingencies strengthening or weakening the impact of eco-innovation on environmental performance. One of the few studies that does so is the meta-analysis conducted by Liao et al. (2021). However, none of the contingent factors considered was found to have a significant effect on the eco-innovation–environmental performance link. In another study, Li (2014) considered resource commitments as another potential moderator but did not find support either. On the positive side, Huang and Li (2018) and Rehman et al. (2021) found, respectively, that a higher resource alignment between eco-innovative partners and proactive environmental strategies strengthens the positive link between eco-innovation and environmental performance.

Nevertheless, to the best of our knowledge, no study has investigated how EMS adoption impacts the eco-innovation–environmental performance relationship, creating an opportunity to contribute to the analysis of linkages between innovation and standardization. This omission is important because, as we argue below, EMS may affect environmental performance both directly and indirectly by means of its interaction with eco-innovation.

2.2. The impact of EMS on environmental performance

Firms have a wide range of choices for improving their environmental performance. One is eco-innovation; another is the adoption of EMS (King et al., 2005). EMS are defined as “the part of the overall management system that includes organizational structure, planning

activities, responsibilities, practices, procedures, processes, and resources for developing, implementing, achieving, reviewing and maintaining the environmental policy” (ISO, 1996). EMS provide practice standardization, ensuring that firms create consistent and stable procedures through process documentation and adherence (Benner and Tushman, 2002). In addition, when certified by third-party auditors, EMS provide external validation, thus sending a signal of good environmental behavior to relevant stakeholders (Delmas and Montiel, 2009). The expectation is that EMS adoption helps firms improve their environmental performance (Boiral et al., 2018).

Previous research analyzing whether EMS improve environmental performance has mainly studied the most widely diffused and recognized EMS: the ISO 14001 standard (Orcos et al., 2018). ISO 14001 is a process-based certifiable standard that guides organizations on implementing EMS (Delmas and Montiel, 2009) and facilitates the inclusion of environmental sustainability as an integral element of core business strategies (Darnall and Edwards Jr., 2006). Recent literature reviews (Boiral et al., 2018; Sartor et al., 2019) and meta-analyses (Erauskin-Tolosa et al., 2020) described a broader scholarship showing a positive relationship between EMS, particularly ISO 14001, and environmental performance. However, these review articles included a handful of empirical studies with the ISO 14001 EMS standard having a neutral (Boiral, 2007; King et al., 2005; Prajogo et al., 2012) or even a negative impact (Zobel, 2013) on environmental performance. One of the main reasons for explaining these mixed results is the administrative burden of the EMS (Boiral et al., 2018), which foreshadows the existence of rigidities in the EMS standardization process, hampering environmental performance. A complex dynamic between EMS and environmental performance seems to exist, which deserves further exploration.

Based on the previous research on the two antecedents of environmental performance—eco-innovation and EMS—we contribute to this debate by investigating

whether and how these two antecedents may interact with each other to have an impact on environmental performance. With this study, we expect to contribute not only to research on eco-innovation, but more generally, to the innovation literature and this particular special issue on the relationship between standardization and innovation (Manders et al., 2016).

3. HYPOTHESES DEVELOPMENT

3.1. Green patents and environmental performance

Eco-innovation is a difficult concept to operationalize (Rennings, 2000), and each proposed measure has advantages and disadvantages. Patent data emerges as one of the few indicators that offers accessible, comparable, and objective information to measure firm-level eco-innovation (Horbach et al., 2013; Oltra et al., 2010). Though past research in the area applied patent data in various ways, including its use as a measure of environmental innovation output (e.g., Marin, 2014; Popp, 2017; Wagner, 2007), we view green patents as a good proxy for a firm's capacity to generate knowledge and develop technologies for achieving environmental sustainability (Nagaoka et al., 2010). This capacity is an integral part of eco-innovation, yet narrower in its focus (Barbieri et al., 2020; Dechezleprêtre et al., 2015; Marin, 2014). Unlike eco-innovation, which is much broader in its scope, this technological capability fails to account for less complex and novel knowledge recombinations and incremental improvements in products or processes (Barbieri et al., 2020; Haščič and Migotto, 2015; Oltra et al., 2010).

Acknowledging these particularities, we focus on green patents as a variable strongly connected to the more novel form of eco-innovation and study its effect on environmental performance. Despite the significant amount of research that has examined this relationship at the macro level (see Barbieri et al., 2016), we are not aware of studies at the firm level. There are, however, reasons to expect a similar positive relationship at this level as it has at the macro one.

The natural resource-based view (Hart, 1995; Hart and Dowell, 2011) and dynamic capabilities (Teece, 2007; Teece et al., 1997) literatures provide a conceptual foundation to examine the environmental consequences of green patents (Carrillo-Hermosilla et al., 2019). According to these literatures, innovations that improve environmental performance tend to require more than incremental improvements in products and processes; companies must generate breakthrough knowledge to address the social and environmental challenges the world is now facing (Hart and Dowell, 2011; Hart and Milstein, 2003). The extent to which firms can generate this knowledge depends on their ability to develop dynamic capabilities (Albort-Morant et al., 2016; Chen and Chang, 2013), which in our context are understood as the firm's ability to integrate, build, and reconfigure internal and external competencies and knowledge for embedding social and environmental considerations into the solutions proposed to face today's growing and rapidly changing sustainability challenges (Dangelico et al., 2017; Inigo and Albareda, 2019; Teece et al., 1997).

The knowledge base of eco-innovations, which is substantiated in firms' green patents (Barbieri, 2015; Dechezleprêtre et al., 2015), is critical for the development of dynamic capabilities linked to environmental improvements (Barbieri et al., 2020; Cainelli et al., 2015; Ghisetti et al., 2015; Marín-Vinuesa et al., 2020), because it may influence the knowledge processes—experience accumulation, knowledge articulation, and knowledge codification—involved in the creation and evolution of dynamic capabilities (Zollo and Winter, 2002). Specifically, in the process of generation of patents, firms engage in activities of experience accumulation, knowledge articulation and, finally, knowledge codification that facilitate the formation of these capabilities. Patenting requires an effort to transform the tacit knowledge of the *experiential learning* that resulted from the enactment of organizational routines into *articulated knowledge* that can be made available throughout the organization in order to adjust operating routines accordingly; and convert the articulated knowledge into *codified*

knowledge or codes—e.g., patents—that can then be processed as information (Cowan and Foray, 1997; García-Muiña et al., 2009; Laaksonen and Peltoniemi, 2018). Patents thus represent a way of transforming experience into meaningful learning. This meaningful learning generates new knowledge that, when incorporated into the execution of firms' internal operating processes, leads to new initiatives to modify existing routines or create new ones that increase firm effectiveness (Teece et al., 1997; Zollo and Winter, 2002).

Through their action over routines, dynamic capabilities allow firms to adapt their operating processes to challenging conditions of the environment through a relatively stable pattern of activity (Zollo and Winter, 2002). Importantly, dynamic capabilities are a platform for learning, which allows firms to develop the new knowledge they need to maintain a continued adjustment to the external business environment (Teece, 2007). In this sense, dynamic capabilities can contribute to developing new knowledge-based capabilities or transforming the existing ones to generate solutions to sustainability challenges, thus improving environmental performance (Chang, 2016; Chen and Chang, 2013; Dangelico et al., 2017; De Marchi, 2012; Ghisetti et al., 2021).

What makes dynamic capabilities particularly important in the context of sustainability is that environmental challenges are multidimensional and unique (Hart and Dowell, 2011; Hart and Milstein, 2003; Scherer and Voegtlin, 2020), so coping with these challenges requires from firms to possess a highly complex and novel knowledge base (Aragon-Correa and Leyva-de la Hiz, 2016; Barbieri et al., 2020; Dechezleprêtre et al., 2015; Fabrizi et al., 2018; Ghisetti et al., 2015; Horbach et al., 2013; Lanjouw and Mody, 1996). Typically, green patents embody this complex and novel knowledge (Barbieri et al., 2020; Cainelli et al., 2015; Ghisetti et al., 2015) and do so to a larger extent than their non-green counterparts (Barbieri et al., 2020). Thus, the complexity and novelty of the knowledge embedded in green patents are essential components for creating new knowledge whose

employment in existing processes and routines may lead to modified or new routines that facilitate improvements in firms' environmental performance.

Characteristics related to complexity and novelty explain, therefore, why green patents may generate environmental performance improvements. First, the solutions that reduce firms' environmental impact (e.g., lower pollution) are based on *complex* knowledge. Such complexity arises from (1) the broad knowledge bases—which depart substantially from traditional knowledge in a particular industry—firms need to access to for developing these environmentally-friendly solutions (Cainelli et al., 2015; De Marchi, 2012; Orsatti et al., 2020), and from (2) the variety of purposes in the use of that knowledge (Ghisetti et al., 2015). For example, because specific environmentally-friendly solutions are used beyond the firm, they are subject to a variety of demands during their development process, including those of regulators and users (Ghisetti et al., 2015). So, only firms with such a green dynamic capability—i.e., firms with green patents—will be able to develop sustainable solutions to cope with current environmental demands.

Second, the challenges our world is currently facing demand radical improvements in green technologies (Hart and Dowell, 2011), that require *novel* green knowledge (Barbieri et al., 2020; Töbelmann and Wendler, 2020). These technologies lay on the technological frontier, and so the skills and knowledge implied fall outside firms' technological domain (Cainelli et al., 2015; Horbach et al., 2013), requiring non-local and exploratory search (Rosenkopf and Nerkar, 2001). Orsatti and colleagues (2020) refer to the “recombinant creation” of inventor teams, understood as the experimentation with unexplored knowledge combinations, as the mechanism driving the development of the green technologies that are behind the improvement of firms' environmental performance. Firms that have successfully developed green patents are in a better position to develop novel, non-obvious knowledge to face sustainability challenges than firms without green patents.

Based on the preceding arguments, we expect that firms that have been able to generate green patents will be able to improve their environmental performance because the more complex and novel knowledge embedded in their green patents will foster the development of dynamic capabilities that enable the recombination of internal and external knowledge for developing complex and novel green knowledge-based solutions to environmental challenges. We therefore predict:

Hypothesis 1 (H1) *Eco-innovation positively impacts firm environmental performance.*

3.2. The role of EMS on the green patents–environmental performance link

We aim to extend the theory by exploring possible contingencies that may strengthen or weaken the impact that eco-innovation has on environmental performance. We claim that EMS may be a moderator. The argument we develop below suggests that EMS operate in combination with the firm's green knowledge base (i.e., green patents) to improve environmental performance. We posit that the dynamic capabilities linked to the firm's green patents can evolve in response to the generation or exploitation of new knowledge. In other terms, the introduction of EMS may enhance the environmental performance of firms with green patents by altering the three knowledge processes—experience accumulation, knowledge articulation, and knowledge codification—that allow the evolution of dynamic capabilities to better accommodate increasing sustainability challenges.

The first of these processes is experience accumulation. The generation of environmental benefits from green patents requires that employees accumulate experience in the green domain and then share this accumulated tacit knowledge within their teams and across the firm (Hart, 1995; Orsatti et al., 2020). The adoption of EMS generates routines that help develop this essential green tacit knowledge through an experiential learning process (Amores-Salvadó et al., 2015; Manders et al., 2016). For example, EMS require firms to

invest in employees training and introduce a standardization of processes that lead to a repetition of activities. Through the combination of these two elements, employees become able to develop an extensive tacit knowledge about environmental management that can enhance the capacity of the firm's green knowledge base to minimize the environmental impact of the firm (Amores-Salvadó et al., 2015; Bansal and Hunter, 2003; Darnall, 2006). In short, the experiential learning triggered by the EMS adoption increases the effectiveness of firms' dynamic capabilities in generating solutions to face environmental challenges.

Knowledge articulation, the second knowledge process, is a prerequisite for converting tacit knowledge into explicit, articulated forms that can enable knowledge sharing and thus collective learning. The tacit knowledge accumulated by employees has to be disseminated throughout the firm to produce an improved collective understanding of the causal linkages between actions (i.e., eco-innovation) and outcomes (i.e., environmental performance), thereby resulting in adaptive adjustments to the existing routines that contribute to firm effectiveness (Zollo and Winter, 2002). In this sense, even in firms that already possess an extensive green knowledge base that allows them to develop dynamic capabilities for environmental improvement, EMS adoption may have significant organizational consequences. EMS introduce formal structures that facilitate the sharing of ideas, information and other resources among all organizational members, including external stakeholders (Darnall and Edwards Jr., 2006; Rondinelli and Vastag, 2000). EMS formalize, for example, the periodical monitoring by external audiences (Darnall and Edwards Jr., 2006), which facilitates the disclosure and transfer of information and introduces mechanisms for engaging internal and external stakeholders to obtain new pro-environmental ideas that can add to the firm's green knowledge base (Bansal and Hunter, 2003; Darnall et al., 2008; Delmas and Montiel, 2009; Delmas and Toffel, 2008; Horbach, 2008; Rennings et al., 2006). As a result, the systematic approach to the articulation and sharing of green experiential

knowledge introduced by EMS can enhance firms' ability to capitalize on existing routines to generate green knowledge-based solutions to environmental challenges.

The third knowledge process is knowledge codification, a process through which individuals develop written tools (e.g., manuals, blueprints, patent filings) from articulated knowledge. Codification is a critical step of the learning process as it facilitates knowledge diffusion and the generation of new proposals to modify and even change the currently available routines (Zollo and Winter, 2002). We argue that the adoption of EMS, because of the codification of knowledge they introduce, can further improve current routines, thereby moderating the relationship between the green knowledge base and environmental performance positively. EMS introduce guidelines and models, and an extensive list of documentation requirements that shows how firms can codify knowledge (Bénézech et al., 2001). This codification facilitates the coordination and implementation of activities that are complex, such as those that involve the development of sustainable solutions (López-Fernández and Serrano-Bedia, 2007; Wagner, 2008). By means of this codification, and the repetition it implies, firm members can identify strengths and weaknesses in the current set of routines (Manders et al., 2016), and thus make proposals directed to their adaptation and improvement (Darnall and Edwards Jr., 2006; Zollo and Winter, 2002). This codification may also positively impact on the firm's data-processing capabilities and decision-making processes. For example, in situations where there is a lack of consensus about the decision to be made, the codification introduced by the EMS standards acts as a norm that guides firm behaviors (King et al., 2005). Overall, EMS adoption may introduce an enhancing structure that allows the evolution of the green knowledge base into a set of capabilities for addressing sustainability challenges effectively and thus enhancing firm's environmental performance.

All these arguments suggest that through its impact on the three knowledge processes that contribute to the evolution of the dynamic capabilities, EMS play a key role in obtaining

environmental benefits from the firm's green knowledge base. Thus, we propose:

Hypothesis 2 (H2) *The effect of eco-innovation on environmental performance is more prominent among firms with EMS.*

4. METHODS

4.1. Sample and data collection

To test our hypotheses, we constructed a dataset by combining five archival data sources: EPO-PATSTAT, Sustainalytics ESG Research, Thomson Reuters ASSET4 ESG, Bloomberg ESG, and COMPUSTAT. As in previous studies (Marin, 2014), we gathered information on green patents from the European Patent Office (EPO)-PATSTAT to measure eco-innovation. Data on environmental performance and some controls were gathered from Sustainalytics and Bloomberg. Sustainalytics offers a multidimensional appraisal of corporate ESG performance, including an environmental performance score, and a unique combination of coverage, methodology, and information outcomes (Surroca et al., 2010). EMS data were collected from ASSET4, which provided audited and systematic information for publicly traded global firms on environmental, social, and governance indicators (Duque-Grisales et al., 2020). Finally, financial information came from COMPUSTAT.

The final dataset is the result of matching the five databases for the period for which data were available and focusing on publicly traded firms from polluting industries (Berrone et al., 2013).² After excluding observations with missing data on our key variables (see Table 1), the final sample resulted in balanced panel data on 798 firm-year observations for 2014–

² Two related arguments explain the selection of heavily polluting industries as setting for our study. The first is that, with such a choice, we can ensure that all firms in our sample are subject to similar institutional pressures, which are typically seen as one of the most important determinants of firms' decisions to engage in proactive environmental behaviors, such as eco-innovation (Aragon-Correa and Leyva-de la Hiz, 2016). Second, for high-pollution firms, eco-innovation becomes a necessity. These firms thus have a higher tendency than their counterparts in other industries to undertake a problemistic search to develop proprietary knowledge and technologies—so patents—to improve their environmental performance (Berrone et al., 2013). Firms in these industries, however, achieve very different levels of environmental performance, even despite the homogeneous pressures they are subject to, which may suggest that sample selection bias is not a big concern—as we discuss further in the Robustness tests section.

2016, representing a total of 266 corporations distributed across 13 industries and headquartered in 7 countries (see Table 1).³

4.2. Measurement of variables

Table 1 describes the variables, while Tables 2 and 3 present, respectively, the descriptive statistics and the correlation matrix for the variables in our study.

Insert Tables 1, 2, and 3 about here

4.2.1. Environmental performance

To measure environmental performance, we relied on Sustainalytics, which is a database considered to be particularly useful for studying sustainability because it applies a strong, consistent, and reliable methodology that has already been validated in sustainability research (e.g., Slager and Gond, 2022). Sustainalytics covers over 6,500 large global companies (with a market capitalization ranging from less than \$2 billion to greater than \$10 billion) across 42 industries. In the Sustainalytics database, companies' environmental performance is rated based on quantitative data on consumption, emissions, pollution, and impact; but it also includes a more qualitative assessment of companies' current policies and programs as well as their involvement in environmental controversies. Sustainalytics uses more than 150 firm-level indicators that assess firms' preparedness, disclosure, and quantitative and qualitative performance across three ESG themes: environmental, social, and governance performance. The final ESG score is the sum of all items averaged by their corresponding weight, which varies industry by industry, and rated on a scale from 0 (worst)

³ The selection of 2014-2016 as the observation window is a consequence of the data availability before 2014 and the effective implementation of a new ISO 14001 standard from 2016. Bloomberg Professional Services, the platform through which we accessed Sustainalytics data, started to offer ESG data in 2014 (GlobeNewswire, 2014). In addition, on 2015 the ISO released a new version of the EMS standard: the ISO 14001:2015 (ISO, 2015), which required no less than one year—so until the end of 2016—for its effective implementation. Thus, to avoid the co-existence of the two ISO 14001 standards (of 2008 and 2015), which could have generated confounding results, we decided to take 2016 as the last year of our series.

to 100 (best). To operationalize our dependent variable, we use the composite percentile index of environmental performance Sustainalytics has generated by averaging the 56 indicators that fall within the environmental performance theme.

4.2.2. Green patents

To measure granted green patents, we created a composite measure that accounts for both eco-innovation quantity—the number of green patents—and eco-innovation quality—the number of green patent forward citations. Patent data was obtained from the global patent database PATSTAT (version 2016), provided by the EPO. PATSTAT contains more than 100 million patent documents from developed and developing countries (Hurtado-Albir et al., 2015). Specifically, it covers 105 patent offices, including the US Patent Office (USPTO), the EPO, and the Japan Patent Office (JPO), the three being known as the “triad,” making it one of the most comprehensive patent databases in the world.

Several approaches have been used in the literature to demarcate green patents from non-green patents. Some studies, for example, have used patent keywords (e.g., Wagner, 2007), abstract terms (e.g., Brunnermeier and Cohen, 2003), or technology fields (e.g., Ley et al., 2016). More recently, a widespread consensus has been reached on the use of patent codes (Aragon-Correa and Leyva-de la Hiz, 2016; Dechezleprêtre et al., 2015). In particular, with the Cooperative Patent Classification (CPC) released in 2013, researchers have had the opportunity to use a more reliable and objective means to identify green patents. PATSTAT includes a retroactive matching with other classification systems, such as the International Patent Code, which is the classification developed by the World Intellectual Property Organisation and included in databases like OECD PATSTAT. We thus used the CPC codes to differentiate between green (Y02 class) and non-green patent applications based on EPO

(2016) and Veefkind et al. (2012).⁴ The Y02 class includes “Technologies or Applications for Mitigation or Adaptation against Climate Change”, which incorporates patents of a wide range of technologies, such as energy efficiency in buildings, energy generation from renewable sources, or sustainable mobility. Based on this characterization, we identified 2,231 green patents filed by our sample firms over the period 2014–2016.

4.2.3. Environmental management systems (EMS)

The most commonly adopted EMS follows the ISO 14001 standard, which is third-party certifiable (Bansal and Hunter, 2003; Orcos et al., 2018). According to the ISO (2020), a total of 487,950 facilities in 179 countries worldwide have been certified with ISO 14001. The use of an internationally adopted EMS such as the ISO 14001 standard, allows meaningful comparisons when using global data. Past research has widely used ISO 14001 standard data to examine the economic and environmental consequences of EMS adoption (Arimura et al., 2016), study EMS drivers (Bansal and Hunter, 2003), and analyze the relationship between innovation and EMS (He and Shen, 2019). Our variable *EMS* is coded 1 when the firm is certified with the ISO 14001 standard, and 0 otherwise. This information is extracted from ASSET4.

4.2.4. Control variables

We include a set of control variables (see Table 1 for details) to account for potential confounding effects in the connection between green patents, EMS, and environmental performance. *Environmental disclosure* is a Bloomberg ESG score (0-100) based on the extent of a company’s environmental disclosure. The inclusion of this variable minimizes problems of omitted variables, as both EMS and environmental performance include disclosure items (Doan and Sassen, 2020). *Non-green patents* control the firm’s ability to

⁴ We use the variable family of patents to unify the different applications with the same invention given that the same patent could be registered in several offices to increase its geographic range of protection.

develop standard innovations based on its technology portfolio and propensity to patent (Berrone et al., 2013). *Firm age* proxies the effect of the experience gained by the firm over time, which can influence the impact of patents (Amore and Bennesen, 2016) and environmental standardization (Melnyk et al., 2003) on environmental performance. Yet, older facilities are also likely to use older equipment and technologies, which may negatively affect environmental performance (Aravind and Christmann, 2011). *Firm size* accounts for the needed resources to register a (green) patent (Brouwer and Kleinknecht, 1999). Also, there may exist differences in environmental performance due to possible economies of scale in the management of environmental issues (Aravind and Christmann, 2011) or in terms of resource availability for environmental standardization (King et al., 2005). *Financial performance* is included, as previous studies found a positive relationship between environmental management and financial performance (Albertini, 2013). Also, financial performance may be connected to green patent applications (Aguilera-Caracuel and Ortiz-de-Mandojana, 2013) and to EMS adoption (Boiral et al., 2018). *R&D Intensity* tackles the spurious correlation that may emerge as R&D investment is a driver of the patent development process (Berrone et al., 2013). Also, R&D investment, as a proxy of innovation capacity, may be connected to environmental performance (Alam et al., 2019).

We also control for *Industry* effects to account for potential patent differences across industries, both in terms of the nature of their technologies (Cohen et al., 2000) or their polluting intensity (Berrone et al., 2013). Liao et al. (2021) show how the relationship between eco-innovation and environmental performance could vary across industries. Next, we include *Country* effects as a way to acknowledge that the patent activity and the citation behavior (Goetzke et al., 2012) as well as the EMS effectiveness (Arimura et al., 2016) varies across countries. Finally, we include *Time* effects.

4.3. Data analysis

A potential problem in our estimations is that some unobserved factors that influence the adoption of EMS are also likely to affect environmental performance (Potoski and Prakash, 2005). Among these common factors, we may find organizational-, sector-, and country-level characteristics. In Table 2, we can see, for example, how firms with and without EMS differ along several organizational dimensions, including environmental performance. We use a Heckman two-stage estimation procedure to correct for endogeneity and selection bias problems (Greene, 2003). In the first stage, we included the factors that are expected to influence the EMS adoption, according to the following model specification:

$$EMS_{it} = \alpha_0 + \alpha_1 \text{Sector Mean (EMS)}_{it-1} + \alpha_2 \text{Green Patents}_{it-1} + \alpha_3 \text{Controls}_{it-1} + \epsilon_{it} \quad (1)$$

As controls, we include the variables defined in Section 4.2.4. We also include an additional explanatory variable, *Industry-level EMS adoption*, which is defined as the sectorial percentage of firms per year with an ISO 14001 environmental standard excluding the focal firm (see Table 1). This variable is necessary to satisfy the exclusion restriction and will not appear in the second-stage estimation. Industry-level EMS adoption (González et al., 2008; Heras-Saizarbitoria et al., 2011) is an incentive for adopting EMS, while it is less likely expected to be connected to the focal firm's environmental performance.⁵

We use a bivariate linear probability panel data model to estimate specification (1). The prediction from the first stage is then used as instrument of EMS in the second-stage estimation of *Environmental performance*. This prediction eliminates the error term in the specification (1) that may be a source of endogeneity problems in specification (2):

$$\begin{aligned} \text{Environmental Performance}_{it} = & \beta_0 + \beta_1 \text{Green Patents}_{it-1} + \beta_2 \text{EMS}_{it-1} \\ & + \beta_3 \text{Green Patents} \times \text{EMS}_{it-1} + \beta_4 \text{Controls}_{it-1} + \epsilon'_{it} \end{aligned} \quad (2)$$

⁵ This variable is significant on the first-stage estimation ($p < 0.001$) (Table 4), satisfying the weak identification condition. However, this variable is not significant if we include it in the second stage, which conforms to the overidentification restriction.

Support for Hypothesis 1 requires β_1 to be significantly positive, and for Hypothesis 2, β_3 must be significantly positive.

To reduce endogeneity problems of reverse causality, we have lagged the explanatory and control variables. Also, following Berrone et al. (2013), the variable connected to patents are lagged two years to better capture the timing in the innovation process. Finally, to eliminate the risk that our results were driven by the power of outliers, we have winsorized at 5% the hypothesis-testing variables: *Green Patents*, *EMS*, and *Green Patents* \times *EMS*.

Due to the panel structure of our data, we ran the Hausman and Lagrange Multiplier Tests, and both recommend the use of random effects regressions to conduct our estimations. So, both specifications are estimated using GLS random-effects regression models. Also, the Variance Inflation Factors are below 5 for all the explanatory variables. Moreover, the condition number for both specifications is clearly below the threshold of 30 (11.71 and 12.64, respectively). These numbers suggest that multicollinearity is not an issue.

5. RESULTS

5.1. Main results

The results of the Heckman two-stage estimation procedure are depicted in Table 4. Model 1 shows the results of the first stage that estimates specification (1). Results indicate that firms in industries with high levels of EMS adoption and firms with fewer non-green patents are more likely to adopt EMS. Model 2, which describes the second stage, on the determinants of environmental performance, shows that green patents have a positive impact on environmental performance ($\beta_1 = 0.282$, $p = 0.011$). This result supports Hypothesis 1.

Hypothesis 2 states that the effect of green patents on environmental performance is larger for firms with EMS. Contrary to our expectations, and thus to Hypothesis 2, the interaction term between green patents and EMS is negative and significant ($\beta_3 = -0.351$, $p = 0.047$). This negative moderation suggests that the adoption of EMS reduces the

effectiveness of eco-innovation in achieving environmental benefits. A possible interpretation is that EMS adoption constraints, rather than allows, the evolution of dynamic capabilities, which originate from the firm's green patents. Figure 1 graphically portrays the interaction for firms without EMS (dashed line), which are firms with a probability of EMS adoption of one standard deviation below the mean; and for firms with EMS (solid line), which are firms with a probability of EMS adoption of one standard deviation above the mean. The slope of the solid line is significantly lower (1.79) than that of the dashed one (5.33).

Insert Table 4 and Figure 1 about here

5.2. Supplementary analyses

We have conducted a series of analyses that seek to identify contexts where the negative influence of EMS on the green patent-environmental performance link is more plausible. We chose to focus on country-, industry-, and organizational-level contexts more prone to make the rigidities introduced by the EMS adoption particularly damaging for the firms' environmental impact.

Institutional framework. First, taking advantage of the international nature of our database, we re-ran specification (2) by splitting our sample among countries. Based on the varieties of capitalism framework (Hall and Soskice, 2001), we distinguish between liberal market economies (LMEs) and coordinated market economies (CMEs) (see the distribution of countries according to this typology in Table 1). In LMEs, firms are subject to pressure from financial markets to generate short-term results. This pressure requires firms to maintain flexibility to change constantly and innovate to improve their competitive position. In contrast, in CMEs, firms have developed the skills to navigate an institutional environment that protects them from the pressure of financial markets through regulation and bureaucratization of business processes. Thus, we expect that firms in CMEs are better positioned than their LME counterparts to adjust their eco-innovation processes to the

requirements imposed by the EMS. Accordingly, the negative effect of EMS on the green patent-environmental performance relationship should be smaller (or even disappear) in CME firms in comparison to LME firms. Table 5 supports our expectations: $\beta_3 = -0.529$, $p < 0.05$ in LMEs; $\beta_3 = -0.053$, $p > 0.10$ in CMEs.

Industry turbulence. Industries vary in their degree of turbulence or unpredictability of environmental changes (Dess and Beard, 1984). In highly turbulent industries, firms rely on exploration to maximize their adaptation: They need to reconfigure their knowledge constantly and depart notably from their current technological capabilities to generate innovations (Barnett and Sorenson, 2002; Benner and Tushman, 2002), which requires organizational flexibility (Ilinitch et al., 1996). In contrast, firms in non-turbulent (more mature) industries focus to a larger extent on exploitation, which builds upon existing knowledge, capabilities, and organizational structures (Benner and Tushman, 2002). Hence, we expect that the negative impact of EMS on the green patent-environmental performance relationship will be larger among firms in highly turbulent industries.

We approached industry turbulence using the industry beta (the covariance of the stocks' price movement in relation to the market's movement). Industries with a beta above the sample mean (0.96) are considered turbulent. Results of Table 5 support our expectations: $\beta_3 = -0.393$, $p < 0.05$ in turbulent industries; $\beta_3 = -0.065$, $p > 0.10$ in mature industries.

Structural complexity. As mentioned, EMS adoption may result in more formalization that might inhibit eco-innovation from actioning solutions that minimize corporate environmental impact. Research (e.g., Damanpour, 1996) has suggested, however, that firms may escape bureaucratic control by adopting flexible structures. Structural complexity, which may be defined by the number of locations at which organizational activities are performed, is mentioned recurrently as a dimension of the organizational design that endows firms with greater flexibility to adapt and improve (Damanpour, 1996). In

organizations with such complex structures, specialist workers of differentiated units work collaboratively to increase the depth and breadth of the firm's knowledge base, which, in turn, stimulates creativity, increases cross-fertilization of ideas, and develops technological capabilities (Damanpour, 1991, 1996). Thus, we expect that more complex firms will better navigate the existing organizational rigidities posed by the adoption of EMS.

We developed a measure of structural complexity based on the collaborative work of specialists in differentiated locations. This measure is the interaction of the number of subsidiaries (deflated by the number of employees) and the existence of collaborative green patents. We expect that such structurally complex firms are more likely to accommodate the organizational rigidities brought by EMS and generate environmental-friendly innovative solutions. Results in Table 5 conforms to our expectation: $\beta_3 = -0.323, p > 0.10$ for firms with more complex structures; $\beta_3 = -1.227, p < 0.01$ for firms with less complex structures.

Insert Table 5 about here

5.3. Robustness tests

To validate our results, we have conducted robustness tests with alternative measures for our variables of interest (environmental performance, EMS) and with different types of firms (high vs. low pollutants, high vs. low diversifiers, internally vs. externally motivated).

Alternative environmental performance measures. We have tried to validate our findings with two narrower proxies of environmental performance instead of the broad scope of the Sustainalytics score used as a dependent variable.⁶ These alternative proxies have already been used in the literature (Busch and Lewandowski, 2018; Guenther and Hoppe, 2014): (i) greenhouse gas emissions (GHG) intensity, measured as emissions/sales ratio from

⁶ The Sustainalytics' *Environmental performance* score may generate two problems: (1) the possible mismatch between the narrowness of our measure of eco-innovation and the broadness of the score and (2) the inclusion of the item of EMS adoption in the score, which may generate reverse causality problems.

Bloomberg ESG, and (ii) a GHG emissions index (0-100) from ASSET4 ESG. Consistent with our main findings, results (see supplementary material, Table A.1) show that the combination of eco-innovation and EMS creates organizational inefficiencies, either in terms of increases in GHG emissions intensity ($\beta_3 = 0.028, p < 0.05$) or decreases in the GHG emissions score ($\beta_3 = -0.016, p < 0.05$).

Alternative EMS measure. In our main analyses, *EMS* is a dummy that captures whether a firm has adopted EMS in any part of its structure (e.g., one facility). A more fine-grained analysis would require a variable of the percentage of a firm's sites or subsidiaries that receive EMS standard. In our main analyses, we did not use such a variable, which is more informative, because of the notable drop in the number of observations (from 798 to 467). Yet, to check the sensitivity of our results to this more fine-grained variable, we re-estimated specifications (1) and (2) using the *Percentage of firm's units with EMS* and found that the coefficient of the interaction term between this latter variable and *Green patents* is still negative ($\beta_3 = -0.033, p < 0.05$) (see supplementary material, Table A.1).⁷

High- vs. low-polluting firms. In our study, we followed Berrone et al.'s (2013) recommendation of selecting polluting industries as an appropriate setting to analyze eco-innovation and performance. Such choice may generate, however, a selection bias problem: Because firms located in these industries, in comparison to their counterparts in non-polluting industries, would need to have higher green knowledge and capabilities to reduce their pollution levels and comply with societal expectations, we would expect a closer relationship between firms' green knowledge base and performance. To explore if these concerns are well-founded, we conducted a test where we split the sample (above and below the mean) in

⁷ In an additional test, we controlled for in-house EMS using a dummy that takes value 1 the year before the firm gets an external EMS certification, as we expect that in preparation for the certification firms will develop their non-certified versions of the management systems. The results including in the specifications this in-house EMS dummy are consistent with our main findings (see supplementary material, last column in Table A.1).

terms of our two GHG measures. The result showing that our main findings are only significant for the less polluting firms suggests that our focus on high-polluting industries does not drive our findings (see supplementary material, Table A.2).

High- vs. low-diversification firms. In an additional test, we analyzed the influence of diversification across different institutional frameworks. In particular, we have re-estimated our basic specification, including a new control variable, which is a dummy that takes the value of 1 if the firm operates in different institutional environments simultaneously (i.e., CME and LME). As alternative proxies for international diversification, we also used a Herfindahl index (Rhoades, 1993) and an entropy measure (Palepu, 1985). Results for our hypotheses-testing variables remained qualitatively unaltered once we introduced these controls, thereby suggesting that firms' geographical diversification does not bias our results (see supplementary material, Table A.3).

Internal vs. external motivations for EMS adoption. According to Manders et al. (2016), firms adopt quality management standards motivated by external reasons—e.g., institutional pressures—or internal reasons—e.g., improving efficiency. The motivation is relevant because, according to the arguments of Section 5.2 on structural complexity, we should expect to find that firms pursuing efficiency gains (internal reasons), which normally employ more mechanistic/bureaucratic structures (rather than more complex ones), would face larger rigidity obstacles to fully benefiting from their eco-innovation. To test this expectation, we replicated our main analyses differentiating those situations in which external pressures to adopt EMS are high. Following the institutional theory rationale that firms mimic widely-adopted practices within their industries, we created a dummy variable (*Sector-ISO*), which is equal to 1 when the focal firm belongs to a sector with a proportion of ISO 14001 adopters larger than the sample median (excluding the focal firm). Once we interact this variable with the key interaction term (*Green patents* \times *Prob. (EMS)*), we can differentiate

the effect for firms subject to high external pressures for the EMS adoption (*Green patents* × *Prob. (EMS)* × *Sector-ISO*) from firms that lack this external motivation (*Green patents* × *Prob. (EMS)*). Our findings, albeit preliminary, suggest that the internal motivation to improve efficiency seems to be more influential than external pressures in hindering the effect of eco-innovation on environmental performance (see supplementary material, Table A.4). Further research is however necessary to assess the influence of the possible variety of internal and external motivations driving the EMS adoption.

6. DISCUSSION AND CONCLUSION

In this study, we sought to assess the environmental impact of eco-innovation and examine how this relationship is shaped by the adoption of environmental management systems (EMS) that follow standardized guidelines. Our empirical results only provided support for the prediction that *eco-innovation* positively impacts *environmental performance*. Yet, contrary to our expectations, our analyses showed that EMS undermined, rather than boosted, the positive impact of eco-innovation on environmental performance. These findings seem to challenge the widely-held view of EMS as a platform that allows the development of new green technological knowledge that nurtures the firm's eco-innovation to develop solutions to improve environmental performance (Darnall and Edwards Jr., 2006). We devoted further attention to these counterintuitive results by conducting a series of additional quantitative analyses and a final qualitative study, the details of which are explained next.

6.1. Post hoc interviews

With the objective of identifying a potential theoretical mechanism to explain the unexpected negative moderating role of EMS in the eco-innovation–performance relationship, we conducted a series of qualitative *post hoc* interviews with elite informants (Aguinis and Solarino, 2019). Following Bluhm et al.'s (2011) guidelines, we embarked on a purposive sampling approach to conduct interviews with individuals exposed to the

phenomena of interest—eco-innovation and/or EMS. Finally, we conducted 20 interviews with eight business scholars, three EMS consultants and auditors, and nine senior managers during the first two months of 2019 (see Table A.5 in the supplementary material for a description of the elite informants). Given their exclusive direct and indirect knowledge about the phenomena, our interviewees can be considered elite informants (Aguinis and Solarino, 2019). These conversations with elite informants should be considered as informal interviews, rather than formal and structured interviews. The informal interviews lasted from 25 to 45 minutes and were performed by two of the authors via phone, video conference, or in person, depending on the elite informants' location and availability. Interviewers took detailed field notes about what was said by the elite informants, together with personal reflections about the ongoing conversation. All this written material was then carefully read by the two authors, prior to writing a summary of the interviews that was shared with the rest of the research team. During the interviews, interviewers used a few initial open-ended questions to allow elite informants to explain their role and share their thoughts, intentions, and actions on the dynamics between EMS and eco-innovation, and help us to gain a deeper understanding of the phenomena (Shah and Corley, 2006). We then presented our findings and directed elite informants to discuss potential drawbacks that EMS could have on eco-innovation initiatives and environmental performance.

Seventeen out of the twenty respondents mentioned that adopting EMS could potentially act as a deterrent to achieving sustainability from eco-innovation. They highlighted the rigidity and bureaucracy of standardized EMS such as ISO 14001, which might negatively impact firms' and employees' predisposition to contribute to the capability-building process. The standardization required by EMS was perceived as a hassle rather than a useful tool to enhance environmental performance. Although our qualitative findings must be interpreted with caution, the evidence provided by these interviews complements the

results of our quantitative analyses to jointly characterize EMS as a potential obstacle to improving the natural environment through eco-innovation.

6.2. Implications for the theorization of the innovation-standards interface

Our study shows that firms' eco-innovation improves environmental performance; yet, the magnitude of such improvement decreases, under certain country-, industry-, and organizational-level conditions, with firms' adoption of EMS. These findings seem to indicate that environmental standards such as EMS may act as an obstacle rather than a facilitator for the evolution of firms' green dynamic capabilities. Even when these findings were unexpected from the prism of mainstream eco-innovation literature, different pieces of work can help us to develop a theoretical explanation for our results.

First and foremost, our findings resonate with the notion of core capabilities vs. core rigidities developed in the resource-based view (RBV) literature. Leonard-Barton (1992) defined core rigidities as the flip side of core capabilities in new product development. One of the core capabilities dimensions she analyzed was management systems, which resembles our EMS. Management systems may constitute part of a core capability “when they incorporate unusual blends of skills, and/or foster beneficial behaviors (...)” (Leonard-Barton, 1992, p. 117). However, these same management systems that “served the company in the past and may still be wholly appropriate for some projects or parts of projects, are experienced by others as core rigidities—inappropriate sets of knowledge” (Leonard-Barton, 1992, p. 118). In our context, it is very likely that some of the standardization requirements set by EMS, such as those included in the ISO 14001 standard, generate a type of core rigidity that reduces the positive impact that eco-innovation may have on environmental performance. In words of Kondo (2000, p. 7), “standardization conflicts with motivation, since it restricts the creativity and ingenuity of the people engaged in the work and reduces their opportunities to exercise those faculties”, which is one more indication of the emergence of organizational rigidities.

Previous research has already foreshadowed potential tensions between standardization and innovation (Blind and Thumm, 2004). These tensions can be associated with the emergence of core rigidities that reduce the organizational flexibility needed for making effective use of the firm's knowledge base. For example, Benner and Tushman (2002) found evidence that the adoption of quality management standards, such as the ISO 9000, leads firms to focus on the exploitation of existing knowledge and capabilities at the cost of crowding out exploratory activities. Prester and Bozac (2012) found in the extra documentation required by the standardization a possible explanation for an empirically counterintuitive result showing that certified quality management standards negatively influence revenues from radically new products. Again, standardization seems to prevent dynamic capabilities from reaching their full potential.

Our study extends this line of inquiry to the realm of eco-innovation and suggests that, under certain conditions, the adoption of EMS may become a core rigidity. The organizational rigidities these systems introduce affect negatively the three knowledge processes—experience accumulation, knowledge articulation, and knowledge codification—that allow the evolution of dynamic environmental linked to firms' eco-innovation to better accommodate increasing sustainability challenges. Previous studies have pointed to over-documentation (Boiral et al., 2018), over-procedurization (Boiral, 2011), generation of extra unnecessary routines (López-Mielgo et al., 2009), and increased internal control (Alonso-Paulí and André, 2015) as mechanisms that are likely to turn dynamic environmental capabilities into rigidities.

In an attempt to better understand the boundary conditions under which this counterintuitive result may hold, we have conducted a series of additional analyses and robustness checks. They show that the negative influence of EMS on the green patent-environmental performance link is more likely for firms with less complex and more

bureaucratic organizational structures (which primarily adopt EMS standards for internal reasons, such as efficiency enhancement), for firms that compete in turbulent industries, and for firms whose headquarters are located in liberal market economies (irrespective of the geographical reach of the firm's operations). Our study, however, is just a first step towards a better understanding of the downsides of EMS adoption, so further research is needed to establish the generalizability of these findings to other country-, industry-, and organizational-level contexts.

6.3. Implications for practice

Our findings have implications for the management of both innovation and practice standardization. For innovation, our results suggest that firms need to promote flexibility in their innovation process to achieve better performance outcomes, especially when pursuing innovations in the environmental space. For practice standardization, our results stress the need for SSOs such as the ISO to acknowledge some potential drawbacks in terms of lack of flexibility in the design of their EMS. We, therefore, see the need for such SSOs to introduce indicators of organizational flexibility in the re-design of standards such as ISO 14001. Otherwise, their standardization efforts may have long-term negative impacts on organizational outcomes such as environmental performance. Here the challenge comes from finding the right balance in the standardization of practices. Standardization should provide both some degree of structure and leave room for the flexibility that firms need for effectively deploying their dynamic capabilities and achieving superior green performance.

It is worth noting that, even when our main results indicate that EMS adoption seems to create organizational rigidities that limit the capacity of eco-innovation to improve environmental performance, the battery of tests we conducted leads us to be cautious about this claim, as it cannot be taken as a general statement. In particular, we have shown that such negative moderation does not appear in (1) coordinated market economies, (2) non-dynamic

sectors, and (3) firms with a certain degree of structural complexity. It should thus not be inferred from our findings that firms determined to improve their environmental performance through eco-innovation should avoid adopting EMS. Instead, our findings suggest that the requirements and procedures that EMS introduce could be (re-)designed to give more room to creativity and flexibility by, for example, setting up less bureaucratic management practices and procedures. In this line, the newest version of ISO14001: 2015 has already introduced more flexibility in its procedures. Unfortunately, this modification in the ISO14001 is not captured by our data because these changes were implemented effectively after the end of our sampling period. Promising future research would, therefore, analyze the changes introduced by the latest version of the ISO 14001 EMS standard and test whether more flexible EMS are less detrimental to the effect of eco-innovation on environmental performance, as we suspect.

Our results speak to companies located in highly polluting industries, which are subject to increasing pressures to improve their environmental performance through innovation. Based on our results, practitioners should learn that EMS can be problematic when eco-innovation becomes an important driver of sustainability because the standards EMS introduce may create organizational rigidities, instead of contributing to evolving the dynamic capabilities needed to reduce the ecological footprint. As highly polluting firms are increasingly scrutinized and poised to reduce their environmental impacts, it is vital to understand how different management practices, such as EMS and eco-innovation, can feed rather than cancel each other.

Finally, our results may explain the relatively new, yet increasingly prevalent, phenomenon of voluntary decertification (Daddi et al., 2018). Despite the variety of factors used to explain the phenomenon, no one study examined the mechanism of rigidity. We can argue that firms that conceive the protection of the natural environment as a transformative

goal that requires carrying on radical eco-innovation may decide to abandon the certification of their EMS and, instead, adopt less rigid and routinized procedures.

6.4. Limitations and future research

Our study is not without limitations that offer opportunities for future research. First, even though our post hoc analyses are insightful in identifying EMS-related organizational rigidities, we do not explore the specific mechanisms that originate rigidities in depth. Future studies could investigate how these obstructing mechanisms operate within the firm to offer solutions for firms to overcome rigidities. In such an in-depth exploration of the mechanisms at work, future studies should look over a more extended time period, as we suspect that learning may limit the rigidities of the EMS adoption. For example, research could examine if pre-EMS adoption experiences with management systems (e.g., in-house EMS) may generate learning that reduces the negative impact of EMS.

Second, despite our extensive list of robustness checks, there is room for improved operationalization of key variables. For example, our narrow measure of eco-innovation, which focuses on patents related to GHG emissions, could encompass other non-GHG environmental impacts. Despite their narrowness of focus, GHG-based patents' individual and cojoin (with EMS) significant impact on a broader outcome variable such as the overall environmental performance score suggests that (1) GHG-based patents are a relevant component of eco-innovation and (2) the effects we have found are a lower bound of the true effects of green patents. In relation to our point (1), it is important to stress that previous research has shown a mutual interdependence between GHG-based patents and non-green patents (Barbieri et al., 2022), which signals that the Y02 patent class may be a good indicator not only of firms' eco-innovation, but also of firms' overall technological capacity. That said, it is possible that the nature of the relationships we study could change as we consider alternative definitions and operationalizations of green patents, and we thus invite

future research to consider different types of patents for a proper understanding of the environmental consequences of eco-innovation.

Similarly, we explored the adoption of certified EMS using a binary variable. New research should analyze how the degree of implementation of different components of EMS—e.g., environmental policy, communication systems, employee training, corrective measures—impacts both environmental performance and the relationship between eco-innovation and environmental performance. Furthermore, since some firms opt to implement in-house EMS without following standards and seeking third-party certification, future studies can study whether the effect of in-house EMS in the eco-innovation–environmental performance relationship is different from that of certified EMS.

Third, despite our efforts, a more fine-grained analysis would be necessary to tease out the mechanism linking eco-innovation, EMS adoption, and environmental performance. An analysis that could incorporate different types of patents (e.g., depending on their degree of radicalness; Dahlin and Behrens, 2005), standards (e.g., certified EMS, noncertified complete EMS, and incomplete EMS; Darnall and Edwards Jr., 2006), and environmental performance indicators (e.g., the environmental performance dimensions of preparedness, disclosure, and performance) could enrich our findings and contribute to a more nuanced understanding of the phenomenon of rigidity.

Fourth, as mentioned, our additional analyses only allowed us to explore superficially the impact on our results of firms' motivations to adopt EMS. Future research may examine the sustainability of our initial expectation that the type of motivation (internal vs. external) behind the EMS adoption may have a differential impact on the relationship between eco-innovation and environmental performance.

Finally, our study of the influence of the institutional context is just a first step to understanding that institutions matter in explaining firms' success in the implementation of

certain structures and practices. Though our sample only includes multinationals headquartered in developed countries, they are present in a variety of institutional contexts. This variety thus opens new lines of inquiry, such as exploring the innovation-standardization-performance dynamics (1) in developing countries, either for subsidiaries or local firms, or (2) in multinationals following different internationalization strategies.

6.5. Conclusion

Even though we initiated our study with the expectation that eco-innovation and EMS would reinforce each other in the quest to improve corporate environmental performance, our quantitative empirical analyses and subsequent post hoc interviews showed the opposite. Rather than contributing to improving environmental performance, under certain country-, industry-, and organizational-level conditions, EMS reduce the environmental benefits of eco-innovation by creating organizational rigidities. These counterintuitive results deserve further exploration and have implications for firms and agencies in charge of designing management tools for environmental improvement. Practice standardization is essential as it guides organizations toward implementing systems that can improve performance. However, standardization needs to be designed in a way that leaves room for the flexibility and dynamism needed for the dynamic environmental capabilities to flourish and evolve so that eco-innovation improves environmental performance effectively.

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Table 1
Description of variables

Variable	Description of measure	Data source
<i>Dependent variables</i>		
EMS (stage 1)	Binary variable to account for EMS based on ISO 14001. Previous studies have used ISO 14001 binary variables (e.g., Bansal and Hunter, 2003; Demirel and Kesidou, 2011).	ASSET4 ESG
Environmental performance (stage 2)	Industry percentile rank for the company's management of its environmental record. This indicator is developed quarterly by Sustainalytics and measures environmental results of the company (0-100). This database has been used to measure environmental performance before (e.g., Husted and Sousa-Filho, 2017; Surroca et al., 2010; Wolf, 2014). They use this indicator to study different drivers and consequences of corporate environmental, social, and governance performance.	Sustainalytics
<i>Independent variables</i>		
Green patents	<p>We use a product of two indicators:</p> <ul style="list-style-type: none"> • Number of green patents registered and granted by the patent office. • Forward citations (e.g., Berrone et al., 2013; Lanjouw et al., 1998; Tseng and Wu, 2007). Because citations are not immediate, 2014 patents are more likely to be cited than 2016 patents. To avoid potential issues, we developed a new related-variable link to the breakthrough of green patents in the sample by year. Thus, we measure the importance of green patents with the quartile (1-4) of the distribution of citations of green patents in the sample by year. In other words, this variable is 4 when the green patents registered by the firm are among the top 25% highly cited in that year in our database. In the case of green patents without citations, the value of this variable is 0. <p>Following Berrone et al. (2013), both indicators are lagged two years to better capture the innovation process timing. Given the nature of the models, it is unlikely that the explanatory variables (most importantly, the number and green patent citations) immediately generate effects in the environmental performance. Additionally, this lag helps us to consider in our estimations the time difference between the priority date, when a patent is filed, and when it receives protection (grant date).</p>	EPO-PATSTAT
Prob. (EMS)	Probability of EMS from our first stage model—the implementation decision model.	Stage 1
<i>Control variables</i>		
Environmental disclosure	Score index (0-100) based on the extent of a company's environmental disclosure.	Bloomberg ESG
Industry-level EMS adoption	Sectorial percentage of firms per year with an ISO 14001 environmental standard excluding the focal firm	ASSET4 ESG
Firm age	Years of existence	Bloomberg ESG

Variable	Description of measure	Data source
Firm size	Number of employees	COMPUSTAT
Financial performance	Return on equity (ROE) ¹	COMPUSTAT
R&D Intensity	Ratio between R&D expenditures and sales	COMPUSTAT & Bloomberg ESG
Non-green patents	Number of non-green patents to take into account a firm's patents that do not have explicit environmental content	EPO-PATSTAT
Industry	Industry dummies ²	COMPUSTAT
Country	Country dummies ³	COMPUSTAT
Year	Year dummies	COMPUSTAT
<i>Additional robustness tests variables</i>		
GHG intensity	Total GHG emissions divided by the number of employees (Bloomberg). In the ASSET4 metric, the measure collects GHG emissions divided by the net sales and it is offered as a score (0-100), where higher values represent less GHG intensity and better environmental performance.	ASSET4 ESG & Bloomberg ESG
% EMS	The percentage of company sites or subsidiaries that are certified with any environmental management system.	ASSET4 ESG
Prob. (% EMS)	Probability of Percentage of EMS implemented from the first stage model—the implementation decision model.	Stage 1
Sector beta	The average covariance of the security's price movement in relation to the market's price movement for all companies from every industry involved in our study.	ASSET4 ESG
Complexity	Complexity is captured in terms of international presence and capacity to cooperate to generate patents. We multiply the standardized percentage of green cooperative patents (developed in collaboration with a third party – EPO-PATSTAT) times the standardized number of international subsidiaries (ASSET4).	ASSET4 ESG & EPO-PATSTAT

Notes:

¹ We also tested the influence of return on assets (ROA), but the result was very similar.

² Distribution of firms among industries: Metal mining (25), Oil and gas extraction (41), Mining and quarrying nonmetallic minerals (2), Food and kindred products (33), Paper-based products (4), Chemical and allied products (74), Petroleum refining and related industries (11), Rubber and miscellaneous plastics products (5), Leather and leather products (2), Stone, clay, glass, and concrete products (4), Primary metal industries (2), Fabricated metal products (9), Electric, gas, and sanitary services (54).

³ Distribution of firms among countries: for Coordinated Market Economies (CME): Switzerland (17), Germany (12), France (16); for Liberal Market Economies (LME): UK (25), US (141), Canada (36), Australia (19).

Table 2
Descriptive statistics

	EMS (mean)	No-EMS (mean)	Full sample		
			Mean	Min	Max
Firms with subsidiaries (%)	98.66%	98.23%	98.48%		
Firms with affiliates (%)	80.65%	64.08%	71.80%		
Joint Ventures (%)	45.16%	32.39%	38.35%		
% firms with operation in...					
1 country	5.65%	17.99%	12.17%		
2 countries	0.81%	8.63%	4.94%		
3 countries	4.03%	5.76%	4.94%		
4 countries	4.03%	3.60%	3.80%		
5 countries	2.42%	4.32%	3.42%		
+ 5 countries	83.06%	59.71%	70.72%		
Environmental performance	65.76	46.58	56.31	1.16	100
GHG intensity ASSET4	53.09	46.39	50.18	0.60	99.65
GHG intensity Bloomberg	528	1,373	859	1.35	21,930
Green patents	14.77	2.15	8.94	0	220
Environmental disclosure	37.15	25.80	31.56	1.38	78.29
Firm age	41.92	33.23	39.34	0	134
Firm size	37.87	22.28	30.91	0.03	318.38
Financial performance	0.26	0.14	0.20	-9.00	81
R&D intensity	0.05	0.06	0.05	0	1.36
Non-green patents	46.38	20.26	34.31	0	1046
Sector beta	0.95	0.97	0.96	0.51	2.25
Complexity	-0.02	0.01	-0.01	-1.6	0.27

Table 3
Pearson's correlations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Environmental performance	1.00													
2. Green patents	0.18	1.00												
3. EMS	0.35	0.21	1.00											
4. Environmental disclosure	0.58	0.20	0.29	1.00										
5. Non-green patents	0.22	0.53	0.15	0.25	1.00									
6. Firm age	0.16	0.07	0.13	0.23	0.07	1.00								
7. Firm size	0.17	0.17	0.18	0.14	0.20	0.12	1.00							
8. Financial performance	-0.03	-0.01	0.02	-0.05	0.00	-0.02	0.01	1.00						
9. R&D intensity	0.21	0.04	0.03	0.16	0.20	0.06	0.34	0.05	1.00					
10. Industry-level EMS adoption	0.31	0.21	0.55	0.26	0.16	0.07	0.16	0.02	0.05	0.16	1.00			
11. Industry beta	0.05	0.11	-0.02	-0.08	0.09	-0.18	0.00	-0.04	-0.04	0.09	-0.10	1.00		
12. Complexity	-0.02	-0.14	-0.09	-0.01	-0.02	0.01	0.01	0.00	0.04	-0.02	-0.06	-0.11	1.00	
13. GHG intensity ASSET4	0.06	-0.12	0.12	0.05	0.04	-0.04	-0.07	0.04	-0.01	0.04	0.15	-0.07	-0.07	1.00
14. GHG intensity Bloomberg	-0.32	0.01	-0.26	-0.14	-0.21	-0.21	-0.19	-0.21	-0.23	-0.21	-0.38	0.11	0.01	-0.39

Notes: (1) N=798. (2) Absolute values above 0.07 are significant at the 5% level.

Table 4
GLS random-effects regression results

Independent variables:	EMS		Environmental performance	
	First-stage: Binary panel linear probability regression		Second-stage: GLS random-effects regression	
Industry-level EMS adoption	0.722***	(4.871)		
Environmental disclosure	0.002*	(1.608)	0.179***	(4.125)
Green patents	-0.000	(-0.553)	0.282***	(2.539)
Prob. (EMS)			8.782**	(2.163)
Green Patents × Prob. (EMS)			-0.351**	(-1.987)
Non-green patents	-0.001**	(-2.309)	0.010	(1.360)
Firm age	-0.009	(-0.264)	3.947***	(2.648)
Firm size	0.001	(1.169)	0.032	(1.469)
Financial performance	0.002	(1.453)	0.089**	(2.443)
R&D intensity	-0.000	(-0.876)	0.002***	(3.491)
Constant	0.072	(0.545)	30.967***	(5.129)
Industry dummies	Yes		Yes	
Country dummies	Yes		Yes	
Year dummies	Yes		Yes	
Observations	849		798	
R2 (%)	29.40		28.95	

Notes: Z-scores are in parentheses. * $p \leq 0.1$; ** $p \leq 0.05$; *** $p \leq 0.01$

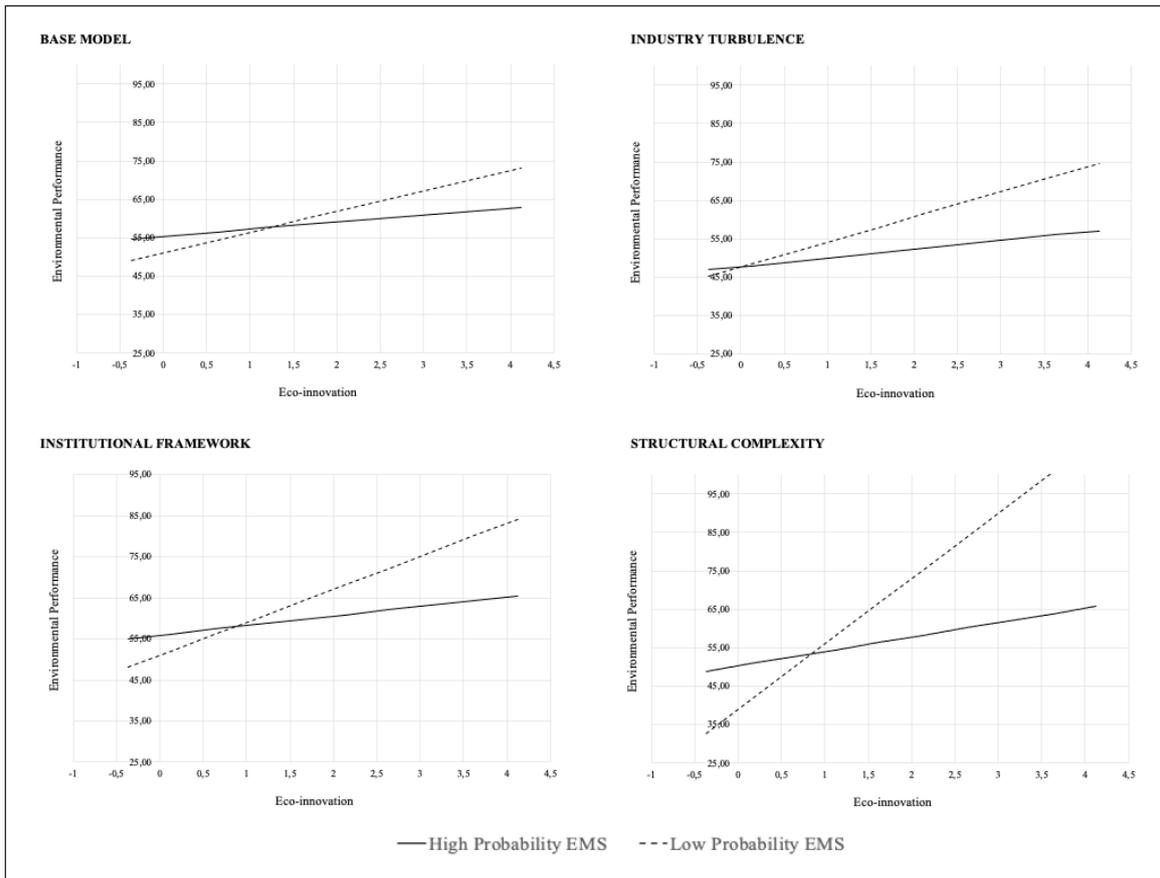
Table 5

Second-stage GLS random-effects regression results: supplementary analyses

Independent variables:	Environmental performance					
	LMEs	CMEs	Turbulent	Non-turbulent	Complex firms	Non-complex firms
Green patents	0.406** (2.306)	0.191 (0.971)	0.344*** (3.419)	0.110 (0.447)	0.267* (1.800)	0.811*** (3.381)
Prob. (EMS)	10.459** (1.915)	14.890 (1.525)	6.960 (1.156)	16.737** (1.908)	13.544*** (2.505)	24.000*** (2.736)
Green patents × Prob. (EMS)	-0.529** (-1.979)	-0.053 (-0.149)	-0.393** (-2.401)	-0.065 (-0.156)	-0.323 (-1.324)	-1.227*** (-3.352)
Environmental disclosure	0.183*** (3.991)	0.393* (1.756)	0.168*** (2.629)	0.225*** (3.348)	0.285*** (4.950)	0.548*** (6.659)
Non-green patents	0.007 (0.803)	0.030** (2.134)	0.014 (1.458)	0.023 (1.438)	0.010 (1.000)	0.018 (0.809)
Firm age	3.617** (2.172)	5.156 (1.166)	3.037 (1.320)	2.480 (1.194)	1.989 (1.198)	3.062* (1.703)
Firm size	-0.010 (-0.260)	0.070*** (2.932)	0.057* (1.850)	0.014 (0.340)	0.037* (1.701)	-0.028 (-0.222)
Financial performance	0.084** (2.084)	13.898 (1.033)	0.108*** (3.091)	-0.159 (-0.191)	-0.976 (-0.974)	0.058** (2.077)
R&D intensity	0.003*** (3.047)	0.001 (0.691)	-0.001 (-0.583)	0.004*** (4.470)	0.002*** (3.053)	0.004*** (3.440)
Constant	26.948*** (4.132)	0.000 (0.000)	29.635*** (2.678)	29.332*** (3.453)	29.503*** (4.929)	16.403** (2.170)
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	663	135	414	384	542	256
R2 (%)	27.46	35.09	34.43	41.52	31.89	46.04

Notes: Z-scores are in parentheses. * $p \leq 0.1$; ** $p \leq 0.05$; *** $p \leq 0.01$

Figure 1. Interaction between green patents and the probability of adopting EMS



Notes: For *Industry Turbulence*, we focus on turbulent industries—industries with a beta above the sample mean (0.96). For *Institutional Framework*, we focus on liberal market economies (LMEs) based on the varieties of capitalism framework (Hall and Soskice, 2001). For *Structural Complexity*, we focus on non-complex firms—firms with a value of *Complexity* below the median of the sample (see Table 1 for the definition of *Complexity*).