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ORIGINAL PAPER

Feminine expertise on board and environmental innovation: the role of critical mass

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Abstract

This paper examines whether women's attitudes toward environmental innovation are impacted by their individual differences in skills, expertise, experience, and technical knowledge, as well as their visibility and legitimacy on boards. Using the categorization of directors developed by Hillman et al (J Manag Stud 37(2):235–256, 2000) and a dataset including the largest non-financial Spanish-listed entities reported on the IBEX-35 between 2015 and 2019, we can confirm the influence of female business expert and support specialist directors on environmental innovation. We find that although female business expert directors seem to positively influence environmental innovation even below a critical mass, female support specialist directors are only significant and positive drivers of eco-initiation when they gain power and authority on the board. This study confirms the need to examine the connection between women directors and eco-innovation based not only on their expertise and experience but also on their position and legitimacy on the board. In this regard, our results provide evidence that female support specialists need to have a large enough representation on boards to be effective in developing green initiatives. Our results are robust to alternative measures of green innovation (i.e., environmental performance) and overcome endogeneity concerns.

Keywords Business expertise · Support specialist · Female directors · Eco-innovation · Green innovation · Environmental performance

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1 Introduction

Environmental innovation (also known as eco-innovation or green innovation) is related to environmental practices such as new procedures, techniques, or products that reduce the environmental impact of alternative practices (OCDE 2009). It is also linked to developing techniques and procedures designed to provide environmental benefits (Nadeem et al. 2020) and create value for consumers and companies (Berrone et al. 2013). Organizations must partake in environmental innovation to prevent the undesirable social and environmental consequences of climate change (Hermundsdottir and Aspelund 2021), gain competitive advantages, and avoid damaging their legitimacy and reputation (Zaman et al. 2022). In the decision-making processes involving environmental innovation, the board of directors plays a key role in formulating strategies that mitigate adverse effects on the environment, guiding successful green innovations, and implementing eco-friendly practices oriented toward sustainable development.

Female characteristics linked to benevolence, universalism, inclination to comply with rules and laws, ethical behavior, and stakeholder orientation suggest that women might be more willing to follow or promote green and eco-friendly initiatives than men (Sun et al. 2021). On boards, the gender socialization theory considers women directors to be tougher monitors, legitimacy providers, signaling tools, and more concerned with all stakeholders' needs. Women also tend to be particularly sensitive to company decisions related to corporate social responsibility and environmental practices (Nielsen and Huse 2010) and often possess a long-term orientation, which might favor adopting greener decisions (Nadeem et al. 2020). There is evidence that women directors promote voluntary climate change disclosure (Ben-Amar et al. 2017), corporate social responsibility disclosure (Ramón-Llorens et al. 2021), process and product innovation (Nadeem et al. 2020), patent development (Chen et al. 2018), and carbon-emissions reductions (Konadu et al. 2022). However, evidence about the association between women directors and environmental innovation is still scarce and not always positive. Some theories and empirical evidence suggest a negative or insignificant effect of women directors on green initiatives due to their increased risk aversion and less confidence in making high-risk, complex, and financially uncertain decisions. Other adverse consequences of board gender diversity might include conflict or slower decision-making (Sheridan et al. 2011). Other investigations have not found any significant effect between women directors and greenhouse gas (GHG) disclosures (Prado-Lorenzo and García-Sánchez 2010), product innovation (Galia and Zenou 2012), or investment in innovation (Bianchi et al. 2012).

The evidence regarding board gender diversity and eco-innovation is even more complex since most previous literature examines women directors as a single homogeneous subgroup without analyzing the differences among females. However, women's attitudes toward environmental innovation are not only affected by their

gender but also by individual differences in skills, expertise, and business knowledge (Hambrick and Mason 1984). Task-related fault lines occur when members have different characteristics in terms of professional history, educational background, and expertise. These attributes may determine the abilities of the group and their attitudes toward innovation (Hutzschenreuter and Horstkotte 2013). Some recent studies have examined the role of different groups of women directors on firm outcomes, stressing that when considering gender influences on business outcomes, it is vital to look beyond gender and take other female attributes into account. Kim and Starks (2016) indicated that women directors can enhance boards' advisory effectiveness by contributing with diverse and unique perspectives, while Ramón-Llorens et al. (2021) revealed that businesses that have female directors with technical and industrial knowledge are successful in implementing CSR disclosure strategies.

Therefore, the main purpose of this paper is to analyze whether there is a relationship between the experience and expertise of female directors and the extent to which they propose and adopt environmental innovations. Throughout, we use Hillman et al.'s (2000) board classification and identify female directors who are business experts and support specialists according to their respective business and technical expertise. We hypothesize that more women business experts and support specialists result in more innovative opportunities and improved innovative processes (Miller and Triana 2009). In addition, we analyze whether the influence of female directors who are business experts and support specialists varies depending on their strength in the boardroom. We base our analyses on the critical mass theory, which states that women can substantially influence board discussions only when there is a high enough number (or proportion) of female directors to form a critical mass (Joecks et al. 2013; Liu et al. 2014). Finally, we conclude by studying whether the effectiveness of female directors is dependent on the amount of female representation in each group of women directors.

In this context, we address two research questions: (i) do female business experts and support specialist directors influence environmental innovation? and (ii) is the influence of women directors conditioned by a critical mass on boards? Using a dataset of 175 non-financial, Spanish-listed observations of firms on the IBEX-35 between 2015 and 2019, we aim to fill these research gaps. The Spanish case is especially interesting due to legal initiatives to incorporate women into the workforce and higher positions in corporate companies initiated in the first decade of this century (García-Meca et al. 2022). Spain provides a unique setting to study these questions as there has been a remarkable increase in women on boards in recent years since the latest amendment to the Spanish Corporate Governance Code (June 2020) recommended a female board gender quota of at least 40%.[1] Furthermore, the importance of environmental concerns in the Spanish economy is rising. This has prompted the Spanish Council of Ministers

[1] According to data gathered from firms' annual corporate governance reports, there were 29.26% more women on the boards of public companies at the end of 2021 than there were at the end of the previous year. This indicates that, on average, businesses have come close to meeting the 2015 Good Governance Code's 30% goal. Given that women make up 34.20 percent of the boards of Ibex-35 firms, the trend among larger businesses is more encouraging. This means that they have just over five percentage points left to achieve the goal of 40% established in the previous Code revision (CNMV) by the end of this year.

to approve the Spanish Science, Technology, and Innovation Strategy 2021–2027. The main goals of this initiative are to boost the amount of public and private investment in R&D+i up to 2.12% of the GDP by 2027 and increase environmental investment, among other measures, to ensure a sustainable and fair future for upcoming generations, in line with the 2030 Sustainable Development Goals.

Our results confirm the influence of female business experts and support specialist directors on environmental innovation. However, it is important to note that the proportion of women on boards influences innovation differently when female business experts and support specialist directors are compared. For instance, the effect of women with technical knowledge only proves significant when the proportion of this group is high enough. Although female business expert directors seem to positively influence environmental innovation with a proportion below a critical mass, the evidence demonstrates that female support specialist directors are only significant and positive drivers of eco-initiatives when they gain power, legitimacy, and authority on the board. Our results are robust to alternative measures of green innovation (i.e., environmental performance) and overcome endogeneity concerns.

Our study makes a number of contributions to previously conducted research. This paper enriches the knowledge about this topic, responds to calls for an exploration of the results of different professionals on boards (Jain and Jamali 2016), and provides possible explanations for the conflicting evidence about the effects of board gender diversity and green initiatives. This is the first paper that highlights the different roles of women board members (depending on their business experience and technical expertise) in green innovation and confirms previous results regarding the outcomes of women with different levels of experience and areas of expertise in sustainable initiatives (Ramón-Llorens et al. 2021). We also contribute to the existing research on green innovation by identifying the role of women directors in environmental innovation and extending the available empirical evidence about the importance of board composition and expertise in green practices. Finally, we add to the research on critical mass by demonstrating how the impact of female directors on eco-innovation can vary due to the diversity of the board as well as their strength, influence, and authority in the boardroom. Particularly, this research supports the idea that not all female directors are equally adept at advancing environmental innovation and that in some cases, especially amongst female support specialists, a high enough proportion of women on boards needs to be reached to develop green initiatives. Lastly, this investigation extends previous empirical evidence concerning the effect of a critical mass of female directors on firm outcomes (e.g., Ben-Amar et al. 2017; García-Meca et al. 2022).

During a period when external pressures for green innovation have become increasingly important, and many governments have started to implement policies to nominate qualified women to boards, an understanding of the outcomes and interrelations between these groups of female directors and green initiatives is an important and timely matter. The results are also relevant for firms that intend to promote eco-innovative practices and appoint new directors to their boards.

The rest of the paper is structured as follows. After this introduction, Sect. 2 provides the theoretical framework supporting the research hypotheses. Section 3 includes the method, detailing the sample of analysis, measurement of the variables

and models, and analysis technique. Finally, Sect. 4 reports the results, and Sect. 5 provides the principle concluding remarks of the paper.

2 Theoretical background: research hypotheses

2.1 Environmental innovation and gender-based fault lines

Environmental issues are of global concern (Long and Liao 2021) and have arisen in the strategic agendas of companies worldwide. Over the past few years, stakeholders' concerns about environmental problems have increased, and companies have begun to face more environmental regulations and pressure to make changes in their strategies, policies, and practices. Companies strive to align their firms' environmental goals with those of their stakeholders (González-Benito and González-Benito 2006).

As a result, environmental innovation, also known as green innovation or eco-innovation (Hermundsdottir and Aspelund 2021), has recently become a hot topic in social policy and academic research. As a crucial indicator of a firm's contribution to environmental concerns, environmental innovation has met or exceeded environmental performance standards in some firms. This innovation consists of creating new products or modifying existing ones. Additionally, it relates to the creation of methods and practices that lessen emissions, thereby providing environmental benefits (Nadeem et al. 2020) and increasing firm value for consumers and companies (Berrone et al. 2013). Clearly, environmental innovation is an essential process for companies. It is also heavily encouraged by governments and demanded by society as a means of contributing to environmentally friendly practices (Bossle et al. 2016; Wen et al. 2022). In return, environmental innovation practices have a positive effect on business performance (Przychodzen and Przychodzen 2015; Khanchel et al. 2023) and allow companies to enhance their legitimacy (Berrone et al. 2013) and reputation (Nadeem et al. 2020).

Previous research recognizes the various external and internal factors that prompt firms' proactive attitudes toward environmental innovation. On the one hand, stakeholders (such as customers and regulatory stakeholders) are essential external drivers when addressing environmental concerns (Henriques and Sadorsky 1996). From the agency perspective, companies should be aware of all their stakeholders' concerns to gain their approval (Elmagrhi et al. 2019). Environmental innovation, therefore, is an issue that has generated a great deal of interest and also exerted pressure in recent decades (Moreno-Ureba et al. 2022). In the case of customers, their awareness of threats to the environment and the need to deal with them has caused changes in consumption choices (Marchi 2012a, b). When regulatory stakeholders gain legitimacy and are able to access resources within the social system in which the company operates, they are encouraged to get involved in environmental issues (Castelló and Lozano 2011). Without active involvement, companies risk losing resources provided by the government, being exposed to public scrutiny, and damaging their social legitimacy (Kassinis and Vafeas 2006). Organizational capabilities are identified as internal driving factors in environmental innovation. They consist of

a set of technological and human resources, such as practical and theoretical knowledge, intangible experience, and specialized knowledge, which allow companies to enhance and develop new green products and processes (Valdez-Juárez et al. 2016). Like any innovation policy, environmental innovation requires significant resources to integrate strategic processes. In addition, the long-term benefits of the innovation remain uncertain even when the processes have been integrated (Markman et al. 2004; Ahuja et al. 2008).

One of the most important resource providers to a company is its board of directors. Based on the agency theory, the corporate board's role is to monitor and supervise functions to prevent managers from behaving opportunistically and prioritizing their own interests over the interests of shareholders (Jensen and Meckling 1976; Goh et al. 2016; Shahab et al. 2019). From a resource-dependency approach, the board provides a company with strategic advice, experience, expertise, knowledge, perspectives, and networking (Pfeffer and Salancik 1978) which, according to the cognitive diversity view, leads to more creative problem-solving and better team performance (Hillman et al. 2000; Horwitz and Horwitz 2007; Sobral and Bisseling 2012). Moreover, boards are considered key factors in supporting innovative strategies that directly impact a company's level of innovation (Zahra et al. 2000). In this regard, the literature has called for a deeper analysis of board composition and board members' individual roles, backgrounds, and other characteristics (Van Ees et al. 2008; Galia et al. 2015).

Among the plausible drivers of sustainability and environmental innovation in boards, it is crucial to examine the role of board diversity. Diverse boards, strenuously supported by regulatory bodies and society at large, are made up of a reasonable number of independent directors (Aggarwal et al. 2019) who provide companies with a broader vision and a greater diversity of external resources to carry out their business strategies (Triana et al. 2015). Gender diversity has become one of the most prominent components of diversity, with research showing that women are more likely to engage in social activities and address the demands of multiple actors (Nuber and Velte 2021). The aforementioned resource dependence theory suggests that independent and gender-diverse boards are more knowledgeable (Campbell and Mínguez-Vera 2008; Conyon and He 2017) and innovative (Torchia et al. 2011) than boards that are not diverse, providing all the positive traits that women contribute to a male-dominated board (Kabongo and Okpara 2019). Additionally, having more women on the board may increase access to talent, which makes external resources more available to companies and provides them with broader perspectives on how to better implement their business strategies and attain better economic outcomes (García-Meca et al. 2015; Reguera-Alvarado et al. 2017; Saggese et al. 2021). Gender diversity has been shown to improve companies' reputations (Navarro-García et al. 2020) and creativity (Torchia et al. 2011), favor problem-solving (Westphal and Milton 2000), generate higher quality decisions (Cruz et al. 2012), increase financial performance (Bennouri et al. 2018; Francoeur et al. 2008; Liu et al. 2014; Nadeem et al. 2019; Reguera-Alvarado et al. 2017; Campbell and Mínguez-Vera 2008), and improve organizations' CSR policies (Bear et al. 2010; Nadeem et al. 2017), among many other positive outcomes. Moreover, research shows that gender diversity can influence not only innovation levels (Torchia et al. 2011) and firms'

ability to innovate (Galia and Zenou 2012) but it also helps companies identify new innovative opportunities in general (Miller and Triana 2009) and environmental innovation opportunities in particular (Nadeem et al. 2020; Pan et al. 2020).

The bounded rationality theory (Simon 1972) states that an individual's ability to make decisions is limited, and when making decisions, he/she will choose the alternative that maximizes their benefits. Gender diversity on a board of directors provides alternative views for company decision-making on environmental innovation since females and males have perceptions, attitudes, and other characteristics that are significantly different from one another (Liao et al. 2018). Similarly, and according to the social role theory[2] (Eagly 1987), gender stereotypes and beliefs have an impact on how men and women behave. These beliefs may function as social norms and as personal dispositions. While social norms are embedded in what others expect, personal dispositions are connected to each person's perception of his/her gender (Wood and Eagly 2009, 2012). In this context, men are perceived as more agentic (e.g., assertive, aggressive, self-confident, competitive, and independent) and with a greater tendency to adopt behaviors appropriate for a leadership position. Women, on the other hand, are thought to be more communal (e.g., helpful, sensitive, kind, and conscious of their social responsibilities) (Eagly and Karau 1991; Fondas 1997; Eagly et al. 2003) and typically demonstrate higher levels of moral awareness, are more empathetic to disadvantaged groups, pay more attention to those who need support, and are more concerned about how businesses interact with their stakeholders due to their empathy and care (Eagly 1987; Campopiano et al. 2022; Eagly et al. 2003; Boulouta 2013). To comply with the gender role spillover (or gender-based expectations for behavior in the workplace), women could feel more pressure to behave in a more caring and communal way and refrain from adopting leadership behaviors that are more often associated with men (Aluchna and Krejner-Nowecka 2016).

Building on this paradigm, female directors are often more receptive and supportive, behave more responsibly and sensitively when faced with moral and ethical issues, and tend to focus most of their attention on groups in need of support (Eagly 1987; Campopiano et al. 2022). Their emotional and altruistic behavior (Boulouta 2013) and stakeholder-oriented attitude (Sun et al. 2021; Alcaide-Ruiz and Bravo-Urquiza 2022) lead them to address stakeholders' requests and decrease environmental damage (Liao et al. 2018).

Moreover, corresponding with their attributed gender role, female directors place great focus on their companies´ image and social relationships and adopt more social than performance-oriented behavior. This leads to a positive relationship between the presence of women on boards and proactive environmental strategies (Hur et al. 2016; De Masi et al. 2021), such as the reduction of greenhouse gas emissions (Tingbani et al. 2020; Konadu et al. 2022), or environmental innovation within firms (Torchia et al. 2011; Fritz and Knippenberg 2017; Liao et al. 2018), among others.

[2] In the literature, the gender role theory (Eagly and Karau 1991) is also referred to as the social role theory (Eagly 1987).

However, to our knowledge, previous studies have focused on social and environmental performance and reporting environmental commitment but have not examined environmental innovation taking into consideration that the influence of female directors on boards depends on their particular experience and expertise. This research gap makes this gender-task-related fault line worthy of our attention.

When discussing gender diversity, we must acknowledge that it not only refers to innate differences or differences in ethical sensitivity between men and women but also what we consider fault lines. According to the similarity-attraction paradigm (Byrne 1971), individuals in a group are not independent members but are attracted to others with similar characteristics. This generates subgroups, also known as fault lines (Wu et al. 2021). According to the fault line theory, a group can be divided into homogeneous subgroups based on the alignment of their members' attributes (Wu et al. 2021; Lau and Murnighan 1998; Pearsall et al. 2008). The literature on gender diversity usually studies the mere presence of female directors, considering them a homogeneous group. However, the task-related fault lines that occur when members have different characteristics in terms of professional experience, educational background, area of expertise, and so on should be taken into account. These attributes determine the knowledge, skills, and abilities of this group and directors' attitudes toward innovation (Hutzschenreuter and Horstkotte 2013). Moreover, according to the upper echelon theory (Hambrick and Mason 1984; Hambrick 2007), executives' background characteristics influence how they make strategic decisions, which also affects how their organizations perform. Recently, Dabbebi et al. (2022) and Lassoued and Khanchel (2022) have provided insights from the upper echelons theory to explain how CEO personality traits influence ESG disclosure.

Depending on the human capital assigned to each director and the taxonomy of directors' resource-dependent functions put forward by Hillman et al. (2000), female board members are classified into two categories called "business experts" and "support specialists" (Hillman et al. 2000). The former are women who provide the board with their knowledge, experience, skills, and professional background acquired in other companies where they held positions as board executives (Hillman et al. 2000). Given their professional background and previous experience, this type of director can identify business threats and opportunities, undoubtedly affecting their firms' decision-making (Faleye et al. 2014). Recent evidence suggests that the experience, skills, knowledge, and broader perspectives provided by female business expert directors lead to better environmental and social performance (Ben Barka and Dardour 2015) and a positive impact on strategic decisions like corporate social responsibility (CSR) disclosure (Ramón-Llorens et al. 2021).

In addition to business experts, boards may be made up of directors the company relies on due to their human capital contributions, that is, talent, experience, and technical knowledge in specific areas such as finance, accounting, law, marketing, and environmental and social issues, among others (Bear et al. 2010; Shaukat et al. 2016). This specific group is known as support specialist directors (Hillman et al. 2000). Unlike business experts, support specialists have general expertise in management issues (Hillman et al. 2000) and oversee decision-making in strategic matters concerning sustainability and the environment (Konrad et al. 2006; Galbreath 2016). Boards with female support specialists are more likely to engage in social

responsibility and sustainable practices (Setó-Pamies 2015), and audit committee directors who have a background in finance are more likely to report on environmental sustainability issues (Helfaya and Moussa 2017). The characteristics that define female support specialists are essential in adopting sustainable environmental initiatives (García Martín and Herrero 2020) since female support specialists are motivated to meet stakeholders' expectations and obtain their approval (Diamantopoulos et al. 2003). Accordingly, these specialists' technical expertise and specific skills lead them to carefully consider companies' situations and think deeply about their firms' innovative decisions (Ma et al. 2021).

To summarize, in this study, we investigate the unexamined issue of gender-based fault lines and the primary drivers for environmental innovation and green initiatives. In other words, we try to determine whether the experience and expertise of women directors are significant in making companies greener and more innovative. We expect that the greater presence of women business experts and support specialists leads to more creative decision-making (Midavaine et al. 2016), the development of new innovative opportunities, and the improvement of innovative processes (Miller and Triana 2009). Thus, a more positive attitude toward investment in environmental innovation is expected as the proportion of female business experts and support specialists increases. In this respect, the following hypotheses are proposed:

H1A. Female business experts are effective in increasing environmental innovation.

H1B. Female support specialists are effective in increasing environmental innovation.

2.2 Critical mass, gender-based faultlines, and environmental innovation

As previously discussed, prior studies report that female presence on control and management teams may support the development of new ideas (Galia et al. 2015), resulting in a positive relationship between board gender diversity and firm innovation (Mukarram et al. 2018). However, contradictory results point to negative (Rossi and Cebula 2015) or non-significant relationships between the two factors (Bianchi et al. 2012; Jiraporn et al. 2017). This raises the question: why do some previous studies exhibit a positive, others a negative, and some, a non-existent effect?

Among the many possible reasons, the quota of female representation appears to be a determining factor, considering that, in line with the critical mass theory (Kanter 1977a), the mere presence of women in boardrooms is not sufficient to influence board decision-making (Torchia et al. 2011). The critical mass theory postulates that when a minority group, such as women directors on boards (Gong et al. 2021), reaches a certain threshold or critical mass of at least 35% of a group (Kanter 1977b), the power of this minority group increases and can change group decisions.

With the growing importance of female participation in boards of directors, previous research finds that female behavior can only be manifested in male-dominated environments when there are more women with seats on the board (Amorelli and García-Sánchez 2021). According to the token theory, the mere presence of a woman is not enough to influence decision-making because she is considered

a token and can be easily ignored. This can make it difficult for her to express her opinions (Konrad et al. 2008). Critical mass theory-based studies on board gender diversity support the idea that "one woman is a token, two is a presence, and three is a voice" (Torchia et al. 2011). If there is only one woman on the board, she will have few opportunities and little power and influence (You 2019) since male directors may overlook her talent or refuse to support her. This idea is supported by the social identity theory (Turner 1987). If we consider the presence of only two female directors on a board, they may be viewed as competition, conspirators, or a type of over-compliance rather than a firm's commitment to improving diversity (You 2019; Konrad et al. 2008; Chang et al. 2018). However, according to the critical mass theory, the contribution that women make to a company becomes more visible when a critical mass of at least three women is reached (De Masi et al. 2021; Schwartz-Ziv 2017; You 2019), considering that the average board size is approximately 10 people (Joecks et al. 2013; Konrad et al. 2008). At this threshold, the typical problem of feeling like part of the 'outsider-group' is minimized, which increases the degree of trust, participation, and influence female directors have in the decision-making process (Arena et al. 2015; Konrad et al. 2008) and promotes the development of more creative and innovative ideas (Konrad et al. 2008; Torchia et al. 2011). It has been shown that increasing the percentage of female directors up to a critical mass positively influences corporate environmental actions (Cabeza-García et al. 2018; Ben-Amar et al. 2017; Gong et al. 2021) and increases corporate transparency through higher ESG disclosure scores[3] (Amorelli and García-Sánchez 2020; Atif et al. 2019; De Masi et al. 2021; Hollindale et al. 2017; Wasiuzzaman and Wan Mohammad 2020).

Regarding the proposed classification of female directors according to their experience (business experts) and specific and technical knowledge (support specialists), we argue that a critical mass of women with these backgrounds increases their self-confidence and decreases their sense of inferiority (Arena et al. 2015; Chau and Quire 2018). Moreover, this threshold makes it easier for them to be heard in board discussions (Konard et al. 2008), which could enhance their involvement in decisions and lead to increased environmental innovation. Therefore, the following hypotheses are proposed in terms of the critical mass of business experts and support specialists:

H2A. A critical mass of female business experts is needed to find a positive effect on environmental innovation.

H2B. A critical mass of female support specialists is needed to find a positive effect on environmental innovation.

[3] Some authors, such as Manita et al. (2018), point out that despite reaching a female critical mass, there is no significant relationship between gender diversity and the disclosure of sustainability issues.

Table 1 Sample selection from 2015 to 2019

	Obs
Initial sample of firm-year observations	
Spanish Stock Market	148 firms × 5 years → 725 observations
Minus:	
Firms not listed in the IBEX 35	113 firms × 5 years → 565 observations
Total firm-year observations available (reports analyzed)	35 firms × 5 years → 175 observations
Single firm observations	35 firms indexed in the IBEX 35

3 Method

3.1 Data and sample

Using a Spanish sample and analysis from 2015 to 2019, this article aims to explore the influence of board gender diversity on environmental innovation by focusing on the role of female directors classified as business experts and support specialists. In addition, it examines the influence of the number of these women on specific environmental performance to test the critical mass vs. tokenism paradigms.

To meet these objectives, data was collected in the following way. First, we selected the companies indexed on the Spanish stock exchange for the period 2015–2019. Our sample at this point consisted of 148 firms indexed on the Spanish stock market. Then, we excluded the companies not included in the IBEX 35[4] from the initial list, resulting in a sample of 35 listed firms from 2015 to 2019. We excluded firms not listed in the IBEX 35 because they lacked information about environmental performance, eco-innovation, and other areas the paper needed to test the proposed models.

In the second stage, we obtained economic, financial, and accounting information from the SABI database, which compiles complete information on Spanish and Portuguese companies, for all 35 firms. In the third stage, we hand-collected and compiled information about board composition and characteristics (board size, number of board meetings, gender diversity, female expertise, female experience, etc.) from the Spanish National Stock Market Commission (CNMV) and firm web pages. We combined this information with the previous data collected from SABI. Finally, in the fourth stage, we obtained and merged ESG data from the Thomson Reuters

[4] IBEX 35, created by Bolsas y Mercados Espaoles, is the primary stock market index used as a benchmark for the Spanish stock market (BME). It is made up of the 35 mostly liquid companies listed on the Spanish Stock Exchange Interconnection System on the four Spanish stock exchanges (Madrid, Barcelona, Bilbao, and Valencia). It is a market capitalization-weighted index, meaning that, similar to indexes like the S&P 500, not every company included in the index has the same weight.

Eikon and ASSET4 databases.[5] ASSET4 aggregates data from a variety of sources, including sustainability reports, annual reports, and information on corporate websites, and delivers statistics on environmental, social, and governance (ESG)-related concerns for businesses worldwide (Konadu et al. 2022).

After merging the information contained in different databases, the above selection strategy gave us a final sample of 35 firms and 175 firm-year observations (i.e., 35 firms over 5 years) (Table 1).

3.2 Measurement of the variables

Increasing gender diversity in boardrooms has been proposed as a way of enhancing corporate governance and as a fundamental factor in strengthening ESG performance and its implications. Nevertheless, diversity cannot be understood only in terms of gender; it is necessary to examine board diversity in terms of experience and expertise. Therefore, this study empirically examines whether boards with more female directors who are business experts or support specialists impact environmental innovation. We focus on the results of board resource diversity on environmental or ecological innovation, understood as (i) the organizational capability to develop eco-efficient products or services (Arena et al. 2018); (ii) the development of new or modified techniques, systems, processes, and product designs to avoid or reduce environmental harm (Kemp and Arundel 1998); and (iii) driving the reduction of toxic emissions (Carrión-Flores and Innes 2010).

Some authors, like Arena et al. (2018) and Konadu et al. (2022), point out that the main problem with implementing measures that represent environmental innovation is that companies are not required to disclose their spending on environmental research and innovation or new ecologically friendly products, services, and systems. Consistent with these authors, we address this weakness by relying on information available in the Thomson Reuters Eikon and ASSET4 databases, widely used in prior ESG literature. Specifically, **Env_Innovation** reflects a company's capacity to reduce environmental costs and burdens for its customers, thereby creating new market opportunities through new environmental technologies, processes, and eco-designed products. Companies are rated from 0 to 100, representing the lowest to highest levels of environmental innovation (Schiessl et al. 2022).

Regarding the main explanatory variables linked to board resource diversity, we focus on female business experts and female support specialists. Using the works of previous authors (e.g., García-Meca and Palacio 2018), we use the Hillman et al. (2000) taxonomy to classify directors, adapting it to women, where **Fem_BE** and **Fem_SS** represent the proportion of female business experts and female support specialists on the board, respectively. **Fem_BE** is measured as the ratio of female business experts to the total number of board directors, while **Fem_SS** is the ratio of female support specialists to the total number of board

[5] As Omran et al. (2021) clearly noted, Semenova and Hassel (2015) report that Eikon-based ESG measures are highly correlated with two other highly regarded indexes, the KLD index and the Global Engagement Services (GES), which suggests that the ASSET4 measurement approach to environmental performance and innovation is relevant, comparable, and consistent.

directors. According to Kroll et al. (2007), business experts are executives from other organizations who were previously part of the company or are currently retired (excluding inside executives and support specialists) who advise management on key decisions. Support specialists are directors who tend to be trained in law, accounting, public relations, or financial investment who offer links and specialized knowledge to companies to help them access sources of financial and legal support.

This paper also explores whether the existence of a critical mass of female business experts or support specialists influences the impact these women have on environmental innovation. With this in mind, we follow the measures proposed by previous studies for the critical mass of women directors (e.g., Torchia et al. 2011; Liu et al. 2018; Saggese et al. 2020; Konadu et al. 2022) and propose the following measures: (i) **CM_Fem_BE** is the proxy for the critical mass of female business experts as a dummy variable coded as 1 if the board has at least three female business experts and 0 otherwise and (ii) **CM_Fem_SS** is the proxy for the critical mass of female support specialists as a dummy variable coded as 1 if the board has at least three female support specialists and 0 otherwise.

3.3 Model and technique of analysis

This paper examines whether women's attitudes toward environmental innovation can be affected by their individual differences in skills, expertise, experience, or technical knowledge, as well as their visibility and legitimacy on boards. Thus, we aim to provide insight into two closely related objectives. First, we examine the implications of female business experts and female support specialists on environmental innovation. Second, we look into whether a critical mass of female business experts and support specialists improves women's ability to influence environmental innovation.

Concerning these objectives, we tested the first objective using the following regression model:

$$\begin{aligned} Env\_Innovation_{it} =& \beta_1 Fem\_BE_{it} + \beta_2 FemSS_{it} + \beta_3 Size_{it} + \beta_4 OwnCon_{it} \\ &+ \beta_5 RD_{it} + \beta_6 CEODual_{it} + \beta_7 BSize_{it} + \beta_8 CSRComSize_{it} \\ &+ \beta_9 BDiv_{it} + \beta_{10} Env\_Innovation\_Lag_{it} + \beta_{11} Industry_i \\ &+ \beta_{12} Year_t + \eta_i + \mu_{it} \end{aligned} \quad \text{(Model I)}$$

where **Env_Innovation**, **Fem_BE**, and **Fem_SS** are the dependent and explanatory variables, respectively, described in Sect. 3.2; **Size** is the natural logarithm of total assets (Saggese et al. 2020); **OwnCon** is measured as the percentage of common stocks owned by the largest and second-largest shareholders (García-Meca and Palacio 2018); **RD** is the R&D expenditures per cash flow (Martínez-Ferrero et al. 2016); **CEODual** is a dummy variable taking the value of 1 if the CEO and chairperson are the same person and 0 otherwise (Liao et al. 2015); **BSize** is the number of directors on the board (Konadu et al. 2022); **CSRComSize** is the number of

directors on the CSR committee (Radu and Smaili 2021); **BDiv** is the percentage of female directors on the board (Konadu et al. 2022; Liao et al. 2015); **Env_Innovation_Lag** is the first lag of the dependent variable; **η** is the unobservable heterogeneity; and **μ** is the classical error term. We also controlled for industry and year. Annex 1 provides a summary of the variables (symbols, measures, and references).

Concerning the second objective, we examine whether environmental innovation is influenced by paradigms from the critical mass theory, testing the following regression model:

$$\begin{aligned} Env\_Innovation_{it} =& \beta_1 CM\_Fem\_BE_{it} + \beta_2 CM\_FemSS_{it} + \beta_3 Size_{it} \\ &+ \beta_4 OwnCon_{it} + \beta_5 RD_{it} + \beta_6 CEODual_{it} + \beta_7 BSize_{it} \\ &+ \beta_8 CSRComSize_{it} + \beta_9 BDiv_{it} + \beta_{10} Env\_Innovation\_Lag_{it} \\ &+ \beta_{11} Industry_i + \beta_{12} Year_t + \eta_i + \mu_{it} \end{aligned} \quad \text{(Model II)}$$

where the dependent and control variables have been previously described, and **CM_Fem_BE** and **CM_Fem_SS** are detailed in Sect. 3.2. We again control for industry and year.

These models are examined for panel data, which allows us to (i) control for unobservable heterogeneity, (ii) reinforce the consistency and explanatory power of the analysis, and (iii) provide more informative data and greater variability.

Regarding the technique of analysis, an important issue that must be addressed regarding the analysis technique is endogeneity. This arises from reverse causality, implying that a change in our dependent variable (environmental innovation) changes the value of at least one of the explanatory variables (e.g., female business experts). This reverse causality occurs because the choice of female directors is not random, and the decision can also be influenced by the level of environmental or ESG performance. The technique of analysis must solve the econometric problem caused by reverse causality.

Due to endogeneity concerns and before estimating the simultaneous equations, it is necessary to test whether a set of estimates obtained by ordinary least squares (OLS) are consistent or not. At this respect, Davidson and MacKinnon (1993) suggest an augmented regression test (Durbin–Wu–Hausman test), which can easily be formed by including the residuals of each endogenous variable, as a function of all exogenous variables, in a regression of the original model. In our case and because of the obtained in the regression is different from 0, the OLS estimate is not consistent and it is necessary to use instrumental variables (IV). IV methods allow for consistent estimation when the explanatory variables (covariates) are correlated with the error terms in a regression model, solving the self-selection bias.

However, IV cannot be employed in the presence of heteroskedasticity and autocorrelation, which are two economic problems that our regression models suffered from once we examined the modified Wald and Wooldridge tests. IV is not efficient when a regression analysis has the aforementioned problems. Given the existence of heteroskedasticity, serial autocorrelation, and endogeneity at this stage, we decided to use the dynamic panel GMM (Arellano and Bond 1991). specifically, we use the

dynamic two-step estimator proposed by Roodman (2009) since it is an IV estimator that controls for the previously mentioned problems.[6]

GMM estimators use the lagged values of the right-hand side variables included in the model as instruments. They are uncorrelated with the error term when deriving the estimator, as Arellano and Bond (1991) demonstrated, that is, E[(μi1, …, μit) | (zi1, …, zit) (wi1, …, wit)] where z and w are instruments for the same explanatory variable. The number of instruments should not be very large in relation to the number of observations because the results could be biased, although the higher the number of instruments, the higher the level of efficiency. The most adequate instruments are the closest lags, since the furthest cannot contain information on the current value of the variables because of there is frequently a delay between the decision taken by an individual and its actual realization. The closest lags in the difference GMM estimator are t − 1 and t for endogenous and predetermined variables (Pindado and Requejo 2015).

4 Descriptive and regression results

4.1 Descriptive results

Table 2 summarizes the statistics of the dependent, test, and control variables for the 175 firm-year observations used as the analysis sample in our regression models. As a dependent variable with a possible range from 0 to 100, overall ecological innovation has a mean value of approximately 54, indicating that there is still room for improvement. Regarding the presence of female business experts and support specialists on the boards, 24.6 percent were female business experts, while 25.1 percent were support specialists, which shows low female presence on boards. However, the data was controlled for differing board size as some had almost 7 directors while others, such as the CSR committee, averaged 5 directors. In 33.1% of the observations, the CEO was also the firm's chairperson. Finally, Table 2 reports the bivariate correlations among variables, showing that there were no multicollinearity problems.[7]

[6] As robustness check, additional regression models are examined using an adequate estimator that considers that the dependent variable is an index in the range 0 to 100. Concretely, several Tobit regressions for panel data models are used. Unlike linear models, this regression considers the extremities of the rating scale (0 and 100) in a special way. In this regard, by using the maximum likelihood method, Tobit models provide efficient, consistent estimates of coefficients, because when the likelihood function is maximized, it incorporates information from both censored and uncensored observations. The basic Tobit model supposes that there is a latent variable (called yit*) that can be explained by an observable.

variable(s) (called xit). Results using Tobit estimator support the main evidence, ensring the robustness of our evidence and are available upon request to the authors.

[7] We calculated the variance inflation factors (VIFs) for each model estimated and reported in Table III. In general, a VIF of 1 means that there is no correlation between a predictor and the remaining predictor variables; the general rule of thumb is that VIF values equal to or exceeding 4 warrant further investigation. Our results comply with this threshold.

Table 2 Descriptive statistics and bivariate correlations

	Mean	SD	Median	Min	Max					
Panel A. Descriptive statistics										
Env_Innovation	54.373	30.697	58.735	0	98					
Fem_BE	0.246	0.432	0	0	1					
Fem_SS	0.251	0.435	0	0	1					
Size	15.231	1.784	15.471	10.764	19.574					
OwnCon	33.460	21.588	30.205	0	72.29					
RD	−0.463	4.809	0	−53.83	5.44					
CEODual	0.331	0.543	0	0	1					
BSize	6.918	6.641	9	3	18					
CSRComSize	5.233	2.653	5	0	10					
BDiv	0.225	0.093	0.222	0.056	0.50					
	1	2	3	4	5	6	7	8	9	10
Panel B. Bivariate Correlations										
1. Env_Innovation	1.000									
2. Fem_BE	0.298***	1.000								
3. Fem_SS	0.434***	0.495***	1.000							
4. Size	−0.026	−0.211***	−0.296***	1.000						
5. OwnCon	−0.165*	−0.117	−0.083	0.131	1.000					
6. RD	−0.067	0.042	0.054	0.184**	0.131	1.000				
7. CEODual	0.130	−0.347***	−0.015	0.005	0.158*	−0.112	1.000			
8. BSize	0.276***	0.269***	0.137*	0.440***	−0.026	0.122	−0.109	1.000		
9. CSRComSize	0.701***	0.347**	0.303**	0.232	0.724***	0.288*	0.105	0.473***	1.000	
10. BDiv	0.108	0.374***	0.364***	0.157**	−0.061	−0.013	0.140*	0.004	−0.345**	1.000

Sample: 175 firm-year observations from 2015–2019 (35 unique firms)

*, ** and *** represent statistical significance at 90%, 95%, and 99%, respectively

Table 3 The influence of female business experts and female support specialists on environmental innovation

	Env_Innovation			
	Model I		Model II	
	Coef	Std. Err	Coef	Std. Err
Main variable				
Fem_BE	5.622**	2.393		
Fem_SS	− 3.794	1.243		
CM_Fem_BE			8.793	1.732
CM_Fem_SS			8.068**	3.119
Control variables				
Size	1.585	1.437	2. 129***	1.742
OwnCon	− 0.147	0.511	− 1.298***	0.197
RD	− 2.624**	1.294	− 9.484***	5.128
CEODual	− 5.926**	2.592	− 1.187**	1.84
BSize	6.382	6.536	0.761	1.592
CSRComSize	− 2.682	1.079	8.075***	3.104
BDiv	− 2.198**	1.079	− 6.682	6.116
Env_Innovation_Lag	0.052	0.232	− 2.673***	1.011
Controlled by year and industry				
AR(2)[a]	Pr > z = 0.354		Pr > z = 0.127	
Hansen test	Prob > chi2 = 0.243		Prob > chi2 = 0.302	
Wald test	Prob > chi2 = 0.000		Prob > chi2 = 0.000	
	VIF Fem_BE: 2.40; Fem_SS: 3.02; Size: 1.81; CSRComSize: 0.989; Bsize: 0.790; BDiv: 0.780; CEODual: 2.46; RD: 2.73; OwnCon: 3.54			
	VIF CM_Fem_BE: 3.21; CM_Fem_SS: 3.22; Size: 1.16; CSRComSize: 0.947; Bsize: 1.31; BDiv: 0.820; CEODual: 1.85; RD: 1.66; OwnCon: 3.04			

Sample: 175 firm-year observations from 2015–2019 (35 unique firms) (The variables are winsorized. Winsorizing our variables implies that the values at the tails of the distribution are not removed but are recoded to fewer extreme values. In this paper, 10 per cent of the lowest values are recoded to the value of the 10th percentile and 10 per cent of the highest values are recoded to the value of the 10th percentile.)

*, ** and *** represent statistical significance at 90%, 95% and 99%, respectively

[a]Wald is a test of the joint significance of the reported coefficients, asymptotically distributed as $\chi 2$ under the null hypothesis of no relationship. Hansen's test of over-identification restrictions is the test for the validity of the over-identifying restrictions for the GMM estimator, asymptotically distributed as $\chi 2$, under the null hypothesis (H0) that "the over-identifying restrictions are valid." AR (2) is a serial correlation test of order i using residuals in first differences. Arellano-Bond's test for AR(2) in first differences is the test for second-order serial correlation in the first differenced residuals, asymptotically distributed as N(0,1) under the null hypothesis (H0) of "no serial correlation of the error terms." The p-value of Arellano-Bond's test for AR(2) suggests that the null hypothesis of "inexistence of serial correlation between the error terms" cannot be rejected; similarly, the *p* value of Hansen's test suggests that the null hypothesis of "validity of over-identifying restrictions" cannot be rejected. Therefore, these results support the instrument validity of each regression model reported

4.2 Regression analysis

Table 3 reports the two-step GMM results for Models I and II, estimating whether female business experts and support specialists are effective in increasing environmental innovation and whether a critical mass is needed to find a positive effect on decision-making in this area.

Model I depicts the effect of female business expert and support specialist directors on environmental innovation. The results show that the coefficient of female business experts is positive and statistically significant (coef. 5.622, $p<0.05$), supporting hypothesis 1A. That is, female business experts are effective in increasing environmental innovation. However, the results do not support hypothesis 1B, given the non-significant effect of female support specialists on environmental innovation (coef. −3.794; $p>0.10$). Based on these findings and the identification of female directors as business experts or support specialists (according to their respective business and technical expertise), the results demonstrate that a greater presence of female business experts leads to the encouragement of innovative opportunities and improved innovation processes. However, greater ecological innovation is not driven by the mere presence of female support specialists. Is it possible that a critical mass is needed?

Building on this question, in Model II, we analyzed whether the influence of female business expert and support specialist directors varies depending on their strength within the board. Thus, Model II tests whether the effect of a critical mass of business experts and support specialists is necessary to produce positive effects on environmental innovation. The test yielded a non-significant effect, so we can conclude that a critical mass of female business experts is not necessary to reinforce firms' commitment to ecological innovation (coef. 8.793; $p>0.10$). The presence of one female business expert on the board is enough to increase environmental innovation. The above result, thus, does not support hypothesis 2A. However, a critical mass of female support specialists has a significant, positive effect on promoting ecological innovation strategies (coef. 8.068; $p<0.01$). Clearly supporting hypothesis 2B, the evidence obtained here allows us to confirm that a critical mass of female support specialists on the board is necessary to improve ecological and green innovation.

Our results confirm the positive influence of female business expert and support specialist directors on environmental innovation. However, we also note that the proportion of female directors influences innovation differently when comparing business experts and support specialists, as the effect of a woman with technical knowledge is only significant when there are enough other female support specialists on the board.

This paper investigates the effects of board resource diversity (female business experts and support specialists) on environmental innovation based on data provided by the ASSET4 database. Corporate ESG performance in general and environmental performance in particular can also be influenced by the proportion of female business experts and support specialists. Could environmental performance gain further relevance and prominence in firms with more female business experts and support specialists on the board? What about their impact on ESG performance?

In addition to the above findings, the following two analyses aim to provide further insight into the influence of female business experts and support specialists on (i) environmental performance and (ii) ESG performance while further examining the role of critical mass.

For the first analysis, regression Models I and II set A replace environmental innovation with environmental performance, while in set B, it is replaced with ESG performance as follows:

$$\begin{aligned} Env\_Performance/ESG_{it} = {} & \beta_1 Fem\_BE_{it} + \beta_2 FemSS_{it} + \beta_3 Size_{it} \\ & + \beta_4 OwnCon_{it} + \beta_5 RD_{it} + \beta_6 CEODual_{it} + \beta_7 BSize_{it} \\ & + \beta_8 CSRComSize_{it} + \beta_9 BDiv_{it} + \beta_{10} Env\_Performance\_Lag_{it} \\ & /ESG\_Performance\_Lag + \beta_{11} Industry_i + \beta_{12} Year_t + \eta_i + \mu_{it} \end{aligned}$$

(Model IA-IB)

$$\begin{aligned} Env\_Performance/ESG_{it} = {} & \beta_1 CM\_Fem\_BE_{it} + \beta_2 CM\_FemSS_{it} + \beta_3 Size_{it} \\ & + \beta_4 OwnCon_{it} + \beta_5 RD_{it} + \beta_6 CEODual_{it} \\ & + \beta_7 BSize_{it} + \beta_8 CSRComSize_{it} + \beta_9 BDiv_{it} \\ & + \beta_{10} Env\_Performance\_Lag_{it}/ESG\_Performance\_Lag \\ & + \beta_{11} Industry_i + \beta_{12} Year_t + \eta_i + \mu_{it} \end{aligned}$$

(Model IIA-IIB)

where **Env_Performance** is the environmental pillar score of the ESG index provided by ASSET4 based on three categories: resource use, emissions, and innovation (Omran et al. 2021). This score ranges from 0 to 100, with 100 indicating the highest level of environmental performance. **ESG_Performance** measures the firms' ESG performance based on ten categories weighted proportionately and according to the three pillar scores (environmental, social, and governance): resource use, emissions, innovation, management, shareholders, CSR strategy, workforce, human rights, community, and product responsibility (Sassen et al. 2016). This score also ranges from 0 to 100, with a higher value indicating better ESG performance, and **Env_Performance_Lag** and **ESG_Performance_Lag** are the first lags of the dependent variables.

The results reported in Table 4 show the evidence obtained from regressed Models IA and IB, where the dependent variable is environmental performance. Table 5 shows the results for Models IIA and IIB, where the dependent variable is global ESG performance. Thus, the findings in Tables 4 and 5 support the conclusions reported in Table 3. Female business expert directors seem to positively influence environmental and ESG performance even below a critical mass. However, women support specialist directors are only significant and positive drivers of environmental and ESG performance when they gain power, legitimacy, and authority on the board; that is, when they constitute a critical mass. This data again confirms that the positive effect of female directors on ESG performance depends not only on the expertise of these directors but also on the proportion of female support specialists on the board. Thus, the effect of female directors' expertise and experience must be

addressed by examining the relevance of critical mass, or the fault line effects, of different positions on the board.

5 Discussion

Under the increasing environmental pressure of recent years, green innovation has become a strategic means of gaining competitive advantages and avoiding damage to firms' legitimacy and reputation. Despite some previous research that has examined the role played by female characteristics in eco-innovative decisions, the evidence is still relatively scarce and sometimes conflicting. Some theories and empirical evidence suggest positive effects on environmental innovation, highlighting female attributes related to universalism, benevolence, and stakeholder orientation, while others suggest women directors have a negative or non-significant effect on green initiatives due to their higher risk-aversion and less confidence when making complex decisions involving high risks and considerable financial support.

Our results find that women with industry expertise gained from experience as executives in other companies contribute to environmental innovation when they are part of a board. Female business expert directors contribute with new, diverse perspectives based on their experience in other environments and often aid in decisions regarding internal matters and markets. They provide useful resources and relevant connections for decision-making involving green innovation. On the other hand, despite the specific backgrounds, technical knowledge, and qualifications of support specialist female directors, the ability of these women to affect innovative decisions is limited by their tokenism within the corporate hierarchy. Our evidence confirms that business expert female directors seem to positively influence environmental innovation even below a critical mass. However, women support specialist directors are only significant and positive drivers of eco-initiatives when they gain power and authority on the board, confirming the critical mass theory. In contrast to business experts, support specialists need to reach a high enough proportion on boards to be effective in developing green initiatives. Although female business expert directors seem to positively influence environmental innovation below a critical mass, female support specialists are only significant, positive drivers of eco-initiatives when they gain power, legitimacy, and authority on the board. This builds upon the critical mass theory as female support specialist directors need to reach a high enough number (or proportion) to form a critical mass to exert a substantial influence on ecological innovation.

Our results confirm that below a critical mass, women directors hired for their technical skills and with no previous managerial experience in the industry seem to act as mere tokens with no influence on innovative decisions due to their limited role, power, authority, and legitimacy on the board. Nevertheless, the critical mass theory does not affect all women directors in the same way. Female directors with prior business expertise in other companies seem to hold a powerful and legitimate position on boards and have been shown to make significant contributions to green innovation despite being under-represented. These findings help

Table 4 Further analysis. The influence of female business experts and female support specialists on environmental performance

	Env_Performance			
	Model I		Model II	
	Coef	Std. Err	Coef	Std. Err
Main variable				
Fem_BE	1.390***	0.352		
Fem_SS	− 4.300	0.473		
CM_Fem_BE			− 2.944	1.06
CM_Fem_SS			8.969***	1.272
Control variables				
Size	3.178***	1.131	2.763***	1.156
OwnCon	− 0.639***	0.094	− 0.571***	0.08
RD	− 1.323***	2.997	− 6.272***	2.091
CEODual	− 1.115***	3.914	− 1.000***	3.604
BSize	1.969***	0.604	1.927***	0.649
CSRComSize	− 3.348***	1.743	− 0.370	1.266
BDiv	− 6.753**	2.975	− 2.922	2.493
Env_Performance_Lag	− 3.807***	2.958	− 3.338***	2.122
Controlled by year and industry				
AR(2)	Pr > z = 0.356	Pr > z = 0.368		Pr > z = 0.127
Hansen test	Prob > chi2 = 0.205	Prob > chi2 = 0.587		
Wald test	Prob > chi2 = 0.000	Prob > chi2 = 0.000		

Sample: 175 firm-year observations from 2015–2019 (35 unique firms)

*, ** and *** represent statistical significance at 90%, 95% and 99%, respectively

explain the contradictory results found in previous studies concerning gender diversity that analyzed the role of women without examining the relevance of critical mass or the fault line effects of different positions on boards according to their experience and expertise.

Once female business experts and support specialists are examined as drivers of ecological innovation, our results are in line with previous studies reporting that female directors contribute to boards with diverse and unique skills and a greater focus on stakeholders (Sun et al. 2021; Campopiano et al. 2022). They promote corporate social responsibility practices (Bear et al. 2010; Nadeem et al. 2017), environmental innovation opportunities (Nadeem et al. 2020; Pan et al. 2020), and ecological and green innovation (e.g., Kim and Starks 2016). However, this paper examines an area that has lacked attention in previous research as it explores more than just gender diversity on boards. We focus on groups of women with different qualities and their impact on environmental innovation and performance. Our evidence is in line with the limited amount of prior research regarding this subject that explains that female directors with industry experience and technical expertise are effective in pursuing CSR disclosure strategies

Table 5 Further analysis. The influence of female business experts and female support specialists on ESG performance

	ESG_Performance			
	Model I		Model II	
	Coef	Std. Err	Coef	Std. Err
Main variable				
Fem_BE	2.056***	0.763		
Fem_SS	− 1.006	0.893		
CM_Fem_BE			− 1.382	1.681
CM_Fem_SS			6.871***	1.203
Control variables				
Size	2.505***	1.447	2.184***	1.987
OwnCon	− 0.544***	0.101	− 0.424***	0.076
RD	− 2.082***	1.226	− 1.032***	1.978
CEODual	− 1.517***	1.214	− 1.279***	1.411
BSize	1.411***	0.65	1.607***	0.614
CSRComSize	− 4.966	1.877	− 1.774	1.198
BDiv	− 4.749	1.203	− 6.089	2.359
ESG_Performance_Lag	− 2.729***	1.094	− 2.500***	3.900
Controlled by year and industry				
AR(2)	Pr > z = 0.816		Pr > z = 0.193	
Hansen test	Prob > chi2 = 0.202		Prob > chi2 = 0.445	
Wald test	Prob > chi2 = 0.000		Prob > chi2 = 0.000	

Sample: 175 firm-year observations from 2015–2019 (35 unique firms)

*, ** and *** represent statistical significance at 90%, 95% and 99%, respectively

(Ramón-Llorens et al. 2021) and environmental and social performance (Ben Barka and Dardour 2015). Our results find evidence that corresponds with other studies pointing out that: (i) female business expert directors contribute to better environmental and social performance (Ben Barka and Dardour 2015) and have a positive impact on strategic decisions such as CSR disclosure (Ramón-Llorens et al. 2021); and (ii) female support specialists are more engaged in socially responsible and sustainable practices (Setó-Pamies 2015; García Martín and Herrero 2020). Female directors with financial expertise in audit committees are more likely to report sustainability and environmental information (Helfaya and Moussa 2017). Furthermore, the results agree with previous research finding that only when women support specialists reach a high enough number (or proportion) to form a critical mass can they substantially influence board discussions (Joecks et al. 2013; Liu et al. 2014).

From a theoretical perspective and the analysis of differences among female directors, our findings support: (i) the gender socialization theory by demonstrating that women tend to be more stakeholder-oriented and show more benevolence, universalism, inclination to comply with rules and laws, ethical behavior, and empathy, as Malik et al. (2021) and Sun et al. (2021) propose; (ii) the upper echelon theory by showing that female expertise on boards (those with business experience and specialization) is associated with more empathetic behavior resulting in attempts to increase ecological innovation and performance (Nadeem et al. 2020; Konadu et al. 2022); (iii) the agency theory, with findings that gender diversity is an essential mechanism to meet stakeholders´ demands (Neville et al. 2019) as ecological innovation is often requested; (iv) the faultline theory by showing that female directors can be divided into homogeneous subgroups (business experts and support specialists) based on the alignment of their attributes (Wu et al. 2021), which determine the knowledge, skills, and abilities of each group and the directors' attitudes towards innovation (Hutzschenreuter and Horstkotte 2013); and (iv) the critical mass theory by showing how female support specialist directors are positive drivers of eco-initiatives when they gain power and authority in the board, coinciding with findings previously reported in other studies (e.g., Joecks et al. 2013; Ben-Amar et al. 2017; Fan et al. 2019).

6 Concluding remarks

In this paper, we suggest that women's attitudes toward environmental innovation can be affected by their individual differences in skill, expertise, experience, and technical knowledge, as well as their role and legitimacy on boards. Using a sample of Spanish firms from the period 2015–2020, we analyzed whether the different skill sets of female directors played a role in how strongly they encouraged environmental innovation. The women were classified according to their business and technical expertise and divided into two groups: business experts and support specialists. In addition, we analyzed whether the effectiveness of both groups of female directors was conditional on the amount of female representation on each board. Controlling for different measures of green innovation and overcoming endogeneity issues, this paper finds support for the premise that female expertise on boards aids in guiding successful green innovations and eco-friendly practices oriented to sustainable development.

From a practical point of view, these findings have implications for managers and highlight the unavoidable link between governance and sustainability. The environmental transformations necessary for the future require more diverse teams with members with different skills, competencies, cultures, and points of view. Overall, firms should be more aware of the unique differences among

female directors to better understand how diversity really impacts environmental innovation. Our findings also provide insight into how women's attitudes toward environmental innovation can be affected by their individual differences in skills, expertise, experience, and technical knowledge. When companies look for "diversity," they should not only focus on "gender diversity" but also on diversity in terms of the competencies, skills, and abilities of these women.

This paper also has implications for policymakers. Our findings support recent regulations and laws for appointing a legitimizing number of women in relevant positions; that is, a gender diversity percentage that leads to real, non-cosmetic, effective participation in decision-making on boards. In this regard, our findings confirm that the mere presence of female support specialists is not enough to influence decision-making on sustainability issues. Gender equality cannot be achieved without considering women's levels of representation and legitimacy on boards.

Finally, we would also like to acknowledge some research gaps that can be examined in future studies. For instance, future research could look into the role of other individual characteristics of female directors related to their education, age, or tenure. Specific female competencies in sustainability skills should also be studied in future work concerning gender diversity and sustainability. Future studies should also solve the lack of robustness checks—because of data availability—using alternative measures of environmental innovation, like the number of green patents that authors like Khanchel et al. (2023) and Wen et al. (2022) proposed. The use of this alternative proxy can ensure the consistency and robustness of the evidence here reported. In addition, we propose that future investigations extend the study sample to other non-European countries and analyze the moderating role of institutional and cultural factors. They could examine, for instance, differences in economic development or education quality. Moreover, future studies should expand the period of analysis to include 2020 and 2021. Additional control variables could be considered in future research (e.g., firm leverage, profitability, age, and industry concentration) according to previous studies (Dabbedi et al., 2023).

Appendix

See Table 6.

Table 6 List of variables and measures

Symbols	Detail	References
Summary of variables		
Dependent variable		
Env_Innovation	It reflects a company's capacity to reduce environmental costs and burdens for its customers, thereby creating new market opportunities through new environmental technologies, processes, and eco-designed products. Companies are scored from 0 to 100, representing lower to higher levels of environmental innovation	Schiesll et al. (2022)
Independent variable		
Fem_BE	It is the proportion of female business experts on the board. According to Kroll et al. (2007), business experts are executives from other organizations who were previously part of the company or who are currently retired (excluding inside executives and support specialists), whose main function is advising management on key decisions	Hillman et al. (2000); García-Meca and Palacios (2018)
Fem_SS	It is the proportion of female support specialists on the board. According to Kroll et al. (2007), support specialists are directors who tend to be trained in law, accounting, public relations, or financial investment and whose main function is to offer links and specialized knowledge to companies to aid them in accessing sources of financial and legal support	Hillman et al. (2000); García-Meca and Palacios (2018)
CM_Fem_BE	Dummy variable coded as 1 if the board has at least three female business experts and 0 otherwise	Torchia et al. (2011); Liu et al. (2018); Saggese et al. (2020); Konadu et al. (2022)
CM_Fem_SS	Dummy variable coded as 1 if the board has at least three female support specialists and 0 otherwise	Torchia et al. (2011); Liu et al. (2018); Saggese et al. (2020); Konadu et al. (2022)
Control variables		
Size	The natural logarithm of total assets	
OwnConc	The percentage of common stocks owned by the largest and second-largest shareholders	García-Meca and Palacio (2018)
RD	R&D expenditures per cash flow	Martínez-Ferrero et al. (2016)
CEOdual	Dummy variable taking the value of 1 if the CEO and chairperson are the same person and 0 otherwise	Liao et al. (2015)
BSize	Number of directors on the board	Konadu et al. (2022)
CSRCom	Number of directors on the CSR committee	Radu and Smaili (2021)
BDiv	The percentage of female directors on the board	Liao et al. (2015); Konadu et al. (2022)

Table 6 (continued)

Symbols	Detail	References
Addittional variables		
Env_Performance	It measures the environmental pillar score of the ESG index provided by Asset4 based on three categories: resource use, emissions, and innovation. This score falls into the range of 0–100, where 100 indicates a higher level of environmental performance	Omran et al. (2021)
ESG_Performance	It measures the firms' ESG performance based on ten categories weighted proportionately and according to the three pillar scores (environmental, social, and governance): resource use, emissions, innovation, management, shareholders, CSR strategy, workforce, human rights, community, and product responsibility. This score also ranges from 0 to 100, where a higher value indicates better ESG performance	Sassen et al. (2016)

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Data availability statement The data that support the findings of this study are available from the corresponding author upon request.

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References

Aggarwal R, Jindal V, Seth R (2019) Board diversity and firm performance: the role of business group affiliation. Int Bus Rev 28(6):101600. https://doi.org/10.1016/j.ibusrev.2019.101600

Ahuja G, Lampert CM, Tandon V (2008) Moving beyond Schumpeter: management research on the determinants of technological innovation. Acad Manag Ann 2:1–98

Alcaide-Ruiz MD, Bravo-Urquiza F (2022) Does audit committee financial expertise actually improves information readability? Revista De Contabilidad - Spanish Account Rev 25(2):257–270

Aluchna M, Krejner-Nowecka A (2016) Why do we need women on boards? A synthesis of theories. Przegląd Organizacji 10:72–80

Amorelli MF, García-Sánchez IM (2020) Critical mass of female directors, human capital, and stakeholder engagement by corporate social reporting. Corp Soc Responsib Environ Manag 27(1):204–221

Arellano M, Bond S (1991) Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. Rev Econ Stud 58(2):277–297

Arena C, Bozzolan S, Michelon G (2015) Environmental reporting: transparency to stakeholders or stakeholder manipulation? An analysis of disclosure tone and the role of the board of directors. Corp Soc Responsib Environ Manag 22:346–361

Arena C, Michelon G, Trojanowski G (2018) Big egos can be green: a study of CEO hubris and environmental innovation. Br J Manag 29(2):316–336

Atif M, Liu B, Huang A (2019) Does board gender diversity affect corporate cash holdings? J Bus Financ Acc 46(7–8):1003–1029

Bear S, Rahman N, Post C (2010) The impact of board diversity and gender composition on corporate social responsibility and firm reputation. J Bus Ethics 97(2):207–221

Ben Barka H, Dardour A (2015) Investigating the relationship between director's profile, board interlocks and corporate social responsibility. Manag Decis 53(3):553–570

Ben-Amar W, Chang M, McIlkenny P (2017) Board gender diversity and corporate response to sustainability initiatives: evidence from the carbon disclosure project. J Bus Ethics 142(2):369–383

Berrone P, Fosfuri A, Gelabert L, Gomez-Mejia LR (2013) Necessity as the mother of "green" inventions: Institutional pressures and environmental innovations. Strateg Manag J 34(8):891–909

Bianchi S, Corvino A, Rigolini A (2012) Board diversity and structure: What implications for investments in inno- vation? Empirical evidence from Italian context. Corp Ownersh Control 10(1):9–25

Bossle M, Barcellos M, Vieira L, Sauvée L (2016) The drivers for adoption of eco-innovation. J Clean Prod 113:861–872

Boulouta I (2013) Hidden connections: the link between board gender diversity and corporate social performance. J Bus Ethics 113:185–197
Byrne D (1971) The attraction paradigm. Academic Press, New York
Cabeza-García L, Fernández-Gago R, Nieto M (2018) Do board gender diversity and director typology impact CSR reporting? Eur Manag Rev 15(4):559–575
Campbell K, Mínguez-Vera A (2008) Gender diversity in the boardroom and firm financial performance. J Bus Ethics 83:435–451
Campopiano G, Gabaldón P, Gimenez-Jimenez D (2022) Women directors and corporate social performance: an integrative review of the literature and a future research agenda. J Bus Ethics 1:3
Carrión-Flores CE, Innes R (2010) Environmental innovation and environmental performance. J Environ Econ Manag 59(1):27–42
Castelló I, Lozano JM (2011) Searching for new forms of legitimacy through corporate responsibility rhetoric. J Bus Ethics 100(1):11–29
Chang EH, Milkman KL, Chugh D, Akinola M (2018) Diversity thresholds: how social norms, visibility, and scrutiny relate to group composition. Acad Manag J 62(1):144–171
Chau VS, Quire C (2018) Back to the future of women in technology: insights from understanding the shortage of women in innovation sectors for managing corporate foresight. Technol Anal Strat Manag 30(6):747–764
Chen J, Leung WS, Evans KP (2018) Female board representation, corporate innovation and firm performance. J Empir Financ 48:236–254
Conyon MJ, He L (2017) Firm performance and boardroom gender diversity: a quantile regression approach. J Bus Res 79(1):198–211. https://doi.org/10.1016/j.jbusres.2017.02.006
Cruz C, Justo R, De Castro JO (2012) Does family employment enhance MSEs performance? Integrating socioemotional wealth and family embeddedness perspectives. J Bus Ventur 27(1):62–76
Dabbebi A, Lassoued N, Khanchel I (2022) Peering through the smokescreen: ESG disclosure and CEO personality. Manag Decis Econ 43(7):3147–3164
Davidson R, MacKinnon JG (1993) Estimation and inference in econometrics. OUP Catalogue
De Marchi V (2012a) Environmental innovation and R&D cooperation: empirical evidence from Spanish manufacturing firms. Res Policy 41(3):614–623
De Masi S, Słomka-Gołębiowska A, Becagli C, Paci A (2021) Toward sustainable corporate behavior: the effect of the critical mass of female directors on environmental, social, and governance disclosure. Bus Strateg Environ 30(4):1865–1878
Diamantopoulos A, Schlegelmilch BB, Sinkovics RR, Bohlen GM (2003) Can socio- demographics still play a role in profiling green consumers? A review of the evidence and an empirical investigation. J Bus Res 56:465–480
Eagly AH (1987) Sex differences in social behavior: a social-role interpretation. Psychology Press, Hillsdale, NJ
Eagly A, Karau SJ (1991) Gender and the emergence of leaders: a meta analysis. J Pers Soc Psychol 60:685–710
Eagly AH, Johannesen-Schmidt MC, van Engen ML (2003) Transformational, transactional, and laissez-faire leadership styles: a meta-analysis comparing women and men. Psychol Bull 129(4):569–591
Elmagrhi MH, Ntim CG, Elamer AA, Zhang Q (2019) A study of environmental policies and regulations, governance structures, and environmental performance: the role of female directors. Bus Strateg Environ 28(1):206–220
Faleye O, Hoitash R, Hoitash U (2014) Industry expertise on corporate boards. Northeastern U. D'Amore-McKim School of Business, Research Paper. https://doi.org/10.2139/ssrn.2117104
Fan Y, Jiang Y, Zhang X, Zhou Y (2019) Women on boards and bank earnings management: from zero to hero. J Bank Finance 107:105607
Fondas N (1997) Feminization unveiled: management qualities in contemporary writings. Acad Manag Rev 22:257–282
Fritz C, Knippenberg DV (2017) Gender and leadership aspiration: the impact of organizational identification. Leadersh Org Dev J 38(9):1018–1037
Galbreath J (2016) When do board and management resources complement each other? A study of effects on corporate social responsibility. J Bus Ethics 136(2):281–292

Galia F, Zenou E (2012) Board composition and forms of innovation: does diversity make a difference? Eur J Int Manag 6(6):630
Galia F, Zenou E, Ingham M (2015) Board composition and environmental innovation: Does gender diversity matter? Int J Entrep Small Bus 24(1):117–141
García Martín CJ, Herrero B (2020) Do board characteristics affect environmental performance? A study of EU firms. Corp Soc Responsib Environ Manag 27(1):74–94
García-Meca E, Palacio CJ (2018) Board composition and firm reputation: the role of business experts, support specialists and community influential. BRQ Bus Res Q 21(2):111–123
García-Meca E, García-Sánchez I-M, Martínez-Ferrero J (2015) Board diversity and its effects on bank performance: an international analysis. J Bank Finance 53:202–214
García-Meca E, López-Iturriaga FJ, Santana-Martín DJ (2022) Board gender diversity and dividend payout: The critical mass and the family ties effect. Int Rev Financ Anal 79:101973
Goh BW, Lee J, Lim CY (2016) The effect of corporate tax avoidance on the cost of equity. Account Rev 91:1647–1670
Gong M, Zhang Z, Jia M, Walls JL (2021) Does having a critical mass of women on the board result in more corporate environmental actions? Evidence from China. Group Org Manag 46(6):1106–1144
González-Benito J, González-Benito O (2006) A review of determinant factors of environmental proactivity·. Bus Strateg Environ 15(2):87–102
Hambrick DC (2007) Upper echelons theory: an update. Acad Manage Rev 32:334–343. https://doi.org/10.5465/amr.2007.24345254
Hambrick DC, Mason PA (1984) Upper echelons: the organization as a reflection of its top managers. Acad Manag Rev 9:193–206
Helfaya A, Moussa T (2017) Do board's corporate social responsibility strategy and orientation influence environmental sustainability disclosure? UK evidence. Bus Strateg Environ 26(8):1061–1077
Henriques I, Sadorsky P (1996) The determinants of an environmentally responsive firm: an empirical approach. J Environ Econ Manag 30(3):381–396
Hermundsdottir F, Aspelund A (2021) Sustainability innovations and firm competitiveness: a review. J Clean Prod 280. Elsevier Ltd
Hillman A, Cannella J, Paetzold R (2000) The resource dependence role of corporate directors: strategic adaptation of board composition in response to environmental change. J Manage Stud 37(2):235–256
Hollindale J, Kent P, Routledge J (2017) Women on boards and greenhouse gas emission disclosures. Account Finance 59(1):277–308
Horwitz SK, Horwitz IB (2007) The effects of team diversity on team outcomes: a meta-analytic review of team demography. Sage Publications, Los Angeles
Hur W-M, Kim H, Jang JH (2016) The role of gender differences in the impact of CSR perceptions on corporate marketing outcomes. Corp Soc Responsib Environ Manag 23(6):345–357
Hutzschenreuter T, Horstkotte J (2013) Performance effects of top management team demographic faultlines in the process of product diversification. Strateg Manag J 34:704–726
Jain T, Jamali D (2016) The effect of corporate governance on corporate social responsibility. Corporate Governance-an Int Rev 45:102–123. https://doi.org/10.1111/ajfs.12121
Jensen M, Meckling W (1976) Theory of the firm: managerial behavior, agency costs and ownership structure. J Financ Econ 3:305–360
Jiraporn P, Lee SM, Park KJ, Song HJ (2017) How do independent directors influence innovation productivity? A quasi-natural experiment. Appl Econ Lett 25(7):435–441
Joecks J, Pull K, Vetter K (2013) Gender diversity in the boardroom and firm performance: What exactly constitutes a critical mass? J Bus Ethics 118(1):61–72
Kabongo JD, Okpara JO (2019) Timing and speed of internationalization: evidence from African banks. J Bus Res 102(1):12–20. https://doi.org/10.1016/j.jbusres.2019.05.003
Kanter RM (1977a) Men and women of the corporation. Basic Books
Kanter RM (1977b) Some effects of proportions on group life. Am J Sociol 82(5):965–990
Kassinis G, Vafeas N (2006) Stakeholder pressures and environmental performance. Acad Manag J 49(1):145–159
Kemp R, Arundel A (1998) Survey indicators for environmental innovation

Khanchel I, Lassoued N, Baccar I (2023) Sustainability and firm performance: the role of environmental, social and governance disclosure and green innovation. Manag Decis (ahead-of-print). https://doi.org/10.1108/MD-09-2021-1252
Kim D, Starks LT (2016) Gender diversity on corporate boards: Do women contribute unique skills? Am Econ Rev 106(5):267–271
Konadu R, Ahinful GS, Boakye DJ, Elbardan H (2022) Board gender diversity, environmental innovation and corporate carbon emissions. Technol Forecast Soc Change 174
Konrad A, Steurer R, Langer ME, Martinuzzi A (2006) Empirical findings on business-society relations in Europe. J Bus Ethics 63(1):89–105
Konrad AM, Kramer V, Erkut S (2008) Critical mass: The impact of three or more women on corporate boards. Org Dyn 37:145–164
Kroll M, Walters BA, Le SA (2007) The impact of board composition and top management team ownership structure on post-IPO performance in young entrepreneurial firms. Acad Manag J 50(5):1198–1216
Lassoued N, Khanchel I (2022) Voluntary CSR disclosure and CEO narcissism: the moderating role of CEO duality and board gender diversity. RMS 17(3):1075–1123
Lau DC, Murnighan JK (1998) Demographic diversity and faultlines: the compositional dynamics of organizational groups. Acad Manag Rev 23(2):325–340
Liao L, Luo L, Tang Q (2015) Gender diversity, board independence, environmental committee and greenhouse gas disclosure. Br Account Rev 47(4):409–424
Liao L, Lin T, Zhang Y (2018) Corporate board and corporate social responsibility assurance: evidence from China. J Bus Ethics 150(1):211–225
Liu Y, Wei Z, Xie F (2014) Do women directors improve firm performance in China? J Corp Finance 28:169–184
Long S, Liao Z (2021) Would consumers pay for environmental innovation? The moderating role of corporate environmental violations. Environ Sci Pollut Res 28(3):29075–29084
Ma Y, Zhang Q, Yin Q (2021) Top management team faultlines, green technology innovation and firm financial performance. J Environ Manage 285:112095
Marchi V (2012b) Environmental innovation and R&D cooperation: empirical evidence from Spanish manufacturing firms. Res Pol 41(2):614–623
Markman GD, Espina MI, Phan PH (2004) Patents as surrogates for inimitable and non-substitutable resources. J Manag 30(3):529–544
Martínez-Ferrero J, Banerjee S, García-Sánchez IM (2016) Corporate social responsibility as a strategic shield against costs of earnings management practices. J Bus Ethics 133(2):305–324
Midavaine J, Dolfsma W, Aalbers R (2016) Board diversity and R&D investment. Manag Decis 54(3):558–569
Miller T, Triana MDC (2009) Demographic diversity in the boardroom: mediators of the board diversity–firm performance relationship. J Manag Stud 46(5):755–786
Moreno-Ureba E, Bravo-Urquiza F, Reguera-Alvarado N (2022) An analysis of the influence of female directors on environmental innovation: When are women greener? J Clean Prod 374:133871
Mukarram SS, Ajmal T, Saeed A (2018) Women directors' propensity towards risk in technology firms. Corporate Governance. Int J Bus Soc 18(2):353–367
Nadeem M, De Silva TA, Gan C, Zaman R (2017) Boardroom gen- der diversity and intellectual capital efficiency: Evidence from China. Pac Account Rev 29(4):590–615
Nadeem M, Suleman T, Ahmed A (2019) Women on boards, firm risk and the profitability nexus: Does gender diversity moderate the risk and return relationship? Int Rev Econ Financ 64:427–442
Nadeem M, Bahadar S, Gull AA, Iqbal U (2020) Are women eco-friendly? Board gender diversity and environmental innovation. Bus Strateg Environ 29(8):3146–3161
Navarro-García JC, Ramón-Llorens MC, García-Meca E (2020) Female directors and corporate reputation. BRQ Bus Res Q
Neville F, Byron K, Post C, Ward A (2019) Board independence and corporate miscon-duct: a cross-national meta-analysis. J Manag 45(6):2538–2569
Nielsen S, Huse M (2010) Women directors' contribution to board decision-making and strategic involvement: the role of equality perception. Eur Manag Rev 7:16–29
Nuber C, Velte P (2021) Board gender diversity and carbon emissions: European evidence on curvilinear relationships and critical mass. Bus Strateg Environ 30(4):1958–1992
Omran MS, Zaid MA, Dwekat A (2021) The relationship between integrated reporting and corporate environmental performance: a green trial. Corp Soc Responsib Environ Manag 28(1):427–445

Pan C, Guo H, Jiang Y, Wang H, Qi W (2020) The double effects of female executives' participation on corporate sustainable competitive advantage through unethical environmental behavior and proactive environmental strategy. Bus Strat Environ 29(6):2324–2337. https://doi.org/10.1002/bse.2505
Pearsall MJ, Ellis APJ, Evans JM (2008) Unlocking the effects of gender faultlines on team creativity: Is activation the key?". J Appl Psychol 93(1):225–234
Pfeffer J, Salancik GR (1978) The external control of organizations: a resource dependence perspective. Harper & Row, New York
Prado-Lorenzo JM, García-Sánchez IM (2010) The role of the board of directors in disseminating relevant information on greenhouse gases. J Bus Ethics 97(3):391–424
Przychodzen J, Przychodzen W (2015) Relationships between eco- innovation and financial performance—Evidence from publicly traded companies in Poland and Hungary. J Clean Prod 90:253–263
Radu C, Smaili N (2021) Alignment versus monitoring: an examination of the effect of the CSR committee and CSR-linked executive compensation on CSR performance. J Bus Ethics 1–19
Ramón-Llorens MC, García-Meca E, Pucheta-Martínez MC (2021) Female directors on boards. the impact of faultlines on CSR reporting. Sustain Account Manag Policy J 12(1):156–1833
Reguera-Alvarado N, de Fuentes P, Laffarga J (2017) Does board gender diversity influence financial performance? Evidence from Spain. J Bus Ethics 141(2):337–350
Roodman D (2009) How to do xtabond2: an introduction to difference and system GMM in Stata. Stand Genomic Sci 9(1):86–136
Rossi F, Cebula RJ (2015) Does the board of directors affect the extent of corporate R&D? Evidence from Italian listed companies. Econ Bull 35(4):2567–2580
Saggese S, Sarto F, Viganò R (2021) Do women directors contribute to R&D? The role of critical mass and expert power. J Manage Governance 25(2):593–623
Sassen R, Hinze AK, Hardeck I (2016) Impact of ESG factors on firm risk in Europe. J Bus Econ 86(8):867–904
Schiessl D, Korelo JC, Cherobim APMS (2022) Corporate social responsibility and the impact on economic value added: the role of environmental innovation. Eur Bus Rev
Schwartz-Ziv M (2017) Gender and board activeness: the role of a critical mass. J Financ Quant Anal 52(2):751–780
Semenova N, Hassel LG (2015) On the validity of environmental performance metrics. J Bus Ethics 132(2):249–258
Setó-Pamies D (2015) The relationship between women directors and corporate social responsibility. Corp Soc Responsib Environ Manag 22(6):334–345
Shahab Y, Ntim CG, Chengang Y, Ullah F, Fosu S (2019) Environmental policy, environmental performance and financial distress in China: Do top management team characteristics matter? Bus Strategy Environ 27:1635–1652
Shaukat A, Qiu Y, Trojanowski G (2016) Board attributes, corporate social responsibility strategy, and corporate environmental and social performance. J Bus Ethics 135(3):569–585
Sheridan A, Mckenzie FH, Still L (2011) Complex and contradictory: the doing of gender on Regional Development Boards. Gend Work Organ 18(3):282–297
Simon HA (1972) Theories of bounded rationality. Decis Organ 1(1):161–176
Sobral F, Bisseling D (2012) Exploring the black box in Brazilian work groups: a study of diversity, conflict and performance. BAR Braz Adm Rev 9:127–146
Sun F, Dutta S, Zhu P, Ren W (2021) Female insiders' ethics and trading profitability. Int Rev Financ Anal 74:101710
Tingbani I, Chithambo L, Tauringana V, Papanikolaou N (2020) Board gender diversity, environmental committee and greenhouse gas voluntary disclosures. Bus Strat Environ 29(6):2194–2210
Torchia M, Calabrò A, Huse M (2011) Women directors on corporate boards: from tokenism to critical mass. J Bus Ethics 102(2):299–317
Triana MC, Miller T, Trzebiatowski T (2015) The double-edged nature of board gender diversity: diversity, firm performance, and the power of women directors as predictors of strategic change. SSRN Electron J. https://doi.org/10.2139/ssrn.2627729
Turner JC (1987) Rediscovering the social group: a self-categorization theory. Blackwell, Oxford
Valdez-Juárez LE, García-Pérez de Lema D, Maldonado-Guzmán G (2016) Management of knowledge, innovation and performance in SMEs. Interdiscip J Inf Knowl Manag 11:141–176
Van Ees H, Van der Laan G, Postma TJB (2008) Effective board behavior in the Netherlands. Eur Manag J 26:84–93

Wasiuzzaman S, Wan Mohammad WM (2020) Board gender diversity and transparency of environmental, social and governance disclosure: evidence from Malaysia. Manag Decis Econ 41(1):145–156
Wen J, Li L, Zhao X, Jiao C, Li W (2022) How government size expansion can affect green innovation—An empirical analysis of data on cross-country green patent filings. Int J Environ Res Public Health 19(12):7328
Westphal JD, Milton LP (2000) How experience and network ties affect the influence of demographic minorities on corporate boards. Adm Sci Q 45(2):366–398
Wood W, Eagly AH (2009) Gender identity. In: Leary MR, Hoyle RH (eds) Handbook of individual differences in social behavior. Guilford Press, New York, pp 109–125
Wood W, Eagly A (2012) Biosocial construction of sex differences and similarities in behavior. Adv Exp Soc Psychol 46:55–123
Wu J, del Triana M, C Richard OC, Yu L (2021) Gender faultline strength on boards of directors and strategic change: the role of environmental conditions. Group Org Manag 46(3):564–601
You J (2019) Beyond "twokenism": organizational factors enabling female directors to affect the appointment ofa female CEO. Strat Org (forthcoming). https://doi.org/10.1177/1476127019893929
Zahra SA, Neubaum DO, Huse M (2000) Entrepreneurship in medium-size companies: exploring the effects of ownership and governance systems. J Manag 26(5):947–976
Zaman R, Jain T, Samara G, Jamali D (2022) Corporate governance meets corporate social responsibility: Mapping the interface. Bus Soc 61(3):690–752. https://doi.org/10.1177/0007650320973415

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