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Independent Female Directors and Green Innovation in China: The Moderating Roles of Ownership Structure and Market Competition

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ABSTRACT

This study examines the impact of independent female directors (IFDs) on green innovation (GI) among Chinese-listed firms from 2008 to 2023. Additionally, we investigate the moderating effects of ownership structure and market competition on the relationship between IFD and GI. Using a total of 22,091 firm-year observations and fixed-effects regressions, we find that IFDs are significantly and positively associated with GI, suggesting that IFDs promote environmentally friendly activities. Furthermore, the results show that ownership structure and market competition influence the relationship between IFD and GI, with the association being more pronounced in state-owned enterprises (SOESs) and weakening when market competition is high. Moreover, we divided our sample and discovered that IFDs foster GI activities in polluting industries more than in nonpolluting ones. Our findings remain robust across various statistical procedures. The results highlight the vital role of IFD in advancing GI and indicate that its effectiveness depends on institutional and competitive factors. Unlike previous research, this paper moves beyond overall board gender diversity by focusing specifically on IFD, while identifying ownership structure and market competition as key contextual factors in an emerging economy. This study offers important implications for policymakers in China by demonstrating that board independence can be strengthened through the appointment of IFD and that it can effectively promote GI, especially in SOES and environmentally sensitive industries.

1 | Introduction

Emerging economies, such as China, are currently facing numerous environmental challenges, leading to significant social pressure to control pollution (Wang and Jiang 2021). In particular, factors such as increased use of fossil fuels and pollution have caused severe environmental problems in China (Bilal et al. 2022). To address these issues, Li et al. (2018) highlighted that the Chinese government is promoting green innovation (GI) activities to achieve environmental sustainability and gain a competitive edge (Yang et al. 2024). Additionally, the 'Paris Agreement' and 'Rio Declaration' have accelerated the call for ecological stewardship, and the concept of 'going green' has grown considerably (Javed et al. 2023). Consequently, Amore and Bennedsen (2016) and Ren et al. (2024) noted that GI enhances cost efficiency and boosts operational productivity. Moreover, GI improves firms' brand equity, legitimacy and fosters financial success (Porter and Linde 1995; Wang et al. 2021). However, environmental issues such as pollution and greenhouse gas emissions are still increasing, bringing the sustainability agenda to the forefront (Nadeem et al. 2020). Experts believe that global warming has surpassed 1.5°C above preindustrial levels. Given these environmental challenges, implementing GI is essential, as it will enhance the quality of life for everyone on our planet.

We are motivated to investigate the association between IFD and GI for various reasons. First, the context of China provides an ideal setting for the study. The reason is that the country has been the world's largest carbon emitter since 2006, contributing around 64.8% of the increase in global carbon emissions from 2007 to 2012 (Wang et al. 2018). By 2013, China emitted approximately 10.2 million kilotons of carbon, accounting for 28.6% of total global emissions and almost twice the 5.2 million kilotons emitted by the United States (Zhang et al. 2022). The country has placed a significant focus on the reduction of carbon emissions and has developed a series of industrial policies for lower carbon growth. For instance, China made a formal commitment in September 2020, vowing to achieve peak carbon emissions by 2030 and attain carbon neutrality by 2060 (Zhongxiang 2022). Due to the significant environmental degradation in emerging economies such as China, Zhang et al. (2021) argue that firms invest more in GI to combat climate emergencies.

Second, there is increasing interest in GI as firms that are actively engaging in GI tend to improve their image and customer loyalty, increase profit and protect the environment from further harm (Nadeem et al. 2020; Shi et al. 2024; Tang et al. 2023). For example, Wurlod and Noailly (2018) pointed out that a 1% increase in GI patents reduces the energy intensity by 0.03%, regardless of the industry, underscoring the crucial role GI plays in maintaining the natural resources of the planet. However, He and Jiang (2019) contend that GI requires long-term financial commitment from firms to maximise returns, making it less appealing for firms. Hence, this context makes GI a strategic outcome that is likely to be influenced by board-level governance mechanisms and not just operational decisions.

Third, in terms of corporate governance mechanisms, prior studies suggest that the corporate board plays a crucial role in aligning the interests of managers and owners (Alnabsha et al. 2018; Ezeani et al. 2024; Gerged et al. 2022). The broad mindedness and capacity of the board's decisions help firms to succeed in various aspects including those that are economic, social and environmental (Al-Najjar and Salama 2022; García-Sánchez 2020). This study considers independent female directors (IFDs) because Fama (1980) pointed out that they play a crucial monitoring role to avoid agency costs. Building on this monitoring perspective, Li and Li (2020) suggested that IFD lowers financial irregularities due to stronger oversight, which may also support their potential role in responsible investments like GI. Although prior literature concluded that gender-diverse boards are more likely to engage in environmental (green) innovation compared to their industry peers (Elmagrhi et al. 2019; He and Jiang 2019; Konadu et al. 2022), Asni and Agustia (2022) claimed that the implication of corporate governance on GI is not yet known. Previous studies established that board gender diversity is linked with the sustainability outcome; however, the majority relied on aggregate measures and were unable to consider the distinct governance role of IFD. Therefore, it would be interesting to examine the association between IFD and GI among Chinese firms.

Although existing research links the board's gender diversity to sustainability outcomes of the firm, the majority of studies treat female directors as a homogeneous group and rely on aggregate measures of the board's gender representation (Adams and Ferreira 2009; Khatri 2023). Therefore, such an approach overlooks a crucial governance distinction between independent and executive female board directors. Previous studies pointed out that IFD perform a distinct advisory and monitoring role and are not likely to be influenced by managerial actions (Cambrea et al. 2023; Terjesen et al. 2009). This would position IFD to effectively influence the long-term strategic decisions of firms, such as GI. Hence, this study focuses on IFD and advances the board gender diversity and sustainability literature beyond the descriptive diversity measures.

Finally, Liu et al. (2020) suggested that firms with different ownership structures tend to implement innovation differently. For instance, state-owned enterprises (SOEs) operate under government influence to align with societal expectations (Bilal et al. 2022). For instance, studies show that private firms (non-SOEs) usually prioritise their main goal of profit maximisation instead of focusing on environmental initiatives like GI (Huafang and Jianguo 2007; Liu 2015). With regards to market competition, studies argued that it impacts the availability of resources, as companies often prioritise short-term financial gains to stay ahead of competitors (Luo et al. 2023; Song and Wang 2018). Hence, such a focus could deter investment in GI, which may require significant upfront investments. Additionally, Duanmu et al. (2018) stated that it would be difficult to implement GI in a highly competitive market as a cost-leadership strategy because it seems to be more effective in increasing market share and enhancing financial performance in the longer term, instead of providing benefits in a shorter period. Hence, we expect that the market and institutional conditions are more likely to moderate the extent to which IFD influence strategic decisions like GI. Therefore, this study fills the research gap by examining the impact of IFD on GI under different levels of market competition and ownership structure in China.

Although recent studies such as Hussain, Gaoliang, et al. (2025) and Wang et al. (2023) investigated the impact of female directors' foreign experience on GI by transmitting international practices and knowledge, they explicitly assumed that influence operates through experiential and informational channels, whereas our paper considers IFD as governance actors whose influence drives from board independence rather than international exposure. The independence of board directors is crucial, as it determines their monitoring capacity, reduces managerial opportunism and facilitates strategic long-term investments, such as GI, specifically within China's complex institutional settings (García-Sánchez et al. 2021).

Our study contributes to the literature in several ways. First, prior studies related to GI considered board gender diversity and ignored IFD (He and Jiang 2019; Nadeem et al. 2020). We contribute to innovation literature by documenting evidence that a higher proportion of IFD increases the firms' engagement in GI, supporting the notion of stakeholder and social role theory. Second, few studies have documented the impact of ownership structure and environmental performance (Issah et al. 2024; Thomsen and Pedersen 2000). We contribute to this growing body of corporate ownership literature by showing that ownership structure moderates the relationship between IFD and GI. Particularly, we show that SOEs with their greater access to

resources should leverage the presence of IFDs to meet sustainability goals. Third, studies have highlighted the role of market competition on firms' innovation (Abbas et al. 2024; Zhang and Zhou 2022). Our study contributes to this area of study by documenting the moderating effect of market competition on the IFD and GI nexus. Our novel findings indicate that the association between IFD and GI is less pronounced in firms facing a higher level of market competition. Interestingly, we document evidence that firms in less competitive markets can enhance competitiveness by fostering gender diversity and using readily available resources for GI. Finally, we added to the environmental literature by showing that IFD promotes GI in polluting industries. Hence, this paper moves beyond general board gender diversity research, as it conceptualises IFD as governance actors and highlights their relevance in China's regulatory and institutional environment.

The remaining paper proceeds as follows: Section 2 covers the institutional background; Section 3 presents the theoretical framework, reviews the relevant literature and develops the study hypotheses; Section 4 presents the sample, variables and regression models; Section 5 discusses and presents the empirical results; and Section 6 provides the conclusion and limitations of the study.

2 | Institutional Background

There has been remarkable economic growth in China over the last decades (Bilal Khan et al. 2024). However, previous studies highlighted that the Chinese government and corporations focused on economic growth while ignoring environmental regulations and policies (Bilal et al. 2022; Zhongxiang 2022). For instance, China is one of the world's largest polluters of carbon dioxide because it consumes the world's largest energy and accounts for 70% of coal energy consumption (Du et al. 2018). The World Health Organization (2014) report disclosed that extreme levels of air pollution in China are one of the main environmental causes of death and raised concerns over the implementation of green policies. As China is accountable for approximately one quarter of worldwide carbon dioxide emissions, it is crucial to investigate the firm-level GI and the corporate governance mechanisms, like IFD, that shape such outcomes.

To overcome the environmental issues, the Chinese government introduced the first Environmental Protection Law in 1989, which was revised in 2014. The China Securities Regulatory Commission issued the first corporate governance code in 2001 (modified in 2004) to ensure firms are involved in good governance practices, such as board independence and gender diversity (Komal et al. 2023), but also promote GI activities (Jia et al. 2009). As we consider Chinese listed firms on both the Shanghai and Shenzhen Stock Exchanges from 2008 to 2023, Noronha et al. (2013) pointed out that both exchanges introduced more guidelines that are aimed at protecting the environment in 2007. The guidelines require listed firms to publish separate environmental and corporate social responsibility (CSR) reports, outlining their social and environmental performance. Furthermore, the National People's Congress Standing Committee in China approved the 'Environmental Protection Tax Law' in December 2016. The law was implemented and came into effect in January 2018, aiming to impose taxes on industrial pollution and emissions.

Furthermore, China also joined the Paris Agreement on Climate Change in 2016 and became one of the major partners to fight against environmental issues like global warming and climate change. Although China has taken significant steps towards reducing carbon emissions in its socioeconomic development projects (Dou and Gao 2022), the country's efforts to ensure a greener environment are still poor due to weaker law enforcement (Du 2015). Hence, corporate governance mechanisms such as the presence of IFD on the board will ensure that firms do involve themselves in GI activities because board monitoring influences firms' actions (Nasr and Ntim 2018). Therefore, it would be interesting to investigate the effectiveness of IFD in promoting GI.

3 | Literature Review and Hypotheses Development

3.1 | Theoretical Framework

This study used agency, stakeholder and social role theory, as they provide a strong foundation to understand the role of IFD in promoting GI activities. The theories elucidate how gender diversity on the board influences sustainability-driven initiatives within the firms (Lu and Abeysekera 2017). The notion of agency theory focuses on the monitoring role of boards to mitigate conflict of interest between managers (agents) and shareholders (principals) (Jensen and Meckling 1976; Usman, Mulchandani, et al. 2025). Due to the autonomy of independent directors from managerial influence, it is expected that they perform a key role in managerial actions and ensure that they are aligned with the long-term interests of the firm (Salem et al. 2021; Usman, Salem, and Ghazwani 2025). Previous studies highlighted that female directors tend to exhibit strong ethical behaviour and great diligence in oversight compared to male directors (Bilal et al. 2025; Usman, Nwachukwu, and Ezeani 2022). In line with the agency perspective, IFDs are well positioned to prioritise long-term strategic investments like GI and restrain managers who solely focus on short-term performance.

The stakeholder theory suggests that the contractual relationship is not limited to management and shareholders but also includes stakeholders (Gerged 2021). Hence, Tauringana and Chithambo (2015) argued that there is a possibility of conflicting interests among managers and stakeholders as both parties might have diverging opinions regarding resource allocation. Kock et al. (2012) argued that stakeholders tend to show a great preference for GI aspects compared to managers. According to Hill and Jones (1992), firms must align their strategies with stakeholders' expectations to sustain competitive advantage and legitimacy. Prior studies claimed that independent directors, specifically women, are likely to support sustainable practices because they bring diverse perspectives and prioritise ethical and long-term value creation instead of solely on short-term financial returns (García-Sánchez et al. 2021; Javed et al. 2023). Hence, the ethical orientation and independent status of IFD are the key drivers for them to promote eco-friendly practices. Also, firms improve their

corporate reputations, enhance operational efficiency and reduce regulatory risks by integrating GI practices (Amore and Bennedsen 2016).

Furthermore, the social role theory posits that cultural expectations and social norms influence the leadership styles of women in corporate decisions, as they tend to be more caring and socially responsible and share a sense of community than their male counterparts (Eagly and Wood 2012; Nadeem et al. 2020). Hence, women are more inclined to prioritise sustainability initiatives such as GI. Elmagrhi et al. (2019) highlighted that IFDs are likely to operate with greater autonomy, making them less susceptible to the influence of management and allowing them to implement sustainable corporate policies. Additionally, the presence of IFD enhances monitoring mechanisms by fostering transparency and accountability, enabling firms to pursue initiatives like GI (Shen and Liao 2023). In contrast to stakeholder theory, which focuses on external pressures, the social role theory highlights intrinsic behavioural tendencies that drive IFD to promote GI initiatives.

Taking the above theoretical perspectives into consideration, the agency, stakeholder and social role theory posit that IFDs influence GI activities through various complementary pathways. From the agency theory viewpoint, the independence of directors strengthens their capacity to monitor effectively, allowing them to restrain managerial short-term preferences and promote long-term sustainable investments like GI, whereas the notion of stakeholder theory suggests that IFD can increase the attention of the board towards environmental concerns by legitimising the sustainability-oriented strategies and incorporating the broader interests of stakeholders. Furthermore, the social role theory indicates that IFD may greatly emphasise environmental and societal welfare, which can increase the board's responsiveness to GI. However, these pathways could be influenced by other institutional factors like state ownership and market competition. Therefore, it would be interesting to investigate the moderating role of these factors on the association between IFD and GI.

3.2 | Independent Female Directors and Green Innovation

Prior literature claimed that gender diversity on corporate boards enhances boards' decision-making (Boone and Hendriks 2009; Ezeani et al. 2023). Our study focused specifically on IFDs, as female directors often promote a higher standard of transparency, ethical practices and accountability (Al-Najjar and Salama 2022). Also, women are more aware of social responsibility compared to their male counterparts (Bilal et al. 2025; Franke et al. 1997). Similarly, the social role theory supports that women are socially inclined to care about ethical and social outcomes (Eagly and Wood 2012). Previous studies highlighted that women are more likely to adopt greener practices and reduce environmental infringements (Al-Najjar and Salama 2022; Elmagrhi et al. 2019; Liu 2018). Also, García-Sánchez et al. (2021) pointed out that IFDs tend to consider the firm's social responsibilities. In line with the notion of agency theory, studies show that the presence of IFD enables them to use their oversight function to ensure that firms embed sustainable

approaches (Atif et al. 2020; Ullah et al. 2022). Hence, these perspectives suggest that the advisory and monitoring role of IFD enables them to influence the long-term strategic investments of firms like GI.

Recent studies investigated the impact of female directors and board gender diversity in shaping the firms' innovation and environmental activities in emerging economies like China. For instance, Hussain, Gaoliang, et al. (2025) and Wang et al. (2023) focused on the foreign experience of female directors in shaping GI, but they mainly considered this experience and ignored other crucial governance mechanisms, such as IFD. Furthermore, other studies broadly focused on board gender diversity and its association with technological or GI (Chu 2024; Dong et al. 2024). Whereas Naveed et al. (2023) claimed that institutional conditions shape the effectiveness of gender diverse boards in promoting GI, this study differs by moving away from experiential attributes and aggregate gender diversity, shifting the attention to IFD as governance actors.

The literature reported mixed results on the association between gender diversity and environmental performance. For instance, Lestari and Soewarno (2024) and Nadeem et al. (2020) found that female directors enhance the firm's environmental performance and GI. In contrast, Boukattaya et al. (2024) and Mahsina and Agustia (2023) reported that gender diversity tends to reduce GI. Hence, the existing empirical evidence on board gender diversity and GI remains inconclusive. Also, most of the prior literature mainly considered an aggregate measure of the female representation on the board and ignored the independence aspect of female directors. The advisory and monitoring role of IFD makes it particularly relevant to investigate its impact on GI activities among Chinese firms. We expect that IFD will strengthen the relationship with stakeholders and improve interest in social and environmental objectives. Also, IFD may improve the external governance by strengthening disclosure quality, accountability and compliance. Therefore, we propose the following hypothesis:

Hypothesis 1. *Independent female directors are positively and significantly associated with green innovation.*

3.3 | Ownership Structure, Independent Female Directors and Green Innovation

Firms in China are either SOEs or non-SOEs. The SOEs are managed and owned by the state, or they own the majority shares, whereas the individual citizens own and manage non-SOEs (Bilal et al. 2025). Previous studies argued that ownership structure plays a key role in shaping corporate governance and firms' performance (Komal et al. 2021; Wang and Yung 2011). For instance, Goldeng et al. (2008) and Wang and Jiang (2021) pointed out that the government helps SOEs to gain access to wider resources for GI activities. Contrastingly, non-SOEs suffer from administrative or legal discrimination in various aspects such as market access, taxation, financing and more (Bilal et al. 2022).

Additionally, Zhou et al. (2017) found that directors of non-SOEs are less bureaucratic than government-appointed SOEs

directors because their main goal is to maximise profit. Jiang et al. (2020) stated that the Chinese government implemented various regulatory instruments and policies to promote GI among SOEs and strengthen monitoring of their environmental protection behaviour. Hence, the bureaucratic nature of SOEs and their mandate to promote environmental sustainability create an environment where female directors, with their propensity for ethical and long-term decision-making, are likely to advocate for GI. Also, the social role theory posits that women excel in caregiving roles both at home and in professional settings, which translates into a greater capacity to care for the environment (Javed et al. 2023). As SOEs gain support from the government and face fewer financial constraints, IFD is more likely to engage more in GI activities in SOEs compared to those working in non-SOEs.

Additionally, SOEs have preferential access to financial resources and government incentives for GI, which could empower IFD to act more decisively in promoting environmental sustainability (Zhao et al. 2024). Also, Li and Lu (2016) highlighted SOEs' sense of greater social expectations than non-SOEs. We expect this social expectation to play a key role in developing GI. Also, this implies that SOEs face stronger regulatory scrutiny, stakeholder expectations and policy alignment that may amplify the monitoring and governance influence of IFD on GI compared to non-SOEs. Therefore, we expect that the ownership structure of the firm conditions the extent to which IFD may translate their governance role into GI outcomes. Based on the discussion, we propose the following hypothesis:

Hypothesis 2. *Ownership structure moderates the relationship between independent female directors and green innovation.*

3.4 | Market Competition, Female Independent Directors and Green Innovation

According to Nguyen et al. (2023), market competition is the level of direct competition and rivalry among firms operating in the same industry and location, mostly with little differentiation in the products and services offered. It represents an external governance force that may impact the degree of discretion available to IFD in influencing GI decisions. Previous studies pointed out that market competition influences a firm's environmental behaviour, as it affects the resources available to them and the benefits they might gain from the investments (Zou et al. 2015). There is a greater level of structural financial pressure among firms that are operating in fiercely competitive industries, resulting in lower cost strategies (van de Ven and Jeurissen 2005). Also, Bagnoli and Watts (2003) pointed out that market competition threatens the profitability and survival of the firm and reduces its capability of investing in social projects. This is due to the reason that firms devote most of their resources and attention to tackling interfirm competition (Song and Wang 2018). However, firms in lower competitive markets are likely to invest more resources in implementing GI (Tang et al. 2023). Therefore, we expect that firms operating in a higher level of market competition are not likely to provide more resources for GI.

Regarding the presence of female directors on the boards in competitive environments, Nielsen and Huse (2010) claimed that female directors may enable firms to cope with competitors effectively due to their unique perspectives and decision-making. Previous studies suggest that female directors foster creativity, enhance problem-solving and contribute to more comprehensive strategies (Elmagrhi et al. 2019; Li and Li 2020). In line with the agency and stakeholder theory, female directors are known to prioritise long-term goals and ethical considerations, which can strengthen stakeholder relationships and improve the firm's adaptability in dynamic markets (Abbasi et al. 2020). However, previous studies pointed out that there is a direct impact of market competition on the environmental behaviour of the firms, as it affects the resources available to them and the benefits they might gain from the investments (Zou et al. 2015). Our interest in this interaction effect stems from Chen et al. (2018), who found that the positive relation between female board directors' representation and corporate innovation was robust when market competition was deemed to be lower. Similarly, findings by Tang and Li (2024) showed that the relationship between female CEOs and GIs was enhanced when the enterprise operates in a business environment that encounters low competitive rivalry. Because market competition impacts the availability of resources, we expect that the IFDs working in less competitive markets effectively engage in GI. Therefore, we propose the following hypothesis:

Hypothesis 3. *Market competition moderates the relationship between independent female directors and green innovation.*

4 | Methodology

4.1 | Data and Sample

To investigate the association between IFDs on GI, we used a sample of all 'A-share' firms listed on the Shanghai and Shenzhen stock exchanges from 2008 to 2023. Data on corporate governance, financials and firm-level characteristics were obtained from the China Stock Market and Accounting Research (CSMAR) Database, whereas data on GI (measured as green patents) were sourced from the Chinese Research Database Services (CRNDS) Database, a reliable source for patent-related information in China. We start our sample period in 2008 to ensure comparability, as the new accounting standards were fully implemented in 2007, and extend it to 2023 to capture the most up-to-date patterns of firm-level GI. The initial sample consisted of 29,001 firm-year observations. After excluding financial institutions, specially treated (ST) firms and observations with missing data, our final dataset comprises 22,091 firm-year observations. Table 1 reports the distribution of firm-year observations by year.

4.2 | Measurement of Green Innovation

In line with Hussain, Qian, et al. (2025) and Quan et al. (2023), we have measured GI by taking the natural logarithm of the number of green patents (plus one). As mentioned above, the CNRDS database has been used to obtain the green patents data, which is a widely recognised database used in academic research.

TABLE 1 | Distribution of firm-year observations by year (2008–2023).

Year	Observations by year
2008	513
2009	555
2010	741
2011	897
2012	1006
2013	1030
2014	1079
2015	1187
2016	1297
2017	1530
2018	1590
2019	1644
2020	1814
2021	2162
2022	2402
2023	2644
Total	22,091

4.3 | Measurement of IFDs and Moderating Variables

Following prior literature, we measured IFDs as the percentage of IFDs over total directors (Adams and Ferreira 2009; Liao et al. 2019) to examine their association with GI. Li and Li (2020) argued that independent directors reduce information asymmetry as they monitor the executives, protect the investors' interests and are less likely to do so due to internal power dynamics. Our study focuses specifically on IFD because previous studies, including Adams and Ferreira (2009), have claimed that female directors perform their duties more independently and diligently compared to male directors. Also, female directors appear to be more ethically oriented and usually more sensitive towards environmental issues (Javed et al. 2023). Hence, we expect that IFD may play a crucial role in driving GI due to their dual focus on ethical consideration and independence.

We have used two key moderating variables, including ownership structure and market competition. To measure ownership structure, a dummy variable is used where a value of 1 is given if the firm is owned by the state, otherwise 0 (Tan et al. 2022; Wang et al. 2008). Following Quan et al. (2023), market competition is measured by using the Herfindahl Index, which equals the sum of the squared share of each firm's sales to total sales in the same industry. If the value of the Herfindahl Index is higher, it suggests that competition is less.

4.4 | Control Variables

Following Gerged (2021), Bilal et al. (2022) and Li et al. (2023), we included various control variables that might influence the association between IFDs and GI. First, following previous studies, we included board characteristics, including board size (BS), board independence (BI) and board female executives (BFE), to isolate the effect of board monitoring on the relationship between IFD and GI (Ezeani et al. 2024; Lo et al. 2010). We also controlled for board ownership (BO) in line with the work of Cordeiro et al. (2020). Previous studies suggest that CEO gender and CEO duality affect firms' outcomes (Isabel-María; García-Sánchez et al. 2021; Owusu et al. 2022). Therefore, we controlled for the effect of CEO gender (C_GEN) and CEO duality (C_DUAL) on the relationship between IFD and GI.

We isolated the effect of firm-level characteristics, including firm size (FS) (Usman, Ezeani, et al. 2022), cash flow (CF) (Dahlmann et al. 2019), capital intensity (CI) (Quan et al. 2023), research and development (R&D) intensity (R&D_I) (Ren et al. 2023), return on assets (ROA) (Salem et al. 2021) and firm age (FA) (Bilal et al. 2022) as they are important to assess a firm's financial risk and performance. Third, we included the largest shareholders (Top_1) (Cordeiro et al. 2020) and institutional ownership (Inst_Own) (Mahoney and Roberts 2007), as ownership structure plays a key role in the firm's decision-making process. Finally, we controlled for year and industry effects. Hence, we used the following regression model to examine the relationship between IFDs and GI:

$$
\begin{aligned}
GI_{it} = {} & \alpha 0 + \alpha 1\, IFD_{it} + \alpha 2\, BS_{it} + \alpha 3\, BI_{it} + \alpha 4\, BO_{it} + \alpha 5\, BFE_{it} + \alpha 6\, C\_GEN_{it} \\
& + \alpha 7\, C\_DUAL_{it} + \alpha 8 FS_{it} + \alpha 9\, CF_{it} + \alpha 10\, CI_{it} + \alpha 11\, R\&D\_I_{it} + \alpha 12\, LEV_{it} \\
& + \alpha 13\, ROA_{it} + \alpha 14\, FA_{it} + \alpha 15\, Top1_{it} + \alpha 16\, Inst\_Own_{it} + \lambda_t + \gamma_j + \mu_i + \varepsilon_{it}
\end{aligned}
\tag{1}
$$

where GI stands for GI and IFD are the IFDs. The definitions of all the variables are provided in Appendix A. All the study variables are indexed by firm (*i*) and year (*t*). We also examine the moderating impact of market competition and ownership structure between GI and IFD by using the following equations:

$$
\begin{aligned}
GI_{it} = {} & \alpha 0 + \alpha 1\, IFD_{it} + \alpha 2\, MC_{it} + \alpha 3\,(IFD_{it} * MC_{it}) + \alpha 4\, BS_{it} + \alpha 5\, BI_{it} + \alpha 6\, B0_{it} \\
& + \alpha 7\, BFE_{it} + \alpha 8\, C\_GEN_{it} + \alpha 9\, C\_DUAL_{it} + \alpha 10\, FS_{it} + \alpha 11\, CF_{it} \\
& + \alpha 12\, CI_{it} + \alpha 13\, R\&D_{it} + \alpha 14\, LEV_{it} + \alpha 15\, ROA_{it} + \alpha 16\, FA_{it} + \alpha 17\, Top1_{it} \\
& + \alpha 18\, Inst\_Own_{it} + \lambda_t + \gamma_j + \mu_i + \varepsilon_{it}
\end{aligned}
\tag{2}
$$

$$
\begin{aligned}
GI_{it} = {} & \alpha 0 + \alpha 1\, IFD_{it} + \alpha 2\, SOE_{it} + \alpha 3\,(IFD_{it} * SOE_{it}) + \alpha 4\, BS_{it} + \alpha 5\, BI_{it} \\
& + \alpha 6\, B0_{it} + \alpha 7\, BFE_{it} + \alpha 8\, C\_GEN_{it} + \alpha 9\, C\_DUAL_{it} + \alpha 10\, FS_{it} \\
& + \alpha 11\, CF_{it} + \alpha 12\, CI_{it} + \alpha 13\, R\&D_{it} + \alpha 14\, LEV_{it} + \alpha 15\, ROA_{it} + \alpha 16\, FA_{it} \\
& + \alpha 17\, Top1_{it} + \alpha 18\, Inst\_Own_{it} + \lambda_t + \gamma_j + \mu_i + \varepsilon_{it}
\end{aligned}
\tag{3}
$$

5 | Data Analysis and Discussion

5.1 | Descriptive Statistics

Table 2 presents the descriptive statistics of the study variables. The logarithmic transformation of GI shows a mean value of 0.677, ranging from 0 to 4.174, which is lower than the one (0.66) reported by Ren et al. (2021). In line with Jin et al. (2023), on average, 9.5% of IFDs are present in our sample. Regarding control variables, the BS ranges from a minimum of five to a maximum of 14 members. Consistent with China's corporate governance code, the mean value of board independence is approximately 37.4%, indicating that at least one third of board directors must be independent (Lo et al. 2010). On average, the sample represents 17.1% of board ownership and around 22.3% female members on the board. Regarding CEO characteristics, the average CEO gender and duality are 0.741 and 0.340, indicating that 74.1% of CEOs in our sample are male. In terms of firm characteristics, the study sample has an average firm size of 21.973, cash flow of 0.051, capital intensity of 2.259, R&D intensity of 0.057, leverage of 0.386 and return on assets (ROA) of 0.041. Lastly, 37.7% and 41.4% shares are owned by the largest shareholders and institutional investors.

Table 3 presents Pearson's correlation matrix of the study variables, which shows the linear associations among quantitative variables. According to Gujarati (2009), the Pearson coefficients must not exceed 80% to avoid the multicollinearity issue. The highest correlation reported was 0.664 between board ownership (BO) and institutional ownership (Inst_own), confirming that the correlation coefficient is below the conventional threshold and there is no multicollinearity. Also, GI and IFD are positively and significantly associated with each other, indicating that IFD encourages eco-friendly activities. The correlations between other regression variables are largely in line with prior studies, such as Quan et al. (2023).

5.2 | Empirical Results

5.2.1 | Main Results

This section reports the empirical results of Hypothesis 1, which proposes a positive relationship between IFDs and GI. Table 4 reports the regression results linking GI to IFD and a comprehensive set of firms and governance level control variables. In line with Quan et al. (2023), we have adopted a fixed effects regression model to control for time-invariant firm-level characteristics. We employed the Hausman test, and the chi-squared statistic is 6.84, and the corresponding p value is 0.0089. Hence, this result implies that the fixed-effects model is used, as it provides reliable and consistent estimates for our analysis. We find that IFD is positively and significantly associated with GI, implying that IFD promotes environmentally friendly activities. Specifically, the coefficient of IFD is 0.034 and statistically significant at the 1% level.

TABLE 2 | Descriptive statistics.

	Mean	Std. dev.	Min	p25	Median	p75	Max
GI	0.677	0.993	0.000	0.000	0.000	1.099	4.174
IFD	0.095	0.083	0.000	0.000	0.111	0.143	0.286
MC	0.503	0.500	0.000	0.000	1.000	1.000	1.000
SOE	0.262	0.440	0.000	0.000	0.000	1.000	1.000
BS	8.486	1.603	5.000	7.000	9.000	9.000	14.000
BI	0.374	0.052	0.333	0.333	0.333	0.429	0.571
BO	0.171	0.214	0.000	0.000	0.043	0.333	0.686
BFE	0.223	0.106	0.000	0.143	0.211	0.294	0.500
C_GEN	0.741	0.438	0.000	0.000	1.000	1.000	1.000
C_DUAL	0.340	0.474	0.000	0.000	0.000	1.000	1.000
FS	21.973	1.170	19.926	21.122	21.801	22.636	25.712
CF	0.051	0.067	−0.146	0.012	0.050	0.090	0.228
CI	2.259	1.533	0.466	1.329	1.843	2.648	9.855
R&D_I	0.057	0.047	0.002	0.021	0.043	0.078	0.219
LEV	0.386	0.196	0.054	0.225	0.376	0.531	0.859
ROA	0.041	0.059	−0.184	0.015	0.041	0.072	0.187
FA	1.876	0.957	0.000	1.099	1.946	2.639	3.332
Top1	0.337	0.141	0.090	0.228	0.317	0.429	0.726
Inst_Own	0.414	0.250	0.005	0.193	0.422	0.619	0.903

Note: Definitions of the variables are provided in Appendix A.

TABLE 3 | Pearson correlation matrix.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1) GI	1.000																
(2) IFD	0.054***	1.000															
(3) BS	0.086**	−0.002*	1.000														
(4) BI	0.030*	0.084***	−0.513***	1.000													
(5) BO	−0.114**	−0.105*	−0.224***	0.089***	1.000												
(6) BFE	−0.071***	−0.125*	−0.199***	0.085*	0.179**	1.000											
(7) C_GEN	−0.018*	0.121	0.118*	−0.063***	−0.042***	−0.181*	1.000										
(8) C_DUAL	−0.035***	−0.071*	−0.195	0.108**	0.235***	0.156**	−0.013*	1.000									
(9) FS	0.449***	0.098***	0.266*	−0.023***	−0.332***	−0.160*	−0.014	−0.165*	1.000								
(10) CF	0.014*	0.005	0.027*	−0.009	0.003	0.035***	−0.018***	−0.012	0.090**	1.000							
(11) CI	−0.023***	−0.026	−0.003	0.015**	0.127*	−0.001	0.006	0.074*	−0.016*	0.105***	1.000						
(12) R&D_I	−0.006	−0.035	−0.037	0.023***	0.009	0.076	−0.055	0.031***	−0.019	−0.199***	−0.014**	1.000					
(13) LEV	0.227***	0.090*	0.184*	−0.030***	−0.321**	−0.175	0.032***	−0.148***	0.478	−0.143	0.002	−0.137*	1.000				
(14) ROA	−0.028***	−0.028***	−0.004	−0.022*	0.177*	0.035	0.031**	0.046	−0.005	0.448***	0.123***	−0.237***	−0.389***	1.000			
(15) FA	0.144**	0.118*	0.164***	−0.032	−0.532**	−0.122*	0.022	−0.250*	0.442***	0.014	−0.231*	−0.036***	0.411**	−0.237***	1.000		
(16) Top1	0.022	−0.002	−0.009	0.041***	−0.024***	−0.026***	0.022	−0.029*	0.113*	0.105***	0.049***	−0.098	−0.003	0.155***	−0.129***	1.000	
(17) Inst_Own	0.143***	0.055*	0.227***	−0.080**	−0.644***	−0.153***	0.046***	−0.175*	0.370***	0.115***	0.029	−0.054***	0.160***	0.107***	0.135***	0.450***	1.000

Note: ***, **, and * present significance at 1%, 5% and 10% levels. Definitions of the variables are provided in Appendix A.

TABLE 4 | The association between independent female directors (IFD) and green innovation (GI).

Variables	GI
IFD	0.034***
	(1.965)
BS	0.013**
	(1.798)
BI	0.297*
	(1.717)
BO	−0.219***
	(−3.779)
BFE	−0.024
	(−1.167)
C_GEN	0.012
	(0.763)
C_DUAL	0.013
	(0.847)
FS	0.222***
	(15.495)
CF	0.106**
	(1.344)
CI	−0.157
	(−1.153)
R&D_I	0.003***
	(3.082)
LEV	−0.092
	(−1.551)
ROA	0.285**
	(2.372)
FA	−0.015
	(−1.439)
Top_1	−0.365**
	(−2.038)
Inst_Own	0.032*
	(1.031)
Constant	−4.700***
	(−16.046)
Observations	20,922
R squared	0.251
Firm effect	Yes
Year effect	Yes

Note: This table presents the findings using firm fixed effects regression. *t* values are in parentheses. Standard errors are clustered at the firm level. Definitions of the variables are provided in Appendix A.

*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

TABLE 5 | Moderating effect of market competition.

Variables	Low market competition	High market competition
IFD	0.059**	0.023
	(2.280)	(0.916)
MC	1.429***	1.400
	(2.893)	(3.345)
IFD*MC	0.687***	0.545
	(2.151)	(2.250)
BS	0.043***	0.022**
	(3.716)	(2.172)
BI	0.558**	0.714***
	(2.185)	(2.944)
BO	0.355***	0.338***
	(4.717)	(4.630)
BFE	−0.021	−0.076**
	(−0.738)	(−2.508)
C_GEN	−0.006	0.027
	(−0.287)	(1.113)
C_DUAL	−0.005	0.027
	(−0.219)	(1.159)
BS	0.016***	0.014***
	(4.343)	(3.341)
CF	−0.169	0.045
	(−1.522)	(0.349)
CI	0.012	0.362
	(0.062)	(1.619)
R&D_I	0.000***	0.000***
	(3.521)	(6.345)
LEV	0.803***	0.709***
	(7.963)	(8.176)
ROA	0.664***	0.378**
	(3.701)	(2.483)
FA	0.084***	0.062***
	(5.789)	(4.251)
Top_1	−0.446*	−1.235***
	(−1.737)	(−4.691)
Inst_Own	0.157***	0.108**
	(3.789)	(1.973)
Constant	−1.078***	−0.918***
	(−6.143)	(−5.076)
Observations	10,595	10,327

(Continues)

TABLE 5 | (Continued)

Variables	Low market competition	High market competition
R squared	0.164	0.172
Firm FE	Yes	Yes
Year FE	Yes	Yes

Note: This table presents the findings using firm fixed effects regression. *t* values are in parentheses. Standard errors are clustered at the firm level. Definitions of the variables are provided in Appendix A.

*p < 0.1.
**p < 0.05.
***p < 0.01.

Our result is consistent with the prior studies, as it confirms that IFD act ethically and make decisions that are eco-friendly compared to their male counterparts, promoting GI (Franke et al. 1997; García-Sánchez et al. 2021). This finding is similar to Lestari and Soewarno (2023), which shows that the presence of a female director boosts GI activities. This finding also supports the notion of stakeholder theory, as IFDs are likely to align board decisions with stakeholder interests, particularly in sustainability (Hill and Jones 1992). Also, the results suggest that IFD adopt long-term perspectives in decision-making, aligning with stakeholder theory, which prioritises ethical business practices over short-term maximisation (Squires and Elnahla 2020). Therefore, IFD's heightened sensitivity to stakeholder concerns drives them to advocate for GI activities that benefit the environment. Overall, our results indicate that the role of independent directors is improved when there is a greater proportion of IFD (Srinidhi et al. 2020). In line with the perspectives of agency theory, the result suggests that the IFD enables them to effectively monitor management and support firms' long-term GI strategies (Salem et al. 2021).

Regarding control variables, the positive relationship between BS and GI is consistent with prior studies (Atif et al. 2020). This finding is premised on the argument that larger boards have diverse skills and expertise that improve their overall decision-making process. Also, we find that firm size (FS), cash flows (CF) and ROA are positively and significantly related to GI, highlighting that larger firms and financially strong firms have more resources to invest in GI activities (Atif et al. 2020; Dahlmann et al. 2019). The presence of female executives on the board positively influences GI as female directors tend to be more ethical and are likely to engage in decisions which do not harm the environment (Liao et al. 2019).

Furthermore, our results show that institutional ownership (Inst_own) shares a positive and significant relationship with GI (Table 4). In line with Mahoney and Roberts (2007), the results indicate that the more the number of shareholders a firm has, the better its social and environmental performance. Furthermore, García-Sánchez et al. (2020) claimed that Inst_own plays a significant role in shaping a firm's GI activities by actively engaging in corporate decision-making related to funding and managing innovation initiatives. Also, institutional investors recognise that GI activities could deliver competitive advantages and

TABLE 6 | Moderating effect of ownership structure.

Variables	Private-owned enterprises (non-SOE)	State-owned enterprises (SOE)
IFD	0.020	0.044**
	(0.510)	(2.119)
SOE	0.650	−0.025***
	(2.790)	(−2.985)
IFD*SOE	0.368	0.231***
	(4.985)	(3.890)
BS	0.042***	0.015
	(2.920)	(1.569)
BI	1.030***	0.186
	(2.913)	(0.867)
BO	0.550***	0.211***
	(3.697)	(3.966)
BFE	0.013	−0.053***
	(0.178)	(−2.613)
C_GEN	0.020	0.012
	(0.437)	(0.685)
C_DUAL	−0.025	0.024
	(−0.411)	(1.483)
BS	0.010	0.013***
	(1.087)	(4.313)
CF	0.001	−0.044
	(0.005)	(−0.458)
CI	0.059	0.219
	(0.156)	(1.339)
R&D_I	0.000***	0.000***
	(3.581)	(5.679)
LEV	0.866***	0.643***
	(5.972)	(8.282)
ROA	0.543*	0.407***
	(1.796)	(3.262)
FA	0.062**	0.070***
	(2.219)	(6.074)
Top_1	−0.574*	−0.748***
	(−1.734)	(−3.062)
Inst_Own	0.455***	0.061*
	(3.593)	(1.761)

(Continues)

TABLE 6 | (Continued)

Variables	Private-owned enterprises (non-SOE)	State-owned enterprises (SOE)
Constant	−1.525***	−0.569***
	(−5.866)	(−3.600)
Observations	15,108	5440
R squared	0.198	0.128
Firm FE	Yes	Yes
Year FE	Yes	Yes

Note: This table presents the findings using firm fixed effects regression. *t* values are in parentheses. Standard errors are clustered at the firm level. Definitions of the variables are provided in Appendix A.
*p < 0.1.
**p < 0.05.
***p < 0.01.

enhance a firm's long-term value and are likely to encourage GI through active monitoring (Luong et al. 2017). Another finding of this study is that firms with more R&D intensity are committed to GI.

5.2.2 | Moderating Effects of Market Competition and Ownership Structure

This subsection evaluates Hypothesis 2, which proposes that market competition (MC) moderates the relationship between IFDs and GI. Table 5 presents the main findings on the moderating effect of MC. The results indicate that the coefficient of the interaction term (IFD*MC) is 0.687 and statistically significant at the 1% level. This suggests a positive association between IFD and GI strengthens when MC is low. This is consistent with Fernández-Kranz and Santaló (2010), which reports that in high competition, top managers pay more attention to interfirm competition. Also, high MC tends to reduce the profit margin of firms and ultimately decrease the ability of the firm to commit to environmental investments. Hence, low MC provides IFD with an opportunity to focus on stakeholder demands related to eco-friendly innovations that enhance corporate legitimacy in the long run (García-Sánchez et al. 2021). This aligns with stakeholder theory, which focuses on the importance of long-term value creation over immediate financial performance. Our finding is supported by Javeed et al. (2023) who argued that firms' engagement in GI rests on the level of MC. In line with Shen and Liao (2023), our results indicate that IFD, being naturally inclined to focus on ethical decision-making and the welfare of stakeholders, is better able to push for GI in less competitive environments where resources are readily available. Also, we employed a fixed effects regression model, and the results remain consistent.

To evaluate Hypothesis 3, we analysed the impact of ownership structure on the association between IFD and GI because Nadeem et al. (2020) acknowledged that innovation intensity varies between SOEs and non-SOEs. In line with Bilal et al. (2022), we used dummy variables (SOE) to proxy ownership structure, where a

TABLE 7 | Additional analysis (polluting vs. nonpolluting industries).

Variable	Polluting industries	Nonpolluting industries
IFD	0.046***	0.023
	(1.971)	(0.781)
BS	0.025***	0.057***
	(2.663)	(3.858)
BI	0.597***	0.774**
	(2.823)	(2.119)
BO	0.358***	0.255**
	(5.285)	(2.579)
BFE	−0.044*	−0.041
	(−1.698)	(−1.045)
C_GEN	0.023	−0.024
	(1.168)	(−0.766)
C_DUAL	0.038*	−0.080***
	(1.877)	(−3.725)
BS	0.021***	−0.001
	(5.807)	(−0.172)
CF	−0.171*	0.227
	(−1.648)	(1.601)
CI	0.210	0.033
	(1.012)	(0.163)
R&D_I	0.000***	0.000**
	(6.590)	(2.320)
LEV	0.872***	0.379***
	(9.571)	(4.031)
ROA	0.489***	0.648***
	(3.332)	(3.572)
FA	0.096***	0.028*
	(7.357)	(1.763)
Top_1	−1.147***	−0.266
	(−4.490)	(−1.039)
Inst_Own	0.140***	0.210***
	(3.423)	(3.617)
_cons	−1.024***	−0.983***
	(−6.487)	(−4.059)
Observations	5826	15,096
R squared	0.182	0.143
Firm FE	Yes	Yes
Year FE	Yes	Yes

Note: This table presents the findings using firm fixed effects regression. *t* values are in parentheses. Standard errors are clustered at the firm level. Definitions of the variables are provided in Appendix A.
*p < 0.1.
**p < 0.05.
***p < 0.01.

TABLE 8 | Endogeneity concerns.

Variable	Additional control variables	First Stage 2 SLS	Second Stage 2SLS
IFD	0.034***	1.137***	1.567***
	(1.981)	(5.271)	(4.135)
BS	0.013*	−0.002	0.002
	(1.814)	(−0.441)	(0.203)
BI	0.291*	1.071***	−1.136***
	(1.688)	(5.480)	(−2.871)
BO	−0.210***	−0.288***	0.047
	(−3.619)	(−7.129)	(0.779)
BFE	−0.023	−0.107***	−0.117***
	(−1.116)	(−4.853)	(−2.743)
C_GEN	0.011	0.128***	−0.083***
	(0.703)	(4.684)	(−3.207)
C_DUAL	0.013	−0.022	0.065**
	(0.851)	(−1.591)	(2.540)
BS	0.223***	0.254***	0.172***
	(15.510)	(33.172)	(6.148)
CF	−0.109	−0.286***	0.130
	(−1.377)	(−3.234)	(1.384)
C_I	−0.156	−0.496***	−0.073
	(−1.142)	(−4.346)	(−0.469)
R&D_I	0.000***	0.000***	0.000***
	(3.067)	(5.724)	(3.310)
LEV	−0.107*	−0.013	−0.071
	(−1.803)	(−0.310)	(−0.861)
ROA	−0.318***	−0.471***	−0.245*
	(−2.597)	(−4.147)	(−1.780)
FA	−0.015	−0.005	−0.002
	(−1.446)	(−0.552)	(−0.093)
Top_1	−0.372**	−0.318*	−0.389*
	(−2.071)	(−1.919)	(−1.908)
Inst_Own	−0.031	−0.041*	0.107
	(−1.026)	(−1.658)	(1.094)
Ind-Avg-IFD	−0.010	—	—
	(−0.218)		
Ind-Avg-Growth	−0.071	—	—
	(−1.263)		
Ind-Avg-Size	1.228***	—	—
	(3.134)		

(Continues)

TABLE 8 | (Continued)

Variable	Additional control variables	First Stage 2 SLS	Second Stage 2SLS
Ind-Avg-ROA	1.015***	—	—
	(4.592)		
IV	—	1.861***	2.022***
		(8.542)	(5.451)
Constant	−3.607***	−5.055***	−5.055***
	(−3.032)	(−34.772)	(−33.972)
Observations	20,922	20,922	20,922
R squared	0.252	0.378	0.378
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes

Note: t values are in parentheses. Definitions of the variables are provided in Appendix A.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

value of 1 is given if the firm is owned by the state, otherwise 0. Table 6 reports the results for the moderating effect of state ownership (SOE). The interaction term (IFD*SOE) has a coefficient of 0.231, which is positive and statistically significant at the 1% level in Column 2. This finding suggests that the positive effect of IFDs on GI is more pronounced in SOEs. The result confirms that the relationship between IFD and GI is more pronounced in SOEs in China (Wang and Jiang 2021) compared to non-SOEs. In line with Li et al. (2015), our study pointed out that SOEs are deemed as government delegates and bear greater responsibility for meeting social expectations than non-SOEs. Hence, they would play an exemplary role in promoting GI activities.

In line with the study findings, Wang and Jiang (2021) and Zhao et al. (2024) claimed that directors in SOEs tend to act as bureaucrats more than their counterparts in non-SOEs, who prioritise profit maximisation. Also, Zhou et al. (2017) argued that privately owned firms tend to focus less on GI because they operate in highly competitive markets. Hence, SOE managers face greater pressure to meet government expectations regarding GI activities. In line with the perspective of stakeholder and social role theory, the result highlighted that the socially responsible orientation of IFD is reinforced by the government's emphasis on GI. Hence, the propensity to prioritise stakeholder welfare over financial outcomes aligns with the strategic goals of SOEs, whereas the profit-driven culture of non-SOEs may dilute IFD's ability to effect change (Lestari and Soewarno 2024).

Similar to Zhong and Peng (2022), our result confirms that the introduction of the New Environmental Protection Law (NEPL) in 2014 has a pronounced impact on promoting GI in SOEs compared to non-SOEs. Zhao et al. (2024) claimed that SOEs, as government-owned organisations, benefit from privileged access to policy information, financial support from the government and priority access to bank loans. Therefore, such advantages help reduce financial barriers to environmental investments and lower the risks tied to pursuing GI activities. Hence, SOEs play a crucial role as a key institutional determinant in emerging economies like China, with the government exerting significant influence over industrial development and economic activities (Yu et al. 2021). This ownership structure highlights the level of direct government control and interference in a firm's business operations (Zhou et al. 2017).

5.2.3 | Additional Analysis

To further investigate the role of IFD in GI, we further divided the sample into two subsamples: polluting and nonpolluting industries. The reason is that heavily polluting industries contribute massively towards overall environmental pollution. Following Xiao and Wang (2020), we used a dummy variable where a value of 1 is given if the industry is classified as polluting, otherwise 0. By using the guidelines for the Industry Classification of Listed Companies (2001) published by the Securities Supervision Commission, the heavily polluting industries are classified into eight categories including biomedical, food and beverage, garment and fur, hydropower and gas, mining, metal and nonmetal, paper printing, petrochemical and plastic industries.

The results in Table 7 below account that the presence of IFD in polluting industries is positively and significantly associated with GI, confirming that IFD promotes GI activities among firms that are operating in polluting industries. For instance, in Column 1, the coefficient of IFD is 0.046 and statistically significant at the 1% level. These results suggest that IFD has a significant positive impact on GI, particularly in polluting industries. In line with Le Loarne-Lemaire et al. (2021) and Javed et al. (2023), our results imply that in sectors with high environmental risks, IFD plays a key role in driving GI by advocating for long-term eco-friendly strategies and strict environmental policies. Also, it highlights the influence of IFD to enhance corporate reputation, improve regulatory compliance and attract socially responsible investors (Dou and Gao 2022). Hence, our results point out that policymakers must consider incentives for promoting gender diversity on boards, specifically in polluting industries, where IFD can promote GI.

Furthermore, the significant and positive impact of IFD in polluting industries suggests that the firms operating in environmentally sensitive sections face increased regulatory scrutiny, stakeholder pressure and reputational risks (Guo et al. 2023). Hence, GI not only serves as a key innovation strategy for firms but also acts as a legitimacy-building mechanism and mitigates risks. Therefore, IFDs, who tend to be more sensitive towards social and ethical concerns, are more impactful in steering companies towards GI when the environmental stakes are high. By investigating this industry distinction explication, this paper extends prior GI and governance research that overlooks how the effectiveness of board composition could be shaped by environmental risks.

5.2.4 | Endogeneity and Robustness

Although we controlled for many factors earlier documented in previous literature that affected GI and used fixed-effect regression models, however, our findings may be subject to endogeneity owing to some omitted variables that may affect the firm's GI and IFD association. To address these concerns, we added some more control variables in our model, including the industry average of ROA (Ind-Avg-ROA), firm size (Ind-Avg-Size), firm growth (Ind-Avg-Growth) and leverage (Ind-Avg-Lev) (Chen et al. 2019; Larcker and Rusticus 2010; Quan et al. 2023). The definitions of these variables are presented in Appendix A. The inclusion of these extra control variables helps to mitigate the omitted variables correlation that may affect the relationship between IFD and firms' GI. Table 8 presents the findings after re-estimating the regression model with the inclusion of additional control variables. In Column 1, IFD is positively and significantly associated with GI (0.034 at the 1% level), like our main finding. Hence, our result remains robust after the inclusion of the additional control variables.

Following Atif et al. (2021), we also used a two-stage least squares (2SLS) approach to address any potential endogeneity concerns. In the first stage, we used the male-to-female ratio in the firm's headquarters city as an instrumental variable (IV) for the presence of IFDs. The theoretical basis for this choice is that the presence of female directors in the firm is likely correlated with local gender composition but reasonably exogenous to the firm's GI, which satisfied the relevance and exclusion criteria for a valid instrument. In the second stage, we use the predicted values of IFD obtained from the first stage to examine their impact on GI, in the second stage. The findings presented in Table 8 (Columns 2 and 3) indicate that IFD remains positively and significantly related to GI. The results confirm that our main results are robust after addressing endogeneity concerns.

Furthermore, this study applied the propensity score matching (PSM) technique to address potential selection bias (Hussain, Qian, et al. 2025). Firms with IFDs were matched to comparable firms without IFD using a calliper of 0.03, resulting in a matched sample of 1250 firms. The results, presented in Table 9 indicate that the coefficient of IFD is 0.028, confirming that the positive impact of IFD on GI is not driven by observable differences between treated and control firms. To overcome some limitations of PSM, such as residual covariate imbalance and sensitivity to matching algorithms, we additionally employed the entropy

TABLE 9 | Propensity score matching (PSM) and entropy balancing (EB).

Variable	PSM	EB
IFD	0.028*	0.034*
	(1.691)	(1.758)
BS	0.013*	0.014*
	(1.708)	(1.915)
BI	0.213	0.127
	(1.182)	(0.698)
BO	−0.202***	−0.238***
	(−3.521)	(−3.446)
BFE	−0.027	−0.024
	(−1.298)	(−1.002)
C_GEN	0.004	0.016
	(0.239)	(0.817)
C_DUAL	0.018	0.017
	(1.202)	(0.940)
BS	0.213***	0.230***
	(14.927)	(13.945)
CF	−0.127	−0.178*
	(−1.597)	(−1.896)
C_I	−0.182	−0.149
	(−1.367)	(−0.842)
R&D_I	0.000***	0.000***
	(3.210)	(3.265)
LEV	−0.075	−0.119*
	(−1.274)	(−1.698)
ROA	−0.220*	−0.316**
	(−1.821)	(−2.188)
FA	−0.015	−0.008
	(−1.464)	(−0.691)
Top_1	−0.410**	−0.435**
	(−2.331)	(−2.068)
Inst_Own	−0.018	−0.024
	(−0.579)	(−0.633)
_cons	−4.478***	−4.826***
	(−15.091)	(−14.564)
Observations	18,413	20,922
R squared	0.241	0.266
Firm FE	Yes	Yes
Year FE	Yes	Yes

Note: t values are in parentheses. Definitions of the variables are provided in Appendix A.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

TABLE 10 | Alternative measure of independent female directors (IFD) and green innovation (GI).

Variable	Female executive directors	Female independent directors
IFD_Alternative (BFE)	0.071	0.503**
	(0.818)	(1.293)
BS	−0.007	−0.026
	(−0.917)	(−0.489)
BI	0.017	0.273
	(0.089)	(0.206)
BO	−0.026	−0.158
	(−0.503)	(−0.536)
BFE	—	−0.015
		(−0.146)
C_GEN	0.017	0.053
	(1.075)	(0.512)
C_DUAL	0.020	0.108
	(1.274)	(1.131)
BS	0.162***	0.674***
	(8.125)	(5.089)
CF	0.076	0.141
	(1.209)	(0.430)
C_I	0.068	0.390
	(0.664)	(0.681)
R&D_I	0.000***	0.000***
	(2.964)	(2.921)
LEV	0.019	−0.251
	(0.351)	(−0.859)
ROA	−0.150	−1.307***
	(−1.589)	(−2.726)
FA	−0.098***	−0.574***
	(−5.606)	(−5.068)
Top_1	0.024	0.564
	(0.191)	(0.756)
Inst_Own	−0.005	0.132
	(−0.094)	(0.381)
_cons	−3.104***	−12.954***
	(−7.373)	(−4.614)
Observations	20,922	20,922
R squared	0.659	0.668

(Continues)

TABLE 10 | (Continued)

Variable	Female executive directors	Female independent directors
Firm FE	Yes	Yes
Year FE	Yes	Yes

Note: This table presents the findings using firm fixed effects regression. *t* values are in parentheses. Standard errors are clustered at the firm level. Definitions of the variables are provided in Appendix A.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

balancing (EB) method. EB ensures an exact balance of covariates between treated and control groups by reweighting the sample, providing a more robust and unbiased estimate of treatment effects. As shown in Table 9 Column 2, the coefficient of IFD is 0.034, further confirming that IFD positively enhances GI.

Lastly, we employed alternative measurements of IFDs to check the robustness of our findings. First, we used the number of executive female directors as a proxy. The results, presented in Table 10, show that the coefficient of executive female directors is 0.071; the impact is positive but statistically insignificant, suggesting that executive female directors alone may not fully capture the influence of IFDs on GI. In Column 2, we used an alternative measure defined as the percentage of female independent directors relative to executive female directors. The results suggest that the proportion of IFD relative to executives has a stronger positive association with GI than executive female directors alone, although the effect may vary when controlling for unobserved firm-level heterogeneity.

6 | Conclusion

Our study examined the association between IFDs and GI among Chinese-listed firms. We also investigated whether ownership structure and market competition moderate the relationship between IFD and GI. This paper contributes to the literature as it focuses on the role of IFD in promoting GI instead of considering aggregate measures of board gender diversity. We found a positive relationship between IFD and GI, implying that IFDs are more likely to engage in eco-friendly activities. Hence, this study highlights the crucial role of governance mechanisms like IFD in shaping the GI strategies of the firms. Furthermore, the findings suggest that ownership structure and market competition moderate the association between IFD and GI. Particularly, we found that the relationship between IFD and GI is more pronounced in SOEs and weakens when market competition is high, indicating that the impact of IFD on GI relies on institutional and market conditions. Using an additional analysis, we show that IFD promotes GI activities in polluting industries compared to nonpolluting industries. We also show that our result is robust to various econometric approaches and endogeneity tests.

Given China's unique governance system and its pivotal role in global environmental efforts, this study offers valuable insights into the role of IFD in promoting GI. Our study has several implications for governance regulators and environmental

policymakers, especially in developing economies. Our novel results support policies encouraging greater IFD representation on corporate boards. Therefore, policymakers could consider incentives or quotas to promote gender diversity. Also, our findings imply that there is a need for incentivising privately owned enterprises and firms in highly competitive environments to engage in GI. The Chinese government can offer tangible incentives such as tax credits for GI activities.

In terms of policy implications, the findings suggest that regulators need to promote the appointment of IFD, specifically in environmentally sensitive industries. Furthermore, policymakers may align disclosure requirements and environmental incentives to enhance the effectiveness of IFD in promoting GI. From a managerial viewpoint, our results highlight that firms managed by the state (SOE) and operating in pollution industries benefit from empowering IFD through greater board involvement in innovation planning and sustainability committees. Such an initiative can help firms balance the competitive pressures and advance GI objectives.

Despite the novelty, this study has several limitations. First, we have used a patent-based measure for GI that captures formal innovation outputs; however, it may not reflect nonpatent or informal environmental initiatives. Second, the analysis controls for firm, year and industry fixed effects, and various robustness checks are included; there is still a possibility of unobserved factors influencing the association between IFD and GI. Third, we acknowledge that the data are limited to those of Chinese firms, which may limit the generalisability of the study findings to other settings. Therefore, we recommend that future studies include a larger sample across several developing and developed countries to examine the impact of country-level factors on the relationship between IFD and GI. Also, future studies can examine the nationality of the IFD to see whether firms with foreign IFD are more likely to engage in GI than Chinese national IFD members.

Conflicts of Interest

The authors declare no conflicts of interest.

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Appendix

Variable	Definition
Independent variables	
Green innovation (GI)	We take the natural logarithm of the number of green patents by adding one
Dependent variables	
Independent female directors (IFD)	The percentage of female independent directors among the total directors of boards.
Moderating variables	
Market competition (MC)	Using the Herfindahl index, we measured MC as the sum of the squared share of each firm's sales to total sales in the same industry (four-digit industry code)
Ownership structure (SOE)	A dummy variable where a value of 1 is given if a firm is a state-owned enterprise, otherwise 0.
Control variables	
Board size (BS)	It represents the number of directors serving on the board
Board independent (BI)	Measured as dividing independent directors by the total directors
Board ownership (B-Own)	We divided the number of shares held by total directors by the total outstanding shares of the firm.
Board female executives (BFE)	The percentage of female executives among the total number of executives
CEO gender (C_GEN)	We take the value 1 if the CEO is male, otherwise 0
CEO duality (C_DUAL)	A dummy variable, 1 If the CEO also holds the position of chairman and zero otherwise
Firm size (FS)	We take the natural logarithm of total assets
Cash flow (CF)	We take the natural logarithm of cash flow
Capital intensity (CI)	We take the natural logarithm of the ratio of PPE to total assets
R&D intensity (R&D_I)	The ratio of research and development expenses to total assets
Leverage (LEV)	Total debt divided by total assets
Return of assets (ROA)	Calculated by dividing the net profit of the firm during a year by total assets of the firm
Firm age (FA)	We take the natural logarithm of the firm since listed on the stock exchange.
Top_1	The percentage of shares owned by the largest shareholders

Variable	Definition
Institutional ownership (Inst Own)	The percentage of shares owned by institutional investors
Ind-Avg-Growth	The industry average of sales growth
Ind-Avg-Lev	The industry average of leverage
Ind-Avg-ROA	The industry average of return on assets (ROA)
Ind-Avg-Size	The industry average of size
Ind-Avg-IFD	The industry average of appointing females as independent directors