Original Article

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Ekonomikalia
Journal of Economics

Vol. 4, No. 1, 2026

Board Gender Diversity as a Conditional Governance Resource: Evidence from Environmental Innovation in China's Low-Carbon Transition

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Article History

Received 26 January 2026
Revised 2 April 2026
Accepted 6 April 2026
Available Online 27 April 2026

Keywords:
Board gender diversity
Environmental innovation
Low-carbon transition
Corporate governance
Ownership structure

Abstract

As firms face increasing pressure to support the transition toward a low-carbon economy, corporate governance has emerged as a critical mechanism shaping environmental innovation. This study examines whether and under what conditions board gender diversity contributes to environmental innovation in China's listed firms. Drawing on upper echelon theory and the resource-based view, we argue that gender-diverse boards enhance cognitive diversity and stakeholder orientation, thereby strengthening firms' capacity to pursue sustainability-oriented innovation. Using panel data from Chinese A-share listed companies over the period 2014-2023, the results show that board gender diversity is positively associated with environmental innovation, measured by green patent output. However, this relationship is not uniform across institutional contexts. The positive effect is significantly stronger in non-state-owned enterprises than in state-owned enterprises, suggesting that organizational flexibility and market-oriented governance conditions influence whether diversity can be effectively translated into low-carbon outcomes. These findings contribute to the literature by demonstrating that board diversity operates as a conditional governance resource rather than a universally effective mechanism. The study also offers implications for policymakers and firms seeking to align governance reforms with low-carbon transition objectives in emerging economies.

1. Introduction

Over the past decades, the green and low-carbon transition has emerged as an important aspect for sustainable development, especially for firms to face environmental challenges while supporting economic growth [1, 2]. It is particularly pertinent in emerging economies like China, where fast-rising industrialization has resulted in a vast amount of environmental degradation [3]. Therefore, the pressure has been put on corporations to adopt business practices that reflect sustainability goals between profitability and ecological responsibility [4]. Corporate governance acts as a driving force and may reinforce the sustainability within the firms [5]. This indicates that boards of directors, as key decision bodies, could play a crucial role in determining the critical strategies that corporations take up in terms of environmental initiatives [6]. China's commitment to

green innovation is clearly articulated in national policy directives, which link carbon reduction to the broader goal of transitioning to a low-carbon economy [2, 7].

However, policy ambition does not always translate into uniform societal and organizational commitment, as climate and low-carbon goals can feel psychologically distant across time and space, weakening perceived urgency and support [8]. This imperative stems from the country's industrial legacy, which has positioned it among the world's largest carbon emitters [9]. Achieving these ambitious sustainability targets requires not only technological advancement but also strategic transformation within corporate practices. In this context, corporate governance structures play a pivotal role in determining how firms engage with environmental innovation and align with national climate objectives.

In the context of emerging markets, boardroom gender diversity has emerged as a key governance factor capable of accelerating the shift toward sustainable corporate strategies. As companies navigate the transition to low-carbon, stakeholder-driven models, gender-diverse boards contribute to this transformation by embedding broader perspectives and values into strategic decision-making. Existing research has shown that gender diversity in the boardroom enhances corporate social responsibility (CSR) and environmental performance [10], and fosters collaborative decision-making that supports sustainability [11, 12]. While most of this evidence comes from Western contexts, the effects of gender diversity on environmental innovation, which serves as a core driver of low-carbon transition, remain underexplored in China, where governance is shaped by state ownership and Confucian cultural norms [13, 14].

This study addresses this issue by examining how board gender diversity, alongside firm-level factors such as size and profitability, influences green innovation outcomes in Chinese listed firms. By highlighting the "green power" of gender-diverse boardrooms, this research aims to contribute to understanding how inclusive governance structures drive sustainable transformation in emerging markets.

Despite growing scholarly interest in board diversity and sustainability, significant research gaps remain, especially within emerging market contexts such as China [15]. While global studies often report a positive relationship between board gender diversity and innovation or sustainability outcomes, limited attention has been given to how this relationship unfolds within China's distinct cultural and institutional environment, which may moderate or even suppress such effects [16]. Much of the existing research in the Chinese context has focused either on the impact of environmental regulation on innovation or on how board diversity influences financial performance, rather than specifically examining its role in driving environmental innovation [17]. Moreover, few studies apply Upper Echelons Theory (UET) [18], which links organizational outcomes to the characteristics of top executives, to explore this relationship in Chinese firms.

Likewise, the Resource-Based View (RBV) [19], which conceptualizes diversity as a valuable, rare, and inimitable resource, has been underutilized in this domain. The intersection of board composition and the firm's dynamic capabilities for green innovation remains empirically underexplored. While Yue et al. [20] touch on governance structures like state ownership and political connections, they fall short of examining their effects on the influence of board diversity on environmental innovation. Recent evidence also suggests that low-carbon goals may be perceived as temporally or spatially distant, shaping how stakeholders interpret and prioritize transition policies, an important contextual layer rarely integrated into board-governance studies of green innovation [8]. Additionally, there is little dynamic insight into how changes in board composition influence green innovation over time [15], nor how mechanisms such as stakeholder engagement and strategic decision-making mediate this relationship [10].

This study aims to fill these gaps by investigating the "green power" of the boardroom, empirically examining how gender-diverse boards drive environmental innovation in Chinese listed firms. By contextualizing the analysis within China's institutional and cultural landscape, the study contributes both theoretically, by extending UET and RBV into the ESG domain, and practically, by offering insights for policymakers and business leaders on aligning board diversity with sustainability transformation. The remainder of this study is organized as follows. Section 2 reviews the relevant literature and theoretical underpinnings. Section 3 presents the methodology and data. Section 4 reports the empirical findings, followed by a discussion in Section 5. The study concludes with final reflections and recommendations in Section 6.

2. Literature Review and Hypothesis Development

2.1. Corporate Governance and Sustainability in Emerging Markets

Corporate governance and sustainability have become increasingly researched topics, particularly due to their critical interaction in the context of emerging markets where environmental sustainability and rapid economic growth often intersect [4]. Corporate governance

mechanisms shape organizational strategy by aligning decision-making and resource allocation with sustainability objectives. From the perspective of the RBV, governance structures can also be considered a strategic resource, capable of conferring competitive advantage through their uniqueness and ability to foster innovation that aligns with sustainability demands [19]. This is especially relevant in emerging economies where governance systems are evolving and adapting to international sustainability pressures [21]. For example, research in other emerging economies like Indonesia shows that strong corporate governance enhances firm value and resilience, particularly during times of economic or environmental crisis.

In China, the significant presence of state-owned enterprises (SOEs) influences how sustainability is pursued at the firm level. SOEs often align closely with national sustainability agendas while maintaining control over key economic sectors [13]. Although they adopt top-down green directives, SOEs may face structural and bureaucratic obstacles to innovation, barriers that are generally less prominent in private firms [22]. Chinese companies also pursue environmental legitimacy as a strategic goal, engaging in green innovation and carbon disclosure in response to both regulatory pressure and societal expectations [3]. However, while studies have identified the role of managerial empowerment and board centralization in shaping environmental innovation outcomes, the specific impact of gender representation on boards remains underexplored.

Domestic environmental regulations and international expectations continue to push Chinese firms toward more sustainable practices. Previous research highlights a link between strong governance and firms' pursuit of green innovation and transparent carbon disclosures, which help secure environmental legitimacy [23]. However, the effectiveness of these efforts is contingent upon board composition and leadership orientation. Managerial empowerment and board structure can either strengthen or hinder the governance–innovation link, adding complexity to the sustainability landscape [24]. Therefore, to better understand how corporate boards in China facilitate environmental innovation, it is essential to consider the unique characteristics of China's governance system and institutional context.

2.2. Gender Diversity in Corporate Governance

In recent years, gender diversity in corporate governance has gained increasing attention as a critical driver of effective decision-making and improved organizational outcomes [25]. According to UET, the characteristics of top management, including gender composition, significantly influence a firm's strategic direction and performance [18]. Gender-diverse boards are more likely to incorporate a broader range of perspectives and values, which fosters decision-making aligned with sustainability and corporate social responsibility [26]. Empirical studies support this, linking gender diversity to improved CSR outcomes and stronger firm innovation [10]. For instance, boards with greater female representation tend to emphasize CSR initiatives and cultivate stakeholder trust and firm reputation [10]. Further, board diversity has been positively linked to firms' participation in initiatives like the Carbon Disclosure Project [16]. A meta-analysis by Post & Byron [26] confirms that gender-diverse boards are associated with enhanced corporate social performance, largely due to their broadened perspective on stakeholder interests. In line with Stakeholder Theory, such boards are better equipped to meet the expectations of diverse stakeholder groups, thereby advancing both social and environmental performance [27, 28].

In the context of dynamic low-carbon transformation, gender diversity also has a direct bearing on environmental innovation. Female directors are more attuned to environmental issues and more likely to promote green technologies and sustainable practices [2, 29]. While the effect of gender diversity may vary across cultural contexts, for example, board diversity has been shown to positively impact sustainability practices in Australia [30], and similar effects have been observed when other dimensions of diversity, such as nationality, are considered [31]. In countries like China, traditional Confucian values can hinder women's representation and influence in boardrooms [32]. Nevertheless, emerging evidence suggests that gender-diverse boards in China remain resilient and positively contribute to firms' environmental performance, even within such cultural constraints [25]. Specifically, greater gender representation in leadership has been shown to enhance ESG performance, reinforcing the importance of inclusive governance structures [33]. Gender-diverse boards are consistently associated with stronger corporate governance, enhanced corporate social responsibility (CSR), and improved firm reputation [22, 25]. These boards are more actively engaged in sustainability initiatives, such as participation in the Carbon Disclosure Project, reflecting a broader commitment to transparency and environmental responsibility [16]. Female directors have been linked to better environmental performance outcomes and higher levels of CSR engagement, underscoring the strategic value of gender inclusion in corporate leadership [2, 29]. Although some studies caution that corporate governance and environmental performance do not always move in

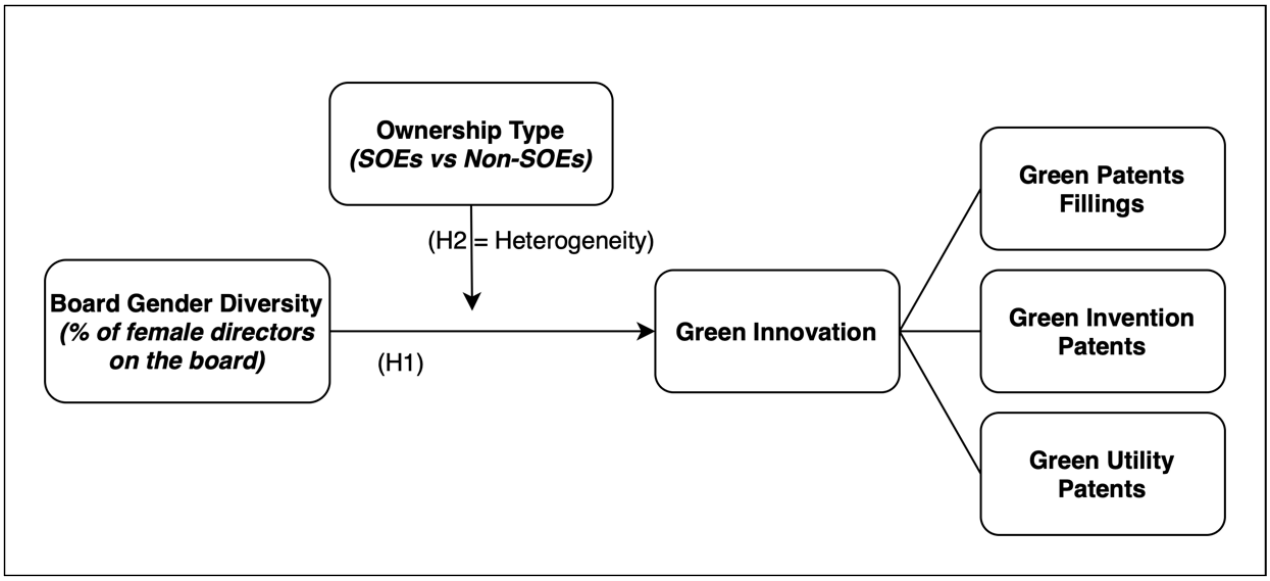

Figure 1. Research framework.

tandem [34] and that sustainability goals are often shaped by financial considerations as well [4], most evidence presents a more optimistic view. Thus, we develop the following hypothesis (H_1):

H_1: Board gender diversity is positively associated with environmental innovation.

2.3. The Chinese Institutional and Regulatory Context

China's green and low-carbon transition is uniquely shaped by strong state influence, where many listed firms are either state-owned or operate under close government oversight. This ownership structure significantly shapes corporate governance dynamics and firms' responsiveness to regulatory pressures [20]. In recent years, China's regulatory landscape has evolved rapidly, particularly following the implementation of the 2015 Environmental Protection Law, which marked a turning point in environmental governance. This policy reform triggered a shift in corporate behavior, encouraging firms to adopt greener practices and enhancing the institutional push for green innovation [17]. However, institutional pressures are not uniform across firm types. SOEs tend to focus more on political and social mandates, often at the cost of flexibility and innovation, while non-SOEs typically face more market-driven pressures and competitive incentives to innovate sustainably.

At the cultural level, traditional Confucian values continue to influence corporate governance in China, particularly regarding gender roles. As a result, female representation on corporate boards remains relatively low [32]. These cultural norms may pose additional barriers to board diversity, especially in SOEs where hierarchical structures are more rigid. In contrast, NSOEs, often being more agile and profit-oriented, may be more willing to leverage gender diversity as a strategic asset for innovation. Moreover, the Chinese government has made sustainability a national priority through initiatives such as the Ecological Civilization strategy, which promotes the integration of economic development with environmental protection [35]. These institutional, regulatory, and cultural factors create a unique setting for examining how board gender diversity influences environmental innovation in Chinese firms. Given the potential for greater strategic flexibility and responsiveness in non-SOEs, it is expected that the positive effect of board gender diversity on green innovation will be more pronounced in these firms compared to SOEs. Therefore, we propose Hypothesis 2 as stated below and visualize the research framework in Figure 1.

H_2: The positive relationship between board gender diversity and environmental innovation is stronger in non-state-owned enterprises than in state-owned enterprises.

3. Methodology

3.1. Data and Sampling

This study employs an unbalanced panel dataset of Chinese A-share listed firms from the Shanghai and Shenzhen stock exchanges, spanning the period 2014 to 2023. The analysis excludes financial firms due to their distinct regulatory frameworks and focuses on companies with complete data on board composition, ownership structure, environmental innovation, and financial indicators. Excluding financial firms does not

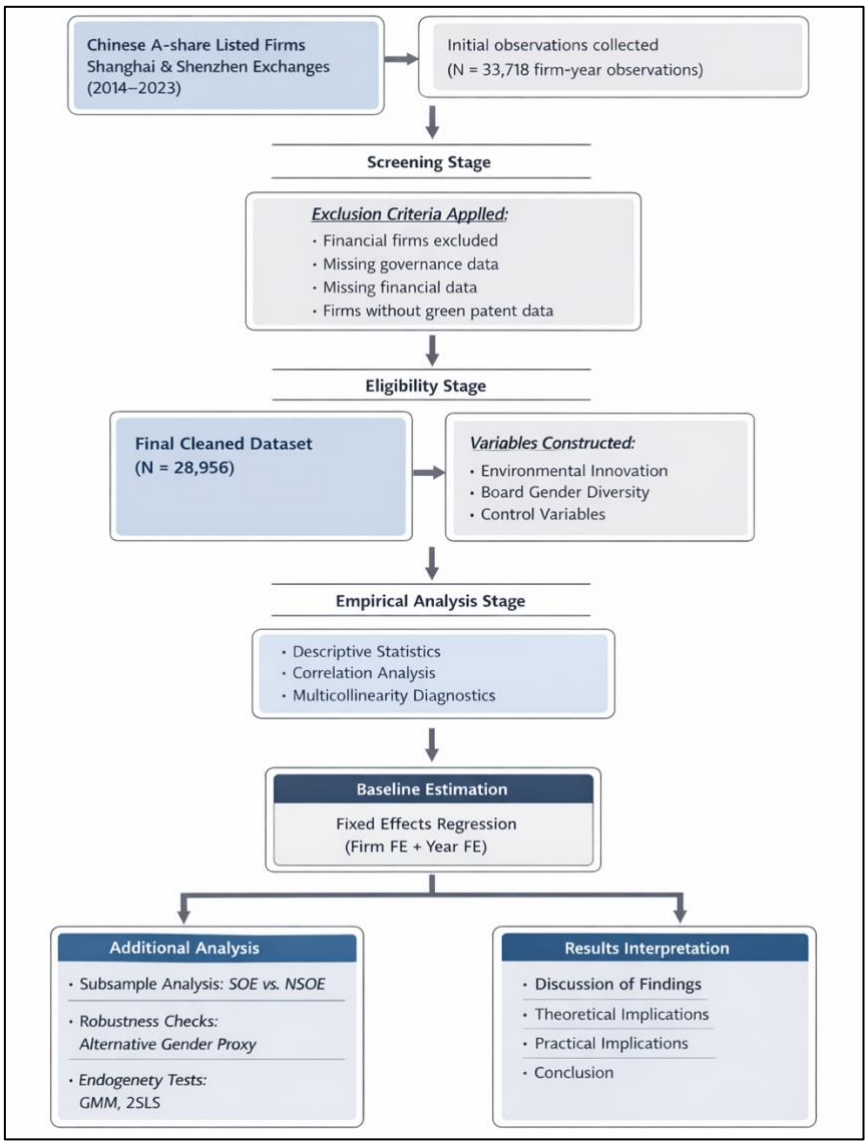

Figure 2. Research design and flow of the study.

bias the results, as their governance structures, regulatory requirements, and financial reporting standards differ substantially from non-financial firms and could otherwise distort the comparability of the analysis [36, 37]. This exclusion is consistent with prior corporate governance and environmental innovation studies and ensures greater homogeneity and reliability of the empirical findings. Firm-level financial and governance data are obtained from the China Stock Market and Accounting Research (CSMAR) Database, a widely used and reliable source [9, 14, 35, 38, 39] for empirical research on Chinese firms. To measure environmental innovation, we adopt the classification framework of the China National Intellectual Property Administration (CNIPA), consistent with previous studies [24]. CNIPA categorizes green patents into three types: green invention patents, green utility model patents, and green design patents. Following prior literature [40], we exclude green design patents due to their limited technological and strategic significance. Our analysis thus focuses on three dependent variables: the number of total green patents, green invention patents, and green utility model patents, which are used to construct logarithmic variables for regression analysis.

3.2. Research Design and Study Flow

To enhance methodological transparency and replicability, Figure 2 presents the overall research design and empirical workflow adopted in this study. The research process follows a structured sequence beginning with the identification of Chinese A-share listed firms from the Shanghai and Shenzhen Stock Exchanges for the period 2014–2023. The screening stage applies exclusion criteria, including financial firms and observations with missing governance, financial, or green patent data, to ensure data consistency. Following this, the eligibility stage involves the construction of key variables, including environmental innovation measures,

Table 1. Variable definitions.

Variable	Type	Measurement	Unit	Description	Data source
EnvrPat	Dependent	ln(1 + total green patents)	Count (log transformed)	Total number of green patents granted to a firm	CNIPA
EnvrInvPat	Dependent	ln(1 + green invention patents)	Count (log transformed)	Number of green invention patents reflecting technological innovation	CNIPA
EnvrUtyPat	Dependent	ln(1 + green utility model patents)	Count (log transformed)	Number of green utility model patents reflecting incremental innovation	CNIPA
BGD_BI	Independent	Blau Index = 1 – Σp^2	Index (0–0.5)	Measures board gender diversity based on gender composition	CSMAR
FDnmb	Independent (Robustness)	Number of female directors	Count	Total number of female directors on the board	CSMAR
Size	Control	ln(total assets)	RMB (log)	Firm size controlling for resource capacity	CSMAR
ROA	Control	Net income / total assets	Ratio (%)	Firm profitability measure	CSMAR
EPS	Control	Earnings per share	RMB	Firm financial performance indicator	CSMAR
Cash	Control	Cash and equivalents / total assets	Ratio	Firm liquidity position	CSMAR
Dual	Control	Dummy (1 = CEO is also Chair)	Binary	CEO duality indicator	CSMAR
Tang	Control	Fixed assets / total assets	Ratio	Asset tangibility	CSMAR
BSize	Control	Total number of directors	Count	Board size	CSMAR
Gearing	Control	Total debt / total assets	Ratio	Financial leverage	CSMAR
Indep	Control	Independent directors/board size	Ratio	Board independence	CSMAR
SOE	Subsample	Dummy (1 = SOE)	Binary	State ownership classification	CSMAR

board gender diversity indicators, and control variables. The empirical analysis then proceeds with descriptive statistics, correlation analysis, and multicollinearity diagnostics. The baseline estimations are conducted using firm and year fixed-effects regression models. Additional analyses, including subsample tests based on ownership structure (SOE vs. non-SOE), robustness checks using alternative gender diversity proxies, and endogeneity tests using GMM and 2SLS approaches, are performed to ensure the robustness of the findings. Finally, the study concludes with an interpretation of results and a discussion of theoretical and practical implications.

3.3. Variables

3.3.1. Green Innovation

Green innovation serves as the dependent variable in this study, measured through firms' output of environmentally oriented patents. As mentioned above, we use green patent filings as a proxy for a firm's environmental innovation capacity by following [3, 24]. Specifically, we include three dimensions: (1) total green patents (EnvrPat), (2) green invention patents (EnvrInvPat), and (3) green utility model patents (EnvrUtyPat). Patent data is sourced from the CNIPA database, which categorizes patents based on technological alignment with green development principles. To normalize the distribution and minimize the impact of extreme values, each green innovation variable is transformed using the natural logarithm of one plus the number of patents in Equation 1.

$$\begin{aligned} EnvrPat_{it} &= ln(1 + Green\ Patents_{it}) \\ EnvrInvPat_{it} &= ln(1 + Invention\ Patents_{it}) \\ EnvrUtyPat_{it} &= ln\,(1 + Utility\ Patents_{it}) \end{aligned} \quad (1)$$

3.3.2. Board Gender Diversity

Board gender diversity is the independent variable in this study. The primary proxy is the Blau index (BGD_BI), a widely used measure to capture diversity in categorical variables such as gender [6, 41, 42]. The index reflects the probability that two randomly selected board members differ in gender. It is calculated in Equation 2.

$$BGD\_Blau_{it} = 1 - \sum_{j=1}^{k} p_{ijt}^2 \quad (2)$$

Where p_{ijt}^2 is the proportion of board members in category j (i.e., male or female) for firm i in year t, and k is the total number of gender categories (here, 2). The index ranges from 0 (no diversity) to 0.5 (maximum diversity with equal male and female representation). As a robustness check, we also use the number of female directors (FDnmb) on the board as an alternative proxy [38, 43]. This raw count captures gender presence rather

Table 2. Descriptive statistics.

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
EnvrPat	33718	0.304	0.621	0	2.079
EnvrInvPat	33718	0.239	0.639	0	6.328
EnvrUtyPat	33718	0.202	0.556	0	5.948
BGD_BI	28956	0.203	0.162	0	0.5
Size	33718	22.174	1.206	19.819	24.701
ROA	33718	0.033	0.066	-0.298	0.127
EPS	33714	0.441	1.166	-10.71	49.93
Cash	33718	0.718	0.809	0.013	3.108
Dual	33718	1.691	0.462	1	2
Tang	33718	0.191	0.144	0.002	0.506
BSize	33718	8.357	1.482	5	11
Gearing	33718	0.412	0.199	0.055	0.777
Indep	33718	0.202	0.038	0	0.533

than proportional balance, providing a complementary perspective on board composition.

3.3.3. Controls

To isolate the effect of board gender diversity on green innovation, several control variables are included based on prior literature. Firm size (Size), measured as the natural log of total assets, controls for resource availability and economies of scale [44]. Return on assets (ROA) and earnings per share (EPS) capture firm profitability and financial performance, which can influence investment in innovation. Cash holdings (Cash) reflect internal liquidity that may fund R&D activities [45]. CEO duality (Dual), a dummy variable indicating whether the CEO also serves as board chair, addresses leadership concentration [46]. Asset tangibility (Tang), the ratio of fixed to total assets, influences flexibility in resource allocation [39]. Lastly, board size (BSize) and board independence (Indep) are included to account for governance structure effects [47]. All the variables are summarized in Appendix 1.

3.4. Model Selection

To examine the relationship between board gender diversity and environmental innovation, we employ a panel data regression model with firm and year fixed effects. The choice between fixed effects (FE) and random effects (RE) was determined using the Hausman test [48]. The test yielded a chi-square statistic of 163.36 with a p-value of 0.0000, strongly rejecting the null hypothesis that RE estimators are consistent. This result confirms the appropriateness of the fixed effects model, which controls for time-invariant, unobserved heterogeneity across firms [49]. The baseline model and subgroup regressions are specified in Equation 3.

$$EnvrPat_{it} = \alpha + \beta_1 BGD\_BI_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

$$EnvrPat_{it}^{SOE=1} = \alpha + \beta_1 BGDBI_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

$$EnvrPat_{it}^{SOE=0} = \alpha + \beta_1 BGDBI_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Where $EnvrPat_{it}$ denotes green innovation for firm i in year t, BGD_BI_{it} is board gender diversity, X_{it} is a vector of control variables, μ_i captures firm fixed effects, λ_t denotes year fixed effects, and ε_{it} is the error term. SOE = 1 stands for state-owned enterprises and SOE = 0 for non-state-owned enterprises. Robust standard errors clustered at the firm level are applied to correct for heteroskedasticity and serial correlation [50]. For clarity and replicability, Table 1 provides detailed definitions, measurements, and data sources for all variables used in the empirical analysis.

4. Empirical Results

4.1. Descriptive Statistics and Correlations

Table 2 presents the descriptive statistics for the key variables. The average EI output (measured by 3 types of green patents) is modest, reflecting the emerging stage of green transformation among Chinese listed firms. The mean value of the board gender diversity index (BGD_BI) is 0.203, indicating relatively low gender representation on boards. The correlation matrix (Table 3) shows a positive and significant correlation between BGD_BI and all three forms of green innovation, suggesting preliminary support for H_1. Multicollinearity is unlikely to be a concern as the correlations among the explanatory variables are below the conventional threshold of 0.70. While the environmental innovation proxies show relatively high correlations, they are treated as alternative dependent variables and are therefore not included simultaneously in the regression models.

4.2. Regression Results and Interpretation

Table 4 reports the baseline regression results. Column (1) shows that board gender diversity (BGD_BI) is positively and significantly associated with total green patents (EnvrPat), with a coefficient of 0.0480 ($p < 0.01$). Columns (2) and (3) show that BGD_BI is significantly related to green invention patents (EnvrInvPat,

Table 3. Matrix of correlations.

No.	Variables	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13
(1)	EnvrPat	1	-	-	-	-	-	-	-	-	-	-	-	-
(2)	EnvrInvPat	0.848	1	-	-	-	-	-	-	-	-	-	-	-
(3)	EnvrUtyPat	0.812	0.675	1	-	-	-	-	-	-	-	-	-	-
(4)	BGD_BI	0.043	0.045	0.028	1	-	-	-	-	-	-	-	-	-
(5)	Size	0.137	0.172	0.142	-0.131	1	-	-	-	-	-	-	-	-
(6)	ROA	0.042	0.042	0.027	0.026	-0.002	1	-	-	-	-	-	-	-
(7)	EPS	0.057	0.062	0.052	0.007	0.102	0.538	1	-	-	-	-	-	-
(8)	Cash	-0.065	-0.051	-0.085	0.058	-0.341	0.261	0.173	1	-	-	-	-	-
(9)	Dual	-0.003	-0.007	-0.002	-0.104	0.198	-0.043	-0.044	-0.105	1	-	-	-	-
(10)	Tang	-0.037	-0.048	-0.007	-0.038	0.091	-0.042	-0.083	-0.197	0.094	1	-	-	-
(11)	BSize	0.036	0.043	0.034	-0.062	0.272	0.01	-0.005	-0.095	0.187	0.13	1	-	-
(12)	Gearing	0.085	0.087	0.103	-0.087	0.52	-0.355	-0.166	-0.668	0.144	0.067	0.147	1	-
(13)	Indep	-0.093	-0.099	-0.077	0.085	-0.219	-0.009	-0.015	0.089	-0.193	-0.061	-0.112	-0.133	1

Table 4. Impact of board gender diversity on environmental innovation.

Variables	(1) EnvrPat	(2) EnvrInvPat	(3) EnvrUtyPat
BGD_BI	0.048***	0.071***	0.046*
	(0.018)	(0.028)	(0.025)
Size	0.052***	0.051***	0.037***
	(0.008)	(0.008)	(0.008)
ROA	0.047	0.010	0.0264
	(0.056)	(0.053)	(0.051)
EPS	0.002	-0.001	0.003
	(0.004)	(0.005)	(0.005)
Cash	-0.018***	-0.012**	-0.009
	(0.006)	(0.006)	(0.006)
Dual	0.003	0.003	0.009
	(0.010)	(0.008)	(0.009)
Tang	0.019	-0.003	0.042
	(0.049)	(0.044)	(0.043)
BSize	-0.008**	-0.008**	-0.006*
	(0.004)	(0.004)	(0.004)
Gearing	0.038	0.035	0.013
	(0.035)	(0.031)	(0.032)
Indep	-0.186	-0.075	-0.278**
	(0.136)	(0.142)	(0.141)
_cons	-0.744***	-0.797***	-0.533***
	(0.189)	(0.182)	(0.182)
Firm-fixed	Yes	Yes	Yes
Year-fixed	Yes	Yes	Yes
N	28956	28956	28956
R^2	0.005	0.005	0.004
Adj. R^2	0.005	0.005	0.003

Note: Standard errors in parentheses (* p < 0.1, ** p < 0.05, *** p < 0.01).

coefficient = 0.071, p < 0.01) and green utility model patents (EnvrUtyPat, coefficient = 0.046, p < 0.1), respectively. These results provide robust support for H_1, indicating that gender-diverse boards are more likely to foster EI performance.

4.3. Marginal Effects and Ownership Heterogeneity

Table 5 reports the results of subgroup regressions examining whether the relationship between board gender diversity and environmental innovation varies across ownership structures. The results reveal clear ownership-based heterogeneity in the effectiveness of board gender diversity. In the SOEs subsample (Table 5, Panel A), the coefficient of BGD_BI remains statistically insignificant across all three environmental innovation measures, suggesting that gender diversity alone does not translate into measurable innovation outcomes within state-controlled firms. In contrast, the NSOEs subsample (Table 5, Panel B) shows a consistently positive and statistically significant association between BGD_BI and environmental innovation. The magnitude of the coefficients is also economically stronger than that observed in the full sample. For example, the coefficient for EnvrInvPat reaches 0.124 (p < 0.01), indicating that gender-diverse boards exert a more substantial influence on green invention activities in market-oriented firms.

Table 5. Ownership heterogeneity: SOEs vs. non-SOEs.

Variables	Panel A: SOE=1			Panel B: SOE=0		
	EnvrPat	**EnvrInvPat**	**EnvrUtyPat**	**EnvrPat**	**EnvrInvPat**	**EnvrUtyPat**
BGD_BI	0.029	0.028	0.036	0.124**	0.090***	0.028**
	(0.045)	(0.042)	(0.037)	(0.063)	(0.035)	(0.014)
Size	0.035***	0.035***	0.017	0.027	0.027	0.008
	(0.013)	(0.012)	(0.013)	(0.018)	(0.017)	(0.009)
ROA	0.186*	0.082	0.145*	0.071	0.010	0.108
	(0.107)	(0.096)	(0.088)	(0.158)	(0.217)	(0.107)
EPS	0.010	0.005	0.007	0.032	0.013	0.001
	(0.009)	(0.009)	(0.007)	(0.024)	(0.038)	(0.015)
Cash	-0.032**	-0.041***	-0.009	-0.026**	-0.018*	-0.021**
	(0.013)	(0.013)	(0.009)	(0.011)	(0.010)	(0.009)
Dual	-0.003	-0.014	0.003	0.008	0.000	0.002
	(0.017)	(0.015)	(0.014)	(0.014)	(0.007)	(0.014)
Tang	-0.137*	-0.098	-0.067	-0.038	-0.029	-0.066
	(0.081)	(0.073)	(0.063)	(0.089)	(0.089)	(0.076)
BSize	-0.007	-0.004	-0.006	-0.001	0.006	0.008
	(0.006)	(0.007)	(0.006)	(0.013)	(0.015)	(0.010)
Gearing	0.096	0.104*	0.073	0.059	0.022	0.078
	(0.064)	(0.059)	(0.054)	(0.060)	(0.055)	(0.059)
Indep	-0.334	-0.210	-0.616***	0.940*	0.776*	0.345
	(0.203)	(0.224)	(0.217)	(0.487)	(0.467)	(0.323)
Constant	-0.244	-0.320	0.038	-0.675	-0.714	-0.209
	(0.317)	(0.291)	(0.302)	(0.494)	(0.512)	(0.227)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	10635	10635	10635	1383	1383	1383
R^2	0.004	0.004	0.003	0.016	0.011	0.006
Adj. R^2	0.003	0.003	0.002	0.009	0.003	-0.001

Note: Standard errors in parentheses (* p < 0.1, ** p < 0.05, *** p < 0.01).

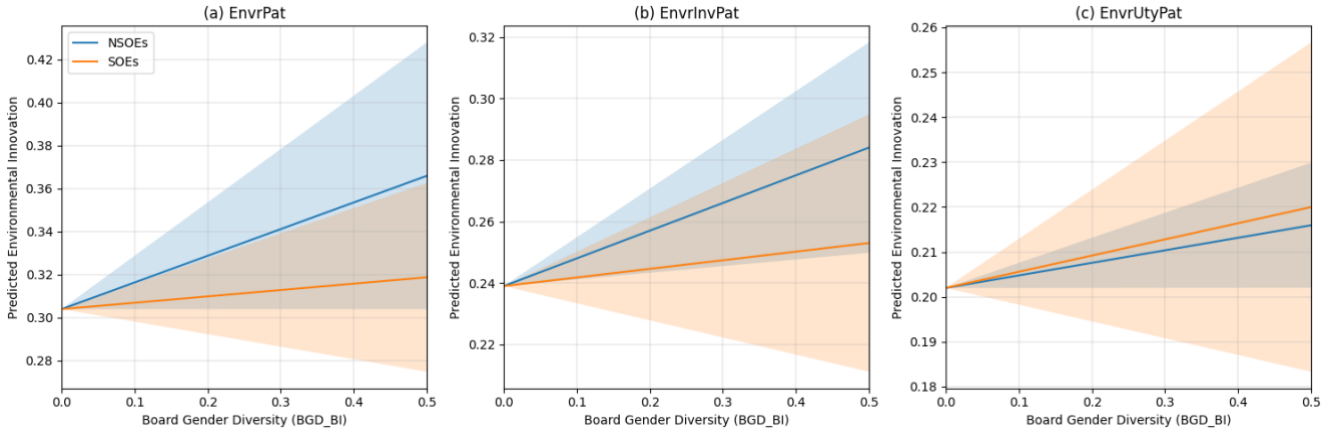

Figure 3. Marginal effects plotting (SOEs vs. non-SOEs).

These findings support Hypothesis 2 and demonstrate that ownership structure conditions the extent to which board diversity contributes to environmental outcomes.

This ownership heterogeneity is consistent with the theoretical arguments derived from UET and the RBV. While gender diversity introduces cognitive variety, broader stakeholder awareness, and longer-term strategic orientation at the board level, the realization of these advantages depends on organizational discretion and institutional flexibility. Non-SOEs typically operate under stronger market competition and performance incentives, allowing diverse perspectives to be more effectively translated into strategic innovation decisions [51]. In contrast, SOEs may face bureaucratic constraints, multiple policy objectives, and limited managerial autonomy, which reduce the capacity of board diversity to influence innovation outcomes [52, 53]. The results, therefore, suggest that board gender diversity functions as a conditional governance resource rather than a universally effective mechanism, directly aligning with this study's central argument that diversity contributes to the low-carbon transition only under supportive institutional conditions.

Table 6. Robustness check: female director representation and environmental innovation.

Panel A: Robustness check using Female Director Number (FD nmb) as proxy for gender diversity			
	-1 EnvrPat	**-2 EnvrInvPat**	**-3 EnvrUtyPat**
FDnmb	0.049***	0.042***	0.031**
	(0.014)	(0.012)	(0.015)
_cons	-0.518***	-0.595***	-0.243
	(0.176)	(0.171)	(0.166)
controls	Yes	Yes	Yes
Firm-fixed	Yes	Yes	Yes
Year-fixed	Yes	Yes	Yes
N	32769	32769	32769
R^2	0.003	0.004	0.002
Adj. R^2	0.003	0.003	0.002

Panel B: Female Director and Environmental Innovation by Ownership Type						
	Panel B1: SOE=1			Panel B2: SOE=0		
	EnvrPat	**EnvrInvPat**	**EnvrUtyPat**	**EnvrPat**	**EnvrInvPat**	**EnvrUtyPat**
FDnmb	0.0742	0.099**	0.057	0.011***	0.064***	0.039***
	-0.052	-0.042	-0.045	-0.003	-0.017	-0.012
_cons	-0.23	-0.291	0.136	-0.654	-0.644	-0.215
	-0.316	-0.298	-0.285	-0.423	-0.43	-0.207
controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm-fixed	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed	Yes	Yes	Yes	Yes	Yes	Yes
N	11666	11666	11666	1507	1507	1507
R^2	0.004	0.004	0.002	0.012	0.007	0.008
Adj. R^2	0.003	0.003	0.001	0.005	0	0.002

Note: Standard errors in parentheses. Subgroup robustness check using FDnmb. We denote SOE=1 represent State-owned enterprise, otherwise 0 (* p < 0.1, ** p < 0.05, *** p < 0.01).

To further illustrate these heterogeneous effects, Figure 3 presents marginal effects plots of board gender diversity on environmental innovation across ownership types for EnvrPat, EnvrInvPat, and EnvrUtyPat. The graphical evidence shows that the marginal slope of board gender diversity is relatively flat for SOEs, indicating negligible changes in predicted environmental innovation as diversity increases. In contrast, the slope is consistently positive and steeper for non-SOEs, visually demonstrating that increases in board gender diversity are associated with stronger improvements in environmental innovation outcomes in market-driven firms. Together, the regression and marginal effect analyses reinforce the study's contribution by showing not only whether diversity matters, but also when and where it works in supporting firms' low-carbon transition strategies.

4.4. Robustness Checks: Female Director Number as the Alternative

To ensure the reliability of the results, we replace BGD_BI with the number of female directors (FDnmb) as an alternative proxy. As shown in Table 6 Panel A, FDnmb remains positively and significantly associated with all three types of environmental innovation, reaffirming the robustness of the baseline findings. The subgroup regressions (Table 6, Panel B) using FDnmb further confirm that the positive relationship is stronger and statistically significant in NSOEs but not in SOEs. For example, the coefficient for FDnmb on EnvrPat in NSOEs is 0.0114 ($p < 0.01$), while it is statistically insignificant in SOEs. This further strengthens the conclusion that gender diversity matters more in firms with greater strategic flexibility and market exposure.

4.5. Endogeneity Treatment

A potential concern in examining the relationship between board gender diversity and environmental innovation is endogeneity arising from reverse causality, omitted variable bias, and dynamic persistence in innovation activities. Firms with stronger environmental innovation capabilities may be more likely to appoint female directors due to reputational considerations or stakeholder expectations, which could bias baseline estimates. To address these concerns, this study employs both the Generalized Method of Moments (GMM) and Two-Stage Least Squares (2SLS) approaches.

As illustrated in Table 7, the system GMM estimator accounts for dynamic panel bias by incorporating lagged dependent variables and using internal instruments derived from lagged levels and differences of endogenous variables, thereby controlling for unobserved heterogeneity and simultaneity. Panel A indicates that board gender diversity (BGD_BI) remains positively and significantly associated with environmental

Table 7. Endogeneity treatment with GMM and 2SLS.

Panel A: Generalized Method of Moments (GMM)			
Variables	**(1) EnvrPat**	**(2) EnvrInvPat**	**(3) EnvrUtyPat**
L.EnvrPat	0.312***	-	-
	(0.041)		
L.EnvrInvPat	-	0.295***	-
		(0.039)	
L.EnvrUtyPat	-	-	0.276***
			(0.036)
BGD_BI	0.063**	0.081**	0.052*
	(0.024)	(0.031)	(0.028)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	26,845	26,845	26,845
AR(1) p-value	0	0	0.001
AR(2) p-value	0.318	0.427	0.391
Hansen p-value	0.274	0.301	0.289

Panel B: Two-Stage Least Squares (2SLS)				
Variables	**1st Stage - BGD_BI**	**(1) EnvrPat**	**(2) EnvrInvPat**	**(3) EnvrUtyPat**
Predicted BGD_BI	-	0.072**	0.094**	0.061*
		(0.029)	(0.036)	(0.033)
Instrument	0.428***	-	-	-
	(0.072)			
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	28,956	28,956	28,956	28,956
R^2	0.312	0.341	0.362	0.355
First-stage F-statistic		21.37	21.37	21.37
Hansen J-test (p)		0.341	0.362	0.355

Note: Robust standard errors clustered at the firm level (* p < 0.1, ** p < 0.05, *** p < 0.01).

innovation after accounting for dynamic endogeneity, while diagnostic tests confirm model validity through insignificant AR(2) statistics and acceptable Hansen test results. As an additional robustness check in Panel B, a 2SLS estimation is conducted using the industry-year average level of board gender diversity (excluding the focal firm) as an instrumental variable, capturing industry governance norms while remaining exogenous to firm-level environmental innovation outcomes. The first-stage results demonstrate strong instrument relevance, and the second-stage estimates remain consistent with the baseline and GMM findings. Collectively, these results alleviate endogeneity concerns and reinforce the conclusion that board gender diversity functions as a conditional governance resource to be more effectively translated into low-carbon innovation outcomes.

5. Discussion

The empirical results offer robust evidence supporting the view that board gender diversity enhances environmental innovation, consistent with both the UET and RBV. According to UET [18], organizational outcomes are influenced by the personal characteristics and cognitive frameworks of top executives. The presence of women on corporate boards introduces new perspectives, ethical considerations, and risk aversion tendencies that may otherwise be absent in homogenous male-dominated boards [28]. These attributes are particularly important when dealing with sustainability issues, which require long-term orientation and a sensitivity to diverse stakeholder interests [2, 24]. The significant positive association between gender diversity and green innovation, therefore, supports the UET premise that the cognitive makeup of leadership teams shapes strategic outcomes, including a firm's innovation trajectory. From the RBV perspective [19], gender diversity represents an intangible strategic resource, valuable, rare, inimitable, and organizationally embedded, that enhances a firm's innovative capacity. Diverse boards can contribute to superior environmental performance by encouraging broader dialogue, reducing groupthink, and integrating non-traditional knowledge into strategic decision-making [6, 16]. The finding that gender diversity consistently predicts higher levels of environmental innovation aligns with the RBV assertion that such unique governance capabilities can be a source of sustained competitive advantage.

In the context of low-carbon transformation, gender diversity in boardrooms positively reflects on sustainability through multiple practical mechanisms [10]. Women directors are often found to exhibit stronger ethical orientation and greater concern for environmental and social issues, which aligns well with the goals of ESG initiatives [29]. Their leadership can enhance stakeholder engagement, improve transparency, and reinforce corporate accountability. Gender-diverse boards are also more likely to support the integration of long-term sustainability objectives into corporate strategy, helping firms adapt to changing regulatory pressures and consumer expectations [15]. In this way, gender diversity not only improves governance quality but also fosters a corporate culture that embraces sustainability as a core value, contributing to transformative change in business practices. Women directors are often found to exhibit stronger ethical orientation and greater concern for environmental and social issues, which aligns well with the goals of ESG initiatives [25]. Their leadership can enhance stakeholder engagement, improve transparency, and reinforce corporate accountability. Gender-diverse boards are also more likely to support the integration of long-term sustainability objectives into corporate strategy, helping firms adapt to changing regulatory pressures and consumer expectations [24, 25]. In this way, gender diversity not only improves governance quality but also fosters a corporate culture that embraces sustainability as a core value, contributing to transformative change in business practices.

The moderating role of ownership type underscores the theoretical argument that context influences how resources and cognitive characteristics are activated within firms. The stronger effect observed in NSOEs suggests that market-driven firms are better positioned to leverage the strategic potential of gender-diverse boards, further supporting the RBV's emphasis on the organizational context in realizing the value of internal resources. Together, these findings reinforce the integrative power of UET and RBV in explaining the role of board diversity in shaping sustainability-oriented innovation strategies.

Beyond the governance and sustainability implications, the findings also carry important economic significance. Environmental innovation is increasingly recognized not only as a sustainability outcome but also as a driver of long-term firm value, operational efficiency, and competitive positioning. Firms investing in green innovation can benefit from cost reductions through resource efficiency, improved risk management, and enhanced access to green financing and ESG-oriented investment capital [4, 5]. In this context, board gender diversity may indirectly contribute to firm economic resilience by strengthening strategic oversight of sustainability investments that generate both environmental and financial returns. Furthermore, gender-diverse boards may enhance firms' ability to respond to carbon transition risks and regulatory pressures, which are increasingly associated with financial performance and capital market expectations [35, 45]. The stronger effects observed in non-SOEs also suggest that market-oriented firms may be more effective in translating governance diversity into economically valuable innovation outcomes due to stronger competitive pressures and performance incentives. Thus, this study extends the governance literature by demonstrating that gender diversity not only strengthens sustainability orientation but may also contribute to the economic logic of green transformation by aligning innovation strategy with long-term value creation.

6. Conclusion

6.1. Summary of the Findings

This study examines the role of board gender diversity in shaping environmental innovation among Chinese listed firms within the broader context of the low-carbon transition. Drawing on Upper Echelons Theory (UET) and the Resource-Based View (RBV), the analysis demonstrates that board gender diversity, measured using the Board Gender Diversity Index (BGD_BI), is positively and significantly associated with environmental innovation, proxied by green patent output. The findings suggest that gender-diverse boards enhance firms' ability to pursue sustainability-oriented innovation by introducing diverse cognitive perspectives, improving stakeholder sensitivity, and encouraging longer-term strategic orientation in decision-making processes. Importantly, the results reveal that this relationship is not uniform across institutional contexts. The positive effect of board gender diversity is significantly stronger in non-state-owned enterprises (NSOEs) than in state-owned enterprises (SOEs), indicating that ownership structure conditions the effectiveness of governance diversity. Firms operating under market-oriented governance environments appear better positioned to translate diversity into tangible innovation outcomes, while SOEs may face institutional constraints that limit the strategic activation of board-level diversity. Additional robustness analyses using the number of female directors (FDnmb) as an alternative proxy further confirm the stability of the results. Overall, the findings suggest that board gender diversity functions as a contingent governance

mechanism whose effectiveness depends on organizational flexibility and institutional incentives.

6.2. Theoretical Implications

This study contributes to the corporate governance and sustainability literature in several important ways. First, it extends Upper Echelons Theory by demonstrating that board demographic characteristics influence not only financial outcomes but also sustainability-oriented strategic decisions, particularly environmental innovation. By showing that the influence of board gender diversity varies across ownership structures, the study refines UET by highlighting the role of institutional context in shaping how managerial and board characteristics translate into organizational outcomes. The findings suggest that executive and board attributes do not operate independently of organizational environments; rather, their strategic influence depends on the degree of discretion and flexibility available within the firm.

Second, the study advances the Resource-Based View by conceptualizing board gender diversity as an intangible strategic resource that enhances innovation capability. Diversity contributes to knowledge heterogeneity, broader information processing, and reduced groupthink, all of which are critical for addressing complex environmental challenges. However, the results also demonstrate that such resources are not automatically valuable; their effectiveness depends on organizational conditions that allow them to be effectively deployed. In this sense, the study moves beyond the conventional assumption that diversity universally improves firm outcomes and instead positions governance diversity as a conditional resource whose value is realized only under supportive institutional and governance arrangements.

Finally, this study contributes to the emerging literature on low-carbon transition by linking board governance structures to environmental innovation outcomes in an emerging economy context. By integrating governance diversity into discussions of sustainability transformation, the findings provide a micro-level explanation for why firms respond differently to similar environmental pressures, thereby enriching existing research on corporate responses to climate-related challenges.

6.3. Practical Implications

From a practical perspective, the findings offer several implications for policymakers, regulators, and corporate decision-makers seeking to accelerate the transition toward low-carbon development. For firms, the results suggest that enhancing board gender diversity is not only a matter of social inclusion or governance compliance but also a strategic mechanism for strengthening innovation capacity and long-term competitiveness. Gender-diverse boards appear more capable of integrating environmental considerations into strategic decision-making and promoting investments in green technologies and sustainability initiatives.

For policymakers, the findings imply that governance reforms aimed at increasing board diversity may contribute to environmental innovation, but their effectiveness depends on broader institutional and organizational conditions. Market-oriented governance environments appear more conducive to translating diversity into innovation outcomes. Therefore, policies encouraging board inclusivity should be accompanied by institutional reforms that enhance managerial autonomy, reduce bureaucratic rigidity, and strengthen market incentives for innovation.

For state-owned enterprises, the results highlight the importance of complementing diversity initiatives with organizational reforms that improve decision-making flexibility and innovation incentives. Without such supporting conditions, diversity alone may not be sufficient to generate meaningful changes in environmental performance. More broadly, the study suggests that inclusive governance structures can serve as catalysts for green and low-carbon transition, helping firms align strategic objectives with low-carbon development goals while enhancing stakeholder trust and organizational resilience.

6.4. Limitation and Future Research Agenda

Despite its contributions, this study has several limitations that provide opportunities for future research. First, the analysis focuses exclusively on Chinese listed firms, which may limit the generalizability of the findings to other institutional or cultural contexts. Future studies could examine whether similar conditional effects of board gender diversity emerge in other emerging or developed economies with different governance structures and regulatory environments. Second, environmental innovation is measured using green patent output, which primarily captures technological innovation rather than broader sustainability practices. Green patents may not fully reflect improvements in operational efficiency, emissions reduction, or environmental management processes. Future research could incorporate alternative measures such as carbon emission intensity, energy efficiency indicators, environmental investment, or ESG performance metrics to provide a more comprehensive

assessment of firms' environmental outcomes. Third, while this study focuses on gender diversity as a key dimension of board composition, other forms of board diversity, such as educational, professional, or cognitive diversity, may also influence sustainability strategies and innovation outcomes. Future research could explore how multiple dimensions of diversity interact and whether complementarities or trade-offs exist among them in shaping low-carbon transformation pathways. Finally, future research may further investigate the mechanisms through which board diversity influences environmental innovation, such as enhanced stakeholder engagement, improved monitoring effectiveness, or changes in strategic risk-taking behavior. Exploring these mechanisms through mixed-method or multi-level approaches could provide deeper insights into how governance structures facilitate or constrain firms' responses to environmental challenges.

Author Contributions: Conceptualization, S.Y. and F.K.; methodology, S.Y.; software, F.K.; validation, S.Y., F.K. and X.L.; formal analysis, S.Y.; investigation, F.K.; resources, S.Y.; data curation, F.K.; writing—original draft preparation, S.Y. and F.K.; writing—review and editing, K.R.M.; visualization, X.L.; supervision, K.R.M.; project administration, K.R.M. All authors have read and agreed to the published version of the manuscript.

Funding: This study does not receive external funding.

Data Availability Statement: Data will be available upon request from the corresponding author.

Acknowledgments: Not applicable.

Conflicts of Interest: All the authors declare that there are no conflicts of interest.

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Appendix.

Appendix 1 – Variable description.

Variables	Description	Source
EnvrPat	Log of 1 plus the total number of green patents filed by a firm	CNIPA
EnvrInvPat	Log of 1 plus the number of green invention patents filed	CNIPA
EnvrUtyPat	Log of 1 plus the number of green utility model patents filed	CNIPA
BGD_BI	Blau Index of board gender diversity	CSMAR
FDnmb	Number of female directors on the board	CSMAR
Size	Natural logarithm of total assets	CSMAR
ROA	Net income divided by total assets	CSMAR
EPS	Earnings per share	CSMAR
Cash	Ratio of cash and cash equivalents to total assets	CSMAR
Dual	Dummy variable: 1 if CEO also serves as board chair, 0 otherwise	CSMAR
Tang	Ratio of fixed assets to total assets	CSMAR
BSize	Total number of board members	CSMAR
Indep	Proportion of independent directors on the board	CSMAR
SOE	Dummy variable: 1 for state-owned enterprises, 0 otherwise	CSMAR