

Article

Director Network Stability and Corporate Green Innovation: Evidence from China's A-Share Market

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Abstract

This study investigates the impact of director network stability on corporate green innovation, emphasizing the moderating roles of network position and media attention. Using a sample of Chinese A-share listed firms from 2009 to 2023, we present three main findings. First, greater director network stability is positively associated with green innovation. Second, this positive relationship is more pronounced among firms that occupy central positions within the network and receive higher levels of media attention. Third, the effect of network stability operates primarily through two mechanisms: heightened corporate social responsibility (CSR) awareness and increased R&D investment. These findings provide novel empirical evidence on how network governance fosters sustainability-oriented innovation. They also offer practical implications for firms seeking to enhance their green innovation capabilities. Finally, we acknowledge certain limitations, including potential imprecision in measuring network stability and remaining concerns about causal identification, which future research should address using richer indicators and more robust identification strategies.

Keywords: director network stability; green innovation; media attention; corporate social responsibility; sustainability



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1. Introduction

Against the backdrop of global climate change and the growing depletion of resources, promoting green and efficient production has become a key strategic choice for enterprises worldwide. As a crucial pathway to achieving coordinated economic development and ecological balance, green innovation has attracted increasing attention [1]. Oriented toward sustainable development, green innovation facilitates low-carbon transformation through comprehensive changes in technology, management, and institutional frameworks, and has become an essential means of addressing environmental challenges and achieving high-quality growth. However, despite its growing strategic significance, enterprises still face multiple obstacles in the implementation of green innovation. Existing research indicates that green innovation exhibits a distinct “dual externality” feature. On the one hand, the environmental benefits it generates are characterized by strong spillover effects, meaning that firms often bear high investment costs while failing to capture commensurate returns. As a result, private returns are substantially lower than social returns, thereby weakening firms' incentives to innovate [2]. On the other hand, green innovation typically involves

high upfront investment, long payback periods, and financing constraints [3], which further hinder firms' profitability and resource allocation efficiency [4]. Consequently, how to effectively stimulate firms' motivation for green innovation and promote their sustainable transformation has become an urgent and important research issue.

Existing studies primarily explore the driving mechanisms of corporate green innovation from two dimensions: the external institutional environment and internal corporate governance. From the perspective of the external environment, government policies and environmental regulations are widely regarded as key forces in promoting green innovation. Policy instruments such as green credit [5,6], carbon trading mechanisms [7], environmental judicial reform [8], and environmental tax policies [9–11] not only alleviate the economic cost pressures of green innovation but also exert external impetus through institutional mechanisms that combine incentives and constraints. Moreover, improvements in institutional quality and policy stability help reduce the uncertainty and risks associated with green innovation, thereby enhancing firms' confidence in innovation [12,13]. The media supervision mechanism also plays an important role by reinforcing firms' motivation to fulfill environmental responsibilities through public opinion guidance and reputational constraints [14,15]. From the perspective of internal corporate governance, managerial characteristics, and board structure are considered important organizational factors influencing green innovation. Executives with environmental backgrounds, green awareness, or international experience are more inclined to promote green projects and enhance firms' green innovation capabilities through cognitive spillovers [15–17]. Research on the role of CEOs further reveals heterogeneity in their impact on green innovation—CEO power is positively associated with green process innovation but may be negatively related to green product innovation [18]; female CEOs, due to their stronger sense of sustainability, are often more effective in facilitating firms' green transformation [19]. At the board level, the degree of participation of independent directors, the diversity of their backgrounds, and whether they possess environmental expertise can all broaden firms' cognitive boundaries, help identify green technology opportunities, and thereby foster the development and expansion of green innovation [17,20,21]. Consistently, firms whose audit committees include members with environmental backgrounds exhibit stronger green innovation, via heightened managerial environmental awareness, greater substantive investment, and tighter compliance—especially under high media attention and stronger committee involvement [22,23].

In recent years, as an informal information transmission and trust building mechanism, director network has attracted more and more attention from academia. Director networks refer to inter-firm relational structures formed when directors simultaneously serve on the boards of multiple companies. Such networks facilitate the transmission of strategic information across firms, accelerate the flow of knowledge, and broaden firms' access to external information sources [24]. Research on director networks and corporate green innovation has revealed that director networks can provide crucial support for companies to acquire environmental knowledge and integrate green resources, thereby playing a positive role in green innovation strategies. Wang et al. find that interlocking director networks with green experience can significantly enhance both the quantity and quality of corporate green innovation [25]. Furthermore, structural features of director networks—such as centrality and structural holes—are closely related to green innovation outcomes [26,27]. Among them, tightly connected networks formed by interlocking directors facilitate the more efficient diffusion and sharing of green technologies across firms [20], thereby laying an institutional foundation for accessing external green resources and achieving collaborative green development.

However, the extant literature primarily concentrates on the static structural attributes of director networks—such as embeddedness, density, and centrality—and typically at-

tributes their impact on green innovation to firms' static positional environments [28–31]. By contrast, far less attention has been paid to the temporal dimension and dynamic evolution of director networks, particularly to how tie stability shapes corporate green innovation.

The stability of director networks reflects the persistence and robustness of interfirm ties [32]. While greater stability is generally thought to enhance interorganizational cooperation and information sharing, excessive stability may entail governance risks. On the one hand, enduring relationships are more likely to facilitate deep information exchange and knowledge sharing, particularly with respect to core strategic knowledge [33]. For green innovation—a strategically oriented, long-term endeavor that relies on sustained resource inputs and knowledge support—stable director networks may provide critical informational resources and trust assurances that surpass the benefits of purely structural advantages. On the other hand, because social networks are initially formed to access complementary information and knowledge, the heterogeneity of information available through stable ties tends to diminish over time [34]; when information and knowledge become excessively redundant, the marginal benefits firms derive from such networks correspondingly decline [35]. Accordingly, it is necessary to systematically investigate—through a dynamic lens of director networks—how network stability influences corporate green innovation.

Based on the above analysis, this study focuses on three core research questions: (1) Does director network stability affect firms' green innovation behavior? (2) Do such effects differ across various internal and external environments? (3) Through what specific mechanisms does director network stability influence corporate green innovation?

Based on panel data of Chinese A-share listed companies from 2009 to 2023, this study provides empirical evidence that the stability of director networks significantly promotes corporate green innovation. In addition, the central position of directors in the network and the degree of media attention received by enterprises have a significant positive moderating effect on the relationship between network stability and green innovation. Further analysis reveals that this influence operates primarily through mechanisms such as strengthening corporate social responsibility awareness and increasing R&D investment. To address potential endogeneity concerns, this study adopts a series of endogenous tests including Heckman two-stage model, instrumental variable method (IV) and propensity score matching method (PSM). In addition, multidimensional robustness examines are conducted by adopting alternative measures of green innovation, restricting the sample to manufacturing firms, and excluding the years affected by the COVID-19 pandemic. The results remain consistent and robust across these tests.

This study selects Chinese A-share listed companies as the research sample for two main reasons. First, China has long operated within a relationship-oriented societal framework, in which establishing and maintaining inter-firm relationships play a crucial role in business operations [36]. The director network constitutes an essential component of the corporate "relationship" system, and its stability is particularly salient under China's institutional environment. As one of the world's largest emerging economies, the Chinese A-share market features a high prevalence of interlocking director ties [37], providing a rich empirical foundation for examining the dynamic evolution and stability effects of director networks. Second, in the broader context of emerging markets, formal institutional constraints remain underdeveloped, while government intervention is relatively strong and market competition mechanisms are still evolving [38]. Consequently, informal institutions—such as inter-firm relationship networks—play a more critical role in resource allocation and corporate decision-making [39]. From this perspective, the Chinese market offers not only an ideal setting for testing the impact of director network stability on corporate governance and green innovation but also valuable insights into the applicability and limitations of network stability mechanisms across different institutional contexts.

The main contributions of this paper can be summarized as follows:

First, this study introduces a novel perspective of director network stability, thereby extending the theoretical research on the driving mechanisms of green innovation. Compared with the existing literature that primarily focuses on the static structural features of director networks, such as centrality and structural holes [26,27,40], this paper constructs a new analytical framework for green innovation from the dynamic dimension of network stability. By examining the long-term and continuous inter-firm relationships formed through interlocking directors, we highlight the crucial role of trust and sustained interaction among directors in the green innovation process. Stable director networks facilitate inter-firm knowledge sharing and resource integration, thereby reducing uncertainty and improving efficiency in green innovation activities.

Second, this study innovatively introduces the concept of “edge persistence” as a measurement of director network stability, thus improving its methodological assessment. Existing research on network stability often relies on the differences in edge additions and removals [32,41], which are typically based on changes between two consecutive periods. Such measures fail to distinguish between long-term stable connections and newly established temporary ties. By incorporating a network mobility perspective, this paper adopts edge persistence defined as the duration of an edge’s continuous existence within the network as a key indicator. This approach more accurately captures the evolutionary dynamics of director networks and provides theoretical support for uncovering their long-term effects in corporate governance.

Third, this paper systematically identifies the mediating and moderating pathways through which director network stability influences green innovation, thereby enriching the explanatory mechanisms. Beyond examining the main effects, this study incorporates two external moderating variables such as director network position and media attention for analyzing the boundary conditions of green innovation. Moreover, we explore how director network stability indirectly promotes green innovation through enhanced corporate social responsibility awareness and increased R&D investment. This mechanism analysis not only deepens the understanding of director networks function but also expands the application of dynamic network research in the context of green development.

2. Theoretical Analysis and Hypothesis

2.1. Director Network Stability and Corporate Green Innovation

Drawing on social network embeddedness theory, strategic resources that are valuable, rare, inimitable, and non-substitutable (VRIN) do not reside solely within the firm but also extend into the external networks in which the firm is embedded [42]. Through these inter-organizational connections, firms can gain access to critical information, knowledge, and capabilities that enhance their innovation performance. According to resource dependence theory, given substantive heterogeneity in resource endowments and constraints on resource mobility, organizations must establish and maintain enduring relationships with external actors that control key resources to ensure reliable access and improve adaptive capacity.

In this context, director network stability (DNS) refers to the temporal persistence and robustness of inter-firm board interlocks, reflecting the continuity and reliability of inter-organizational relational structures. DNS embodies the firm’s long-term embeddedness within the broader corporate network, providing a stable foundation for knowledge exchange, resource coordination, and the transfer of legitimacy across firms.

According to social network embeddedness theory [43], embeddedness can be divided into relational embeddedness and structural embeddedness. The former emphasizes trust, reciprocity, and cooperative relationships formed through repeated interactions,

whereas the latter focuses on the configuration of an actor's position within the broader network structure.

On the one hand, based on structural embeddedness, the degree of closure and openness of a stable network may lead to different innovation outcomes. Excessive stability can generate information redundancy and cognitive lock-in. Rodan and Galunic [44] argue that stable relationships tend to produce overlapping information and redundancy, creating inertia or path dependence that constrains access to non-redundant (heterogeneous) knowledge, thereby reducing firms' innovative capacity. Abernethy et al. further demonstrate that the flow of heterogeneous resources available through stable ties declines over time; as redundancy accumulates, the resource advantages derived from director network stability are likely to diminish [35]. From this perspective, excessive network stability may indeed hinder corporate green innovation performance.

On the other hand, from the perspective of relational embeddedness, long-term stable relationships cultivate trust and cooperation, which play a crucial role in fostering green innovation. A long-term stable director network not only signals close cooperation among firms but also provides substantial informational and resource advantages in the process of green innovation. First, stability implies the existence of strong and trusted ties between firms and their partners. Such ties are typically associated with frequent communication, deep cooperation, and shared values, enabling firms to access greater social capital [45]. On the basis of trust and reciprocity, firms are more willing to share critical green technologies and managerial practices, thereby obtaining high-quality information and knowledge more efficiently [46]. Timely access to such high-quality knowledge is vital for green innovation, as it supports firms in maintaining a competitive edge in technological R&D and the strategic deployment of green projects [47]. Second, long-term stable partnerships can significantly reduce transaction and coordination costs associated with repeated contracting and bidding [48]. They also generate economies of scale and lower the costs of information collection and verification for each transaction [49]. As a result, firms can allocate more financial and managerial resources to green innovation activities, thereby enhancing both the quantity and speed of green innovation outputs. Third, the trust mechanisms embedded in strong and stable relationships effectively suppress opportunism and moral hazard [50]. In stable cooperative networks, firms that violate established norms risk losing important partners and substantial orders, imposing high penalties on opportunistic behavior. Such constraints ensure the longevity and regularity of cooperation. For green innovation, this means lower uncertainty and smoother collaboration in the transfer of resources and technologies, ensuring the efficient flow of green resources and knowledge across firms [51]. Finally, from both the "quantity" and "quality" dimensions of green innovation, director network stability not only provides firms with continuous and reliable sources of information and knowledge but also creates a stable external environment by reducing transaction costs and uncertainties. This environment enables firms to accelerate green technology development and diffusion while ensuring that innovation outcomes carry higher market value and sustainability.

In summary, director network stability shapes corporate green innovation through two opposing yet interrelated mechanisms. While excessive structural stability may generate information redundancy and constrain exploratory learning, relational stability fosters trust-based cooperation, reduces coordination costs, and ensures reliable access to green resources and knowledge. In emerging market contexts characterized by resource scarcity and institutional uncertainty, the relational benefits of stability are likely to outweigh its potential structural drawbacks. Firms embedded in stable director networks can thus sustain long-term collaboration, gain consistent access to external green technologies and policy information, and improve the efficiency and effectiveness of green innovation activities.

Based on the above theoretical analysis, this paper proposes Hypothesis H1:

Hypothesis H1: *Director network stability significantly enhances corporate green innovation.*

2.2. The Moderating Role of Director Network Position

Director network position reflects the degree of a firm's embeddedness and structural characteristics within a broader social relationship network, and it is typically measured by centrality indicators [52]. Firms with high centrality maintain connections with a larger number of partners, enabling them to access more heterogeneous information and technologies, accumulate rich industry experience, and capture the latest market dynamics. The aggregation of such knowledge and resources creates a broad resource pool for green innovation [52,53]. Moreover, firms located at the center of networks are closer to other core nodes, holding key green resources and technological channels within the industry, which gives them strong attractiveness and influence over other firms. This control over resources and information not only enhances firms' ability to identify high-quality partners but also makes it easier for them to collaborate with environmentally reputable and resource-abundant partners to overcome innovation bottlenecks, thereby promoting high-quality green innovation [54].

In pursuing green technological innovation, firms often face challenges such as technological barriers, regulatory pressures, market volatility, and resource constraints [55]. Resource dependence theory suggests that successful green innovation cannot be achieved without external resource support [56]. Although long-term stable director networks can provide firms with low-cost information and knowledge, their effectiveness may be constrained by information asymmetry and communication barriers [57]. When firms simultaneously occupy more central positions within networks, such structural advantages can significantly alleviate these constraints. On the one hand, highly central firms can acquire green knowledge and information more quickly and extensively, thereby improving the timeliness and accuracy of strategic decision-making [32,58,59]. On the other hand, central firms can leverage their authority and coordinating power within the network to integrate technologies, funding, and cooperation opportunities from diverse nodes, thereby maximizing the positive impact of director network stability on green innovation [60,61]. In addition, when director network stability is relatively low, high centrality helps broaden channels for resource acquisition, mitigating the adverse effects of insufficient stability on innovation [62]. Conversely, when stability is high, centrality further enhances the likelihood of accessing heterogeneous resources and facilitates the recombination of innovative elements, thereby improving green innovation performance [63]. Based on the above theoretical analysis, this paper proposes Hypothesis H2:

Hypothesis H2: *Director network position positively moderates the relationship between director network stability and corporate green innovation.*

2.3. The Moderating Role of Media Attention

As a major channel through which the public acquires information, news media play an important role in reducing information asymmetry between firms and external stakeholders, and serve as a critical external supervisory force in modern corporate governance [64]. In the field of environmental governance, the media not only raise public awareness of environmental issues, but also urges enterprises to improve environmental performance and adopt greener strategies through the pressure of public opinion [65–67]. Against this backdrop, continuous media attention to firms' environmental behaviors has gradually evolved into an informal institutional constraint, generating additional social pressure [68]. From the perspective of institutional economics, media discourse can be re-

garded as an informal institutional arrangement that shapes public perception and thereby influences corporate behavior. The monitoring hypothesis posits that media coverage generates external monitoring effects, enhances corporate transparency, and constrains firms' behavioral choices. Meanwhile, signaling theory emphasizes that, when faced with media scrutiny, firms are incentivized to disclose high-quality environmental information as a positive signal to the market in order to establish a favorable reputation [69].

Director network stability essentially reflects long-term and enduring interlocking relationships among firms. Such stable connections not only foster trust mechanisms but also facilitate the effective sharing of environmental experiences, technologies, and knowledge. When media attention is high, the informational and resource advantages derived from network stability are further amplified: media pressure compels firms to place greater emphasis on green image-building and innovation outcomes, while stable inter-director ties strengthen the motivation for resource integration and the implementation of green projects. Empirical evidence shows that media disclosure of environmental information effectively motivates firms to increase environmental investment [70,71] and enhances green technology innovation outputs [72]. Based on the above theoretical analysis, this paper proposes Hypothesis H3:

Hypothesis H3: *Media attention positively moderates the relationship between director network stability and corporate green innovation.*

Figure 1 illustrates the integrated theoretical framework that reconciles the competing perspectives on the role of director network stability (DNS) in shaping corporate green innovation (GI). Prior studies suggest two opposing mechanisms: a facilitating mechanism, through which stable interlocking relationships foster trust, coordination efficiency, and reliable access to green knowledge and resources; and a constraining mechanism, whereby excessive stability may generate information redundancy, cognitive lock-in, and reduced exposure to novel ideas. This study acknowledges both perspectives but argues that, within the context of China's emerging market—characterized by environmental uncertainty and relational governance—the facilitating effects of DNS dominate. Accordingly, Hypothesis H1 proposes a positive relationship between DNS and GI. Moreover, this effect is expected to vary by context: director network position (H2) strengthens the access to diverse knowledge and mitigates over embeddedness, while media attention (H3) amplifies the reputational and monitoring effects that enhance green innovation outcomes. By integrating these dual perspectives but emphasizing the net positive pathway, this framework provides a more comprehensive and context-sensitive theoretical explanation of how director network stability promotes sustainability-oriented innovation.

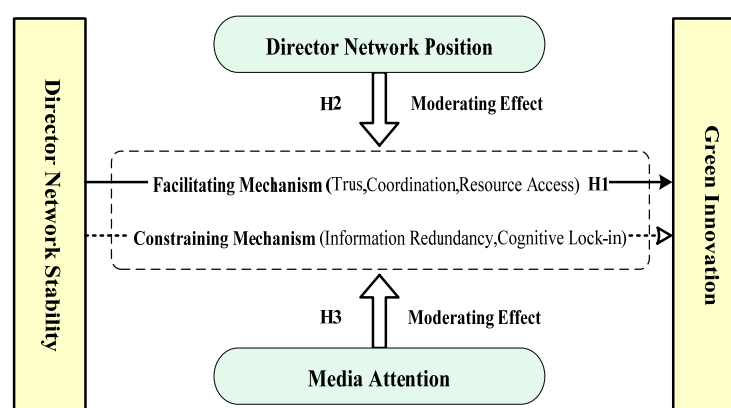


Figure 1. Theoretical framework diagram.

3. Data and Methodology

3.1. Data and Sample Selection

This study focuses on Chinese A-share listed companies from 2009 to 2023 as the research sample. Data on corporate green innovation and media coverage were obtained from the China Research Data Service Platform (CNRDS). Information on directors' appointments was collected from the "Company Profile" series in the CSMAR database and the "Executive Profile" database in WIND. Based on company codes and director IDs, we constructed the director network. Financial indicators and other firm characteristics were also sourced from the CSMAR database. To ensure the representativeness and reliability of the sample, the following data screening and processing procedures were applied: (1) excluding companies in the financial industry as well as firms marked with ST or *ST status; (2) removing firms with missing data during the sample period; and (3) winsorizing all continuous variables at the 1% and 99% levels to mitigate the influence of extreme values. After these steps, we obtained an unbalanced panel dataset comprising 5075 firms, with a total of 43,696 firm-year observations. Data processing and analysis were primarily conducted using Python 3.9 and Stata 17.1. The construction and analysis of the director network were implemented using the NetworkX package in Python.

3.2. Variable Measurement

3.2.1. Dependent Variable

The dependent variable in this study is corporate green innovation (GI). Following the method of Yan et al. (2024) [73], we measure firms' green innovation by the number of green patent applications filed by each firm in a given year. Each patent application contains an International Patent Classification (IPC) code, which enables the identification of detailed technological subfields. Based on the Green Technology List published by the World Intellectual Property Organization (WIPO), we identify and count all patents that fall under green technology classifications. The total number of green patent applications includes both green invention patents and green utility model patents, which together capture the overall output of a firm's green technological innovation. To reduce skewness and improve comparability across firms, we take the natural logarithm of one plus the total number of green patent applications. However, recognizing that patent applications alone may not fully reflect the technological impact and practical outcomes of green innovation, we further introduce two alternative indicators in the robustness tests: (1) the number of green patents granted to each firm, which reflects the realization of innovation output, and (2) the number of citations to green invention patents, which captures the academic and technological influence of innovation. These complementary indicators strengthen the validity and robustness of our measurement of corporate green innovation.

3.2.2. Independent Variable

The independent variable in this study is the stability of the director network (Stab). First, information on directors' appointments in listed companies was obtained from the CSMAR and WIND databases. Using company codes and director IDs, a "company-director" two-mode matrix was constructed. Following prior studies [74–76], the two-mode projection method in social network analysis was applied to convert the company-director two-mode network into a company-company one-mode network (as shown in Figure 2).

This study constructs an interlocking directorate network based on annual board linkages among firms. Each firm is represented as a node, and an undirected edge is established between two firms if they share at least one director in a given year, thereby forming an inter-firm director network. Unlike previous studies that primarily rely on static structural indicators (e.g., centrality, density) to describe network characteristics, this

study adopts a dynamic network perspective and employs a mobility-based measurement approach, taking the persistence of inter-firm relationships as the core indicator of director network stability. Specifically, we introduce a network mobility measurement framework that tracks the formation, dissolution, and duration of edges within the network, with edge persistence serving as the central measure of stability. Edge persistence refers to the length of time that a specific edge remains in the network, reflecting the durability of inter-firm connections. Short-lived edges typically indicate temporary or informal relationships, whereas long-lived edges are more likely to represent stable and enduring cooperative ties. In the empirical measurement, the time window is set at the annual level. For each firm in the sample, the average duration of all edges associated with that firm's node is calculated to obtain its director network stability value. In other words, a firm's director network stability is measured by the mean existence time of all its board linkages.

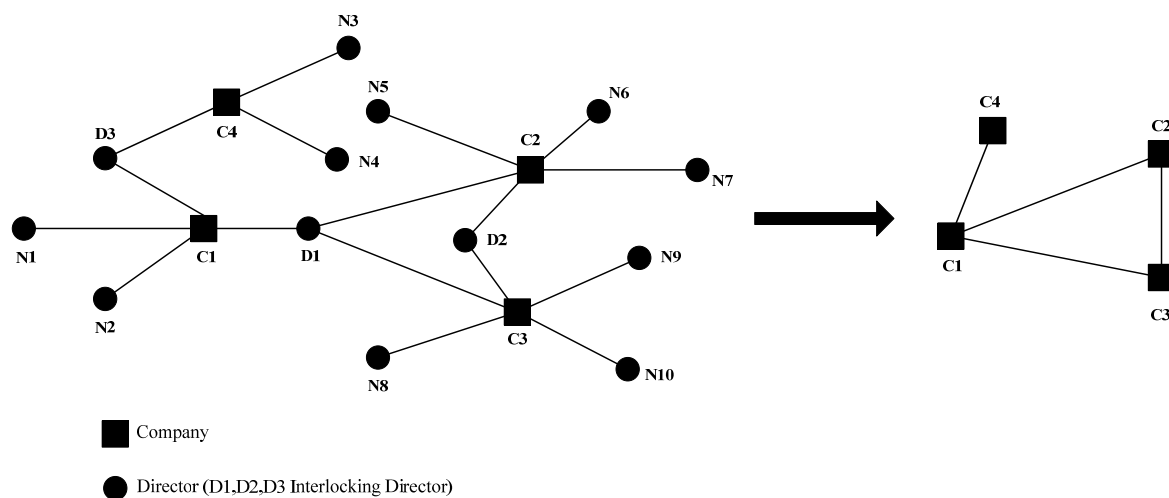


Figure 2. "Company-to-company" model director network.

This edge persistence-based dynamic indicator effectively distinguishes between short-term and long-term relationships, providing a more accurate depiction of a firm's long-term embeddedness in the director network. Compared with traditional stability measures that only consider year-to-year edge changes, this approach offers a more comprehensive representation of the dynamic evolution of director networks. It captures not only whether a relationship exists, but also whether it can be sustained over time, which is theoretically linked to trust accumulation, coordination efficiency, and information reliability among firms.

3.2.3. Moderation Variables

This study introduces two moderating variables: director network position (Centrality) and media attention (Media) to explore how the static network structure characteristics of enterprises and external media supervision regulate the impact of director network stability on corporate green innovation.

(1) Director Network Position

Based on the "company-company" one-mode network constructed above, this paper measures the location of the director network. Specifically, Degree centrality is used as a measure. Degree centrality is a static network index, which is used to reflect the degree of direct connection of a node in the network. Its calculation formula is:

$$C_D(i) = \sum_{j=1}^n x_{ij} \quad (1)$$

Among them, $C_D(i)$: the degree centrality of the node; n : total number of nodes in the network; x_{ij} : if there is an edge (connection) between nodes, then $x_{ij} = 1$; otherwise $x_{ij} = 0$.

In the research context of this paper, network nodes represent companies. When two companies share at least one director, a link is established between them. The higher the centrality value of the degree, the higher the centrality value of the degree, indicating that the company has a interlocking director relationship with more other companies, is in a more active and critical position in the network, and has access to more information and resources. This paper calculates the degree centrality value of each company node at the annual level and uses it as the measurement result of the director network position.

(2) Media Attention

Following existing literature, media attention is measured by the number of news reports on target firms retrieved through online news search engines. In this study, we employ the “Newspaper Media Coverage” indicator provided by the China Research Data Services Platform (CNRDS) to capture the intensity of media attention received by sample firms during the study period. Specifically, this indicator is calculated by counting the total number of news headlines in mainstream newspapers that mention the firm’s name within a given year. To smooth the data distribution and avoid the influence of zero values, the total count is transformed by adding 1 and then taking the natural logarithm.

3.2.4. Control Variables

To mitigate the potential influence of confounding factors, this study incorporates several control variables commonly used in previous literature. Specifically, return on assets (Roa) measures firm profitability; board size (Board) represents the total number of board members; enterprise age (Age) is calculated as the number of years since the firm’s establishment; company size (Size) is measured by the natural logarithm of total assets at the end of the year. leverage ratio (Lev) reflects the level of financial leverage. state ownership (SOE) is a dummy variable equal to 1 for state-owned enterprises and 0 otherwise. institutional investor ownership (Indsh) represents the shareholding ratio of institutional investors at year-end. ownership concentration (Top1) is measured by the shareholding ratio of the largest shareholder. CEO duality (Dual) is a dummy variable equal to 1 if the CEO also serves as the board chair, and 0 otherwise.

In addition, industry dummy variables (Ind) and year dummy variables (Year) are included to control for unobservable heterogeneity associated with industry characteristics and macroeconomic conditions. Detailed definitions and descriptions of these variables are presented in Table 1.

Table 1. Definition of variables with the measurement methods for each statistical variable.

Type	Name	Symbol	Definitions
Dependent Variable	Green Innovation	GI	Log of 1 plus the sum of green invention patents and green utility model patents independently applied for by the firm in a given year.
Independent Variable	Director network stability	Stab	Log of 1 plus the average duration of all edges associated with the firm’s node.
Moderator Variable	Director Network Position	Centrality	Firm’s degree centrality within the director network.
	Media Attention	Media	Log of 1 plus the total number of news headlines in mainstream newspapers containing the firm’s name.

Table 1. Cont.

Type	Name	Symbol	Definitions
Control Variable	Return on Assets	Roa	Ratio of net profit to average total assets.
	Board Size	Board	Total number of board members.
	Enterprise Age	Age	The number of years from the firm's establishment to the observation year.
	Company Size	Size	The natural logarithm of the company's total assets.
	Leverage Ratio	Lev	The ratio of total liabilities at the end of the year to total assets at the end of the year.
	State Ownership	SOE	The value of state-owned enterprises is 1, and the value of non-state-owned enterprises is 0.
	Institutional Investor Ownership	Indsh	Shareholding ratio of institutional investors at year-end.
	Ownership Concentration	Top 1	Largest shareholder's shareholding ratio at year-end.
	CEO duality	Dual	A dummy variable equal to 1 if the CEO and board chair are the same person.
	Industry Dummy Variables	Ind	A set of dummy variables for industry classification.
	Year Dummy Variables	Year	A set of dummy variables for each year to control for time effects.

3.3. Model Setting

3.3.1. Basic Regression Model

In order to empirically test the impact of director network stability on corporate green innovation, this paper constructs the following benchmark regression model (Model 2) to verify Hypothesis H1:

$$GreenInnov_{i,t} = \alpha_0 + \alpha_1 Stab_{i,t} + \sum \alpha_k Controls_{i,t} + \alpha_m Year + \alpha_n Ind + \varepsilon_{i,t} \quad (2)$$

In the equation, the firm is indexed by i while the year by t . Controls are control variables and ε is a random perturbation term.

3.3.2. Modelling the Moderating Effects of Director Network Position

In this section, Model (3) is used to test the moderating role of director network position in the relationship between director network stability and corporate green innovation, so as to verify Hypothesis H2:

$$GreenInnov_{i,t} = \alpha_0 + \alpha_1 Stab_{i,t} + \alpha_2 Centrality_{i,t} + \alpha_3 Stab_{i,t} \times Centrality_{i,t} + \sum_k \alpha_k Controls_{i,t} + \alpha_m Year + \alpha_n Ind + \varepsilon_{i,t} \quad (3)$$

3.3.3. Modelling the Moderating Effects of Media Attention

Model (4) is used to test the moderating role of media attention in the relationship between director network stability and corporate green innovation, so as to verify Hypothesis H3:

$$GreenInnov_{i,t} = \alpha_0 + \alpha_1 Stab_{i,t} + \alpha_2 Media_{i,t} + \alpha_3 Stab_{i,t} \times Media_{i,t} + \sum_k \alpha_k Controls_{i,t} + \alpha_m Year + \alpha_n Ind + \varepsilon_{i,t} \quad (4)$$

4. Empirical Analysis

4.1. Descriptive Statistics

Table 2 presents the descriptive statistics of the main variables. The mean value of green innovation (GI) is 0.340, with a maximum of 6.848, indicating that during the sample

period, most firms remained in the early stages of green technology research and patent output, while only a few exhibited outstanding performance in green innovation. This phenomenon may be constrained by factors such as high investment costs, long innovation cycles, and insufficient policy incentives. The mean value of director network stability (Stab) is 4.307, with a minimum of 1 and a maximum of 15, suggesting substantial variation in the stability of director network structures across firms.

Table 2. Results of descriptive statistics.

Variable	N	Mean	Std. Dev.	Min	P25	Median	P75	Max	VIF
GI	43,696	0.340	0.776	0.000	0.000	0.000	0.000	6.848	
Stab	43,696	4.307	2.097	1.000	2.720	4.136	5.688	15.000	1.16
Roa	43,696	0.048	0.095	−4.803	0.025	0.050	0.081	0.831	1.13
Board	43,696	9.000	1.687	5.000	7.000	9.000	9.000	15.000	1.15
Age	43,696	2.920	0.358	0.693	2.708	2.944	3.178	4.248	1.10
Size	43,696	22.117	1.342	14.942	21.245	21.987	22.925	28.644	1.07
Lev	43,696	0.422	0.214	0.007	0.253	0.412	0.576	4.026	1.29
SOE	43,696	0.334	0.474	0.000	0.000	0.000	1.000	1.000	1.44
Indsh	43,696	43.844	24.812	0.000	23.163	45.122	63.847	101.140	1.63
Top 1	43,696	34.120	15.067	0.290	22.510	31.890	44.085	89.990	1.42
Dual	43,696	0.293	0.454	0.000	0.000	0.000	1.000	1.000	1.14
Centrality	43,696	3.582	1.207	0.000	3.219	3.871	4.357	6.061	1.10
Media	43,696	0.366	0.488	0.010	0.086	0.199	0.438	6.610	1.05

Furthermore, as shown in the last column of Table 2, all variance inflation factor (VIF) values are below 5, indicating that there is no serious multicollinearity in the regression models. This suggests that correlations among the variables are unlikely to cause significant bias in the regression estimates, thereby providing a reliable data foundation for subsequent analyses.

4.2. Basic Regression Results

Table 3 presents the baseline regression results examining the impact of director network stability (Stab) on firms' green innovation (GI). Column (1) reports the estimates controlling only for year and industry fixed effects, while Column (2) further incorporates corporate governance and financial characteristics. The coefficient of Stab is 0.057 and statistically significant at the 1% level, indicating that higher director network stability is positively associated with a greater level of corporate green innovation. Economically, a one-standard-deviation increase in director network stability corresponds to approximately a 5.7% increase in green patent output. This finding suggests that persistent inter-firm board connections enhance firms' green innovation capacity and long-term strategic coordination. Overall, the baseline regression results support Hypothesis H1, which posits that greater director network stability increases the likelihood of firms engaging in green innovation activities.

Regarding the control variables, return on assets (ROA), board size (Board), firm size (Size), leverage (Lev), state-owned enterprise status (SOE), institutional ownership (Indsh), and CEO duality (Dual) are all positively and significantly associated with green innovation, suggesting that strong financial performance, sound corporate governance structures, and efficient resource allocation contribute to enhancing green innovation capacity. In contrast, firm age (Age) is significantly and negatively related to green innovation, implying that, compared with younger firms, more mature firms may be subject to path dependence or innovation inertia in pursuing green innovation.

Table 3. The regression results of the impact of director network stability on corporate green innovation.

Variable	GI	GI
	(1)	(2)
Stab	0.082 *** (12.90)	0.057 *** (8.62)
Roa		0.437 *** (12.07)
Board		0.024 *** (9.20)
Age		−0.008 *** (−11.92)
Size		0.001 *** (10.69)
Lev		0.324 *** (17.37)
SOE		0.059 *** (6.35)
Indsh		0.001 *** (7.06)
Top 1		−0.001 (−0.63)
Dual		0.026 *** (3.11)
Year	Control	Control
Industry	Control	Control
Constant	−0.160 (−6.88)	−0.519 (−14.14)
R ²	0.132	0.169
Observations	43,696	43,696

Note: z-statistics are shown in brackets. *** $p < 0.01$.

4.3. Moderation Effect Test

Table 4 presents the impact of director network stability on firms' green innovation under different moderating variables. To test the moderation effects, the models incorporate director network position (Centrality) and media attention (Media) as moderating variables. In Column (1), the interaction term between director network stability and director network position ($\text{Stab} \times \text{Centrality}$) has a coefficient of 0.015, which is significant at the 1% level, indicating that when a firm occupies a more central position in the network, the positive effect of director network stability on green innovation becomes more pronounced. In Column (2), the interaction term between media attention and director network stability ($\text{Stab} \times \text{Media}$) has a coefficient of 0.016, also significant at the 1% level. This suggests that in contexts with stronger external media supervision, the positive effect of director network stability on green innovation is further enhanced. Media attention increases information transparency and strengthens external constraints, thereby amplifying the advantages of stable networks in resource acquisition and transfer. These results provide strong support for the study's hypotheses regarding moderation effects.

Table 4. The moderating effect results of director network position.

Variable	GI	GI
	(1)	(2)
Stab	0.003 (0.23)	0.011 (0.66)
Centrality	−0.005 (−0.78)	
Stab × Centrality	0.015 *** (3.48)	
Media		0.065 *** (8.55)
Stab × Media		0.016 *** (2.99)
Roa	0.430 *** (11.98)	0.297 *** (9.12)
Board	0.022 *** (8.49)	0.019 *** (7.36)
Age	−0.008 *** (−11.92)	−0.007 *** (−11.28)
Size	0.001 *** (10.68)	0.001 *** (8.50)
Lev	0.320 *** (17.20)	0.229 *** (12.75)
SOE	0.056 *** (6.01)	0.058 *** (6.39)
Indsh	0.001 *** (6.80)	0.001 *** (2.53)
Top 1	−0.001 (−0.56)	0.001 (0.53)
Dual	0.025 *** (3.04)	0.022 *** (2.70)
Year	Control	Control
Industry	Control	Control
Constant	−0.473 (−11.79)	−0.671 (−15.81)
R ²	0.170	0.188
Observations	43,696	43,696

Note: z-statistics are shown in brackets. *** $p < 0.01$.

5. Endogeneity and Robustness Test

5.1. Endogeneity Test

To mitigate potential endogeneity concerns in the association between director network stability (DNS) and corporate green innovation (GI), we employ a comprehensive identification strategy that targets different sources of bias. First, we apply instrumental variable two-stage least squares (IV–2SLS) estimation using theoretically justified instruments that capture exogenous variations in DNS, thereby addressing simultaneity, reverse causality, and unobserved confounding. We further incorporate Heckman’s two-step correction procedure to reduce potential sample-selection bias resulting from missing or delisted firms. In addition, lagged dependent and explanatory variable specifications are introduced to ensure that variations in DNS temporally precede changes in GI. This time-lagged design helps to reduce short-run reverse causality and enhances the causal interpretation of the estimated effects. Firm fixed-effects (FE) regressions are also employed to control for unobserved, time-invariant firm heterogeneity, while propensity score matching (PSM) minimizes selection bias on observables by comparing firms with similar characteristics.

Finally, a first-difference (FD) estimator is used to eliminate remaining time-invariant confounders by relating within-firm changes in DNS to changes in GI over time. Collectively, these complementary methods address distinct channels of endogeneity—including reverse causality, omitted variables, and sample-selection bias—and jointly strengthen the causal identification of the relationship between director network stability and corporate green innovation.

- (1) To mitigate potential endogeneity concerns, this study employs the instrumental variable (IV) method and selects director tenure (IV) as an exogenous instrument for director network stability. Director tenure reflects the length of time a director continuously serves within a firm, which is closely related to the formation of stable inter-firm connections, thereby exhibiting a strong correlation with director network stability. At the same time, director tenure is primarily influenced by factors such as individual career planning, health conditions, and corporate personnel arrangements, and is unlikely to have a direct causal relationship with a firm's green innovation output, thus meeting the exogeneity requirement for an instrumental variable. To verify the validity of the instrument, a weak instrument test is also conducted. Table 5 reports the regression results for both the first and second stages. In the first-stage regression, the coefficient of director tenure (IV) on director network stability (Stab) is 0.917, and is highly significant at the 1% level, indicating that the instrument has strong relevance to the endogenous variable and satisfies the relevance condition. In the second-stage regression, the coefficient of director network stability is 0.082, and remains significant at the 1% level, suggesting that even after controlling for endogeneity, the positive impact of director network stability on corporate green innovation remains robust, thereby further supporting the research hypothesis of this study.

Considering that director tenure may affect green innovation through unobservable channels (such as director experience and corporate culture), we further adopt the method proposed by Hu et al. [40] and Zeng et al. [77]. This method uses the prediction residuals of director network stability and selects corporate green innovation as the explanatory variable. These residuals are uncorrelated with green innovation and other control variables but are highly correlated with director network stability. Therefore, they are used as instrumental variables in this study. As shown in column (4) of Table 5, director network stability is significantly and positively associated with corporate green innovation at the 1% level, which is consistent with the baseline regression results.

- (2) To further control for potential sample selection bias, this study employs the Heckman two-stage model for regression analysis, with the results reported in columns (5) and (6) of Table 5. Following the methodology of Yan et al. (2024) [73], in the first stage, we construct a dummy variable based on green innovation: if a firm files at least one green patent application in a given year, the variable takes the value of 1; otherwise, it is 0. This dummy variable is used as the dependent variable in the first stage and estimated using a Probit model, from which the inverse Mills ratio (IMR) is calculated to capture potential systematic bias in sample selection. In the second stage, the IMR is included as a control variable in the green innovation model to correct for estimation bias caused by non-random sample selection. As shown in the columns (5) and (6) of Table 5, the first-stage Probit regression results indicate that most variables significantly influence a firm's decision to apply for green patents. The IMR coefficient is 3.871 with a t-value of 14.83, which is positive and significant at the 1% level, suggesting the existence of systematic selection bias in green patent applications. This finding underscores the necessity of applying the Heckman correction method.

The second-stage regression results show that, after controlling for selection bias, the coefficient of director network stability (Stab) remains positive and significant at the 1% level, with its magnitude showing little change compared with the baseline regression results. This further confirms the robustness of the main conclusions.

- (3) To further mitigate potential endogeneity issues between the explanatory variable (Stab) and the dependent variable (GI), this study lags the green innovation variable by one year and employs a lagged dependent variable regression for robustness testing. As shown in column (1) of Table 6, when using lagged green innovation as the dependent variable, the coefficient of director network stability is 0.063 and remains significantly positive at the 1% level. This indicates that even when the observation period for green innovation is shifted one year earlier, the positive effect of director network stability on firms' green innovation remains robust, providing additional validation of the baseline findings from a temporal perspective.

Table 5. Endogeneity test results: Using the instrumental variable approach and Heckman two-stage method.

Variable	IV-2SLS				Heckman	
	(1)	(2)	(3)	(4)	(5)	(6)
	IV	GI	IV	GI	GI	GI
Stab		0.082 *** (10.32)		8.907 *** (11.91)		0.058 *** (8.84)
IV	0.917 *** (347.15)		0.623 *** (11.99)			
Roa	−0.012 (−0.87)	0.436 *** (11.33)	0.005 (0.20)	0.072 (0.3)	1.150 *** (10.83)	4.066 *** (16.18)
Board	0.004 *** (5.24)	0.024 *** (10.86)	0.002 (1.53)	−0.019 (−1.34)	0.05 *** (10.47)	0.175 *** (16.35)
Age	−0.002 *** (−8.23)	−0.008 *** (−12.51)	0.009 *** (10.35)	−0.163 *** (−11.88)	−0.015 *** (−11.05)	−0.054 *** (−16.48)
Size	0.001 (1.34)	0.001 *** (27.53)	0.001 *** (3.18)	−0.001 (−1.32)	0.001 *** (7.11)	0.001 *** (14.36)
Lev	0.027 *** (3.81)	0.312 *** (16.03)	0.235 (9.93)	−3.831 *** (−10.32)	0.636 ** (15.14)	2.272 *** (16.84)
SOE	−0.024 *** (−7.18)	0.055 *** (6.03)	0.083 *** (9.52)	−1.327 *** (−10.2)	0.132 *** (6.64)	0.456 *** (15.69)
Indsh	−0.001 (−0.47)	0.001 *** (6.97)	−0.001 (−0.68)	0.003 *** (2.64)	0.001 ** (2.45)	0.004 *** (15.93)
Top 1	0.001 ** (2.38)	−0.001 (−0.25)	−0.002 *** (−8.01)	0.037 *** (10.35)	0.001 * (1.90)	0.004 *** (9.75)
Dual	−0.007 ** (−2.30)	0.028 *** (3.51)	−0.044 ** (−6.20)	0.891 *** (10.04)	−0.005 (−0.27)	0.017 ** (2.02)
IMR						3.871 *** (14.83)
Year	Control	Control	Control	Control	Control	Control
Industry	Control	Control	Control	Control	Control	Control
Constant	−0.340 (6.54)	−0.544 (−9.40)	0.998 (24.90)	−9.496 (11.31)	−2.550 (16.86)	−11.260 (−15.48)
R ²	0.800	0.169	0.242	0.164	0.157	0.180
Observations	43,696	43,696	43,696	43,696	43,696	43,696

Note: z-statistics are shown in brackets. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Moreover, to further strengthen causal inference, we also employ a two-period lag of the dependent variable as an additional robustness test. As reported in column (2) of

Table 6, the coefficient of Stab remains positive and statistically significant at the 1% level, consistent with the baseline regression results. This suggests that the impact of director network stability on green innovation is not merely a short-term correlation but persists even after controlling for potential reverse causality and temporal dependence, thereby enhancing the causal identification of the study's findings.

Table 6. Endogeneity test results.

Variable	GI	GI	GI	GI	GI
	Lag One Phase	Lag Two Phase	Fixed Effect	PSM	FD
	(1)	(2)	(3)	(4)	(5)
Stab	0.063 *** (7.43)	0.068 *** (7.09)	0.072 *** (30.22)	0.063 *** (7.84)	0.072 *** (7.51)
Roa	0.375 *** (10.36)	0.285 *** (7.83)	0.011 *** (5.67)	0.465 *** (10.84)	0.05 * (1.67)
Board	0.023 *** (8.11)	0.020 *** (6.85)	0.000 (0.68)	0.025 *** (8.60)	0.001 (0.77)
Age	−0.007 *** (−9.87)	−0.007 *** (−9.10)	−0.002 *** (−13.32)	−0.008 *** (−11.19)	0.001 (−0.49)
Size	0.001 *** (10.90)	0.001 *** (11.27)	−0.001 *** (−3.43)	0.001 *** (10.32)	0.001 (−1.13)
Lev	0.340 *** (16.77)	0.316 *** (14.94)	−0.000 *** (−5.85)	0.317 *** (15.30)	−0.006 (−0.37)
SOE	0.060 *** (6.04)	0.061 *** (5.95)	0.005 *** (17.13)	0.063 *** (6.33)	0.012 * (1.72)
Indsh	0.001 *** (6.48)	0.001 *** (5.15)	0.030 *** (36.99)	0.001 *** (6.91)	0.001 (0.61)
Top 1	−0.001 (−1.04)	−0.001 (−0.68)	−0.112 *** (−21.30)	−0.001 (−0.72)	0.001 (−0.09)
Dual	0.025 *** (2.76)	0.020 ** (2.11)	−0.001 *** (−7.25)	0.026 *** (2.62)	−0.002 (−0.37)
Year	Control	Control	Control	Control	Control
Industry	Control	Control		Control	Control
Firm			Control		
Constant	−0.535 (−13.52)	−0.490 (−11.66)	−0.322 (−5.84)	−0.578 (−14.28)	−0.004 (−0.08)
R ²	0.177	0.179	0.160	0.179	0.100
Observations	37,630	33,075	43,696	35,314	37,630

Note: t-statistics are shown in brackets. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

- (4) To effectively control for potential omitted variable bias, this study adopts a firm fixed-effects regression model. According to the results reported in column (3) of Table 6, the coefficient of director network stability (Stab) is 0.072 and is significant at the 1% level. This suggests that even after controlling for unobservable, time-invariant firm-specific effects, the positive impact of director network stability on green innovation remains robust, thereby further confirming the validity of the research hypothesis.
- (5) To address potential endogeneity problems caused by sample self-selection, this study further employs the Propensity Score Matching (PSM) method for robustness testing. The procedure is as follows: First, the annual median value of director network stability (Stab) is used as the threshold to divide the sample into a treatment group (stability above the median) and a control group (stability below the median). Second, nine covariates—return on assets (Roa), board size (Board), firm age (Age), firm size (Size), leverage (Lev), state ownership (SOE), institutional shareholding ratio (Indsh), largest shareholder's ownership (Top1), and CEO duality (Dual)—are selected. With

a caliper of 0.05, a 1:1 nearest-neighbor matching method with replacement is applied to match treatment group firms with control group firms of similar characteristics. Finally, the matched sample is re-estimated. The results in column (4) of Table 6 show that the coefficient of the key explanatory variable *Stab* is 0.063 and remains significant at the 1% level. This indicates that after effectively controlling for sample self-selection bias, the positive effect of director network stability on firms' green innovation remains robust, further confirming the reliability and robustness of the study's conclusions.

- (6) To further purge time-invariant firm-specific heterogeneity, we estimate a first-difference (FD) specification. As reported in Table 6, column (5), the coefficient on *Stab* is 0.072 and positive at the 1% significance level, indicating that the association between director network stability and green innovation persists under the FD design. The estimates are consistent with the baseline results, suggesting that our conclusions remain robust after leaving out time-invariant unobservables.

5.2. Robustness Test

- (1) Given the limitations of measuring corporate green innovation solely by the number of green patent applications, we employ two alternative indicators for robustness testing, following prior studies [78,79]. First, to capture the academic and technological impact of green innovation, we use the number of citations to green invention patents: *GI1* is defined as the natural logarithm of 1 plus the number of citations, in year *t*, to the firm's independently obtained green invention patents. Second, to reflect a broader scope of innovative output, we use the total number of independently obtained green patents: *GI2* is defined as the natural logarithm of 1 plus the number of green patents (including invention, utility model, and design patents) independently obtained by the firm in year *t*. The corresponding regression results are reported in Table 7, which remain consistent with the baseline findings and further support the robustness of the study's conclusions.
- (2) To further verify the robustness of the findings, we conduct a robustness examine by replacing the key explanatory variable. Following Kumar and Zaheer [32], we redefine director network stability (*Stab1*) as the degree to which a firm's board network remains unchanged relative to the previous year. This measure captures the dynamic persistence of interlocking director ties by considering both newly added and exited interlocking firms. The calculation is expressed as follows:

$$Stab1 = 1 - \frac{X_{ia} + X_{il}}{X_{it}} \quad (5)$$

where X_{ia} denotes the number of newly added interlocking firms for firm *i* in year *t* compared with *t* − 1, X_{il} represents the number of interlocking firms that exited during the same period, and X_{it} is the total number of non-duplicated interlocking firms maintained between *t* − 1 and *t*. A smaller network churn implies greater network stability. The regression results based on this alternative measure remain consistent with the baseline estimates, providing further evidence of the robustness of our conclusions.

Table 8 reports the regression results using *Stab1* as an alternative explanatory variable. As shown in column (1), the results are consistent with the baseline estimates, indicating that director network stability remains positively associated with corporate green innovation. Column (2) also confirms the moderating effect of network centrality, with direction and significance levels similar to the previous findings. However, in column (3), the moderating effect of media attention becomes insignificant. A plausible explanation is that this

alternative measure of stability captures only short-term network changes between two consecutive periods, rather than the long-term persistence of director interlocks. Given that media supervision often exerts a cumulative and long-lasting influence, short-term variations in network stability may fail to adequately reflect its moderating role, resulting in reduced statistical significance. Overall, except for the media interaction term, the results remain consistent with the baseline analysis, further confirming the robustness of the study's conclusions.

Table 7. Robustness test results: Alternative measurement of the dependent variable.

Variable	GI1			GI2		
	(1)	(2)	(3)	(4)	(5)	(6)
Stab	10.062 *** (3.97)	−2.489 (−0.38)	−4.474 (−1.47)	0.160 *** (12.97)	0.065 ** (2.04)	0.122 *** (8.32)
Centrality		−1.114 (−0.43)			−0.001 (−0.10)	
Stab × Centrality		3.527 ** (1.98)			0.026 *** (3.04)	
Media			−5.963 (−0.83)			0.352 *** (10.16)
Stab × Media			38.447 *** (8.25)			0.090 *** (4.00)
Roa	10.312 (0.72)	8.554 (0.60)	−10.42 (−0.73)	0.982 *** (14.12)	0.967 *** (13.89)	0.788 *** (11.43)
Board	2.111 *** (2.62)	1.704 ** (2.09)	1.309 (1.63)	0.055 *** (13.98)	0.051 ** (12.89)	0.047 *** (12.15)
Age	1.128 *** (4.68)	1.128 ** (4.68)	1.185 *** (4.94)	−0.022 *** (−18.56)	−0.021 ** (−18.57)	−0.021 *** (−18.25)
Size	0.001 *** (67.22)	0.001 *** (67.11)	0.001 *** (58.92)	0.001 *** (19.74)	0.001 *** (19.58)	0.001 *** (8.77)
Lev	16.711 *** (2.33)	15.715 ** (2.19)	3.262 (0.45)	0.171 *** (4.95)	0.163 *** (4.67)	0.040 (1.16)
SOE	12.397 *** (3.59)	11.691 *** (3.47)	11.808 *** (3.53)	−0.045 *** (−2.59)	−0.049 *** (−2.97)	−0.048 *** (−2.97)
Indsh	0.101 (1.55)	0.091 (1.38)	−0.013 (−0.19)	0.001 *** (3.60)	0.091 *** (3.21)	0.001 (0.05)
Top 1	−0.037 (−0.36)	−0.032 (−0.32)	0.005 (0.05)	0.003 *** (6.64)	0.003 *** (6.74)	0.004 *** (7.33)
Dual	0.827 (0.28)	0.690 (0.23)	−0.519 (−0.17)	0.037 *** (2.51)	0.035 *** (2.43)	0.026 * (1.85)
Year	Control	Control	Control	Control	Control	Control
Industry	Control	Control	Control	Control	Control	Control
Constant	−85.923 (−4.02)	−75.435 (−3.29)	−71.369 (−3.33)	−0.816 (−7.82)	−0.749 (−6.70)	−0.818 (−7.89)
R ²	0.185	0.186	0.191	0.309	0.310	0.326
Observations	43,696	43,696	43,696	43,696	43,696	43,696

Note: t-statistics are shown in brackets. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Furthermore, to verify the robustness of the measurement of director network stability (DNS), we construct an alternative indicator, Stab2, which measures the logarithm of the number of inter-firm board ties with a persistence duration of three years or longer within the firm–firm director network. This variable captures more enduring and trust-based in-ter-organizational relationships, thereby reflecting a stricter form of network stability. The regression results reported in Table 8 (Columns 4–6) show that the coefficient of Stab2 re-mains significantly positive in the baseline and moderating effect models. Specifically,

Stab2 is positively associated with green innovation (GI) at the 5% significance level, and its interaction terms with network centrality and media attention also exhibit positive and significant effects. These findings are consistent with those based on the original measure, indicating that the main and moderating effects of DNS on GI are robust and theoretically stable across alternative operationalizations.

Table 8. Robustness test results: Alternative measurement of the independent variable.

Variable	GI	GI	GI	GI	GI	GI
	(1)	(2)	(3)	(4)	(5)	(6)
Stab1	0.038 ** (2.21)	−0.092 (−1.28)	0.060 (1.19)			
Stab2				0.023 *** (5.40)	0.003 (0.29)	0.001 (0.09)
Centrality		0.016 (1.64)			0.004 (0.63)	
Stab1/2 × Centrality		0.034 * (1.69)			0.005 ** (2.15)	
Media			0.099 *** (12.19)			0.070 *** (10.02)
Stab1/2 × Media			−0.004 (−0.27)			0.008 ** (2.54)
Roa	0.45 *** (11.68)	0.443 *** (11.57)	0.302 *** (8.75)	0.442 *** (12.21)	0.436 *** (12.13)	0.302 *** (9.26)
Board	0.025 *** (8.87)	0.023 *** (8.1)	0.02 *** (7.12)	0.023 *** (9.04)	0.022 *** (8.4)	0.018 *** (7.18)
Age	−0.006 *** (−9.59)	−0.007 *** (−9.78)	−0.006 *** (−9.05)	−0.007 *** (−11.19)	−0.007 *** (−11.18)	−0.007 *** (−10.55)
Size	0.001 *** (10.48)	0.001 *** (10.51)	0.001 *** (8.19)	0.001 *** (10.73)	0.001 *** (10.72)	0.001 *** (8.61)
Lev	0.358 *** (17.76)	0.351 *** (17.49)	0.257 *** (13.31)	0.332 *** (17.74)	0.329 *** (17.59)	0.237 *** (13.12)
SOE	0.069 *** (7.02)	0.066 *** (6.64)	0.071 *** (7.28)	0.062 *** (6.65)	0.059 *** (6.33)	0.061 *** (6.66)
Indsh	0.001 *** (6.48)	0.001 *** (6.06)	0.001 * (1.91)	0.001 *** (6.99)	0.001 *** (6.72)	0.001 ** (2.49)
Top 1	−0.001 (−1.04)	−0.001 (−0.88)	0.001 (−0.05)	−0.001 (−1.03)	−0.001 (−0.97)	0.001 (0.11)
Dual	0.02 ** (2.27)	0.021 ** (2.33)	0.016 * (1.85)	0.024 *** (2.87)	0.023 *** (2.79)	0.020 ** (2.47)
Year	Control	Control	Control	Control	Control	Control
Industry	Control	Control	Control	Control	Control	Control
Constant	−0.463 (−11.69)	−0.487 (−9.64)	−0.728 (−15.65)	−0.497 (−13.57)	−0.668 (−16.07)	−0.481 (−12.06)
Pseudo R ²	0.169	0.170	0.188	0.169	0.187	0.169
Observations	39,317	39,317	39,317	43,696	43,696	43,696

Note: t-statistics are shown in brackets. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

- (3) To further validate the robustness of the regression results, this paper replaced the measurement method of the moderator variable. We measure director network position using degree centrality in the “director -to- director” model director network and Media attention is measured by the total number of online news reports containing the company’s name. The regression results (columns (1) and (2) in Table 9) remain consistent with the baseline moderation findings.

Table 9. Robustness Test Results: Alternative Measures of Moderating Variables.

Variable	GI (1)	GI (2)	GI (3)	GI (4)	GI (5)	GI (6)
Stab	0.012 (0.67)	−0.043 (−1.05)	0.004 (0.28)	0.040 *** (3.67)	−0.048 (−1.63)	−0.013 (−0.53)
Degree	0.001 (0.40)					
Stab × Degree	0.002 ** (2.34)					
Media		0.084 *** (7.34)	0.060 *** (6.85)	0.074 *** (7.97)	0.083 *** (7.71)	0.070 *** (7.07)
Stab × Media		0.018 ** (2.26)	0.020 *** (3.35)	0.013 ** (2.01)	0.024 *** (3.19)	0.020 *** (2.84)
Roa	0.434 *** (12.02)	0.458 *** (9.15)	0.379 *** (7.56)	0.369 *** (10.66)	0.287 *** (5.64)	0.427 *** (11.71)
Board	0.019 *** (7.14)	0.018 *** (7.03)	0.016 *** (6.24)	0.021 *** (8.11)	0.016 *** (6.52)	0.021 *** (8.39)
Age	−0.008 *** (−12.02)	−0.007 *** (−10.74)	−0.007 *** (−10.7)	−0.008 *** (−11.67)	−0.007 *** (−10.26)	−0.007 *** (−11.36)
Size	0.001 *** (10.67)	0.001 *** (12.82)	0.001 *** (12.81)	0.001 *** (8.85)	0.001 *** (12.09)	0.001 *** (8.66)
Lev	0.317 *** (17.07)	0.201 *** (10.47)	0.199 *** (10.41)	0.248 *** (13.61)	0.194 *** (10.16)	0.244 *** (13.37)
SOE	0.055 *** (5.93)	0.076 *** (8.29)	0.055 *** (6.06)	0.061 *** (6.63)	0.071 *** (7.86)	0.072 *** (7.86)
Indsh	0.001 *** (6.68)	0.001 (1.02)	−0.001 (−0.14)	0.001 *** (3.76)	0.001 (0.03)	0.001 *** (4.20)
Top 1	−0.001 (−0.52)	0.001 (1.30)	0.001 (0.51)	0.001 (0.13)	0.001 (1.32)	0.001 (1.08)
Dual	0.024 *** (2.90)	0.017 ** (2.10)	0.019 ** (2.41)	0.022 *** (2.64)	0.016 ** (2.00)	0.02 ** (2.41)
Year	Control	Control	Control	Control	Control	Control
Industry	Control	Control	Control	Control	Control	Control
Constant	−0.441 (−10.68)	−0.744 (−11.12)	−0.515 (−12.87)	−0.613 (−15.84)	−0.621 (−11.58)	−0.662 (−13.54)
R ²	0.170	0.191	0.195	0.182	0.195	0.182
Observations	43,696	43,696	43,696	43,696	43,696	43,696

Note: t-statistics are shown in brackets. *** $p < 0.01$; ** $p < 0.05$.

As a primary intermediary for information dissemination, media coverage plays a crucial role in shaping public attention and perceptions of corporate behavior, and in some cases, negative reporting may even distort public opinion. Considering the heterogeneity of media sentiment, we further divide media attention into positive and negative news coverage to examine whether the emotional tone of media reporting leads to differential effects of director network stability on firms' green innovation. The results are presented in Columns (3)–(6) of Table 9, where Columns (3) and (4) correspond to positive and negative newspaper reports, and Columns (5) and (6) correspond to positive and negative online reports, respectively. The findings show that both positive and negative media coverage exert a significant positive moderating effect on the relationship between director network stability and green innovation, all significant at the 1% level. Moreover, the estimated coefficients indicate that the moderating effect of positive media coverage is stronger than that of negative coverage. This suggests that, as a key channel for shaping corporate image and reputation, favorable media reporting enhances firms' environmental reputation and creates reputational incentives, thereby further promoting corporate green technological innovation.

- (4) In order to further verify the robustness of the regression results, this paper draws on the research method of Yan et al. (2024) [72] on the selection of green innovation model,

and uses Poisson pseudo maximum likelihood regression (PPML) model instead of OLS model for estimation. Unlike the traditional Poisson regression, which requires the dependent variable to be count data, PPML relaxes this distributional assumption and only requires the dependent variable to be non-negative [80]. Therefore, it can be widely applied to various non-negative continuous variables, including green innovation (GI).

The regression results are presented in the Table 10. Column (1) reports the baseline regression results, where the coefficient of director network stability (Stab) is 0.185 and is significantly positive at the 1% level, consistent with the main regression results. This finding indicates that director network stability significantly promotes corporate green innovation. Columns (2) and (3) further introduce director network position (Centrality) and media attention (Media), respectively, along with their interaction terms with director network stability. The results show that both interaction terms are significantly positive at the 1% and 5% significance levels, respectively, suggesting that improvements in director network centrality and increased external media attention can further strengthen the positive effect of director network stability on corporate green innovation.

Table 10. Robustness test results: Alternative measurement of the regression model.

Variable	GI	GI	GI
	(1)	(2)	(3)
Stab	0.185 *** (8.85)	−0.021 (−0.38)	0.130 *** (5.48)
Centrality		−0.02 (−0.94)	
Stab × Centrality		0.055 *** (3.72)	
Media			0.370 *** (6.62)
Stab × Media			0.069 ** (2.13)
Roa	1.985 *** (13.39)	1.940 *** (13.09)	1.680 *** (11.83)
Board	0.075 *** (11.07)	0.068 *** (10.01)	0.065 *** (10.22)
Age	−0.024 *** (−12.32)	−0.024 *** (−12.43)	−0.022 *** (−11.63)
Size	0.001 *** (11.15)	0.001 *** (11.70)	0.001 *** (5.35)
Lev	1.156 *** (19.82)	1.140 *** (19.58)	0.936 *** (16.01)
SOE	0.169 *** (6.51)	0.160 *** (5.81)	0.157 *** (5.92)
Indsh	0.004 *** (7.20)	0.003 *** (6.75)	0.002 *** (4.59)
Top 1	0.001 (0.27)	0.001 (0.47)	0.001 (0.80)
Dual	0.095 *** (4.00)	0.093 *** (3.93)	0.064 *** (2.80)
Year	Control	Control	Control
Industry	Control	Control	Control
Constant	−4.901 (−17.86)	−4.714 (−16.72)	−4.860 (−17.72)
Pseudo R ²	0.178	0.179	0.193
Observations	43,635	43,635	43,635

Note: z-statistics are shown in brackets. *** $p < 0.01$; ** $p < 0.05$.

- (5) To further control for potential industry-specific effects on the empirical results, this study restricts the sample to annual observations of manufacturing-listed companies and re-estimates the regression models. The results, presented in columns (1) to (3) of Table 11, show that director network stability (Stab) continues to exert a significant positive effect on corporate green innovation within the manufacturing subsample, remaining robust at the 1% significance level. In columns (2) and (3), after introducing the moderating variables—director network position (Centrality) and media attention (Media)—and their interaction terms with director network stability, the interaction terms are consistently and significantly positive. This finding indicates that the moderating effects are also present in the manufacturing subsample. Therefore, even when restricting the analysis to manufacturing-listed companies, the positive impact of director network stability on corporate green innovation remains robust, further supporting the hypotheses of this study.

Table 11. Robustness test results: Based on Manufacturing Sample and Full Sample.

Variable	GI (1)	GI (2)	GI (3)	GI (4)	GI (5)	GI (6)
Stab	0.046 *** (5.58)	−0.019 (−1.00)	−0.017 (−0.85)	0.061 *** (9.73)	0.002 (0.17)	0.004 (0.25)
Centrality		−0.019 ** (−2.49)			−0.004 (−0.66)	
Stab × Centrality		0.019 *** (3.51)			0.016 *** (3.94)	
Media			0.063 *** (6.59)			0.074 *** (9.11)
Stab × Media			0.023 *** (3.40)			0.019 *** (3.38)
Roa	0.478 *** (9.27)	0.473 *** (9.24)	0.305 *** (6.70)	0.006 *** (0.98)	0.008 (0.96)	0.005 (0.76)
Board	0.031 *** (8.74)	0.030 *** (8.49)	0.026 *** (7.37)	0.019 *** (9.17)	0.024 *** (9.69)	0.020 *** (7.98)
Age	−0.009 *** (−10.53)	−0.009 *** (−10.54)	−0.009 *** (−10.52)	−0.004 *** (−8.64)	−0.007 *** (−11.20)	−0.007 *** (−10.38)
Size	0.001 *** (14.13)	0.001 *** (14.06)	0.001 *** (12.58)	0.001 *** (11.67)	0.001 *** (11.33)	0.001 *** (8.69)
Lev	0.371 (14.46)	0.371 *** (14.49)	0.268 *** (10.85)	0.003 (1.01)	0.004 (0.96)	0.002 (0.64)
SOE	0.043 *** (3.45)	0.043 *** (3.39)	0.043 *** (3.45)	0.071 *** (9.64)	0.063 *** (7.19)	0.063 *** (7.26)
Indsh	0.001 *** (4.87)	0.001 *** (4.80)	0.001 (1.29)	0.001 *** (9.96)	0.001 *** (8.91)	0.001 *** (3.32)
Top 1	−0.001 * (−1.77)	−0.001 * (−1.75)	−0.001 (−0.74)	0.001 * (−1.79)	0.001 (0.01)	0.001 (1.22)
Dual	0.031 *** (3.16)	0.031 *** (3.14)	0.030 *** (3.11)	0.028 *** (4.35)	0.025 *** (3.19)	0.023 *** (2.87)
Year	Control	Control	Control	Control	Control	Control
Industry	Control	Control	Control	Control	Control	Control
Constant	−0.416 (−8.79)	−0.340 (−6.68)	−0.568 (−10.56)	−0.262 (−8.50)	−0.269 (−6.81)	−0.530 (−12.07)
R ²	0.178	0.178	0.196	0.137	0.158	0.183
Observations	43,696	43,696	43,696	47,628	47,628	47,628

Note: z-statistics are shown in brackets. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

- (6) In the baseline analysis, we exclude financial firms and ST/*ST firms to improve estimation stability; however, this may tilt the sample toward healthier firms and potentially overstate the benefits of director network stability. We therefore re-estimate the models using a full sample that includes financial and ST/*ST listed firms. As reported in columns (4) to (6) of Table 11, the results are consistent with the baseline. This confirms that our main conclusion is robust to expanding the analysis to the full sample.
- (7) To eliminate potential interference of the COVID-19 pandemic on corporate green innovation activities, this study excludes sample data from 2020 to 2023 and reconstructs the research sample for the period from 2009 to 2019. The regression results are reported in Table 12. Specifically, the results in Column (1) show that the coefficient of director network stability (Stab) remains significantly positive at the 1% level, indicating that its positive effect on green innovation remains robust after removing the pandemic years. In Columns (2) and (3), moderation variables are added to the model. The results reveal that the coefficient of the interaction term is significantly positive at the 5% level in Column (2) and at the 1% level in Column (3), suggesting that the moderating variables further strengthen the positive impact of director network stability on green innovation. Therefore, even after excluding the influence of the COVID-19 pandemic, the research hypothesis of this paper remains valid.

Table 12. Robustness test results, excluding the impact of the COVID-19 pandemic.

Variable	GI	GI	GI
	(1)	(2)	(3)
Stab	0.050 *** (6.32)	0.012 (0.97)	0.024 (−1.02)
Centrality		−0.001 (−0.18)	
Stab × Centrality		0.009 ** (2.45)	
Media			0.052 *** (5.02)
Stab × Media			0.021 *** (2.97)
Roa	0.381 *** (9.15)	0.281 *** (8.37)	0.261 *** (6.97)
Board	0.024 *** (7.72)	0.017 *** (6.19)	0.019 *** (6.31)
Age	−0.007 *** (−8.83)	−0.004 *** (−6.33)	−0.007 *** (−8.89)
Size	0.001 *** (12.53)	0.001 *** (12.73)	0.001 *** (10.35)
Lev	0.262 *** (12.19)	0.180 *** (10.37)	0.166 *** (7.99)
SOE	0.047 *** (4.39)	0.049 *** (5.44)	0.049 *** (4.59)
Indsh	0.001 *** (4.07)	0.001 *** (4.85)	0.001 (0.99)
Top 1	−0.001 (−0.63)	−0.001 * (−1.87)	0.001 (0.31)
Dual	0.032 *** (3.14)	0.033 *** (3.99)	0.026 *** (2.68)

Table 12. Cont.

Variable	GI	GI	GI
	(1)	(2)	(3)
Year	Control	Control	Control
Industry	Control	Control	Control
Constant	−0.463 (−11.34)	−0.347 (−9.68)	−0.552 (−10.72)
R ²	0.173	0.158	0.190
Observations	27,854	27,854	27,854

Note: z-statistics are shown in brackets. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

6. Further Analysis

6.1. Mediating Effect of Corporate Social Responsibility

In the mechanism through which director network stability influences corporate green innovation, corporate social responsibility (CSR) may play an important mediating role. Existing studies suggest that director networks foster long-term trust relationships and communication channels among firms, enabling them to access external information and best practices regarding social responsibility and sustainable development [51]. Stable and enduring director connections not only facilitate the incorporation of environmental, social, and governance (ESG) concepts into corporate strategy but also enhance firms' awareness of social responsibility [81].

First, director network stability promotes the transmission of CSR-related information and the diffusion of normative practices. Firms embedded in stable networks often maintain long-term interactions with peers that exhibit high CSR performance. Such interactions exert “role-model effects” and encourage “institutional imitation,” thereby influencing firms' CSR strategies and prompting them to increase investments in environmental protection, employee rights, and public welfare initiatives [82].

Second, the fulfillment of CSR helps strengthen firms' relationships with stakeholders while reducing external conflicts and policy risks. High levels of CSR improve corporate reputation capital and social trust, which in turn grant firms advantages in securing resources, gaining policy support, and expanding market opportunities necessary for green innovation [83]. In this process, director network stability indirectly enhances firms' capacity and willingness to pursue green innovation through its positive effect on CSR.

Finally, CSR may support green innovation by improving internal governance structures. Engaging in socially responsible practices requires firms to balance economic and social benefits, encouraging the allocation of greater resources to long-term, development-oriented activities such as green innovation. Taken together, director network stability not only directly influences corporate green innovation but may also exert an indirect effect by enhancing CSR performance, which serves as a key transmission channel.

Following Zou (2018) [84], this study measures CSR quality based on 12 aspects included in the “Basic Information Table of Corporate Social Responsibility Reports of Listed Companies” from the CSMAR database. These 12 dimensions cover the main responsibilities of firms toward stakeholders and reflect the authenticity and standardization of CSR disclosure. Each item is assigned a binary score: a value of 1 if the firm disclosed the relevant information, and 0 otherwise; a value of 1 if the disclosure was verified by a third-party institution, and 0 otherwise. The scores are then summed to obtain a raw CSR score ranging from 0 to 12. To facilitate empirical analysis, the raw scores are standardized by dividing by 12, resulting in a CSR index ranging from 0 to 1, with higher values indicating better CSR quality.

Based on the baseline regression model (2), we further develop models (6) and (7) to test the mediating role of CSR. Specifically, Model (6) uses CSR as the dependent variable to examine the effect of director network stability, while Model (7) incorporates CSR into the green innovation model to evaluate its transmission effect. The set of control variables remains consistent with the baseline model.

$$CSR_{i,t} = \alpha_0 + \alpha_1 Stab_{i,t} + \sum \alpha_k Controls_{i,t} + \alpha_m Year + \alpha_n Ind + \varepsilon_{i,t} \quad (6)$$

$$GreenInnov_{i,t} = \alpha_0 + \alpha_1 Stab_{i,t} + \alpha_2 CSR_{i,t} + \sum \alpha_k Controls_{i,t} + \alpha_m Year + \alpha_n Ind + \varepsilon_{i,t} \quad (7)$$

The regression results are reported in Table 13. Column (1) shows that Stab has a coefficient of 0.043 on CSR, significant at the 1% level, indicating that director network stability enhances CSR performance. In Column (2), after including CSR in the green innovation model, the coefficient of CSR is 0.173 (1% significance), while Stab remains positive and significant (coefficient = 0.050). Furthermore, Sobel and Bootstrap tests are conducted to assess mediation. The Sobel test yields a Z-value of 10.08 ($p = 0$), confirming the significance of the mediating effect. In the Bootstrap test (1000 resamples), the bias-corrected confidence interval is [0.006, 0.008], excluding zero, which further verifies the robustness of the mediation effect. Therefore, director network stability not only directly promotes green innovation but also indirectly enhances it by improving CSR performance, highlighting CSR as a critical transmission mechanism in this relationship.

Table 13. Results of the mediation effect test for CSR.

Variable	CSR	GI
	(1)	(2)
CSR		0.173 *** (12.61)
Stab	0.043 *** (19.50)	0.050 *** (7.50)
Roa	0.178 (12.93)	0.406 *** (11.43)
Board	0.007 *** (9.87)	0.023 *** (8.75)
Age	−0.001 *** (−5.65)	−0.008 *** (−11.62)
Size	0.001 *** (15.45)	0.001 *** (10.34)
Lev	0.046 *** (7.20)	0.316 *** (17.03)
SOE	0.031 *** (10.27)	0.053 *** (5.78)
Indsh	0.001 *** (16.41)	0.001 *** (6.13)
Top 1	−0.001 *** (−2.58)	−0.001 (0.48)
Dual	0.008 *** (3.25)	0.024 *** (2.94)
Year	Control	Control
Industry	Control	Control
Constant	−0.080 (−3.98)	−0.505 (−13.86)
R ²	0.255	0.172
Observations	43,696	43,696

Note: z-statistics are shown in brackets. *** $p < 0.01$.

6.2. Mediating Effect of R&D Investment

In the mechanism through which director network stability influences corporate green innovation, R&D investment may play a crucial mediating role. Unlike general technological innovation, green innovation is typically characterized by high costs, high risks, and long cycles, requiring firms to continuously commit substantial resources in terms of capital, technology, and human talent.

First, stable director networks can promote greater investment in R&D. On the one hand, network stability fosters long-term trust and cooperative mechanisms among firms, reducing monitoring costs and the likelihood of opportunistic behavior while facilitating the sharing of information and resources [85]. Such stable relationships also allow firms facing financial constraints to obtain commercial credit support from partners; moreover, when internal funds are insufficient, partners may provide guarantees or collateral, thereby improving credit ratings and enabling access to bank loans and external financing [86]. This financial support serves as a critical foundation for green R&D activities.

Second, firms embedded in stable director networks enjoy more pronounced advantages in resource acquisition. Leveraging their reputation and influence, such firms are better positioned to attract the attention of external organizations, gain access to green-related information and resources, and secure policy support and targeted subsidies through extensive cooperative networks and close government connections [87–90]. These financing and policy advantages effectively alleviate the shortage of funds for green R&D, ensuring stability and continuity in investment.

Finally, increased R&D investment plays a central role in driving green innovation. On the one hand, sufficient financial input helps firms accumulate green knowledge capital, which can be transformed into productivity through practice, thereby enhancing green technological capabilities [91,92]. On the other hand, greater R&D investment allows firms to introduce new technologies, purchase or upgrade production equipment, and adopt new production and management models, improving the efficiency of resource allocation [93]. Moreover, green R&D investment helps attract more professional talent, which not only strengthens firms' capacity to absorb and apply existing technologies but also fosters the creation of new ones, thereby significantly improving the quality of green innovation [94].

In summary, director network stability enhances firms' ability to access resources and promotes increased R&D investment, which in turn indirectly strengthens green innovation. In other words, R&D investment serves as a critical mediating pathway through which director network stability affects green innovation.

Building on the baseline regression model (2), this study further constructs models (8) and (9) to test the mediating effect of R&D investment. Model (8) employs R&D as the dependent variable to examine the impact of director network stability, while model (9) incorporates R&D into the green innovation framework to investigate its transmission effect. The control variables remain consistent with those in the baseline specification.

$$Investment_{i,t} = \alpha_0 + \alpha_1 Stab_{i,t} + \sum \alpha_k Controls_{i,t} + \alpha_m Year + \alpha_n Ind + \varepsilon_{i,t} \quad (8)$$

$$GreenInnov_{i,t} = \alpha_0 + \alpha_1 Stab_{i,t} + \alpha_2 Investment_{i,t} + \sum \alpha_k Controls_{i,t} + \alpha_m Year + \alpha_n Ind + \varepsilon_{i,t} \quad (9)$$

The regression results are reported in Table 14. Column (1) shows that the coefficient of director network stability (Stab) on R&D investment is 0.396, significant at the 1% level, indicating that stable director networks significantly enhance firms' R&D intensity. Column (2) shows that when R&D investment is included in the green innovation model, the coefficient of the mediating variable is 0.109, also significant at the 1% level, suggesting that R&D investment plays a partial mediating role between director network stability and green innovation. Further statistical tests confirm this finding: the Sobel test yields a Z-value of

22.72 with a p -value of 0, indicating a significant mediating effect, while the Bootstrap test, based on 1000 resamples, produces a Bias-Corrected confidence interval of [0.039, 0.047], which does not include zero, further verifying the robustness of the mediation effect.

Therefore, director network stability not only directly promotes green innovation but also indirectly enhances it through the mediating channel of increased R&D investment, underscoring the pivotal role of R&D in this mechanism.

Table 14. Results of the mediation effect test for investment.

Variable	Investment	GI
	(1)	(2)
Investment		0.109 *** (32.71)
Stab	0.396 *** (32.12)	0.013 * (1.71)
Roa	3.518 (30.93)	0.324 *** (5.66)
Board	0.055 *** (12.41)	0.018 *** (6.01)
Age	−0.007 *** (−5.70)	−0.008 *** (−10.12)
Size	0.001 *** (61.09)	0.001 *** (8.59)
Lev	1.027 ** (24.87)	0.237 *** (10.28)
SOE	0.026 (1.37)	0.058 *** (5.14)
Indsh	0.008 *** (27.27)	−0.001 * (−1.81)
Top 1	−0.002 *** (−4.75)	−0.001 (0.47)
Dual	0.020 (1.57)	0.023 *** (2.59)
Year	Control	Control
Industry	Control	Control
Constant	13.660 (114.36)	−1.967 (−28.71)
R ²	0.481	0.188
Observations	35,884	35,884

Note: z-statistics are shown in brackets. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

7. Conclusions and Implications

7.1. Conclusions

With environmental challenges increasingly threatening human survival, green innovation has become an urgent priority for corporate sustainable development. Given that green innovation represents a major strategic decision at the board level, this study systematically investigates the impact of director network stability on corporate green innovation and its underlying mechanisms. The main findings can be summarized as follows.

First, director network stability significantly promotes corporate green innovation. According to social network embeddedness theory, firms continuously embedded in stable networks are able to establish long-term trust and cooperative norms, thereby reducing opportunism risks and enhancing the efficiency of information and resource flows. Such embeddedness provides sustained knowledge and financial support that facilitates green innovation.

Second, director network position and media attention exert significant moderating effects on the relationship between director network stability and green innovation. Firms located at the center of networks are better positioned to leverage the resource advantages of stable networks, while external media supervision—by enhancing transparency and strengthening external constraints—further amplifies the positive effect of director network stability on green innovation. This finding highlights the importance of network structure and the information environment, and also echoes reputation theory, which emphasizes the role of external monitoring in enhancing reputational capital.

Third, corporate social responsibility (CSR) and R&D investment serve as partial mediators in the relationship between director network stability and green innovation. A stable director network not only directly enhances green innovation but also indirectly strengthens innovation capacity by promoting CSR engagement and increasing R&D investment. This aligns with both social capital theory and resource dependence theory: the former highlights the role of relational networks in the diffusion of norms and value consensus, while the latter underscores the importance of external resource acquisition for corporate innovation strategies. Taken together, these results enrich the theoretical understanding of director networks and green innovation, while providing empirical evidence for optimizing governance structures and external network relationships in the pursuit of green development.

The conclusions should be interpreted within clear boundaries. First, the sample consists of Chinese A-share listed firms, so extrapolation to unlisted or foreign markets should be made with caution. Second, green innovation is measured by patents, which capture technological outputs but may underrepresent non-patent or organizational practices. Third, DNS is operationalized via edge persistence, emphasizing the temporal continuity of ties rather than their strength or quality. Fourth, despite multiple robustness examines, endogeneity concerns cannot be fully ruled out, including unobserved time-varying strategies and selection into stable networks.

In addition, alternative mechanisms may coexist with our preferred interpretation. Firms with stronger governance or greater resource slack may both maintain more stable director ties and invest more in green innovation; conversely, excessive stability may induce information redundancy and path dependence that dampen exploratory green R&D. While our additional analyses mitigate these concerns to some extent, they cannot eliminate them entirely. It is therefore likely that DNS operates jointly with governance quality, resource endowments, industry dynamism, and the regulatory environment, implying that its positive association with green innovation is context-dependent.

Although the empirical analysis is based on Chinese A-share listed firms, the underlying mechanisms may have broader relevance. In China's relationship-based governance environment, director network stability (DNS) facilitates trust building and resource sharing, which are critical for green innovation under institutional uncertainty. However, in more market-oriented or transparent governance systems (e.g., the U.S. or Europe), excessive network stability may generate information redundancy or reduce strategic flexibility, leading to a weaker or even opposite effect. Future research could therefore test the moderating role of institutional transparency or ownership structure across different countries and industries to further evaluate the generalizability of our findings.

From a managerial perspective, our results suggest that firms should maintain an optimal level of director network stability—stable enough to ensure long-term collaboration and resource continuity, but sufficiently dynamic to avoid cognitive lock-in. Regulators and policymakers can promote sustainable innovation by encouraging inter-firm board diversity and transparency in director interlocks, while media institutions play an important role in monitoring excessive embeddedness and promoting open information flows. These

insights provide actionable guidance for balancing relational governance and innovation dynamism in the pursuit of sustainable corporate development.

7.2. Theoretical Contributions

This study makes several theoretical contributions to the literatures on corporate green innovation, corporate governance, and social networks.

First, in contrast to prior work that primarily emphasizes the static structural features of director networks (e.g., centrality, structural holes) [25,26,29], we introduce and theorize a temporal dimension—director network stability, thereby developing a new analytical framework for studying green innovation. Viewing interlocking directorships as long-term, persistent cooperative ties across firms, we underscore the pivotal role of trust accumulation and repeated interactions in green innovation: stable director networks facilitate knowledge sharing and the diffusion of best practices, while enhancing the reliability of resource integration and interorganizational coordination. These conditions reduce uncertainty, improve innovation efficiency, and ultimately foster green outcomes at the implementation stage. This perspective shifts the focus of social embeddedness and resource dependence from structural snapshots of “who is connected to whom” to the dynamic property of “whether ties persist reliably over time,” offering a new lens for understanding how director networks drive firms’ green innovation.

Second, we mechanize and integrate social embeddedness and resource dependence into a testable transmission framework that specifies how director network stability (DNS) shapes firms’ green innovation (GI). DNS operates through two mediating channels enabled by persistent inter-firm interactions: it internalizes CSR awareness and governance—thereby, via reputation and legitimacy, improving policy support and access to external resources for green projects—and it increases R&D investment by reducing coordination and monitoring costs and easing financing constraints, which provides a reliable sequencing and orchestration of resources for long-horizon, high-commitment green R&D. In doing so, we move beyond a static notion of mere “resource access” toward a dynamic account of “reliable access-orchestrated deployment-patentable outcomes.” This contribution translates embeddedness and resource dependence from macro background notions into operational firm-level mechanisms and offers a clear, empirically supported chain—through CSR and R&D—by which DNS drives green innovation.

Third, moving beyond prior work that emphasizes the direct effect of director networks while under-specifying contextual dependence, we incorporate network position (centrality) and media attention into a unified framework and show that both moderate the relationship between director network stability (DNS) and green innovation (GI). Firms located closer to the network core, building on stable ties, can access richer and less redundant knowledge and resources, shorten information paths, and improve interorganizational coordination, thereby converting stability more effectively into patentable green outcomes. Stronger media scrutiny increases transparency and external discipline, amplifies the reputational and legitimacy signals embedded in stable ties, and enhances policy and financing access for green projects. Taken together, these insights provide a more systematic account of the external relational mechanisms that strengthen the effectiveness of director networks in promoting firms’ green innovation.

7.3. Theoretical Reflection on Competing Perspectives and Contradictory Dynamics

Although the empirical results demonstrate that director network stability significantly promotes firms’ green innovation, this relationship is not universally linear or unidirectional. Several competing frameworks and contradictory dynamics merit further discussion.

First, from the perspective of social capital theory, stable director networks enhance inter-firm trust and cooperation, facilitating resource sharing and knowledge exchange that improve green innovation performance. However, excessive stability may also lead to information redundancy and path dependence, limiting firms' ability to absorb new knowledge and access diverse external resources. To address this potential drawback, this study introduces director network centrality as a moderating variable to capture firms' structural advantages within the network. The results show that network centrality significantly strengthens the positive impact of network stability on green innovation, suggesting that firms occupying more central positions can leverage more efficient knowledge flows and resource integration to mitigate the potential downsides of over-stability—thus achieving a dynamic balance between stability and openness.

Second, from the perspective of sample selection and external validity, the exclusion of financial and ST/*ST firms enhances internal consistency but may bias the sample toward financially healthier and better-governed firms, potentially overstating the benefits of network stability. To test this concern, we re-estimate the models using the full sample of all A-share listed firms, including financial and ST/*ST companies. The results remain significantly positive, indicating that our findings are not driven by sample selection and are robust across broader contexts.

Third, from a temporal perspective, the positive effect of director network stability may reflect short-term behavior. Stable board relationships can foster rapid information exchange and coordination, increasing green patent applications in the short term. However, if such effects fail to generate sustained innovation outcomes, the economic implications may be overstated. To verify this, we replace green patent applications with the number of granted green patents and their citation counts, capturing innovation quality and long-term impact. The results remain robust, suggesting that director network stability contributes not only to short-term innovation inputs but also to sustained and impactful innovation outputs.

Finally, considering the dual role of media supervision, the conventional measure of media attention may conflate reputational promotion and substantive monitoring. To address this, we further distinguish between positive and negative media coverage in the robustness analysis. The results show that both types of media reports significantly enhance the positive relationship between network stability and green innovation, and that the interaction term for positive coverage is notably larger than that for negative coverage. This indicates that reputational incentives generated by favorable publicity exert a stronger influence in promoting green innovation. Overall, media attention demonstrates a double-edged nature in corporate environmental governance: positive coverage strengthens firms' motivation for proactive green innovation through reputational incentives, while negative coverage exerts external pressure that drives substantive improvement.

In summary, by incorporating competing theoretical perspectives and contextual reflections, this study reveals that the effect of director network stability on corporate green innovation is bidirectional and context-dependent, offering a more comprehensive understanding of the dynamic complexity underlying corporate governance networks.

7.4. Recommendations

Based on the empirical results, this paper formulates the following recommendations: First, governments and regulators should cultivate an institutional environment that supports transparent, flexible, and sustainable inter-firm networks. Encouraging moderate director mobility and cross-industry exchanges can prevent excessive network closure and improve firms' access to diverse information and green technologies. Policy tools such as inter-firm collaboration platforms and joint R&D initiatives can further reduce coordination

costs and stimulate knowledge spillovers, particularly in regions with limited innovation capacity. Strengthening media oversight and information disclosure is also crucial for reinforcing reputational incentives and ensuring that DNS leads to substantive rather than symbolic green innovation. Moreover, policy design should consider contextual differences in ownership, regional development, and institutional settings, adopting governance approaches tailored to local innovation ecosystems.

Second, firms should strategically manage their board structures and external linkages to balance relational stability with openness. Long-term director relationships help build trust and reduce coordination costs, but boards should also maintain structural diversity by appointing directors from different industries and knowledge domains. Such diversity facilitates the inflow of non-redundant information, enabling firms to pursue more diverse and exploratory green projects. Furthermore, incorporating corporate social responsibility (CSR) awareness and green R&D investment into board-level decision-making can amplify the governance benefits of DNS and align network-based collaboration with long-term sustainability objectives.

Third, managers should adopt a dynamic approach to network management that continuously evaluates and adjusts the efficiency of network stability over time. Regular assessments of whether existing partnerships still provide novel resources can help prevent relational redundancy and sustain innovation vitality. Firms should periodically refresh cooperative ties while preserving trust-based relationships to maintain the optimal balance between stability and openness. Additionally, constructive use of media attention—leveraging positive publicity to enhance stakeholder trust and addressing negative coverage through transparent corrective actions—can strengthen firms' reputational governance and reinforce the innovation benefits derived from stable network relationships.

8. Research Limitations and Future Prospects

Despite these contributions, this study has several limitations that warrant further exploration. First, the sample scope remains limited. By focusing on Chinese A-share listed firms, this study reflects governance characteristics unique to China's institutional and relational context, where interlocking director networks are highly prevalent and formal governance mechanisms are still evolving. This setting provides a valuable environment to test the theoretical mechanisms proposed in this paper. However, given China's distinctive market features—such as strong government intervention, high ownership concentration, and active media oversight—the external validity of the findings in other institutional contexts requires cautious interpretation. Future research could extend the analysis to other emerging and developed economies to conduct cross-national comparisons, verify whether the effects of director network stability persist under different institutional and cultural settings, and assess the boundary conditions for the generalizability of these conclusions. Second, the measurement of variables could be further refined. This study uses the number of green patents to measure green innovation, which is widely adopted but may not fully capture the quality and practical value of innovation. Future studies may incorporate indicators such as citation frequency of green patents or the share of revenue from green products to provide a more comprehensive assessment of innovation outcomes. Third, the exploration of mechanisms remains incomplete. While this study emphasizes the mediating roles of CSR and R&D investment, green innovation is a complex process that may also be influenced by executive incentives, corporate culture, and regulatory intensity. In addition to CSR and R&D, future studies could explore other potential mediating mechanisms such as executive compensation incentives, stakeholder engagement, and institutional pressures. Examining these alternative channels may provide a more comprehensive understanding of how corporate strategies translate into sustainable and socially responsible outcomes.

Future research can use a multi-level theoretical perspective to construct a more systematic framework to explain the mechanism by which director network stability affects corporate green innovation. In conclusion, future research can deepen the understanding of the link between director networks and green innovation by expanding sample scope, refining measurement methods, and exploring additional mechanisms.

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