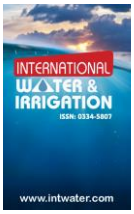

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The Influence of Board Network on Green Innovation Behavior in the Context of Water Risk: Empirical Evidence from High Water- consuming Enterprises

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Abstract: Against the backdrop of escalating water resource crises, water-related risks have emerged as one of the greatest threats facing society at large. How enterprises, particularly high water-consuming ones, cope with water risk has become a focal point of attention. Board networks, which provide as an unofficial governance framework for businesses to get knowledge and resources, are essential for encouraging risk-taking and green innovation among high water-consuming enterprises. Using a sample of 316 high water-consuming companies listed on the Shanghai and Shenzhen stock exchanges from 2010 to 2022, this study empirically examines the impact of board networks on corporate green innovation, exploring the mediating role of risk-taking and the moderating effect of environmental uncertainty. Results indicate a positive relationship between both board network centrality and structural hole richness and green innovation, with structural hole richness showing a more pronounced effect. Risk-taking partially mediates the influence of board networks on green innovation. Regarding the moderating effect of environmental uncertainty, environmental dynamism and complexity intensify the positive impact of board networks on green innovation. This study provides theoretical support and practical evidence for high water-consuming enterprises to improve board selection criteria and facilitate access to resources and reduce agency costs to drive green innovation.

Keywords- High water-consuming companies, board network, corporate green innovation, risk-taking, environmental uncertainty, water risk.

1. Introduction

Since the beginning of human civilization, water has been a vital resource for industry. Thus, sustainable development depends on efficient management of water resources [1]. Three indicators are commonly used to describe water risk, which refers to the uncertainties brought on by crises involving water resources: physical water quantity risk, physical water quality risk, and regulatory and reputational risks [2]. During water resource emergencies, businesses, especially those with high water use, suffer from adverse effects on productivity, reputation, and financial performance since they are big freshwater consumers and substantial contributors to water pollution [3]. Investors, governmental organizations, and customers are growing more worried about how businesses handle water risks and resource management as water resource emergencies worsen. As a result, businesses need to match their strategy to the needs of these stakeholders [4]. Thus, many high water-consuming companies have shifted from passive to proactive and innovative environmental practices, striving to achieve low-energy production, reduce water resource depletion, and comprehensively address water risks.

One of the most important strategic choices for reducing water risks for businesses with high water use is incorporating water resource management into an innovative system that is both green and efficient. Using water-saving technology, preventing pollution, encouraging water efficiency, and reusing wastewater are all examples of corporate green innovation. Businesses may speed up their transition to sustainability by implementing cutting-edge green technology to reinvent their management and production systems, drastically lowering their environmental impact and water usage [5]. The main subjects of current study on the forces behind corporate green innovation include market demand, environmental policy regulation, and a variety of internal issues. However, high water-consuming companies face significant challenges in their green innovation practices due to structural barriers, limited market acceptance, and narrow cooperation models, which hinder their transition to green, water-efficient enterprises [6]. High water users need to break down organizational barriers, build strong

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relationships with other businesses and organizations, and aggressively take advantage of outside innovation resources to improve the efficacy and efficiency of green innovation in order to get over these challenges.

There is still room to improve the current study on the connection between board networks and corporate green innovation. On the one hand, the legitimacy approach has been used to study the impact of board networks primarily in relation to direct economic activities including risk management, capital allocation, and company innovation [7, 8]. However, the importance of board networks in promoting sustainable value creation for high water-consuming companies is not given enough emphasis, especially when it comes to green innovation and effective use of water resources [9]. Woolcock et al. [10] identified the influence of board networks on corporate green innovation, but their research primarily emphasizes the vertical channel effects of board network centrality, neglecting the horizontal characteristics of structural holes and failing to account for differentiated conditions within and outside the firm. This research gap hinders a comprehensive understanding of the dual externalities between board networks and corporate green innovation, thus impeding the sustainable development of firms [10]. On the other side, green innovation is crucial to the green development of businesses that use a lot of water. Internal variables that affect green innovation behaviors connected to water resources receive less attention in the literature on the determinants of green innovation than external market circumstances and environmental regulatory regulations [11]. In actuality, from the standpoint of internal governance, board networks support the green development of high water-consuming companies by addressing the negative environmental externalities linked to these companies, improving the firm's ability to access resources for innovation, improving the oversight of water resource management and utilization efficiency, and providing incentives for companies to adopt more ecologically friendly production methods.

In order to overcome the shortcomings of previous research, this study examines the ways in which board network centrality and structural hole richness influence corporate green innovation using resource dependence theory and a sample of A-share listed high water-consuming businesses from 2010 to 2022. It also investigates the moderating influence of external environmental uncertainty and the mediating role of corporate risk-taking. It provides management insights for the micro-operational decisions of high water-consuming enterprises and offers a theoretical foundation for the optimization and adjustment of government policies related to water resources [12]. Theoretically, this study adds to our knowledge of the forces underpinning green innovation, increases research on the impact of board networks on corporate strategic decisions, and provides references for further research. This study offers a fresh approach for reevaluating the regulatory environment and intensity of green innovation by looking at how environmental uncertainty affects the interaction between board networks and corporate green innovation. It investigates whether high water-consuming enterprises can enhance their ability to acquire green innovation resources in the process of elevating their risk-taking capacity when faced with water risks. This provides a theoretical basis for companies to overcome green innovation resource constraints and achieve sustainable development. Practically, as the uncertain risks induced by the water crisis continue to increase, understanding the mechanism of how board networks impact corporate green innovation is instrumental for high water-consuming enterprises to clarify the strategic advantages of their board networks, identify water risks, and strengthen water resource management. This research can facilitate management in making scientific decisions within corporate governance, enhancing the level of green innovation within enterprises. This helps tackle urgent problems like climate change, advances the larger objectives of economic and social green transitions.

2. Literature Review and Hypotheses Development

2.1 Board Networks and Corporate Green Innovation

A board network is the collective set of linkages formed through interlocking director relationships. A direct relationship is created when two directors are on the same board; an indirect link is created when two directors are not on the same board but share a directorship with a third director. The board network is made up of both direct and indirect linkages [13] and has two dimensions: horizontal structural holes and vertical centrality. Board network centrality reflects a firm's ability to acquire resources and information through its social network position and to influence relevant decisions. It shows where a company stands in the board network, with centrally located companies enjoying better resources and more significant power benefits. Conversely, structural holes are the "gaps" that arise when a business joins forces with unrelated entities. Firms that have a lot of structural holes can take use of information flow control and informational advantages, which will increase their access to resources for innovation and boost the efficiency of green innovation [14].

From the perspective of water resource management, the green transformation and innovation of high water-consuming companies are deeply rooted in the efficient utilization and protection of water resources, a process that depends on the availability of sufficient water resources and related support. The role of the board network in this context is manifested in its ability to provide information and resource linkages, thus alleviating the company's reliance on traditional sources of water acquisition [15]. The contributions of the board are multifaceted: offering advice on water-saving technologies, opening channels for accessing water resource management information, providing operational guidance on water conservation, and prioritizing access to information and resources regarding water resource management and alternative technologies. These efforts reduce water-related risks in corporate operations and help accumulate valuable social capital for the firm. Bjørnskov et al. [16] argue that board networks become a valuable resource for high water-consuming companies' water resource management and value creation because they expand the boundaries of the board's information and resource networks, accelerate the dissemination of knowledge and technologies related to water resource management, reduce the costs of resource allocation, and open up avenues for acquiring external water resources and water-saving technologies. This provides the necessary human, financial, and technical support for the company's green transformation and innovation, ensuring the continued implementation of water-saving and green innovation activities. The more conducive the characteristics of a board network are to the company, the stronger its ability to mobilize and integrate the water resources and related resources needed for the green transformation [17].

Moreover, the board network strengthens the board's supervisory role in water resource management and efficiency, reducing the "cognitive gap" between the company and the public, government, and other stakeholders regarding water resource management information [18]. This enhances the company's ability to promptly capture market opportunities related to water-saving technologies and green innovations, enabling more informed and high-quality decision-making during the green transformation process. Specifically, an increase in the centrality of the board network implies that the company can connect with more partners experienced in water resource management or possessing relevant technologies. Shortened connection paths improve the efficiency of information transmission, making the process of acquiring water-saving technologies and water resource management knowledge from the network smoother. Board network centrality not only reflects the company's influential position within the network but also indicates that centrally positioned firms have access to more green R&D resources and water-saving technologies, thereby driving their green innovation efforts. The number and richness of structural holes that a company occupies within its board network also have a positive impact on the efficiency of its green transformation. The more structural holes a company fills, the more it can access cutting-edge information related to green transformation and water-saving technologies. By leveraging its central position in the network and the informational advantages it holds, the company can more effectively acquire the resources needed for green transformation, accelerate the adoption and innovation of water-saving technologies, and ultimately enhance the efficiency and outcomes of its green transformation. In light of this,the following hypotheses are proposed:

H_{1a}: Board network centrality is positively associated with corporate green innovation.

H_{1b}: The richness of structural holes in the board network is positively associated with corporate green innovation.

2.2 The Relationship between Board Networks, Risk-Taking, and Corporate Green Innovation

Risk-taking refers to a company's willingness and ability to undertake uncertain returns in order to enhance performance and promote high-quality development [19]. A company's level of risk-taking is influenced not only

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by its subjective willingness to take on risk but also by its objective capacity to bear risk. Water risk, as a key component of environmental risk, arises not only from the depletion of available water resources but also from reputational risks associated with environmental mismanagement, such as improper wastewater discharge or misleading water-related disclosures. Regarding risk-taking willingness, executives of high water-consuming companies, in their efforts to safeguard economic interests and operational stability, typically adopt a conservative approach to water resource management. This may result in missed high-risk, high-reward opportunities for cost-saving and environmental benefits through water-saving technological innovations and efficient water use, ultimately harming shareholder interests and impeding the company's value creation. However, the board network plays a critical role in managing water risk for high water-consuming companies by facilitating the flow of water-related information. It helps the board acquire advanced knowledge and management experience regarding water resource management and water-saving technologies [20], thus enhancing the board's ability to oversee water resource use and respond to risks effectively. This facilitates more forward-looking and environmentally responsible decision-making, driving water conservation, emissions reduction, and green innovation. At the same time, the flow of information increases the reputational risks that high water-consuming companies face due to improper water resource management. This encourages the board to place greater emphasis on reputation protection and corporate social responsibility, strengthening its supervision of management in water resource management and encouraging the board to take responsibility for water risk management. This, in turn, reduces management's conservative tendencies regarding water resource use and increases the company's willingness to assume water-related risks, providing strong support for high-risk, long-term beneficial activities such as water conservation, emissions reduction, and green innovation.

From the perspective of risk-bearing capacity, water conservation, emissions reduction, and green innovation projects in high water-consuming companies are often associated with high research and development costs and the risk of technological failure. Additionally, external environmental uncertainties further increase the demands on a company’s ability to bear water risks [21]. However, companies with strong water risk-bearing capacity are more likely to accept the uncertainties associated with water conservation, emissions reduction, and green innovation. These companies are more proactive, inclined to adopt new water resource management technologies, acquire advanced water-saving equipment, and integrate environmental protection resources. As a result, they are better positioned to seize market opportunities, drive innovation in water-saving technologies, and achieve efficient water resource utilization, thereby ensuring their sustainable development.

In summary, the level of risk-taking in high water-consuming companies is influenced by their resource acquisition capabilities. Adequate water resources, advanced water-saving technologies, and environmental protection resources are the objective conditions necessary for companies to assume water-related risks. Without these resources, companies face constraints in water resource utilization. High water-consuming companies located at the center of industry networks, with extensive information channels, are more likely to acquire the various resources required for water conservation, emissions reduction, and green innovation. This, in turn, enhances their risk-bearing capacity, reduces internal agency problems, strengthens the oversight of management, and emphasizes the protection of shareholder interests. Ultimately, this facilitates the efficient use of water resources and drives green innovation. In light of this, the following hypotheses are proposed:

H_{2a}: Risk-taking mediates the relationship between board network centrality and corporate green innovation.

H_{2b}: Risk-taking mediates the relationship between the richness of structural holes in the board network and corporate green innovation.

2.3 The Moderating Role of Environmental Uncertainty

Environmental uncertainty refers to the challenges faced by corporate decision-makers in perceiving and predicting market changes due to limited information and bounded rationality. Currently, the intensifying water resource crisis has increased the resource depletion of high water-consuming companies, and with the rising uncertainty in water resource supply, the pressures on the survival and development of these companies have grown significantly. To ensure the stability of water supply, high water-consuming companies are enhancing their exploration and integration of water resources to improve their adaptability in the water resource environment. These companies leverage advantages in resource allocation, such as those provided by board networks, to drive the transformation and upgrading of their development models through strategies like water conservation, emissions reduction, and green innovation [22]. Specifically, due to the dynamic changes in the water resource environment, competitors are able to rapidly adjust their strategies and enter or exit markets, posing a challenge to high water-consuming companies in maintaining a competitive advantage. Therefore, managers need to continuously update the company's water resource utilization capabilities and related technologies, employing strategies such as water-saving, emissions reduction, and green innovation to enhance the company's competitive edge. High water-consuming companies, through their board networks' resource acquisition capabilities, can effectively utilize the strategic consulting function of the board to promote the transformation towards water conservation, emissions reduction, and green innovation, improving the company's adaptability to changes in the water resource environment [23]. Moreover, as the market environment becomes increasingly complex, formal information channels often fail to meet the timely information exchange needs of high water-consuming companies regarding water resources, which deepens their reliance on the informal information transmission channels provided by the board network. Directors in a dominant position within the board network can access key information about water resource management, water-saving technologies, and investment opportunities earlier than others, thus leveraging their first-mover advantage in resource acquisition to enhance the company's water conservation, emissions reduction, and green innovation efforts.

Resource Dependence Theory posits that organizations are embedded in their environments and rely on these environments to acquire key resources. Given the uncertainty in the supply of water resources, organizations tend to adopt strategies like water conservation, emissions reduction, and green innovation to reduce their dependence on external water resources and improve their survival conditions. In this process, organizations become dependent on external environmental factors, which often attempt to control the organization from outside, thereby weakening the organization's autonomy [24]. However, the board network broadens the pathways through which high water-consuming companies can access resources, helping to reduce their dependence on single water resource channels. As a potential resource, the board network does not reduce uncertainty by controlling other firms; rather, it enables high water-consuming companies in complex water resource environments to develop water resources and technologies, adapt to environmental changes, and generate benefits [25]. When the uncertainty of the water resource environment increases, the centrality and structural hole richness of the board network become even more crucial, amplifying their positive impact on the water conservation, emissions reduction, and green innovation efforts of high water-consuming companies. Based on this, the following hypotheses are proposed:

H_{3a}: Environmental dynamism enhances the positive effect of board network centrality on corporate green innovation.

H_{3b}: Environmental dynamism enhances the positive effect of board network structural hole richness on corporate green innovation.

H_{4a}: Environmental complexity enhances the positive effect of board network centrality on corporate green innovation.

H_{4b}: Environmental complexity enhances the positive effect of board network structural hole richness on corporate green innovation.

The conceptual model constructed for this study is illustrated in Figure 1.

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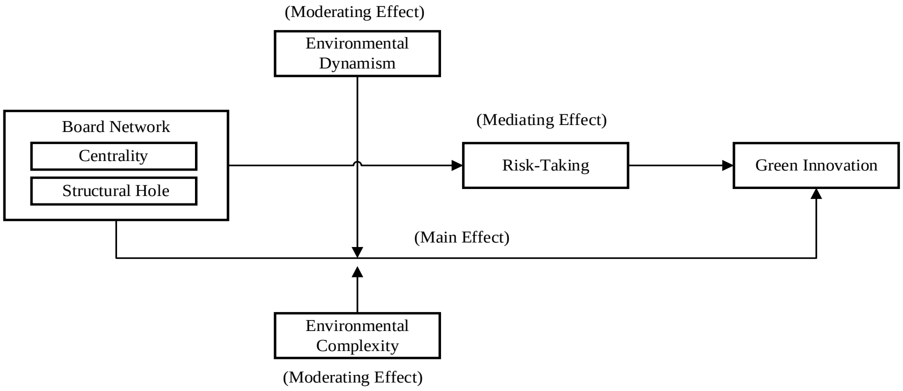


Figure 1. Conceptual model

3. Methodology

3.1 Research Design and Data Source

The research sample in this paper is selected from high water-consuming enterprises listed on the Shanghai and Shenzhen A-share markets in China from 2010 to 2022. The selection of high water-consuming enterprises is based on the high water-consuming industries mentioned in the "Water Use Efficiency Guidelines for Key Industrial Sectors" jointly published by the Ministry of Industry and Information Technology, the Ministry of Water Resources, the National Bureau of Statistics, and the National Water-Saving Office of China. These industries mainly include steel, textile, chemical, and petrochemical industries. High water-consuming enterprises were screened using industry codes, with the following enterprises excluded: (1) ST and *ST companies; (2) companies with missing or abnormal relevant data. After screening, an unbalanced panel dataset of 3,275 observations from 316 enterprises was obtained. To mitigate the impact of outliers, we Winsorized the continuous variables at the 1% level. The raw data for board network centrality and structural hole richness proxies were sourced from the CSMAR database and calculated using PAJEK to obtain the centrality and structural hole richness indicators. Data on corporate green innovation were obtained from the CNRDS database, while other data came from the CSMAR database. Some missing data were manually compiled from the Shanghai Stock Exchange, Shenzhen Stock Exchange, company annual reports, and Tianyancha. Data processing and analysis were conducted using Stata 17.0.

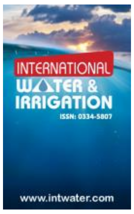
3.2 Measurement of Variables

3.2.1 Dependent variable

Corporate Green Innovation (GI). Following Wang et al. [26], this study uses the proportion of green patents to represent corporate green innovation, calculated as the ratio of green invention and utility model patent applications to the total patents applied for by the firm in a given year. Total patents include the sum of invention patents, utility model patents, and design patents.

3.2.2 Independent variables

Board Network Centrality (Centrality) and Structural Hole Richness (SH). A firm's position within the board network can be measured using centrality and structural hole indicators. Centrality metrics primarily include four types: degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality [27]. Each metric has strengths and weaknesses, and relying on a single type to represent board network centrality can be overly simplistic [28]. Therefore, following Chen [29], this study constructs a composite board network centrality index by weighting these four centrality measures, using the maximum value as the main research indicator and the average value as a robustness check. Constraint, a mainstream algorithm for measuring structural holes, reflects



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an individual's ability to leverage structural holes within the network. Referring to Martin et al. [30], this study measures structural hole richness in the board network using "1 - constraint."

3.2.3 Mediation variable

Risk-Taking (RT). The higher a firm's level of risk-taking, the greater the uncertainty in its future cash inflows. Following the approach of Wright [31] and John et al. [32], this study measures risk-taking using earnings volatility (ROAi), calculated as the ratio of firm i 's earnings before interest, taxes, depreciation, and amortization (EBITDA) to total assets at year-end.

3.2.4 Moderation variable

Environmental Dynamism (ED) and Environmental Complexity (EC). Following Fu et al. [33], this study divides environmental uncertainty into environmental dynamism and environmental complexity, both measured through sales revenue. Specifically, using sales revenue from years t, t-1, t-2, t-3, and t-4 as the dependent variable, we conduct a regression analysis where the independent variables are weighted by 5, 4, 3, 2, and 1, respectively. The standard error of the regression coefficient divided by the mean sales revenue represents environmental dynamism, while the regression coefficient divided by mean sales revenue represents environmental complexity.

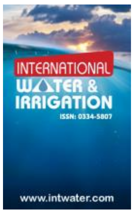
3.2.5 Controls

Following the studies of Amore [34], Lin [35], and Qin [36], this paper includes the following control variables in the regression analysis model: firm age (Age), board size (Board), return on assets (ROA), ownership concentration (Top1), managerial ownership proportion (MShare), R&D investment (RD), leverage ratio (Lev), and Big Four audit status (Big4). Additionally, to ensure the robustness of the fixed effects model, individual effects (Code), year effects (Year), and industry effects (Industry) are incorporated as control variables.

The definitions and measurements of these variables are presented in Table 1.

Table 1. Definition of variables

	Variable	Symbol	Definition
Dependent variable	Green Innovation	GI	Green patent applications / total patent applications
Independent variable	Board Network Centrality	Centrality	Composite index, calculated using PAJEK
	Structural Hole Richness	SH	Calculated using PAJEK
Mediation Variable	Risk-Taking	RT	Volatility of corporate profitability
Moderation Variable	Environmental Dynamism	ED	Details in the text
	Environmental Complexity	EC	Details in the text
Controls	Firm Age	Age	Ln (years from the firm establishment)
	Board Size	Board	Ln (number of board members)
	Return On Assets	ROA	Net profit / average total assets
	Ownership Concentration	Top1	Shareholding ratio of the largest shareholder
	Managerial Ownership Proportion	Mshare	Management shareholding / total shares
	R&D Investment	RD	R&D expenditure / operating revenue
	Leverage Ratio	Lev	Total liabilities at year-end / total assets at year-end
	Big Four Audit Status	Big4	dummies
	State-owned Enterprises	SOE	dummies
	Year	Year	Year dummies



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3.3 Models

To test Hypotheses 1a and 1b, which examine the effects of board network centrality and structural hole richness on corporate green innovation, this study constructs the following research model:

$$GI_{i,t} = \beta_0 + \beta_1 Centrality_{i,t} + \beta_2 Controls_{i,t} + \varepsilon_{i,t} \tag{1}$$

$$GI_{i,t} = \beta_3 + \beta_4 SH_{i,t} + \beta_5 Controls_{i,t} + \varepsilon_{i,t} \tag{2}$$

To test Hypotheses 2a and 2b, this study adopts the mediation effect testing method proposed by Wen et al. [33] and constructs the following research model:

$$GI_{i,t} = \alpha_0 + \alpha_1 Centrality_{i,t} + \alpha_2 Controls_{i,t} + \varepsilon_{i,t} \tag{3}$$

$$\mathrm{RT}_{\mathrm{i,t}} = \beta_6 + \beta_7 Centrality_{i,t} + \beta_8 Controls_{i,t} + \varepsilon_{i,t} \tag{4}$$

$$GI_{i,t} = \delta_0 + \delta_1 Centrality_{i,t} + \delta_2 RT_{i,t} + \delta_3 Controls_{i,t} + \varepsilon_{i,t} \tag{5}$$

$$GI_{i,t} = \alpha_3 + \alpha_4 SH_{i,t} + \alpha_5 Controls_{i,t} + \varepsilon_{i,t} \tag{6}$$

$$\mathrm{RT}_{\mathrm{i,t}} = \beta_9 + \beta_{10} SH_{i,t} + \beta_{11} Controls_{i,t} + \varepsilon_{i,t} \tag{7}$$

$$GI_{i,t} = \delta_4 + \delta_5 SH_{i,t} + \delta_6 RT_{i,t} + \delta_7 Controls_{i,t} + \varepsilon_{i,t} \tag{8}$$

To further test Hypotheses 3a, 3b, 4a, and 4b, which explore the moderating effects of environmental dynamism and environmental complexity on the relationship between board networks and corporate green innovation, this study constructs the following research model:

$$GI_{i,t} = \theta_0 + \theta_1 ED_{i,t} + \theta_2 Centrality_{i,t} + \theta_3 (ED_{i,t} * Centrality_{i,t}) + \theta_4 Controls_{i,t} + \varepsilon''''_{i,t} \tag{9}$$

$$GI_{i,t} = \theta_5 + \theta_6 ED_{i,t} + \theta_7 SH_{i,t} + \theta_8 (ED_{i,t} * SH_{i,t}) + \theta_9 Controls_{i,t} + \varepsilon''''_{i,t} \tag{10}$$

$$GI_{i,t} = \theta_{10} + \theta_{11} EC_{i,t} + \theta_{12} Centrality_{i,t} + \theta_{13} (ED_{i,t} * Centrality_{i,t}) + \theta_{14} Controls_{i,t} + \varepsilon''''_{i,t} \tag{11}$$

$$GI_{i,t} = \theta_{15} + \theta_{16} EC_{i,t} + \theta_{17} SH_{i,t} + \theta_{18} (EC_{i,t} * SH_{i,t}) + \theta_{19} Controls_{i,t} + \varepsilon''''_{i,t} \tag{12}$$

In this model: i represents each listed company, and *t* denotes the year. The independent variables, Centrality and SH, represent board network centrality and structural hole richness, respectively, while the dependent variable, GI, stands for corporate green innovation. The mediating variable RT reflects risk-taking, and the moderating variables ED and EC indicate environmental dynamism and environmental complexity. The interaction terms ED(EC)*Centrality (SH) capture the moderating effects of environmental dynamism and complexity on the relationships between board network centrality, structural hole richness, and green innovation. The Controls variables include firm age (Age), board size (Board), return on assets (ROA), ownership concentration (Top1), management shareholding ratio (Mshare), R&D investment (RD), leverage ratio (Lev), audit by a Big Four firm (Big4), and state ownership (SOE). ε represents random disturbance terms, and α0-α2, β0-β2, δ0-δ3, θ0-θ4are the parameters to be estimated.

4. Empirical Results

4.1 Descriptive statistics

From the descriptive statistics of the variables in Table 2, the mean value of Corporate Green Innovation (GI) is 0.080, which is lower than the median of 0.019. This indicates a pronounced "top-end effect" in green innovation among high water-consuming companies. Additionally, GI values range from 0 to 0.714, with a standard deviation of 0.136, suggesting that green innovation among sample companies is relatively balanced but predominantly at a low to medium level, highlighting an urgent need for improvement across firms.The median centrality of board networks (Centrality) is 8.987, with a mean of 9.203 and a standard deviation of 2.900, while the median structural hole richness (SH) is 0.288, with a mean of 0.305 and a standard deviation of 0.097. These figures suggest a generally balanced connection status among different high water-consuming firms' boards, indicating that inter-firm linkages are fairly well-developed. For risk-taking (RD), the median is 0.018 and the mean is 0.034, revealing considerable variation in risk-taking levels, with most firms exhibiting relatively low levels of risk-taking. Regarding environmental uncertainty, the standard deviation for environmental dynamism (ED) is 0.042, showing limited fluctuation and indicating a relatively stable operating environment for Chinese listed high water-consuming companies from 2010 to 2022. In contrast, environmental complexity (EC) has a minimum value of -0.275, a maximum of 0.557, and a standard deviation of 0.150, reflecting greater variability compared to environmental dynamism. Control variables vary across firms and exhibit a degree of data variability, which accounts for firm-specific differences in the dataset.

Table 2. Descriptive statistics of variables

Variable	Obs	Mean	SD	Min	Max	Median
GI	3275	0.080	0.136	0	0.714	0.019
Centrality	3275	22.515	9.781	3.333	48.731	22.055
SH	3275	0.364	0.095	0.192	0.666	0.353
RT	3275	0.034	0.047	0.001	0.274	0.018
ED	3275	0.049	0.042	0.005	0.243	0.037
EC	3275	0.121	0.150	-0.275	0.557	0.114
Age	3275	2.946	0.305	2.026	3.539	2.983
Board	3275	8.506	1.616	5	14	9
ROA	3275	0.030	0.070	-0.308	0.204	0.033
Top1	3275	32.218	14.113	8.630	71.210	29.990
Mshare	3275	11.066	16.406	0	61.982	0.735
RD	3275	4.615	4.615	0.029	26.880	3.590
Lev	3275	0.443	0.190	0.075	0.880	0.440
Big4	3275	0.066	0.249	0	1	0
SOE	3275	0.336	0.472	0	1	0

Table 3 presents the correlation analysis results for the variables. To mitigate potential multicollinearity issues in the regression analysis, we examined the correlation coefficients and confidence levels between variables. The results show that the correlation coefficients between control variables and corporate green innovation are statistically significant at the 5% level, indicating that these control variables have a significant impact on green innovation and supporting the validity of the selected control variables. Additionally, the Variance Inflation Factor (VIF) values for all variables are below 5, and none of the correlation coefficients between variables exceed 0.5. This suggests that there is no severe multicollinearity among the variables, making the sample data suitable for regression analysis.

4.2 Multivariate Analysis

This study employs a fixed-effects regression model to test the research hypotheses. In the first step, we conduct a regression analysis of the model. The F-test for the panel setup shows a result of p=0.000, indicating significant individual effects and confirming that the fixed-effects model outperforms the pooled regression. In the second step, a Hausman test is performed, and the results reject the assumption of the validity of random effects estimation, indicating that a fixed-effects model is more suitable. Additionally, given the potential heteroscedasticity in the panel data, we apply the Modified Wald test to the residuals, yielding a Prob > chi2 of 0.000, which confirms significant heteroscedasticity in the sample. To ensure the robustness of the test results, we further adjust for clustered robust standard errors.

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Table 3. Correlation coefficient between variables

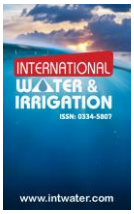
	VIF	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
GI		1														
Centrality	1.530	0.087***	1													
SH	2.170	-0.108***	-0.570***	1												
RT	1.440	0.003	0.007	-0.002	1											
ED	1.260	0.046***	-0.032***	-0.012	0.279***	1										
EC	1.360	0.093***	-0.004	0.015*	-0.116***	0.296***	1									
Age	1.090	0.039***	0.070***	-0.085***	0.048***	0.0001	-0.125***	1								
Board	1.600	0.059***	0.230***	-0.570***	-0.105***	-0.036***	-0.002	0.063***	1							
ROA	1.660	-0.019**	0.007	0.021**	-0.453***	-0.123***	0.292***	-0.061***	0.050***	1						
Top1	1.150	0.002	0.031***	-0.010	-0.133***	-0.025***	-0.011	-0.071***	0.021***	0.139***	1					
Mshare	1.360	-0.044***	-0.121***	0.200***	0.019**	-0.001	0.164***	-0.211***	-0.183***	0.074***	-0.125***	1				
RD	1.180	0.005	-0.047***	0.102***	0.112***	0.001	-0.019**	-0.075***	-0.135***	-0.054***	-0.186***	0.205***	1			
Lev	1.420	0.145***	0.107***	-0.147***	-0.033***	0.047***	0.051***	0.124***	0.144***	-0.292***	0.073***	-0.248***	-0.300***	1		
Big4	1.060	0.013	0.073***	-0.058***	-0.051***	-0.041***	0	0.026***	0.065***	0.058***	0.161***	-0.125***	-0.061***	0.122***	1	
SOE	1.450	0.092***	0.148***	-0.252***	-0.119***	-0.054***	-0.129***	0.179***	0.283***	-0.041***	0.234***	-0.446***	-0.179***	0.250***	0.144***	1

Table 4. Benchmark regression results

Variable	H1a	H1b
	GI	GI
Centrality	1.634*** (0.343)	
SH		4.701*** (1.062)
Age	-0.029 (0.018)	-0.035* (0.019)
Board	0.005 (0.008)	0.036*** (0.008)
ROA	-0.018 (0.015)	-0.012 (0.017)
Top1	-0.040*** (0.014)	-0.025* (0.014)
Mshare	0.015 (0.012)	0.006 (0.013)
RD	-0.010 (0.038)	0.008 (0.041)
Lev	0.011 (0.008)	0.028*** (0.010)
Big4	-0.013** (0.007)	-0.009 (0.007)
SOE	-0.000 (0.005)	-0.003 (0.006)
Constant	0.129** (0.058)	0.070 (0.060)
N	3275	3275
R-sq	0.545	0.554
Company-Year-Industry	Yes	Yes
F	F (10, 12334) =20.33, P-value = 0.0000	F (10,12333) =13.73, P-value=0.0000
Hausman	Hausman=120.36, P-value=0.0000	Hausman=87.53, P-value=0.0000
Modified Wald	Prob>chi2=0.0000	Prob>chi2=0.0000

*p < 0.10; **p < 0.05; ***p < 0.01; t errors are shown in parentheses.

Table 4 presents the main effects regression results, analyzing the impact of board network centrality and structural hole richness on corporate green innovation. The results indicate that centrality (Centrality) (β=1.634, p<0.01,



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where β represents the regression coefficient and p indicates the probability of rejecting the null hypothesis) and structural hole richness (SH) ($\beta=4.701$, $p<0.01$) are both positively correlated with green innovation (GI). This suggests that firms with higher board network centrality and greater structural hole richness demonstrate higher levels of green innovation. Board networks enhance high water-consuming firms' resource allocation efficiency, and firms within these networks tend to prioritize reputation maintenance, thereby fostering a stronger willingness and capacity for green innovation. Thus, hypotheses H_{1a} and H_{1b} are supported.

Table 5. Regression results of mediating effect

Variable	H_{2a}			H_{2b}		
	GI	RT	GI	GI	RT	GI
Centrality	1.634*** (0.343)	0.782*** (0.131)	0.066** (0.028)			
SH				4.701*** (1.062)	0.912** (0.401)	4.620*** (1.062)
RT			1.583*** (0.344)			0.088*** (0.032)
Age	-0.029 (0.018)	-0.002 (0.007)	-0.029 (0.018)	-0.035* (0.019)	-0.005 (0.007)	-0.034* (0.019)
Board	0.005 (0.008)	-0.013*** (0.004)	0.006 (0.008)	0.036*** (0.008)	-0.001 (0.004)	0.036*** (0.008)
ROA	-0.018 (0.015)	-0.271*** (0.010)	-0.000 (0.017)	-0.012 (0.017)	-0.264*** (0.010)	0.011 (0.018)
Top1	-0.040*** (0.014)	-0.028*** (0.006)	-0.038*** (0.014)	-0.025* (0.014)	-0.026*** (0.006)	-0.022 (0.014)
Mshare	0.015 (0.012)	-0.037*** (0.006)	0.017 (0.012)	0.006 (0.013)	-0.035*** (0.005)	0.010 (0.013)
RD	-0.010 (0.038)	-0.007 (0.020)	-0.010 (0.038)	0.008 (0.041)	-0.018 (0.019)	0.009 (0.041)
Lev	0.011 (0.008)	-0.016*** (0.004)	0.012 (0.008)	0.028*** (0.010)	-0.014*** (0.004)	0.030*** (0.010)
Big4	-0.013** (0.007)	0.002 (0.003)	-0.013** (0.007)	-0.009 (0.007)	0.004 (0.003)	-0.009 (0.007)
SOE	-0.000 (0.005)	-0.002 (0.002)	0.000 (0.005)	-0.003 (0.006)	-0.000 (0.002)	-0.003 (0.006)
Constant	0.129** (0.058)	0.089*** (0.022)	0.123** (0.059)	0.070 (0.060)	0.072*** (0.022)	0.064 (0.061)
N	3275	3275	3275	3275	3275	3275
R-sq	0.545	0.573	0.546	0.554	0.569	0.555
Company-Year-Industry	Yes	Yes	Yes	Yes	Yes	Yes

Table 5 presents the regression results for the mediating effect of risk-taking. Following Wen et al.'s [37] mediation testing method, we observe a significant positive correlation between centrality (Centrality) and risk-taking (RT) ($\beta=0.782$, $p<0.01$), as well as between risk-taking (RT) and green innovation (GI) ($\beta=1.583$, $p<0.01$). This indicates a partial mediating role of risk-taking in the relationship between centrality and corporate green innovation, supporting hypothesis H_{2a}. Similarly, structural hole richness (SH) is significantly positively correlated with risk-taking (RT) ($\beta=0.912$, $p<0.01$), and risk-taking (RT) is also significantly positively correlated with green innovation (GI) ($\beta=0.088$, $p<0.01$), indicating that risk-taking also plays a partial mediating role in the relationship between structural hole richness and green innovation, supporting hypothesis H_{2b}.

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The above results suggest that as the centrality and structural hole richness of the board network increase, high water-consuming companies exhibit a stronger willingness at the board level to prevent damage to their reputation due to excessive water resource consumption. This willingness helps correct the self-interested behavior of management, alter their risk-aversion attitude, and enhance executives' awareness of water resource management and risk investments, thereby improving the company's risk-bearing capacity. As a buffering mechanism to address water risks and other adverse factors, risk-taking becomes an intrinsic driver for high water-consuming companies to achieve efficient water resource utilization and promote sustainable economic development. Companies with a higher level of risk-taking capacity are more tolerant of the potential failures associated with high-risk, high-investment green water-saving technological innovations and are better able to bear the opportunity costs of green transformation. As a result, they are more likely to invest in water-saving technologies and green innovation activities. These companies are more proactive in learning advanced water-saving technologies and integrating related resources, which increases the likelihood of success in green innovation and demonstrates investment wisdom that matches risk and reward. Therefore, within the board network, high-risk-taking high water-consuming companies are more inclined to promote green water-saving innovation.

The regression results for the moderating effects are presented in Tables 6 and 7. The findings reveal that environmental dynamism (ED) strengthens the positive impact of board network centrality (Centrality) (β=25.795, $p<0.01$) and structural hole richness (SH) (β=61.518, $p<0.01$) on green innovation (GI), confirming hypotheses H3a and H3b. The moderation effect plots in Figures 2 and 3 further validate that as board network centrality and structural hole richness increase, firms operating in highly dynamic environments experience a stronger positive influence from board networks on green innovation. Environmental complexity (EC) also enhances the positive effect of board network centrality (β=5.989, $p<0.01$) and structural hole richness (SH) (β=26.313, $p<0.01$) on corporate green innovation, supporting hypotheses H_{4a} and H_{4b}. The moderation effect plots in Figures 4 and 5 similarly demonstrate that with higher board network centrality and structural hole richness, firms in complex environments benefit more from the positive impact of board networks on green innovation.

In the face of the uncertainty surrounding water resource management and utilization, high water-consuming companies tend to leverage their position within the board network to improve the conditions for implementing technologies and green innovations, thereby aligning with the global trends of water conservation and sustainable development and enhancing their core competitiveness. These companies actively build and strengthen relationships within their board networks, optimizing their position within the network to fully capitalize on the resources and information advantages provided by the board network. Through these efforts, high water-consuming companies can better adapt to the uncertainty arising from the dynamic and complex nature of the water resource environment, thereby strengthening the positive impact of the board network on their green innovation practices.

As illustrated in Figure 2, in environments with low complexity, the positive correlation between board network centrality and green innovation is significantly greater than in high-complexity settings. However, since the slope value for high-complexity environments is steeper, the positive correlation between board network centrality and green innovation ultimately becomes significantly stronger in high-complexity environments as centrality increases. This suggests that compared to firms in low-complexity environments, those in high-complexity environments experience a stronger positive influence of board network centrality on green innovation. Similarly, Figure 3 shows that the positive relationship between structural hole richness and green innovation will be significantly greater in high-complexity environments than in low-complexity ones, indicating that firms in high-complexity environments benefit more from the positive impact of structural hole richness on green innovation.

4.3 Robustness Tests

4.3.1 Replace independent variables measures

To ensure the robustness of the test results, this study conducted a robustness test by replacing the explanatory variables with the mean values of board network centrality and structural hole richness, instead of the maximum values used in the previous regressions. Table 7 displays the robustness test results for the mediating effects. Centrality (Centrality) is significantly positively correlated with risk-taking (RT) (β=0.173, p<0.01), and risk-taking (RT) is significantly positively correlated with green innovation (GI) (β=0.067, p<0.05), indicating that risk-taking serves as a partial mediator between centrality and green innovation, thus reaffirming hypothesis H_{2a}. Similarly, structural hole richness (SH) is significantly positively correlated with risk-taking (RT) (β=1.305, p<0.01), and risk-taking (RT) is significantly positively correlated with green innovation (GI) (β=0.087, p<0.01), indicating that risk-taking also partially mediates the relationship between structural hole richness and green innovation, confirming hypothesis H_{2b}.

Table 8 presents the robustness test results for the moderating effects. Environmental dynamism (ED) strengthens the positive impact of board network centrality (Centrality) (β=9.701, p<0.01) and structural hole richness (SH) (β=57.852, p<0.01) on green innovation (GI), supporting hypotheses H3a and H3b. Environmental complexity (EC) also enhances the positive effect of board network centrality (β=1.660, p<0.01) and structural hole richness (SH) (β=25.270, p<0.01) on green innovation, further validating hypotheses H_{4a} and H_{4b}.

Table 6. Regression results of moderating effect

Variable	H_{3a}	H_{3b}	H_{4a}	H_{4b}
	GI	GI	GI	GI
Centrality	1.708*** (0.346)		1.581*** (0.342)	5.041*** (1.066)
SH		4.868*** (1.069)		
Age	-0.029 (0.018)	-0.034* (0.019)	-0.029 (0.018)	-0.032* (0.019)
Board	0.005 (0.008)	0.036*** (0.008)	0.003 (0.008)	0.033*** (0.008)
ROA	-0.018 (0.015)	-0.013 (0.017)	-0.047*** (0.015)	-0.030* (0.018)
Top1	-0.043*** (0.014)	-0.025* (0.014)	-0.045*** (0.014)	-0.029** (0.014)
Mshare	0.016 (0.012)	0.007 (0.013)	0.010 (0.012)	0.002 (0.013)
RD	-0.011 (0.038)	0.010 (0.041)	0.023 (0.039)	0.041 (0.041)
Lev	0.010 (0.008)	0.028*** (0.010)	0.002 (0.009)	0.022** (0.010)
Big4	-0.014** (0.007)	-0.008 (0.006)	-0.014** (0.007)	-0.009 (0.007)
SOE	-0.000 (0.005)	-0.003 (0.006)	0.002 (0.005)	-0.001 (0.006)
ED	0.045* (0.024)	0.019 (0.026)		
ED*Centrality	25.795*** (7.309)			
ED*SH		61.518** (23.963)		
EC			0.043*** (0.007)	0.028*** (0.007)
EC*Centrality			5.989*** (1.970)	
EC*SH				26.313*** (5.974)
Constant	0.130** (0.058)	0.067 (0.061)	0.135** (0.058)	0.066 (0.060)
N	3275	3275	3275	3275
R-sq	0.546	0.554	0.547	0.555
Company-Year-Industry	Yes	Yes	Yes	Yes

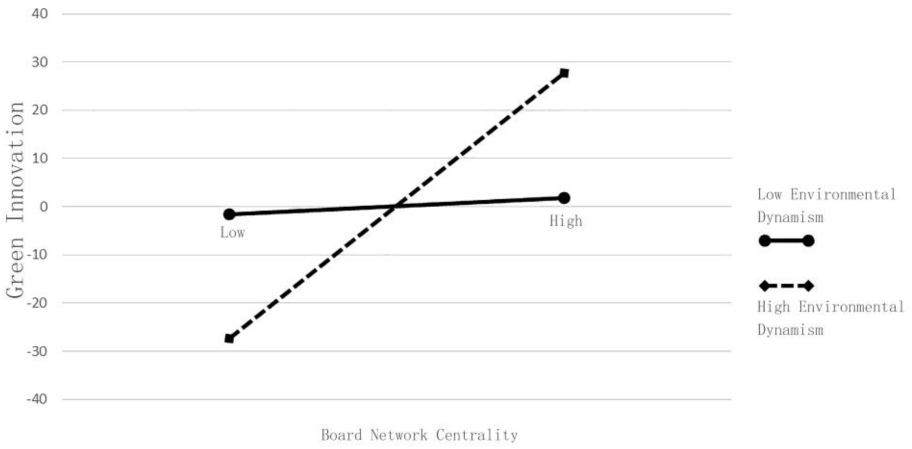

Figure 2. Diagram of the moderating effect of H_{3a}

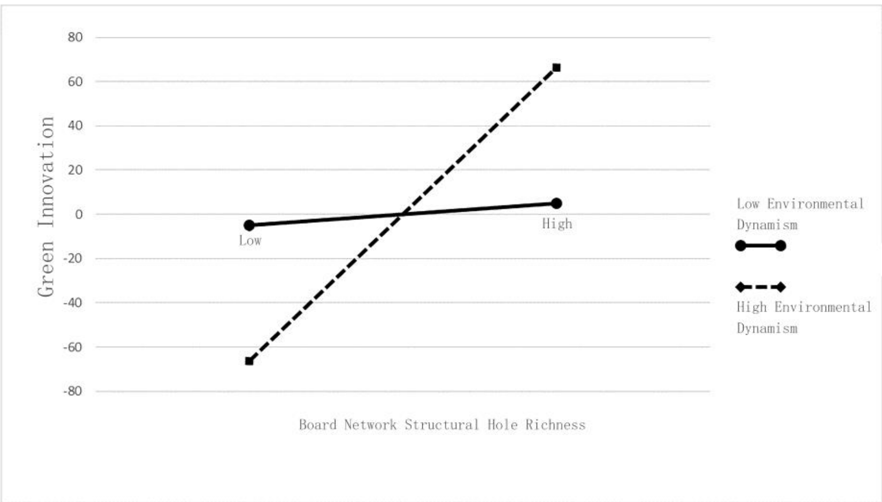

Figure 3. Diagram of the moderating effect of H_{3b}

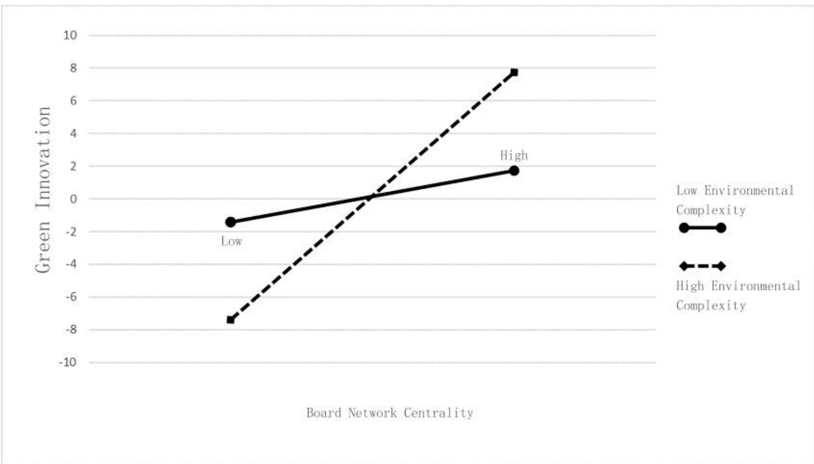

Figure 4. Diagram of the moderating effect of H_{4a}

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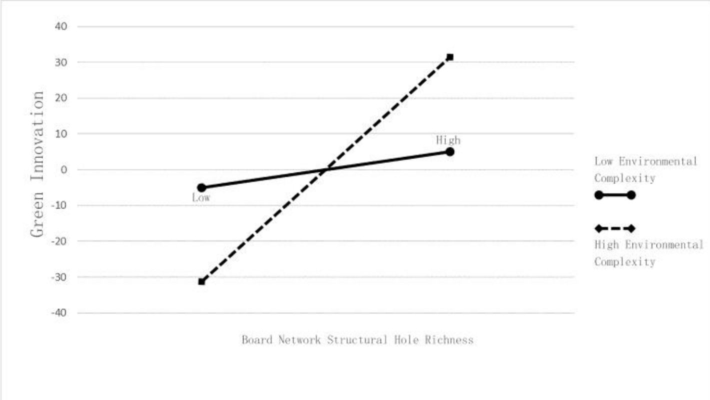

Figure 5. Diagram of the moderating effect of H_{4b}

Table 7. Robustness test of mediating effect

Variable	H_{2a}			H_{2b}		
	GI	RT	GI	GI	RT	GI
Centrality	0.428*** (0.094)	0.173*** (0.035)	0.417*** (0.094)			
SH				5.343*** (1.047)	1.305*** (0.386)	5.229*** (1.049)
RT			0.067** (0.028)			0.087*** (0.032)
Age	-0.030 (0.018)	-0.003 (0.007)	-0.029 (0.018)	-0.036* (0.019)	-0.005 (0.007)	-0.035* (0.019)
Board	0.007 (0.008)	-0.011*** (0.004)	0.008 (0.008)	0.039*** (0.009)	-0.000 (0.004)	0.039*** (0.009)
ROA	-0.018 (0.015)	-0.271*** (0.010)	-0.000 (0.017)	-0.013 (0.017)	-0.264*** (0.010)	0.010 (0.018)
Top1	-0.040*** (0.014)	-0.028*** (0.006)	-0.038*** (0.014)	-0.025* (0.014)	-0.026*** (0.006)	-0.023 (0.014)
Mshare	0.014 (0.012)	-0.037*** (0.006)	0.016 (0.012)	0.006 (0.013)	-0.036*** (0.005)	0.009 (0.013)
RD	-0.010 (0.038)	-0.007 (0.020)	-0.010 (0.038)	0.008 (0.041)	-0.018 (0.019)	0.010 (0.041)
Lev	0.011 (0.008)	-0.016*** (0.004)	0.012 (0.008)	0.028*** (0.010)	-0.014*** (0.004)	0.029*** (0.010)
Big4	-0.014** (0.007)	0.002 (0.003)	-0.014** (0.007)	-0.008 (0.006)	0.004 (0.003)	-0.009 (0.007)
SOE	-0.000 (0.005)	-0.002 (0.002)	-0.000 (0.005)	-0.002 (0.006)	0.000 (0.002)	-0.002 (0.006)
Constant	0.132** (0.058)	0.091*** (0.022)	0.126** (0.059)	0.059 (0.061)	0.068*** (0.022)	0.053 (0.061)
N	3275	3275	3275	3275	3275	3275
R-sq	0.545	0.573	0.546	0.554	0.570	0.555
Company-Year-Industry	Yes	Yes	Yes	Yes	Yes	Yes

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Table 8. Robustness test of moderating effect

Variable	H_{3a}	H_{3b}	H_{4a}	H_{4b}
	GI	GI	GI	GI
Centrality	0.478*** (0.096)		0.429*** (0.094)	
SH		5.459*** (1.052)		5.638*** (1.050)
Age	-0.030 (0.018)	-0.035* (0.019)	-0.029 (0.018)	-0.033* (0.019)
Board	0.007 (0.008)	0.040*** (0.009)	0.004 (0.008)	0.037*** (0.008)
ROA	-0.018 (0.015)	-0.013 (0.017)	-0.048*** (0.015)	-0.030* (0.018)
Top1	-0.043*** (0.014)	-0.025* (0.014)	-0.045*** (0.014)	-0.029** (0.014)
Mshare	0.015 (0.012)	0.006 (0.013)	0.009 (0.012)	0.001 (0.013)
RD	-0.011 (0.038)	0.011 (0.041)	0.027 (0.038)	0.043 (0.041)
Lev	0.010 (0.008)	0.028*** (0.010)	0.002 (0.009)	0.022** (0.010)
Big4	-0.014** (0.007)	-0.008 (0.007)	-0.014** (0.007)	-0.009 (0.007)
SOE	-0.000 (0.005)	-0.002 (0.006)	0.002 (0.005)	-0.001 (0.006)
ED	0.051** (0.024)	0.020 (0.026)		
ED*Centrality	9.701*** (2.191)			
ED*SH		57.852** (22.966)		
EC			0.043*** (0.007)	0.028*** (0.007)
EC*Centrality			1.660*** (0.571)	
EC*SH				25.270*** (5.858)
Constant	0.131** (0.058)	0.056 (0.061)		0.055 (0.060)
N	3275	3275	3275	3275
R-sq	0.546	0.554	0.547	0.555
Company-Year-Industry	Yes	Yes	Yes	Yes

4.3.2 Two-stage instrumental variable method

Firms with stronger green innovation capabilities are more likely to build robust board networks. To account for potential bidirectional causality and outcome bias between board networks and green innovation, this study uses the lagged first period of the explanatory variables as instrumental variables, employing a two-stage least squares (2SLS) approach to re-estimate the main effects. The regression results are presented in Table 9. In the first stage, the instrumental variable for board network centrality (l. Centrality) and the instrumental variable for structural hole richness (l.SH) are both significantly positively correlated at the 1% level. In the second stage, the

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instrumented board network centrality (Ins_Centrality) and structural hole richness (Ins_SH) are also significantly positively correlated at the 1% level. The F-statistics in both stages meet the requirements for a significant correlation between the instrumental variables and endogenous variables, indicating no evident endogeneity in the study results and confirming the robustness of the main effects.

Table 9. Regression results of instrumental variable

Variable	(1)	(2)	(1)	(2)
	Centrality	GI	SH	GI
l.Centrality	0.550*** (0.008)			
Ins_Centrality		3.024*** (0.583)		
l.SH			0.486*** (0.010)	
Ins_SH				11.882*** (2.260)
Controls	Yes	Yes	Yes	Yes
Constant	-0.002*** (0.001)	-0.007 (0.021)	0.004*** (0.000)	-0.152*** (0.027)
F-Value	799.89	4374.56	136.47	2565.75
N	3275	3275	3275	3275
R-sq	0.461	0.152	0.455	0.159
Company-Year-Industry	Yes	Yes	Yes	Yes

4.3.3 Propensity score matching (PSM) approach

The influence of a firm's board network may stem from its own green innovation capabilities. To address endogeneity issues caused by sample self-selection, this study applies propensity score matching (PSM). Using the median values of board network centrality and structural hole richness as thresholds [38], nearest-neighbor matching yielded 14,624 and 14,608 matched samples, respectively, as shown in Tables 10 and 11. Samples above the median were classified as the experimental group, while the rest formed the control group. Control variables were used as covariates, and the matching passed the balance test. The paired regression results, presented in Table 12, are consistent with the baseline regression results, confirming the robustness of the main effects.

Table 10. Equilibrium test results of centrality

Variable	Unmatched	Matched	Experimental Group	Control Group	T	P
Age	U		2.964	2.923	8.25	0.000
		M	2.962	2.952	2.04	0.041
Board	U		2.285	2.191	34.47	0.000
		M	2.280	2.275	1.97	0.049
ROA	U		0.032	0.032	0.00	0.998
		M	0.032	0.029	2.45	0.014
Top1	U		0.328	0.320	3.51	0.000
		M	0.328	0.331	-1.28	0.202
Mshare	U		0.087	0.137	-18.37	0.000
		M	0.088	0.088	0.18	0.860
RD	U		0.043	0.050	-9.58	0.000
		M	0.043	0.042	1.21	0.228
Lev	U		0.463	0.415	15.38	0.000
		M	0.460	0.477	-5.20	0.000
Big4	U		0.081	0.053	6.64	0.000
		M	0.077	0.086	-1.92	0.055
SOE	U		0.425	0.251	22.65	0.000
		M	0.418	0.435	-2.06	0.039

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Table 11. Equilibrium test results of SH

Variable	Unmatched	Matched	Experimental Group	Control Group	T	P
Age	U		2.925	2.963	-7.40	0.000
		M	2.925	2.920	1.06	0.289
Board	U		2.185	2.297	-42.10	0.000
		M	2.185	2.184	0.50	0.618
ROA	U		0.032	0.031	0.90	0.368
		M	0.032	0.032	-0.06	0.954
Top1	U		0.322	0.326	-2.04	0.041
		M	0.322	0.324	-0.87	0.386
Mshare	U		0.140	0.084	20.94	0.000
		M	0.140	0.136	1.16	0.245
RD	U		0.050	0.043	9.05	0.000
		M	0.050	0.0490	1.38	0.168
Lev	U		0.417	0.462	-14.69	0.000
		M	0.417	0.419	-0.71	0.480
Big4	U		0.056	0.081	-6.09	0.000
		M	0.056	0.052	0.91	0.361
SOE	U		0.247	0.432	-24.15	0.000
		M	0.247	0.253	-0.90	0.371

Table 12. Regression results after PSM test

Variable	GI	GI
Centrality	0.004** (0.002)	
SH		0.008*** (0.002)
Age	-0.003 (0.021)	-0.067*** (0.022)
Board	-0.006 (0.010)	0.042*** (0.010)
ROA	-0.041** (0.017)	-0.046*** (0.017)
Top1	-0.034** (0.016)	-0.031* (0.017)
Mshare	0.024* (0.015)	0.032** (0.014)
RD	-0.020 (0.045)	-0.053 (0.050)
Lev	0.010 (0.009)	0.026** (0.011)
Big4	-0.021** (0.009)	-0.009 (0.008)
SOE	-0.005 (0.005)	0.001 (0.005)
Cons.	0.087 (0.068)	0.162** (0.069)
N	3264	3258
R-sq	0.635	0.696
Company-Year-Industry	Yes	Yes

4.4 Heterogenous Test

To verify the impact of board network centrality and structural hole richness on corporate green innovation, this study uses firm ownership (state-owned vs. non-state-owned) as a criterion and conducts a heterogeneity analysis via subgroup regression to examine whether ownership differences affect the influence of board networks on green innovation. The test results, shown in Table 13, indicate that for state-owned enterprises (SOE), both centrality (Centrality) (β=1.351, $p<0.05$) and structural holes (SH) (β=8.104, $p<0.01$) have a significant positive impact on green innovation. For non-state-owned enterprises, centrality (Centrality) (β=1.647, $p<0.01$) and structural holes (SH) (β=2.988, $p<0.05$) also significantly and positively influence green innovation. These findings align with hypotheses H1a and H1b.

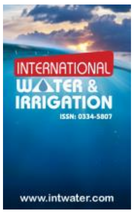
Compared to non-state-owned enterprises, the coefficients for SOEs are larger in the significance tests. This suggests that Chinese SOEs, due to their advantages in access to innovation resources and green pilot reforms, experience a more pronounced positive effect from their board networks on green innovation than non-state-owned firms.

Table 13. Heterogeneity test

Variable	SOE		NSOE	
	GI	GI	GI	GI
Centrality	1.647*** (0.427)		1.351** (0.578)	
SH		8.104*** (1.930)		2.988** (1.280)
Age	-0.011 (0.023)	-0.070* (0.037)	-0.043 (0.033)	-0.006 (0.024)
Board	0.004 (0.010)	0.054*** (0.016)	0.020 (0.015)	0.034*** (0.011)
ROA	-0.007 (0.016)	-0.024 (0.036)	-0.083** (0.041)	-0.015 (0.020)
Top1	-0.036** (0.017)	-0.011 (0.023)	-0.029 (0.025)	-0.037* (0.019)
Mshare	0.005 (0.013)	0.123 (0.091)	0.194** (0.096)	-0.000 (0.014)
RD	0.007 (0.044)	-0.016 (0.085)	-0.085 (0.084)	0.002 (0.048)
Lev	0.020** (0.010)	-0.003 (0.017)	-0.016 (0.017)	0.044*** (0.013)
Big4	-0.016** (0.008)	0.000 (0.012)	-0.009 (0.012)	-0.016** (0.008)
Constant	0.068 (0.074)	0.148 (0.120)	0.168 (0.110)	-0.013 (0.076)
N	1259	1259	2016	2016
R-sq	0.570	0.577	0.544	0.552
Company-Year-Industry	Yes	Yes	Yes	Yes

5. Conclusions

Companies must give green innovation first priority as the demand for water resources rises and problems like freshwater scarcity brought on by climate change gain attention. For companies that use a lot of water, pursuing technical advancements and efficient water usage is not only a crucial component of green practices, but it also serves as a significant representation of their social duty and allows them to actively contribute to global green



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development. Businesses must immediately help change social and economic structures to ensure that water resources are used sustainably. Based on Resource Dependence Theory, this study investigates how board networks affect green innovation in high water-consuming companies and comes to the following conclusions:

(1) Both the centrality of the board network and the richness of structural holes have a positive effect on green innovation in high water-consuming companies. Current research primarily focuses on the relationship between board networks and short-term economic performance, with less emphasis on their impact on green innovation. However, innovation activities in companies must not only meet the demands of economic development but also consider water resource conservation and social responsibility. Green innovation, therefore, aligns more closely with the perspective of sustainable water resource use. Board networks promote green innovation in two ways: centrality enhances a company’s resource acquisition capabilities, facilitates efficient resource sharing and optimal allocation, and improves the company’s ability to respond to risks associated with water-saving transformation. The richness of structural holes enables companies to leverage their informational control advantages, accurately capture innovation opportunities, assess decision-making risks, and reduce uncertainty in the green innovation process. In conclusion, this paper not only enriches the theoretical model of board networks and green innovation in high water-consuming companies, but also validates the mechanisms through which board networks influence green innovation. Furthermore, it extends the boundaries of research on board networks and corporate green innovation in the context of water resource management.

(2) Risk-Taking as a Partial Mediator in the Positive Effect of Board Network Centrality and Structural Hole Richness on Green Innovation. Increased structural hole richness and board network centrality encourage regular information sharing within board networks, which boosts board members' reputational costs and encourages thorough management supervision. By reducing regulatory and reputational risks for enterprises, this oversight increases businesses' risk-taking propensity and fosters green innovation. Furthermore, board networks, an unofficial institutional structure, make it easier to obtain resources from other businesses, which lessens information asymmetry and increases risk-taking propensity. High-risk investments, including green innovation projects, are supported by this efficient inter-firm resource distribution.

(3) Environmental uncertainty amplifies the positive impact of board network centrality and structural hole richness on corporate green innovation. This study demonstrates that board networks fortify their interdependencies to withstand environmental volatility and maintain green innovation initiatives in the face of dynamic external environmental changes. Additionally, it implies that companies should take proactive steps to optimize board networks rather than depending entirely on outside environmental factors. Businesses in China face more challenging settings as the country moves into a new normal development era. By adding environmental uncertainty and the mediating function of risk-taking to the theoretical framework, this study broadens the contextual factors influencing the influence of board networks on corporate green innovation. This method tackles how major risks and worldwide instability affect how well board networks support green innovation, providing a practical setting and a novel viewpoint for board network research in the context of water risks.

(4) The impact of board networks on corporate green innovation exhibits heterogeneity, with board networks in state-owned enterprises (SOE) showing a stronger positive effect on green innovation. State-owned enterprises have substantial advantages in terms of capital, policy support, and access to resources and information within their board networks, which significantly mitigates the adverse effects of environmental uncertainty and the risks associated with green innovation. For state-owned enterprises, green innovation not only promotes high-quality corporate development but also enhances local industrial chains and regional industrial value. Consequently, state-owned enterprises demonstrate a stronger commitment to green innovation and contribute more significantly to emissions reduction compared to non-state-owned enterprises. This aligns with prevailing perspectives in current research and provides a theoretical foundation for deepening state-owned enterprise reform and promoting green transformation across high water-consuming companies.

Based on the findings of this study, our findings suggest several managerial implications:

(1) Upgrade Board Selection Standards and Optimize Green Governance Structures. Facing issues such as low levels of industrial water reuse, inefficient water use, and severe water resource wastage, enterprises should recognize that while pursuing economic benefits, they are also an indispensable part of the social system and should contribute to the stable development of society. High water-consuming enterprises should take green innovation as their starting point and utilize relevant green technologies to achieve efficient water resource utilization, thereby realizing green transformation. In order to do this, businesses should hire people with low structural constraints and central roles in board networks, giving structural hole richness and board network centrality top priority when choosing and assessing board members. By strengthening the "weak ties" impact and "information bridge" function of board networks, this strategy can lower agency costs, secure resources like cash and technology, and increase the firm's willingness and ability to take risks. In turn, this will enable more robust corporate green innovation and support the "dual carbon" policy and goals.

(2) Proactively Address Environmental Uncertainty. Management needs to change their perspective from one that is crisis-focused to one that sees environmental instability as a chance for development. In unpredictable times, businesses can use board networks to support sustainable development and green innovation. This calls for constant improvement of green innovation procedures, increasing investment in water-saving technology through measures such as advanced water-saving engineering technology renovations and the commercialization of scientific and technological achievements. Through promoting the transformation of water-saving technological achievements into practical productivity, high water-consuming companies achieve a shift from extensive management to refined management. In the new growth phase, companies should minimize opportunistic inclinations, strengthen their commitment to green development, and improve equity incentives for leaders through top-level corporate governance frameworks. Through the integration of "internal" and "external" governance viewpoints, businesses can successfully promote green innovation.

(3) Enhance Government Support for Green Innovation Policies. Individual businesses cannot be the exclusive source of sustainable corporate green innovation due to the diverse variety of parties involved. Promoting corporate green innovation and national green development requires a multi-stakeholder structure run by the government with assistance from businesses. The government should intensify its efforts in cultivating scientific and technological talents, and incentivize researchers and outstanding talents with innovative thinking and potential to devote themselves to heavily polluting enterprises, in order to enhance the quality and professional competence of teams in the field of water-saving technology. At the same time, the government also needs to increase financial support, with sewage treatment as the core and heavily polluting enterprises as the implementation subject, to accelerate the process of establishing industrial water-saving enterprises. To this end, a water-saving incentive system should be established and improved to incentivize high water-consuming enterprises to implement innovations in water-saving technology, upgrades of processes and equipment, and optimization of pipeline network systems, thereby achieving effective utilization of water resources.

6. Limitations and Future Research

There are several restrictions on this study. First, from the standpoint of study, board networks may be categorized from a number of ways. For example, networks can be categorized by relationships like graduates, colleagues, and hometown networks, or they can be divided into executive and independent director networks according to the functions of the directors. Future studies might examine the ways in which various board network configurations impact corporate green innovation. Second, in terms of measuring indicators, this study represents corporate green innovation by using the percentage of green invention patents. However, it could be oversimplified to merely sum up green utility patents and green invention patents, as the former are more inventive. Metrics like the percentage of sales of green products to overall revenue might be used in future research to get more thorough results. Additionally, there is disagreement in the literature on the extent of environmental uncertainty. Environmental complexity and dynamism are often used metrics, yet they are still somewhat restricted. In order to gather primary data based on sample characteristics, future research might create targeted scales that would give the enterprises under study a more customized portrayal of environmental uncertainty. Finally, a more specific analysis can be conducted on how high water-consuming enterprises utilize board networks to achieve corporate green innovation, taking into account their current situations and through the form of typical case studies. Furthermore, the informatization of board networks is under increased pressure because to the quick growth of big data and other information technologies. Future research might look at how board networks and green innovation change in this setting and how corporate green innovation applications can be aided by information technology.

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