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Climate Risk Perception and Corporate Green Innovation: From Cognitive Awareness to Behavioral Response

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Abstract

Enhancing corporate green innovation is a critical component of advancing sustainable transformation and addressing escalating climate-related risks. From a cognition-to-behavior perspective, this paper constructs a climate risk perception index based on annual report texts from Chinese A-share listed firms from 2003 to 2023 and examines its impact on corporate green innovation, as well as the underlying mechanisms. The study finds that stronger climate risk perception significantly promotes both the quality and quantity of corporate green innovation. Mechanism analyses show that this effect operates through alleviating financing constraints, increasing research and development (R&D) investment, and improving environmental, social, and governance (ESG) performance. Heterogeneity tests further indicate that the positive impact is more pronounced among firms located in eastern China and among state-owned firms. Regarding scale heterogeneity, climate risk perception boosts the quantity of green innovation more effectively in large firms and boosts the quality of green innovation more effectively in small firms. This study provides micro-level evidence and theoretical insights into corporate green transformation behaviors under climate uncertainty.

Keywords: climate risk perception; corporate green innovation; financing constraints; R&D investment; ESG performance

1. Introduction

Climate change has emerged as one of the most severe global challenges [1]. Climate-related risks are expected to affect human society in unprecedented ways, disrupting economic systems, altering ecological balance, and reshaping patterns of production and consumption. In climate economics, these risks are generally categorized into physical risks and transition risks. Physical risks arise from direct impacts such as extreme weather events, sea-level rise, and natural disasters, whereas transition risks stem from policy changes, technological transformation, and shifts in market preferences associated with the global transition to a low-carbon economy [2]. In recent years, a growing body of research has examined how climate change affects macroeconomic performance, financial stability, and corporate behavior, underscoring the pervasive and systemic nature of climate risks in modern economic and business environments.

Green innovation refers to technological or organizational innovations that reduce environmental impact, improve resource efficiency, and support the transition toward sustainable development [3]. As a critical pathway to achieving low-carbon growth, green

Check for updates

Academic Editor: Pierfrancesco De Paola

Received: 14 December 2025
Revised: 4 January 2026
Accepted: 8 January 2026
Published: 12 January 2026

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innovation enables firms to improve environmental performance while remaining competitive under tightening climate and regulatory pressures [4]. Extensive research has examined the determinants of corporate green innovation, highlighting the roles of macroeconomic conditions [5], institutional and policy environments [6], industry-level characteristics [7], and firm-level attributes such as resources, capabilities, and governance structures [8]. Despite these advances, prior studies have focused primarily on the objective drivers of green innovation, with limited attention to the cognitive processes through which firms interpret external shocks. In this study, climate risk perception refers to a firm's managerial awareness and attention to climate-related physical and transition risks, rather than a firm's objective exposure to such risks. We measure it using a text-based index constructed from the Management Discussion and Analysis (MD&A) sections of annual reports.

Firms are the primary agents of technological innovation, and such innovation is essential for adapting to external environmental changes, maintaining competitiveness, and achieving sustainable development. Knight argues that uncertainty is a fundamental reason for the existence of firms, laying the foundation for subsequent theories of the firm [9]. Schumpeter further emphasizes that firms drive economic evolution through innovation and "creative destruction." From a resource-based view, firms create value by effectively integrating and allocating resources [10]. Lazonick similarly contends that firms respond to external uncertainty through technological and organizational innovation [11]. This rationale aligns with dynamic capabilities theory, which posits that firms must be able to sense, seize, and reconfigure resources to sustain innovation under uncertainty [12]. In the context of climate change, firms are increasingly exposed to policy pressures, shifts in market preferences, and physical shocks, making climate risk a new and critical source of strategic uncertainty. Firms' perception of climate risk is the starting point for activating dynamic capabilities. Such perception shapes not only how firms identify external threats and opportunities but also how they allocate resources, determine research and development (R&D) intensity, and select technological trajectories. On the one hand, heightened climate risk perception may encourage firms to increase investment in green technologies and develop low-carbon business strategies to capture emerging policy incentives and market opportunities [13]. On the other hand, climate-related uncertainty may heighten firms' risk aversion and suppress green innovation, given its high costs, long time horizon, and uncertain returns [14]. As a result, the relationship between climate risk perception and corporate green innovation remains inconclusive. Moreover, the mechanisms through which climate risk perception translates into concrete innovation behaviors—and whether these effects vary across different internal firm characteristics or external environments—remain insufficiently understood. Accordingly, this study seeks to address the following questions: Does corporate climate risk perception influence green innovation? Through what mechanisms does this influence operate? And does this effect vary across different contexts?

This study makes three main contributions to the existing literature. First, it offers a novel analytical perspective. Previous research has primarily examined the impact of climate change on firms using objective measures such as macro-level climate policies, carbon risk exposure, or the stringency of environmental regulations, while largely neglecting firms' subjective perception of climate risks. This paper introduces climate risk perception as a micro-level cognitive construct and argues that such perception activates firms' dynamic capabilities, which in turn shape strategic choices. This approach enriches the theoretical lens applied to corporate green innovation. Second, the study advances mechanism analysis. Rather than focusing solely on whether climate risk affects green innovation, this study draws on dynamic capabilities theory to construct a transmission framework encompassing resource reallocation, organizational learning and innovation investment, and external coordination. It systematically examines how climate risk per-

ception promotes green innovation by alleviating financing constraints, increasing R&D investment, and improving environmental, social, and governance (ESG) performance, thereby revealing the internal logic linking perception, capability, and innovation. Third, it expands the empirical context and application scenarios. Using a panel dataset of Chinese A-share listed firms from 2003 to 2023, this study situates climate risk research within the context of an emerging economy, where institutional environments and policy regimes are more dynamic. It provides new micro-level evidence on how external climate uncertainty interacts with firms' environmental strategies. Furthermore, by examining heterogeneous effects across ownership types and firm characteristics, the study broadens the applicability of climate risk research at the corporate level.

The remainder of this paper is organized as follows. Section 2 reviews the relevant theories and develops the research hypotheses. Section 3 presents the research design, including sample selection, variable definitions, and model construction. Section 4 reports the empirical results and analysis, including descriptive statistics, baseline regressions, mechanism tests, robustness checks, and heterogeneity analyses. Section 5 concludes the paper and offers corresponding policy implications.

2. Theoretical Analysis and Research Hypotheses

Within the dynamic capabilities framework [12,15], climate risk perception represents the sensing process through which firms identify emerging threats and opportunities associated with climate change [16]. Once such risks are perceived, firms activate a set of seizing capabilities, including resource reallocation, organizational learning and innovation investment, and external coordination, to formulate appropriate responses [17,18]. These capabilities operate through three primary mechanisms: mitigating financing constraints, increasing R&D investment, and improving ESG performance. Ultimately, green innovation reflects the reconfiguring stage, during which firms realign technologies, processes, and organizational structures to adapt to climate-related pressures [19]. Accordingly, and as illustrated in Figure 1, this study outlines the theoretical logic linking climate risk perception to corporate green innovation within a cognition-to-behavior framework.

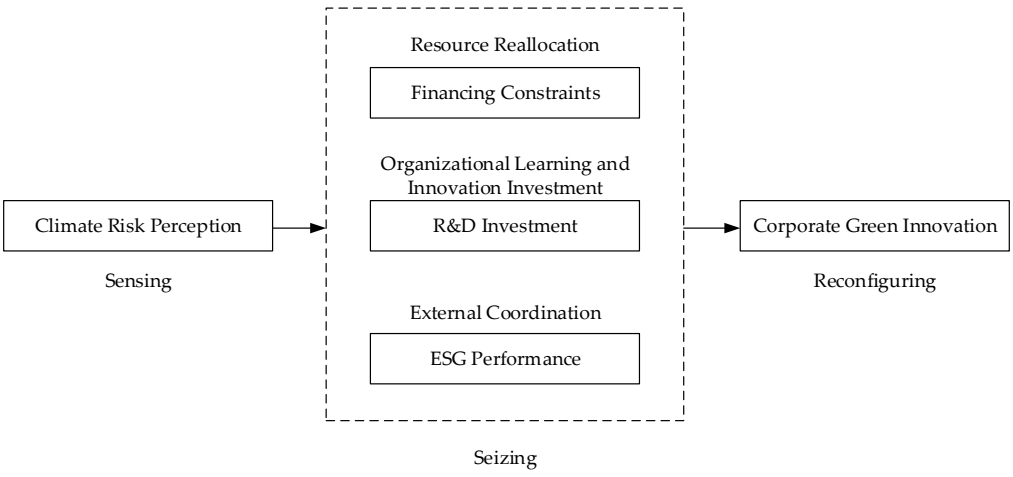


Figure 1. Theoretical framework of climate risk perception and corporate green innovation.

2.1. The Direct Influence of Climate Risk Perception on Corporate Green Innovation

Climate risk perception provides a critical cognitive foundation through which firms interpret external climate-related shocks and reassess their strategic priorities [20]. Within the dynamic capabilities framework [12,15], such perception reflects the sensing process that enables firms to identify emerging policy, market, and physical risks associated with climate change. When firms perceive heightened climate uncertainty, they devote greater

attention to potential regulatory tightening, carbon-pricing pressures, and increased volatility in resource and energy markets [21]. This heightened awareness amplifies the strategic importance of developing green technologies to ensure long-term compliance, competitiveness, and resilience [22].

Climate risk perception shapes a set of forward-looking expectations that jointly motivate firms to pursue green innovation. First, perceiving stronger climate policies and greater regulatory uncertainty increases firms' incentives to adopt cleaner technologies early, thereby reducing potential transition costs and avoiding penalties or compliance risks [23]. Second, firms that recognize structural market shifts toward low-carbon and environmentally responsible products are more likely to engage in green innovation to capture emerging demand and secure new competitive advantages [24]. Third, awareness of potential technological lock-in and stranded-asset risks encourages firms to accelerate the upgrading of production processes and R&D trajectories toward low-carbon alternatives, supporting long-term strategic transformation [25]. Existing research indicates that firms' risk perceptions strongly influence strategic innovation choices under uncertainty, particularly when innovation outcomes are closely tied to evolving institutional and market expectations [26–28].

Taken together, climate risk perception enhances firms' motivation to pursue green innovation proactively as a rational adaptive response to an uncertain climate environment. Accordingly, this study proposes the following hypothesis:

H1. *Climate risk perception promotes corporate green innovation.*

2.2. The Mechanisms of Climate Risk Perception's Impact on Corporate Green Innovation

Climate risk perception triggers a series of seizing activities that reshape firms' resource allocation under uncertainty. Within the dynamic capabilities framework, seizing refers to a firm's ability to mobilize and reallocate critical resources in response to perceived external shocks [12,15]. When firms anticipate that climate change will increase regulatory stringency, operational volatility, or exposure to climate-related liabilities, they reassess their capital structure and financing strategies to ensure sufficient resources for strategic transformation [22]. This cognitive response encourages firms to strengthen transparency, improve environmental disclosure, and signal a long-term commitment to sustainable development, which can substantially reduce information asymmetry between firms and financial institutions [29,30].

Climate risk perception thus becomes an important driver of reduced financing constraints. First, firms that more proactively articulate climate-related risks are better able to communicate long-term transition strategies, alleviating lenders' concerns about policy uncertainty and technological lock-in [31]. Heightened climate awareness motivates firms to adopt more credible environmental governance practices, thereby improving their creditworthiness and attractiveness to banks and institutional investors [32]. Second, as climate-related financial instruments such as green credit, sustainability-linked loans, and transition finance increasingly reward firms with stronger climate governance, perceived climate risks incentivize firms to align with these financing channels [33]. This alignment facilitates resource reallocation toward cleaner technologies, as firms gain access to lower-cost capital and longer-term financing structures designed to support green innovation [34]. Third, by reducing the adverse effects of financing frictions, firms can increase investment in long-term R&D activities and overcome liquidity constraints that often impede green innovation [35].

Therefore, climate risk perception alleviates financing constraints and enables firms to secure the financial resources necessary to pursue green innovation. Based on this reasoning, we propose the following hypothesis:

H2a. *Climate risk perception promotes corporate green innovation by mitigating financing constraints.*

Climate risk perception not only reshapes firms' financial decisions but also activates learning-oriented seizing capabilities, which play a critical role in translating climate risk awareness into green innovation outcomes. Within the dynamic capabilities framework, seizing the learning dimension reflects firms' ability to absorb new knowledge, update technological trajectories, and make forward-looking innovation investments in response to perceived shocks [12,15]. When firms perceive heightened risks associated with climate change, they reassess the adequacy of their existing knowledge base and production technologies [36]. This cognitive shift increases managers' awareness of the potential obsolescence of high-carbon technologies and reinforces the strategic necessity of investing in cleaner, more resilient innovation pathways [37,38].

First, climate risk perception increases firms' incentives to accumulate technological knowledge that supports low-carbon transformation. Anticipating stricter environmental regulations and the potential phase-out of carbon-intensive technologies, firms intensify R&D activities to explore alternatives that enhance energy efficiency, reduce emissions, and improve environmental performance [39]. This forward-looking learning response enables firms to upgrade technological capabilities before regulatory or market pressures fully materialize. Second, heightened climate awareness encourages firms to engage in strategic learning through experimentation, technological exploration, and the strengthening of absorptive capacity. Firms perceiving greater climate uncertainty are more likely to acquire external knowledge, collaborate with research institutions, and integrate sustainability-oriented technologies into their innovation portfolios. This process enhances their ability to internalize emerging technological opportunities arising from the green transition and expand their R&D pipelines [40]. Third, recognizing the risks associated with technological lock-in and stranded high-carbon assets, firms perceiving elevated climate risks tend to accelerate the replacement and upgrading of obsolete technologies [41]. This requires sustained R&D investment to support the redesign of production processes, development of low-carbon products, and enhancement of green technological competitiveness [42]. Thus, climate risk perception motivates firms to invest more heavily in innovation activities that strengthen long-term resilience under climate-related uncertainty.

Therefore, climate risk perception fosters organizational learning, motivates technological exploration, and promotes long-term innovation investment, all of which increase firms' commitment to R&D activities central to green innovation. Accordingly, we propose the following hypothesis:

H2b. *Climate risk perception promotes corporate green innovation by increasing the R&D investment.*

Climate risk perception also activates external-coordination-oriented seizing capabilities, which are manifested through improvements in corporate ESG performance and subsequently facilitate the reconfiguration of firms' green innovation activities. When firms perceive heightened climate risks, they become increasingly aware of the expectations and pressures exerted by external stakeholders [43]. These pressures intensify the need for firms to strengthen their ESG practices as a means of enhancing transparency, legitimacy, and long-term credibility in the face of climate-related uncertainty [44]. Consequently, climate risk perception encourages firms to improve ESG performance as a strategic response that aligns with evolving institutional norms and stakeholder demands [45].

First, heightened climate awareness incentivizes firms to strengthen environmental management practices, including carbon disclosure, pollution control, and resource efficiency initiatives. These improvements enhance compliance with environmental regulations and reduce information asymmetry with external stakeholders, thereby strengthening firms' legitimacy and lowering the perceived risks associated with supporting green innovation activities [46,47]. Second, improvements in social performance, such as greater employee participation, community engagement, and responsible supply chain management, create a more supportive external environment for green innovation. Firms with stronger social credibility encounter fewer external frictions when implementing technological upgrades or environmental projects, which facilitates long-term innovation efforts [48]. Third, advancements in governance practices, including enhanced board oversight of sustainability issues and the integration of climate-related risks into strategic decision-making, further strengthen stakeholder trust [49,50]. Strong governance signals that the firm is better equipped to manage transition risks, increasing investors' willingness to provide capital for long-horizon green innovation projects [42].

By improving environmental transparency, strengthening stakeholder relationships, and enhancing governance credibility, climate risk perception indirectly promotes firms' green innovation through the channel of enhanced ESG performance. Accordingly, we propose the following hypothesis:

H2c. *Climate risk perception promotes corporate green innovation by improving ESG performance.*

3. Research Design

3.1. Data and Samples

The research sample consists of Chinese A-share listed enterprises from 2003 to 2023. Financial firms, enterprises designated as ST or ST*, and firms with incomplete or missing data are excluded. The climate risk perception index is constructed by applying text-analysis techniques to the annual reports of Chinese A-share listed firms and winsorizing the resulting values at the 1% and 99% quantiles. Firm-level financial and accounting data, along with green patent information, are obtained from the China Stock Market and Accounting Research (CSMAR) database and the China Research Data Services (CNRDS) platform, respectively. ESG rating data are sourced from the Huazheng ESG Rating Agency. Regional-level data are collected from the official website of the National Bureau of Statistics of China.

3.2. Variable Selection

3.2.1. Dependent Variable

Green innovation constitutes the pivotal variable in this research, and its measurement incorporates both quantitative and qualitative dimensions. This study employs patent application counts as a primary metric, based on the rationale that applications provide a timelier and less externally contingent measure of innovation effort than patent grants, which are subject to administrative review delays [51]. Accordingly, the quantity of green innovation is operationalized as the number of green patent applications. To capture innovation quality, we use the number of citations received by green patents [52]. In the baseline regression, the citation count of green patents serves as the dependent variable to assess the quality of corporate green innovation, while the number of green patent applications measures the quantity of corporate green innovation.

3.2.2. Independent Variable

This study quantifies corporate climate risk perception following Lei et al. and applies the method to textual data extracted from the MD&A sections of annual reports [53]. The MD&A section reflects management's forward-looking assessments of operational risks, strategic challenges, and future development paths, and is widely used in the literature as a proxy for managerial cognition and risk perception.

The construction of the climate risk perception index proceeds in three steps. First, we develop a climate-risk lexicon by combining manually selected seed terms with word2vec-expanded candidates. Based on conceptual definitions, the lexicon is categorized into climate physical risk and climate transition risk dimensions (see Table 1). Second, we apply the Jieba tokenizer in Python (version 3.13) to segment MD&A texts and extract climate-risk-related terms for each firm-year observation. Third, we construct the climate risk perception index as the total frequency of climate-risk-related terms divided by the total word count of the MD&A section and multiplied by 100. A higher index value indicates a stronger level of climate risk perception at the firm level.

Table 1. Climate risk perception lexicon.

Dimension	Keywords
Climate Physical Risks	Disaster, earthquake, typhoon, storm surge, drought, extreme weather, pest outbreak, internal flooding, sandstorm, hail, frost, waterlogging, wind disaster, mudslide, landslide, drifting sand, ice disaster, snowstorm, freezing rain, blizzard, storm tide, high temperature, heatwave, cold wave, severe cold, rainfall, extreme precipitation, flood, drought, rainfall season, rainy season, heavy rain, torrential rain, downpour, prolonged rain, extreme heat, cold spell, winter chill, abnormal climate, low water level, water shortage, high temperature, heat stress, cold spell, landslide, subsidence, groundwater level, rainfall patterns, seismic activity
Climate Transition Risks	Energy saving, energy efficiency, cleaner production, ecological protection, environmental protection, transition, solar energy, upgrade, recycling, resource utilization, nuclear power, wind power, natural gas, capacity reduction, coal reduction, transformation, renewable energy, emission reduction, pollutant reduction, environmental regulation, green development, low-carbon transition, emission peak, green electricity, high efficiency, retrofitting, oil refining, electrification, wind power, photovoltaic, energy efficiency

It should be noted that, by construction, terms related to physical risks and transition risks are treated with equal weight in the baseline index. The classification of keywords into physical and transition risk categories serves a conceptual purpose, rather than introducing differential weighting schemes. This approach avoids imposing subjective assumptions regarding the relative importance of different types of climate risks and allows the index to capture firms' overall attention to climate-related uncertainty.

A potential concern with text-based measures is that they may be influenced by managerial impression management or strategic disclosure behavior, rather than purely

reflecting firms' genuine risk perceptions. While such disclosure incentives cannot be entirely ruled out, several considerations mitigate this concern. First, MD&A disclosures are subject to regulatory oversight and auditing standards, which constrain excessive strategic manipulation. Second, climate risk-related narratives often involve forward-looking discussions of operational exposure, regulatory pressure, and technological transition, making them closely aligned with managers' internal assessments of climate-related uncertainty. Third, the empirical analysis incorporates firm fixed effects and year fixed effects, which help absorb time-invariant disclosure styles and common reporting trends.

3.2.3. Mediator Variable

This study establishes three mediator variables that explain the linkage between corporate climate risk perception and green innovation: financing constraints, R&D investment, and ESG performance.

To quantify the degree of financing constraints, we adopt the SA index and KZ index [54]. The index is computed as $SA = -0.737 \times Size + 0.43 \times Size^2 - 0.040 \times Age$, where $Size$ and Age denote the firm's size and age, respectively. Because the computed SA value is typically negative, its absolute value ($absSA$) is used as the proxy measure. A higher $absSA$ value indicates more stringent financing constraints facing the firm. The KZ index is computed as $KZ = -1.002 \times (CF/A) - 39.368 \times (DIV/A) - 1.315 \times (C/A) + 3.139 \times LEV + 0.283 \times Q$, where CF/A is operating cash flow over lagged assets, DIV/A is cash dividends over lagged assets, C/A is cash holdings over lagged assets, LEV is total liabilities/total assets, and Q is Tobin's Q (market value/book value of assets). The KZ index, similar to the SA index, exhibits a positive correlation with the degree of corporate financing constraints.

The SA index is constructed using two core variables: firm size and firm age. This metric posits that smaller firms and those with shorter operating histories typically exhibit higher levels of information opacity, making it more difficult for them to access external financing. Consequently, a larger absolute value of the SA index indicates a higher degree of financing constraints faced by the firm. In contrast, the KZ index is derived from a comprehensive set of financial indicators, including operating cash flow, cash dividend payments, cash holdings, leverage ratio, and Tobin's Q. The underlying logic of its design is that constrained external financing capacity is often reflected in insufficient operating cash flow, low dividend payouts, minimal cash reserves, and high leverage. Thus, a higher KZ index value signifies more severe financing constraints for the enterprise.

R&D investment is measured using the natural logarithm of a firm's R&D expenditure. This variable reflects the firm's commitment to research and development activities.

Corporate ESG performance is measured using the Huazheng ESG rating. This rating system employs a nine-tier scale, where a score of 1 represents the lowest performance level and a score of 9 represents the highest. The Huazheng index is selected because it provides comprehensive coverage of Chinese A-share listed companies and incorporates policy elements specific to the Chinese context, which enhances its suitability for this study.

3.2.4. Control Variable

A set of control variables related to firm-level financial and governance characteristics is incorporated into the regression model to mitigate potential confounding effects [25,55]. The key variables in this study are measured as follows. Corporate scale (*size*) is quantified by the firm's year-end total assets. Asset structure is captured by the fixed asset ratio (*tan*), calculated as net fixed assets divided by year-end total assets. Capital asset expansion is measured by the fixed asset growth rate (*tagr*). The degree of financial leverage (*lev*) is assessed through the debt-to-asset ratio. The cash flow position is proxied by the cash

growth rate (*cash*). Ownership structure is represented by ownership concentration (*top*1), defined as the percentage of shares held by the largest shareholder. Board composition is measured by the proportion of independent directors (*indep*), calculated as the ratio of independent directors to the total number of directors. Leadership structure is captured by a binary variable (*dual*), which equals 1 if the Chairman and Chief Executive Officer positions are held by the same individual and 0 otherwise. Table 2 presents the descriptive statistics for these primary variables.

Table 2. Detailed description of key variables.

Variable Type	Variable Name	Symbol	Definition
Dependent variable	Quality of corporate green innovation	$CGIQ$	The natural logarithm of (the citation count of green patents + 1)
	Quantity of corporate green innovation	$CGIA$	The natural logarithm of (the number of green patent applications + 1)
Independent variable	Climate risk perception	CRP	Our estimate
Mediator Variable	Financing Constraints	$absSA$	The absolute value of the SA index
		$absKZ$	The absolute value of the KZ index
	R&D investment	RD	The R&D investment
	ESG performance	ESG	The Huazheng ESG rating
Control Variable	Corporate size	$size$	The firm's year-end total assets
	The proportion of fixed assets	tan	The net fixed assets divided by total assets at year-end
	The fixed assets growth rate	$tagr$	The fixed assets growth rate
	The debt-to-asset ratio	lev	The debt-to-asset ratio
	The cash growth rate	$cash$	The cash growth rate
	Ownership concentration	$top1$	The percentage of shares held by the largest shareholder
	The proportion of independent directors	$indep$	The ratio of independent directors to the total number of directors
	Chairman-CEO Duality	$dual$	A binary variable that equals 1 if the positions of Chairman and CEO are held by the same individual, and 0 if these roles are separate

3.3. Model

To empirically examine the direct effect of corporate climate risk perception on corporate green innovation, the following baseline regression model is established [56]:

$$CGI_{i,t} = \beta_0 + \beta_1 CRP_{i,t} + \sum \beta_k Controls_{i,t} + corporatedum + yeardum + \varepsilon_{i,t} \quad (1)$$

where i and t denote the corporation and the year, respectively. CGI represents corporate green innovation, which includes two dimensions: the quality of corporate green innovation and the quantity of corporate green innovation. CRP denotes climate risk perception. $Controls$ is a vector of firm-level control variables. $corporatedum$ and $yeardum$ represent corporate fixed effects and year fixed effects. The term $\varepsilon_{i,t}$ is a stochastic disturbance term.

$$Media_{i,t} = \beta_0 + \beta_2 CRP_{i,t} + \sum \beta_k Controls_{i,t} + corporatedum + yeardum + \varepsilon_{i,t} \quad (2)$$

$$CGI_{i,t} = \beta_0 + \beta_3 CRP_{i,t} + \beta_4 Media_{i,t} + \sum \beta_k Controls_{i,t} + corporatedum + yeardum + \varepsilon_{i,t} \quad (3)$$

Equation (3) is employed to examine the influence of corporate climate risk perception on the mediator variables, namely financing constraints, R&D investment, and ESG performance. Equation (3) incorporates both the independent variable and each mediator variable within a unified regression framework. The statistical significance of the coefficients β_2, β_3, and β_4 would indicate that the proposed mediation channels are operative. Such evidence would support the hypothesis that climate risk perception functions as a significant conduit, indirectly influencing corporate green innovation through the alleviation of financing constraints, the enhancement of R&D investment, and the improvement of ESG performance. When the average number of green patent applications is sufficiently high and the sample size is adequate, results from linear models and count-based models tend to be highly consistent. In such cases, linear models offer a more intuitive interpretation of coefficients. Therefore, for ease of interpreting the regression results, we employed a linear fixed-effects model.

4. Empirical Result

4.1. Descriptive Statistics

Table 3 presents the descriptive statistics for the key variables. The mean value of corporate green innovation quality is 0.521, with a standard deviation of 1.022. The minimum and maximum values are 0 and 8.062, respectively. The mean value of corporate green innovation quantity is 0.344, with a standard deviation of 0.781. The minimum and maximum values for this measure are 0 and 7.062, respectively. These statistics suggest a substantial degree of heterogeneity in green innovation practices across firms. For climate risk perception, the average value is 1.046, with a standard deviation of 1.305. The relatively large standard deviation indicates considerable variation in firms' perception of climate risks over the sample period. This variation provides a solid empirical basis for examining how corporate green innovation responds to differing levels of perceived climate risk. The statistical characteristics of the remaining variables are generally consistent with those documented in the existing literature.

Table 3. Descriptive statistics of key variables.

Variable	Sample Size	Mean	Standard Deviation	Minimum	Maximum
CGIQ	50,814	0.521	1.022	0	8.062
CGIA	45,248	0.344	0.781	0	7.062
CRP	50,814	1.046	1.305	0	6.120
size	50,814	1.322	6.199	0.001	290.332
tan	50,814	0.217	0.163	0.002	0.949
tagr	50,814	0.187	0.528	−1	5.075
cash	50,814	0.217	0.159	0.016	0.981
lev	50,814	0.416	0.197	0.007	0.832
*top*1	50,814	0.34	0.143	0.018	0.701
indep	50,814	0.37	0.051	0.071	0.571
dual	50,814	0.284	0.451	0	1

4.2. Baseline Regression Result

The outcomes of the baseline regression are reported in Table 4. Columns (1) and (2) present the results using corporate green innovation quality as the dependent variable. Column (1) includes only financial control variables, while column (2) incorporates the full set of control variables. The estimated coefficients for climate risk perception are 0.0931 and 0.0929, both statistically significant at the 1% level. Columns (3) and (4) report the regression results with corporate green innovation quantity as the dependent variable. Column (3) uses only financial control variables, and column (4) includes the full set of

control variables. Climate risk perception produces statistically significant coefficients of 0.0368 and 0.0369, respectively, also significant at the 1% level. These results provide robust evidence of a positive and significant association between heightened climate risk perception and enhanced corporate green innovation.

Table 4. Baseline regression result.

Variables	(1) *CGIQ*	(2) *CGIQ*	(3) *CGIA*	(4) *CGIA*
CRP	0.0931 ***	0.0929 ***	0.0368 ***	0.0369 ***
	(0.0082)	(0.0082)	(0.0068)	(0.0068)
size	0.0148 ***	0.0151 ***	0.0137 ***	0.0138 ***
	(0.0034)	(0.0034)	(0.0044)	(0.0044)
tan	0.2217 ***	0.2168 ***	0.1257 ***	0.1232 ***
	(0.0655)	(0.0655)	(0.0422)	(0.0421)
tagr	−0.0378 ***	−0.0359 ***	−0.0143 ***	−0.0132 ***
	(0.0060)	(0.0060)	(0.0049)	(0.0049)
cash	−0.1839 ***	−0.1725 ***	−0.0186	−0.0116
	(0.0432)	(0.0434)	(0.0346)	(0.0349)
lev	0.2875 ***	0.2848 ***	0.1228 ***	0.1206 ***
	(0.0469)	(0.0469)	(0.0329)	(0.0330)
*top*1		−0.3044 ***		−0.1508 **
		(0.0938)		(0.0706)
indep		−0.1024		0.0229
		(0.1328)		(0.1044)
dual		−0.0214		−0.0184
		(0.0150)		(0.0121)
Year FE	YES	YES	YES	YES
Corporate FE	YES	YES	YES	YES
Observation	50,814	50,814	45,248	45,248
R-squared	0.6528	0.6532	0.6237	0.6239

*, **, *** denote statistical significance at 10%, 5%, and 1%, respectively; (.) is robust standard errors; throughout the paper, standard errors are clustered at the corporate level.

The results presented in column (2) indicate that a one-unit increase in climate risk perception is associated with an approximately 9.29% rise in corporate green innovation quality, as measured by the number of citations received by green patents. To further assess the economic significance of this relationship, we examined the dispersion of the variables. An increase of one standard deviation (1.305) in climate risk perception leads to an approximately 12.12% improvement in green innovation quality. Meanwhile, the estimates in column (4) show that a one-unit increase in climate risk perception corresponds to an approximately 3.69% growth in the quantity of green patent applications. When scaled by one standard deviation (1.305) in climate risk perception, this translates into an approximate 4.81% increase in green innovation quantity.

This finding supports the contention that firms' awareness of climate risks has a promotive effect on their green innovation activities. Therefore, the basic research hypothesis (H1) is validated. The empirical findings further corroborate core propositions of dynamic capabilities theory [15]. Specifically, when firms integrate climate risk into their strategic cognitive framework, they engage in proactive reconfiguration of their value chain through mechanisms such as scenario simulation and the activation of redundant resources. This

strategic reengineering enables firms to move beyond a reactive risk response model. Such reconfiguration serves not only as a tactical adjustment to mitigate risks but also as a foundational mechanism for achieving sustainable corporate transformation [57]. In doing so, it becomes a critical driver of green innovation within the organization.

4.3. Robustness Check and Endogeneity Discussion

4.3.1. Robustness Check

This study conducts robustness tests using two approaches to verify the reliability of the baseline findings [58]. First, we replace the original metrics of corporate green innovation. We use the number of non-self-citations of green patents (CGI_1) as an alternative measure of corporate green innovation. The regression results, reported in column (1) of Table 5, show that climate risk perception maintains a statistically significant positive effect at the 1% level. The impact of climate risk perception on green innovation extends beyond enhancing the quality of green innovation as measured by self-citations to significantly improving the quality reflected in non-self-citations. Such improvement demonstrates that the enhanced innovation quality is widely acknowledged by the wider research community, attracting substantial external attention and citations.

Table 5. Robustness check result.

Variables	(1) CGI_1	(2) *CGIQ*	(3) *CGIQ*	(4) *CGIA*	(5) *CGIA*
CRP	0.0903 *** (0.0080)				
CRP_{t-1}		0.0845 *** (0.0054)		0.0259 *** (0.0046)	
CRP_{t-2}			0.0820 *** (0.0061)		0.0252 *** (0.0053)
Controls	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Corporate FE	YES	YES	YES	YES	YES
Observation	50,814	43,160	38,083	38,757	34,233
R-squared	0.6398	0.6756	0.6923	0.6357	0.6447

*, **, *** denote statistical significance at 10%, 5%, and 1%, respectively; (.) is robust standard errors.

Second, to account for the potential lagged effect of climate risk perception, we estimate models using one-period and two-period lag values of the climate risk perception variable. The regression results are presented in columns (2) through (5) of Table 5. The coefficients for climate risk perception are 0.0845, 0.0820, 0.0259, and 0.0252, all statistically significant at the 1% level. These findings indicate that the effect of climate risk perception on corporate green innovation remains positive and significant even after incorporating lagged values. These findings indicate that the influence of climate risk perception exhibits significant persistence. Once a firm perceives climate-related risks, the subsequent adjustments in its decision-making and resource reconfiguration processes demonstrate enduring effects, which can shape strategic planning and deployment over multiple subsequent years, thereby enhancing its green innovation.

4.3.2. Endogeneity Discussion

In the empirical analysis, this study may face endogeneity issues arising from omitted variables, sample self-selection, and reverse causality. First, we address the issue of omitted

variable bias. The study controls for corporate financial characteristics and corporate governance characteristics, and also incorporates macroeconomic variables such as GDP growth rate and CPI growth rate to reduce the influence of unobserved factors on the regression results. Columns (1) and (2) of Table 6 report the results, indicating that climate risk perception has a significant positive impact on both the quality and quantity of corporate green innovation at the 1% confidence level.

Table 6. Endogeneity discussion result.

Variables	(1) *CGIQ*	(2) *CGIA*	(3) *CGIQ*	(4) *CGIA*	(5) *CRP*	(6) *CGIQ*	(7) *CRP*	(8) *CGIA*
CRP	0.0992 *** (0.0089)	0.0539 *** (0.0066)	0.0910 *** (0.0093)	0.0369 *** (0.0078)		0.2594 *** (0.0252)		0.1113 *** (0.0234)
CRP_others_1					0.4057 *** (0.0117)		0.3766 *** (0.0126)	
CRP_others_2					0.2436 *** (0.0355)		0.2316 *** (0.0385)	
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	NO	NO	YES	YES	YES	YES	YES	YES
Corporate FE	YES	YES	YES	YES	YES	YES	YES	YES
Observation	50,740	45,177	33,230	28,820	42,144	42,144	37,787	37,787
R-squared	0.5643	0.6143	0.6752	0.6406		0.2341		0.0505
F-value					630.24		467.49	
Sargan Test						0.5725		0.2841

*, **, *** denote statistical significance at 10%, 5%, and 1%, respectively; (.) is robust standard errors; the Sargan test reports the corresponding *p*-value.

Second, we address potential bias from sample self-selection. Because the level of corporate climate risk perception is not random but jointly determined by internal firm characteristics and external environmental factors, we divide the sample into experimental and control groups using the median value of climate risk perception. We then perform robustness checks using propensity score matching. The regression results are shown in columns (3) and (4) of Table 6. After matching, climate risk perception continues to exhibit a significant positive effect at the 1% confidence level, confirming the robustness of the baseline results.

Finally, we address the issue of reverse causality. This study adopts a two-stage least squares (2SLS) approach, following the method of Wang et al. [59]. Relying solely on the "industry-year average climate risk perception" as an instrumental variable raises concerns regarding its exogeneity, potentially compromised by intra-industry information contagion effects or common shocks. Consequently, we use the average climate risk perception of other firms in the same year and industry (CRP_others_1) and the average climate risk perception of other firms in the same year and region (CRP_others_2) as instrumental variables for corporate climate risk perception [59,60]. The two-stage regression results are reported in columns (5) through (8) of Table 6. The results of the first-stage regression are reported in Columns (5) and (7). The corresponding F-statistic values are 630.24 and 467.49, respectively, which are substantially greater than the conventional threshold of 10. This indicates that the selected instrumental variables exhibit a strong correlation with the endogenous variable, and the concern of weak instruments can be ruled out [61].

The exogeneity of the instruments under over-identification is assessed by the Sargan test. The test's null hypothesis posits that all instruments are exogenous. The resulting *p*-values of 0.5725 of Column (6) and 0.2841 of Column (8) lead to a failure to reject the null hypothesis, indicating that the selected instruments can be considered exogenous. The results indicate that climate risk perception continues to have a significant positive impact on both dimensions of corporate green innovation at the 1% confidence level.

4.4. Mechanism Analysis

To elucidate the mediating channels through which climate risk perception influences corporate green innovation, this study identifies and empirically validates three specific pathways based on theoretical analysis and econometric testing: the alleviation of financing constraints, the increase in R&D investment, and the improvement of ESG performance. Beyond these three primary mechanisms, additional factors such as management incentives, supply chain pressures, and regulatory intensity may also serve as potential mediators in the relationship between climate risk perception and corporate green innovation, as suggested by existing literature [62,63]. However, constrained by the specific scope of this research, the analysis focuses exclusively on the three mediating variables of financing constraints, R&D investment, and ESG performance.

4.4.1. Mechanism Effect of Financing Constraints

The regression outcomes pertaining to the mediating role of corporate financing constraints are presented in columns (1) through (3) of Table 7. The estimates in columns (1) and (4) show a statistically significant effect of climate risk perception on financing constraints at the 1% level, indicating that heightened climate risk perception contributes to a relaxation of these constraints. Columns (2) and (5) demonstrate that financing constraints exert a significant negative influence on the quality of corporate green innovation at the 1% confidence level, suggesting that tighter financing constraints undermine firms' ability to pursue high-quality green innovation. Similarly, columns (3) and (6) show that financing constraints significantly inhibit the quantity of corporate green innovation. Taken together, these findings confirm the presence of a significant mediating effect and provide support for hypothesis H2a. This empirical pattern is consistent with the financial resource reconfiguration mechanism proposed by dynamic capabilities theory. Specifically, climate risk perception encourages firms to reallocate financial resources and enhances the transparency of their ESG disclosures. Greater transparency strengthens the credibility of firms' climate-related narratives, which facilitates access to targeted financing instruments and enables firms to overcome traditional financing limitations [64].

Table 7. Mechanism analysis result of financing constraints.

Variables	(1) *absSA*	(2) *CGIQ*	(3) *CGIA*	(4) *absKZ*	(5) *CGIQ*	(6) *CGIA*
CRP	−0.7154 ***	0.0909 ***	0.0347 ***	−0.0161 *	0.0908 ***	0.0376 ***
	(0.1198)	(0.0082)	(0.0040)	(0.0090)	(0.0048)	(0.0041)
absSA		−0.0029 ***	−0.0037 ***			
		(0.0008)	(0.0005)			
absKZ					−0.0182 ***	−0.0061 ***
					(0.0021)	(0.0018)
Controls	YES	YES	YES	YES	YES	YES

Table 7. *Cont.*

Variables	(1) *absSA*	(2) *CGIQ*	(3) *CGIA*	(4) *absKZ*	(5) *CGIQ*	(6) *CGIA*
Year FE	YES	YES	YES	YES	YES	YES
Corporate FE	YES	YES	YES	YES	YES	YES
Observation	50,814	50,814	45,248	48,901	48,901	44,054
R-squared	0.8461	0.6544	0.6264	0.437	0.6577	0.626

*, **, *** denote statistical significance at 10%, 5%, and 1%, respectively; (.) is robust standard errors.

4.4.2. Mechanism Effect of R&D Investment

Columns (1) through (3) of Table 8 present the regression results for the R&D investment mechanism. The estimates in column (1) indicate a statistically significant positive effect of climate risk perception on corporate R&D investment at the 1% level. Column (2) shows that R&D investment exerts a significant positive influence on the quality of corporate green innovation, also at the 1% confidence level. Column (3) further demonstrates that R&D investment significantly enhances the quantity of corporate green innovation. The significantly positive total effect of climate risk perception on green innovation suggests that heightened climate risk perception promotes corporate green innovation by increasing R&D investment, thereby confirming hypothesis H2b. This empirical pattern aligns with the technological resource reconfiguration pathway proposed by dynamic capabilities theory. Specifically, when firms perceive climate risks, they activate a set of seizing capabilities related to organizational learning and innovation investment in order to develop appropriate responses [17,18]. This process drives an increase in R&D expenditure, which in turn strengthens firms' capacity for green innovation [65].

Table 8. Mechanism analysis result of R&D investment and ESG performance.

Variables	(1) *RD*	(2) *CGIQ*	(3) *CGIA*	(4) *ESG*	(5) *CGIQ*	(6) *CGIA*
CRP	0.0545 *** (0.0095)	0.0557 *** (0.0078)	0.0169 ** (0.0066)	0.0185 *** (0.0050)	0.0485 *** (0.0047)	0.0177 *** (0.0040)
RD		0.0816 *** (0.0097)	0.0544 *** (0.0070)			
ESG					0.0380 *** (0.0045)	0.0378 *** (0.0039)
Controls	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Corporate FE	YES	YES	YES	YES	YES	YES
Observation	32,295	32,295	31,739	45,536	45,536	40,383
R-squared	0.8241	0.7701	0.6619	0.4992	0.7112	0.6709

*, **, *** denote statistical significance at 10%, 5%, and 1%, respectively; (.) is robust standard errors.

4.4.3. Mechanism Effect of ESG Performance

Columns (4) through (6) of Table 8 present the regression results testing the mediating role of ESG performance. Column (4) shows a statistically significant positive effect of climate risk perception on ESG performance. Column (5) and (6) indicate that ESG performance, in turn, significantly enhances both the quality and quantity of corporate green innovation at the 1% confidence level. Collectively, these findings support hypothesis H2c,

suggesting that heightened climate risk perception fosters green innovation by improving ESG performance.

Firms' perception of climate risks triggers strategic adjustments beyond passive recognition. This awareness activates dynamic capabilities, prompting firms to reconfigure their value chains against potential climate constraints. Such reconfiguration manifests across all ESG dimensions: environmentally, through increased capital expenditures on pollution control and energy efficiency; governance-wise, by integrating climate scenarios into internal controls to reshape strategic orientation [20,27]; and socially, through enhanced external communication to meet stakeholder disclosure demands. Thus, climate risk perception drives green innovation by systematically improving ESG performance.

4.5. Heterogeneous Analysis

The synergistic interaction between heterogeneity in the external environment and diversity in firm-specific resource endowments is a pivotal factor shaping the sustainable development trajectories of Chinese enterprises [65,66]. This section examines heterogeneity across three critical dimensions: geographical distribution, corporate scale, and ownership structure.

4.5.1. The Regional Heterogeneity

The estimation results presented in column (1) of Table 9 show a statistically significant positive impact of climate risk perception on the quality of corporate green innovation among firms located in China's Eastern region, with a coefficient of 0.0996. A similarly significant effect at the 1% level is observed for firms in the Central and Western regions, as shown in column (2), although the coefficient is substantially smaller at 0.0935. Column (3) demonstrates that, for Eastern firms, climate risk perception exerts a significant stimulative effect on the quantity of green innovation, with a coefficient of 0.0326. In contrast, column (4) indicates that the effect is statistically insignificant for firms in the Central and Western regions. This comparative analysis reveals that the marginal effect of heightened climate risk perception on green innovation is more pronounced for enterprises operating in the Eastern region.

Table 9. Regional heterogeneity analysis results.

Variables	(1) *CGIQ*	(2) *CGIQ*	(3) *CGIA*	(4) *CGIA*
CRP	0.0996 *** (0.0050)	0.0935 *** (0.0256)	0.0326 *** (0.0040)	0.0187 (0.0218)
Controls	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Corporate FE	YES	YES	YES	YES
Observation	45,336	2803	42,616	2540
R-squared	0.6561	0.817	0.6016	0.781

*, **, *** denote statistical significance at 10%, 5%, and 1%, respectively; (.) is robust standard errors.

This observed regional heterogeneity can be attributed to differences in firms' dynamic capabilities, particularly their ability to translate climate risk perception into effective resource reconfiguration. Firms in the Eastern region generally possess stronger financial reserves, more advanced technological assets, and a deeper talent pool [22], which jointly enhance their seizing and reconfiguring capabilities once climate risks are perceived. Heightened climate risk perception incentivizes these firms to undertake immediate resource reallocation, such as easing financing constraints through internal cash flow or green bonds, accelerating low-carbon R&D by leveraging existing patent portfolios, and

upgrading environmental equipment with support from specialized engineering teams. This systematic reconfiguration produces amplified effects in regions with well-developed capital markets and robust innovation ecosystems. By contrast, firms in Central and Western China often face constraints that weaken the conversion of risk perception into effective capability deployment, resulting in less pronounced green innovation responses.

4.5.2. The Scale Heterogeneity

The impact of climate risk perception on the green innovation of small enterprises, as shown in column (1) of Table 10, is significant at the 1% confidence level, with a coefficient of 0.0632. Column (2) of Table 9 indicates that the effect of climate risk perception on the green innovation of large enterprises is also significant at the 1% confidence level, with a coefficient of 0.0478. These results suggest that the marginal effect of climate risk perception on the quality of corporate green innovation is more pronounced for small enterprises than for large firms.

Table 10. Firm scale heterogeneity analysis results.

Variables	(1) *CGIQ*	(2) *CGIQ*	(3) *CGIA*	(4) *CGIA*
CRP	0.0632 *** (0.0047)	0.0478 *** (0.0179)	0.0173 *** (0.0038)	0.0537 *** (0.0186)
Controls	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Corporate FE	YES	YES	YES	YES
Observation	45,719	5001	40,791	4361
R-squared	0.6197	0.8155	0.6003	0.7598

*, **, *** denote statistical significance at 10%, 5%, and 1%, respectively; (.) is robust standard errors.

The stronger effect on green innovation quality among small and medium-sized enterprises (SMEs) can be understood in terms of differences in dynamic capability emphasis across firm size. SMEs tend to exhibit greater vulnerability to climate risk exposure and possess limited organizational slack, which heightens the importance of effective climate risk sensing. As a result, SMEs that perceive climate risks are more likely to channel limited resources toward targeted and high-quality green innovation to enhance resilience under climate-induced uncertainty [67].

Columns (3) and (4) of Table 9 show that climate risk perception exerts a statistically significant positive influence on the quantity of corporate green innovation for both small and large enterprises, with coefficient estimates of 0.0173 and 0.0537, respectively. Notably, the marginal effect on the quantity of green innovation is more pronounced among large firms. Large enterprises typically possess stronger seizing capabilities, including greater internal cash flows and more stable access to external financing, which allow them to rapidly scale up green R&D investment when climate risks are perceived. In contrast, SMEs often must divert limited resources to short-term adjustment or compliance, weakening their ability to translate climate risk perception into large-scale innovation output [68].

4.5.3. The Ownership Heterogeneity

As shown in column (1) of Table 11, the impact of climate risk perception on the quality of corporate green innovation in private enterprises is significant at the 1% confidence level, with a coefficient of 0.0792. Column (2) of Table 10 indicates that the effect of climate risk perception on the quality of corporate green innovation in state-owned enterprises (SOEs) is also significant at the 1% level, with a higher coefficient of 0.1233. Column (3) shows that

the effect of climate risk perception on the quantity of green innovation is 0.0209 for private enterprises, whereas column (4) reports a stronger effect of 0.0607 for SOEs. These results indicate that the marginal effect of climate risk perception on corporate green innovation is more pronounced in state-owned enterprises than in private firms.

Table 11. Ownership heterogeneity analysis results.

Variables	(1) *CGIQ*	(2) *CGIQ*	(3) *CGIA*	(4) *CGIA*
CRP	0.0792 *** (0.0059)	0.1233 *** (0.0089)	0.0209 *** (0.0049)	0.0607 *** (0.0074)
Controls	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Corporate FE	YES	YES	YES	YES
Observation	29,103	18,179	26,958	17,315
R-squared	0.6736	0.6812	0.6281	0.6236

*, **, *** denote statistical significance at 10%, 5%, and 1%, respectively; (.) is robust standard errors.

This ownership heterogeneity reflects differences in firms' institutionally embedded dynamic capabilities, particularly in terms of external coordination and resource mobilization. When confronting climate transition risks, SOEs possess a relative advantage in accessing government special funds, green credit, and R&D subsidies [68], which strengthens their seizing and reconfiguring capabilities once climate risks are perceived. In addition, SOEs maintain stable trust relationships and communication channels with government agencies and financial institutions, facilitating effective external coordination. These features enable SOEs to more effectively align climate risk perception with strategic resource reallocation, resulting in greater improvements in both the quality and quantity of green innovation [69].

5. Conclusions and Policy Implications

5.1. Conclusions

This study examines the influence of corporate climate risk perception on green innovation, focusing on its direct effects, underlying mechanisms, and heterogeneous impacts across different contexts. The key findings are as follows: (1) the principal results reveal a statistically significant positive association between climate risk perception and both the quantity and quality of corporate green innovation; (2) the analysis identifies three significant mediating pathways, namely the alleviation of financing constraints, the promotion of R&D investment, and the improvement of ESG performance; and (3) climate risk perception promotes corporate green innovation more effectively for firms located in the Eastern regions and for state-owned enterprises, while it enhances the quantity of green innovation more strongly in large firms and enhances the quality of green innovation more prominently in small firms.

This study makes three theoretical contributions. First, it introduces climate risk perception as a micro-level cognitive construct into the green innovation literature, shifting the analytical focus from objective climate exposures to firms' subjective recognition of climate-related threats and enriching the understanding of how climate uncertainty influences internal decision-making. Second, drawing on dynamic capabilities theory, the study develops an integrated mechanism framework linking climate risk perception to green innovation through resource reallocation, organizational learning, and external coordination, thereby advancing existing research by clarifying how cognitive assessments

are translated into innovation-oriented actions. Third, by examining listed firms in an emerging economy, the study provides micro-level evidence on how institutional context shapes firms' adaptive responses to climate risks, extending the applicability of dynamic capabilities theory to climate economics and deepening the understanding of corporate behavior under climate uncertainty.

Although the empirical analysis is conducted within the context of China's A-share listed firms, the core theoretical insights of this study are not limited to a single institutional setting. The cognition-to-behavior mechanism identified in this paper-whereby firms sense climate-related risks, seize strategic opportunities through resource reallocation and capability deployment, and ultimately reconfigure innovation activities-reflects a general dynamic capability process that is relevant across different regulatory and market environments. In both emerging and developed economies, firms increasingly face climate-related physical and transition risks, and managerial perception of such risks is likely to play a similar role in shaping green innovation strategies, albeit with context-specific manifestations.

5.2. Implications

5.2.1. Management Implications

Based on the findings of this study, we propose the following three policy recommendations for enterprises: (1) enterprises should establish a dynamic climate risk management system by integrating real-time monitoring into strategic decision-making, with tailored support for eastern coastal firms and SMEs. Adding a "Climate Risk Disclosure Section" to investment evaluation forms and granting ESG committees veto power ensures formal documentation of climate risks and enables the blocking of high-risk projects. Central to this effort is the use of tools such as scenario analysis and stress testing to transform climate factors from external constraints into endogenous strategic variables; (2) fostering climate-driven innovation is essential for building core competitiveness, requiring increased investment in low-carbon R&D and the reallocation of resources toward green sectors. This approach reframes climate response costs as strategic investments that enhance process efficiency and support new market development; and (3) strengthening financial and governance resilience through the use of diversified green financing instruments and embedding climate oversight into board-level responsibilities, linked to executive KPIs, ensures institutional accountability. Concurrently, climate-related metrics—such as carbon intensity, renewable energy proportion, and inventory turnover days in high-risk regions—should be integrated into annual KPIs alongside traditional financial targets.

5.2.2. Policy Implications

We also propose the following three policy recommendations for governments. Firstly, public authorities should establish a dynamic climate risk governance system that integrates real-time monitoring, early-warning platforms, and data infrastructure. Developing region-specific climate risk maps using technologies like remote sensing and big data would enable firms to accurately assess threats and integrate them into strategic planning. Secondly, climate policies must be differentiated to reflect regional and firm-specific conditions. Eastern coastal areas, facing higher climate vulnerabilities, may need stricter disclosure rules and innovation-focused incentives, while central and western regions could benefit more from transition support programs and targeted resilience investments. Thirdly, governments should enhance financial and institutional support mechanisms to lower firms' green transition costs and build long-term adaptive capacity. This can be achieved by expanding green credit, transition finance, and climate bonds, while strengthening ESG disclosure rules and incorporating climate objectives into regulatory evaluations.

5.3. Future Research Directions

First, we recommend the pursuit of action research with specific firms or industrial parks. In-depth case studies, such as examining the Ningbo-Zhoushan Port's integration of resilient infrastructure and green technological upgrades under typhoon risk, or analyzing how South Africa's indebted power utility employs hybrid financing for renewable retrofits amid coal asset stranding risks, can validate the proposed causal mechanisms and offer replicable governance templates for emerging markets.

Secondly, we suggest that the discrepancy between perceived and objective climate risk be investigated. Considering the validity of the proxy variable for managerial perception, particularly in light of the influences stemming from differences in corporate reporting styles and the distinction between strategic reporting and cognitive reporting, future research could directly match micro-level managerial perception data with region- or firm-specific objective risk indicators, such as physical climate risk models and carbon pricing data. This would clarify how the "perceived-objective" risk gap influences green innovation, thereby isolating the distinct marginal effects of cognitive bias from actual risk exposure.

Finally, the generalizability of the empirical results should be interpreted with appropriate caution. China's A-share listed firms operate within a distinctive institutional environment characterized by strong government involvement, policy-driven green finance mechanisms, and the prominent role of state-owned enterprises. These features may amplify certain channels-such as access to green credit or policy-aligned innovation incentives—through which climate risk perception affects green innovation. Future research could extend the analytical framework developed in this study to other emerging economies or developed markets with different regulatory regimes, ownership structures, and financial systems, in order to further assess the external validity of the findings and explore how institutional variation moderates the perception–capability–innovation linkage. Future research should also explore alternative transmission channels in the relationship between climate risk perception and green innovation across diverse institutional contexts.

Author Contributions: Conceptualization, X.B.; methodology, X.B.; software, X.Z.; validation, X.B., and X.Z.; formal analysis, X.B. and X.Z.; investigation, X.B. and X.Z.; resources, X.B.; data curation, X.B. and X.Z.; writing—original draft preparation, X.B.; writing—review and editing, X.B.; visualization, X.B.; supervision, X.B.; project administration, X.B.; funding acquisition, X.B. and X.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Social Science Foundation of China (No. 21AJY014).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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