

Article

From Green to Adaptation: How Does a Green Business Environment Shape Urban Climate Resilience?

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Abstract

Strengthening climate resilience constitutes a foundational approach through which cities adapt to climate change and mitigate associated environmental risks. However, research on the influence of economic policy environments on climate resilience remains limited. Guided by institutional theory and dynamic capability theory, this study employs a panel dataset comprising 272 Chinese cities at the prefecture level and above, covering the period from 2009 to 2023. It constructs a composite index framework for evaluating the green business environment (GBE) and urban climate resilience (UCR) using the entropy weight method. Employing a two-way fixed-effect regression model, it examined the impact of GBE optimization on UCR empirically and also explored the underlying mechanisms. The results show that improvements in the GBE significantly enhance UCR, with green innovation (GI) in technology functioning as an intermediary mechanism within this relationship. Moreover, climate policy uncertainty (CPU) exerts a moderating effect along this transmission pathway: on the one hand, it amplifies the beneficial effect of the GBE on GI; on the other hand, it hampers the transformation of GI into improved GBEs. The former effect dominates, indicating that optimizing the GBE becomes particularly critical for enhancing UCR under high CPU. To eliminate potential endogenous issues, this paper adopts a two-stage regression model based on the instrumental variable method (2SLS). The above conclusion still holds after undergoing a series of robustness tests. This study reveals the mechanism by which a GBE enhances its growth through GI. By incorporating CPU as a heterogeneous factor, the findings suggest that governments should balance policy incentives with environmental regulations in climate resilience governance. Furthermore, maintaining awareness of the risks stemming from climate policy volatility is of critical importance. By providing a stable and supportive institutional environment, governments can foster steady progress in green innovation and comprehensively improve urban adaptive capacity to climate change.

Keywords: green business environment; urban climate resilience; green technological innovation; climate policy uncertainty; intermediary mechanism; moderating effect



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1. Introduction

In recent years, disasters such as floods triggered by torrential rainfall [1] and wildfires induced by extreme heat [2] have posed serious threats to human life and property. Among the various causes of climate-related disasters, global warming driven by greenhouse gas emissions stands out as one of the most significant. As of 2023, more than half of the global population lives in urban areas, and this share is expected to rise to about 70% by 2050 [3]. Their high population density, intensive economic activities, and frequent social and cultural interactions position cities at the forefront of climate vulnerability. According to the Carbon Disclosure Project's 2021 report, 93% of cities face significant climate-related threats [4]. Against this backdrop, cities must reduce greenhouse gas emissions and enhance their capacity to withstand climate risks. As a major source of greenhouse gas emissions, China faces acute climate risk challenges amid its rapid industrialization and urbanization processes [5]. Therefore, exploring governance pathways for Chinese cities to respond to climate disasters is not only necessary but also of considerable practical significance.

To mitigate the impacts of climate-related disasters, enhancing urban climate resilience (UCR) has emerged as an effective strategy for addressing the climate crisis and has attracted increasing scholarly interest [6,7]. UCR reflects a city's capacity to absorb climate shocks, adapt to changing conditions, and recover from disasters [8]. In 2010, the United Nations Office for Disaster Risk Reduction launched the global initiative "Making Cities Resilient" [9]. More recently, the COP29 reached an agreement on the operational guidelines for Article 6 of the Paris Agreement and set post-2025 climate finance targets, underscoring the critical role of financial mechanisms in addressing climate change. China has demonstrated proactive engagement with the United Nations' climate governance agenda by promulgating a series of policy directives, such as the National Strategy for Addressing Climate Change and the Urban Climate Adaptation Action Plan. Notably, the Notice on Deepening the Pilot Program for Climate-Adaptive City Construction outlines a clear objective: achieving comprehensive climate-adaptive urban development across all cities at the prefecture-level and above by 2035 [10].

Cities are complex, multi-layered systems characterized by dynamic evolution, in which economic, natural, and social subsystems differ in nature yet remain deeply interdependent [11]. This complexity implies that achieving sustainable development across both natural and social dimensions requires targeted efforts by governments at the economic level. As a critical external condition influencing the behavior of microeconomic actors, the business environment encompasses all aspects of the economic, social, and environmental performance of enterprises [12] and is inherently linked to urban resilience. Building on this, the concept of the green business environment (GBE) places additional emphasis on environmental friendliness and sustainable development [13], and serves as a comprehensive reflection of a region's suitability for fostering and supporting green industries. In areas where green economic development remains underdeveloped, optimizing the GBE helps address environmental externalities arising from business operations. Governments can promote GBE optimization through low-carbon policy guidance, the agglomeration of green production factors, and the provision of green financial support, thereby promoting the synchronized progression of economic development and ecological sustainability.

However, the institutional incentives and resource allocation systems established by governments through the optimization of the GBE may face policy implementation deviations in the process of enhancing UCR, and the specific transmission mechanisms remain to be further explored. Existing studies have shown that the implementation of green innovation (GI) is not only a key indicator of a firm's green transformation but also a critical pathway for strengthening its capacity to adapt to and withstand climate-related risks [14,15]. Positioning GI as a mediating mechanism through which the GBE influences

UCR aligns with a logical transmission path, from institutional construction by the government to behavioral transformation at the firm level, and ultimately to improvements in urban attributes. This perspective helps illuminate how the actions of microeconomic entities, through innovation-driven agglomeration and diffusion effects, can collectively foster resilience-building at the broader urban scale.

When climate-related policy environments undergo frequent and drastic changes, regional capacity to cope with climate risks may be subject to corresponding uncertainty shocks [16,17]. In recent years, the economic and social impacts of climate policy uncertainty (CPU) have, in some cases, surpassed those of general economic policy uncertainty [18]. Existing research has shown that CPU significantly elevates urban climate risk levels [4,19]. A policy-side variable shaped by macro-level conditions, similar to the GBE-CPU, may influence local governments' efforts to optimize the GBE and enhance UCR. Introducing CPU as a moderating variable is thus crucial for clarifying the interaction mechanisms among these variables. Moreover, the CPU may exert both inhibiting [20,21] and facilitating effects [22–24] on GI. To explore the role of CPU within the mediating mechanism, this study constructs a moderated mediation model to capture its influence across the transmission pathway.

This study utilizes a sample of 272 Chinese cities at the prefecture level and above to empirically investigate the impact of GBEs on UCR, while also exploring the roles of GI and CPU within this mechanism. The potential marginal contributions are summarized as follows. First, this research innovatively bridges the perspectives of economic policy environment and resilience governance. It uncovers the logical relationship whereby the GBE enhances UCR through the promotion of green technological innovation, thereby offering a novel pathway for strengthening urban climate adaptability. Second, the direction of CPU's impact on GI and UCR remains inconclusive in the existing literature. This study advances the discussion by identifying CPU's dual moderating role within the mechanism: it facilitates the positive effect of the GBE on GI while simultaneously hindering the transmission of GI to improved UCR. This dual perspective goes beyond the prevailing one-dimensional understanding of CPU and enriches the theoretical discourse on the relationship between policy uncertainty and resilience governance. Third, this study constructs context-specific index systems for GBEs and UCR in China using the entropy weight method and conducts a comprehensive assessment of prefecture-level cities. By incorporating a perspective of locational heterogeneity, this study proposes context-sensitive policy optimization strategies, providing practical guidance for local governments in advancing UCR.

The remainder of this paper is structured as follows. Section 2 reviews the relevant literature and formulates hypotheses. Section 3 details the research methodology. Section 4 reports the empirical findings. Section 5 concludes with a discussion of key insights and policy implications.

2. The Literature Review and Theoretical Hypotheses

2.1. Green Business Environments and Urban Climate Resilience

In the view of the World Bank, the business environment refers to the external context within which firms operate—including government policies, market orientation, and legal–cultural frameworks—that significantly influence the entire life cycle of enterprises, from market entry and operations to eventual exit. Building on this foundation, the GBE refers to a comprehensive institutional and financial context in which governments provide favorable policy guidance and stable financing channels to support enterprises in undertaking green transformation [13]. While the literature on the general business environment is relatively extensive, studies focusing specifically on the GBE have largely concentrated on the financial and firm-level dimensions. Existing research primarily addresses aspects

such as financial resources [25] and foreign direct investment [13]; however, a notable gap persists in the literature regarding the role of GBEs at the urban scale, particularly in shaping cities' capacity to strengthen climate resilience. Given the growing importance of green development in urban governance, it is essential to explore how improvements in the GBE contribute to the formation of more resilient urban systems.

UCR encompasses the adaptive and restorative capacities of various subsystems within the urban complex ecological system, including the natural environment, infrastructure, social governance, and economic structures [26]. At its core, UCR emphasizes dynamic coordination across multiple factors and levels, enabling cities to maintain functional continuity and sustainable development in the face of climate-related risks. Existing policy documents largely focus on optimizing climate governance strategies within specific sectors or pilot cities. Meanwhile, the academic literature primarily examines the implementation outcomes of established climate policies [4,27] and conducts comprehensive assessments of regional climate resilience. While many studies have acknowledged the influence of human capital [28], infrastructure [29], financial resources [30], institutional frameworks [31], and technological capabilities [32] on overall resilience, few have approached UCR from the perspective of optimizing the business environment. There remains a lack of research integrating policy instruments with firm-level behavior as a mechanism for enhancing UCR—a critical analytical gap this study seeks to fill.

From the perspective of the relationship between the two, most existing studies have taken specific industries or sectors as entry points. In the financial domain, some research highlights how capital flows and incentive mechanisms—such as green bonds and carbon pricing—can be leveraged to strengthen climate resilience [33]. Meanwhile, digital finance has been shown to promote urban ecological resilience by facilitating green technological innovation, improving energy efficiency, and fostering agglomeration in productive service industries [34,35]. Studies on environmental regulation primarily focus on the role of government-led standards in mitigating urban climate risks [36,37]. While previous research has extensively examined the enhancement of climate resilience through themes such as green finance and environmental governance, this study offers a marginal contribution by proposing a cross-domain integration of indicators, offering a novel framework for understanding the interplay between green development and urban climate adaptation. As previously defined, the essence of the GBE lies in the integration of environmental regulation and market mechanisms. By aligning compliance pressures with policy incentives, GBEs can effectively shape enterprises' low-carbon behavior, thereby exerting a positive impact on UCR. On the one hand, government-led optimization of the GBE can reduce institutional barriers to firms' participation in green transformation. In the short term, corporate carbon reduction efforts contribute to improved urban environmental quality [38]; over the long run, green transformation at the enterprise level can upgrade the overall industrial structure toward greater environmental sustainability [39], promote the development of green public service systems, and enhance cities' adaptive and restorative capacities to climate risks from the supply side. On the other hand, according to signaling theory, governments can enhance GBEs by strengthening information disclosure mechanisms and establishing robust green standards. These measures send clear environmental signals to the public, improving both corporate environmental responsibility and public awareness of environmental protection [40]. This, in turn, fosters social capital and collaborative governance, enabling more effective resource mobilization and quicker recovery in response to extreme climate events.

In summary, the optimization of the GBE may yield significant environmental and social benefits, helping to mitigate climate change and serving as a critical foundation for

enhancing urban climate adaptability in the pursuit of sustainable development. Drawing on the above rationale, this study puts forward the following research hypothesis:

Hypothesis 1. *Optimization of the GBE promotes improvement in UCR.*

2.2. The Mediating Role of Green Innovation

GI refers to a series of innovative activities undertaken by enterprises under the dual drive of environmental and economic objectives. These activities—centered around products, processes, or management models—aim to reduce resource consumption, lower pollutant emissions, and enhance corporate sustainability [41,42]. As a critical antecedent of urban GI capacity, the GBE plays a pivotal role in shaping firms' innovation behavior.

Governments can promote GBE optimization by adjusting policy instruments such as green credit schemes and preferential green tax policies, thereby encouraging firms to engage in green technological R&D as well as enhancing the region's overall level of GI [43]. In turn, GI contributes positively to UCR [44]. It helps reduce urban carbon emissions [45], thereby mitigating the adverse effects of greenhouse gas emissions and alleviating climate change at its source. GI also facilitates urban renewal by improving green infrastructure and expanding green urban spaces [46], thus enhancing cities' risk resistance from a climate-adaptation perspective.

From this logical chain, it follows that GBE optimization indirectly strengthens cities' capacity to cope with and recover from extreme climate events by stimulating green technology development and application. Accordingly, the second hypothesis is formulated as follows:

Hypothesis 2. *GI mediates the relationship between the GBE and UCR.*

To further clarify the specific pathways within this mediating mechanism, we decompose the above hypothesis into two sub-hypotheses.

As a form of innovation that simultaneously exhibits both environmental and technological externalities [47], GI serves as a core mechanism for advancing green transformation. In recent years, research on GI has gradually expanded from the firm level to the urban level, placing increasing emphasis on the guiding role of the macro-institutional environment [48,49]. In line with the weak Porter hypothesis, well-designed environmental regulations can stimulate GI [50]. Compared with coercive regulatory approaches, the GBE emphasizes green-oriented policies and market-based incentives. Government support in areas such as financing, cost reduction, and market access lowers the initial investment threshold for enterprises undertaking green R&D. In doing so, GI shifts from being perceived as a "burden of externalities" to a "market opportunity," thereby increasing expected returns and strengthening firms' motivation to innovate in green technologies. Based on this logic, the following hypothesis is proposed:

Hypothesis 2a. *Optimization of the GBE promotes GI.*

The contribution of GI to UCR manifests in two principal ways. In the context of climate change mitigation, the application of green technologies can effectively minimize carbon footprints. For example, pathways such as energy structure optimization [51], the promotion of new energy vehicles [52], and green building design [53] help to reduce environmental harm at the source and alleviate climate risks. From the perspective of climate change adaptation, GI plays a critical role in advancing green infrastructure [54] and enhancing resource circularity and efficiency [55]. Successfully applying green innovations improves a city's responsiveness and recovery in the face of climate shocks. Accordingly, the following hypothesis is proposed:

Hypothesis 2b. *Improvement in GI enhances UCR.*

2.3. The Moderating Role of Climate Policy Uncertainty

CPU refers to the ambiguity, unpredictability, and frequent fluctuations in governmental policies related to climate change [56,57]. This includes the vacillation of policy objectives, frequent revisions of implementation guidelines, and volatility in regulatory intensity. A high level of policy uncertainty can have significant negative impacts on environmental governance and low-carbon transitions [4,22]. Under heightened uncertainty, enterprises may postpone green technology development and transformation plans to mitigate the risks arising from policy shifts [58].

Uncertainty may also stimulate interaction between governments and enterprises [59], enhance firms' sensitivity to policy changes, and promote proactive strategic adaptation and risk avoidance—sometimes even serving as a driver of innovation [60]. In this process, a well-developed GBE becomes a key institutional anchor for enterprises to hedge against macro-level uncertainty.

From the perspective of institutional economics, GBEs essentially function as a safeguard mechanism, which becomes particularly important under uncertain conditions. As climate policy volatility increases, firms exhibit greater demand for a predictable institutional environment. In this context, policy incentives embedded not only stabilize market expectations but also reduce transaction costs and institutional friction, thereby encouraging firms to invest more in cleaner production [61]. Consequently, CPU may reinforce the signaling and stabilizing functions of the GBE, ultimately enhancing its effectiveness in promoting UCR.

Based on organizational behavior theory, external policy uncertainty is one of the key triggers for firms to adjust their resource allocation and strategic behavior [62]. CPU increases the urgency and feasibility of firms undertaking green transitions to manage climate risks. Under such fluctuating policy conditions, institutional features of a GBE provide a robust foundation for strategic realignment. Therefore, CPU may compel firms to rely more heavily on GBEs to guide green transformation, thereby improving their organizational resilience and, in turn, enhancing UCR.

At the city governance level, CPU exerts a similar effect. According to risk society theory, in a highly uncertain social context, institutional arrangements play a crucial role in shaping public risk perception and enabling effective response mechanisms [63]. As an institutional platform for risk governance, the GBE contributes to building a stable policy implementation framework through its normative and transparent characteristics. During periods of rising uncertainty, the GBE also serves as a basis for increasing public trust and mobilizing green actions. CPU thus amplifies the governance mobilization effect of GBEs, an effect that is particularly pronounced in regions with strong local governance capacity and well-developed green institutions.

In summary, CPU enhances the functional role of the GBE in incentivizing GI, stabilizing market expectations, and reducing transformation risks, thereby strengthening its impact on UCR. Accordingly, the following hypothesis is proposed:

Hypothesis 3. *CPU positively moderates the effect of GBE optimization on UCR.*

2.4. Moderated Mediation Effect

The mediating role of GI is not necessarily stable. Its effectiveness may be contingent upon the level of CPU. On the one hand, based on dynamic capability theory, firms are capable of proactively responding to environmental uncertainty [64]. Under conditions of high CPU, firms face increased compliance pressures and market volatility risks, which may prompt them to seek green technological breakthroughs to enhance both environmental

adaptability and competitive advantage. These opportunistic and adaptive behaviors can be further strengthened when governments optimize the GBE. Existing research suggests that under high-CPU scenarios, the incentivizing effect of GBEs on GI may be amplified [22,24]. In such cases, firms' green investments are not suppressed but become more targeted and forward-looking, thereby facilitating GI and ultimately enhancing UCR.

On the other hand, risk management theory posits that firms tend to exhibit conservative, risk-averse behavior under conditions of elevated environmental uncertainty [65]. Compared with general innovation, GI is characterized by greater public good attributes, higher environmental externalities, inherently higher costs, technological uncertainties, and longer return cycles. Its successful transformation depends heavily on clear and stable long-term policy support. When climate-related policies are inconsistent or frequently adjusted, firms may adopt a more cautious stance in investment and R&D decisions, reducing their willingness to engage in GI [20,21]. This rational avoidance behavior weakens the translation of GBEs into UCR through GI. These two competing mechanisms reveal the dual role of the CPU in shaping the mediating effect of GI. In certain contexts, the CPU acts as a pressure source, motivating firms to leverage GBEs for GI and thereby strengthening the mediation pathway. In other contexts, the CPU functions as a risk factor, undermining firms' willingness to innovate and thereby weakening the effectiveness of GBEs in enhancing UCR. Therefore, the direction and intensity of this moderating effect require further empirical exploration.

Based on the above reasoning, this study constructs a moderated mediation model to explore the stage-specific and context-dependent effects of CPU. Accordingly, we propose the following hypothesis:

Hypothesis 4. *The pathway through which GBE optimization enhances UCR via GI is moderated by CPU.*

Summarizing the above hypotheses, this paper constructs the following theoretical framework, as shown in Figure 1.

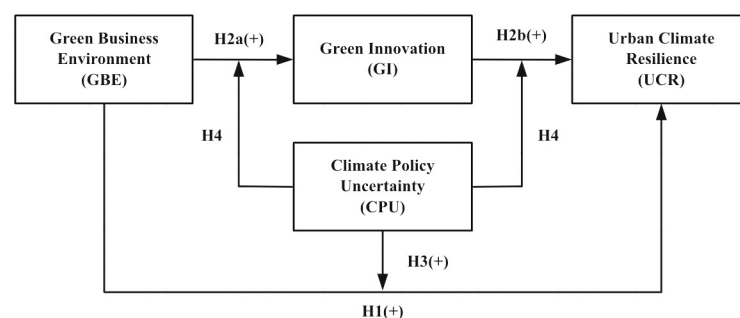


Figure 1. Theoretical framework.

3. Research Methodology

3.1. Construction of Key Variables

3.1.1. Independent Variable: The GBE

At the city level, the GBE involves multiple dimensions of the socio-economic system. Multidimensional evaluation based on objective economic data has become a mainstream approach in recent research. Drawing on the China Business Environment Report and prior index systems [13,66–68], this study incorporates an additional dimension—the government administrative environment—to construct a comprehensive measurement framework for urban GBEs (as shown in Table 1).

Table 1. GBE indicator system.

Composite Ecosystem	The First Indicators	The Second Indicators	The Third Indicators	Indicator Types
Economic system	Public service	Medical supply	Number of medical beds per 10,000 people (tiers)	+
		Business scale	Number of personnel in the financial industry (1000 people)	+
	Financial system	Credit services	Green credit scale (CNY 10,000)	—
		Optimization level of industrial structure	The ratio of the added value of the tertiary industry to that of the secondary industry	+
		Enterprise structure	The number of large-scale industrial enterprises participating in green projects (units)	+
		Cultural environment	Number of museums (units) Average number of public library collections per person (in units of copies)	+
Ecological system	Ecosystem	Sulfur dioxide	Industrial sulfur dioxide emissions (tons)	—
		Wastewater treatment	Life sewage treatment rate (%)	+
	Human resources	Reusing water	Reutilization rate of industrial water (%)	+
		Human resources reserve	Net population inflow (1000 people) Number of employees of the unit at the end of the year (person)	+
Social system	Administrative system	Labor cost	Average wage level (CNY)	+
		Financial transparency	Local government fiscal transparency index	+
		Government's environmental concern	The frequency percentage of environmental-protection-related words in the prefectural-level city government work reports $\times 100$	+

Owing to the lack of publicly available statistical data on green credit, this study uses the loan volume to key high-polluting, high-energy-consuming industries in six major sectors above the designated size as a reverse indicator of green credit availability. The number of enterprises involved in green projects is approximated by the number of listed companies categorized under concept sectors such as “new energy,” “green recycling,” and “energy conservation,” based on data from Sina Finance.

Government environmental concern is measured following the method proposed by Chang et al. [69], which calculates the proportion of environment-related keywords in local governments’ annual work reports relative to the total word count, serving as a proxy for local policy emphasis on environmental protection.

Subsequently, the entropy weight method is applied to compute a composite index of the GBE. To facilitate interpretation of the regression coefficients, the final GBE index is rescaled by multiplying it by 10.

The calculation process is as follows: first, we perform standardization.

$$gbe_{ij} = \frac{X_{ij} - \text{Min}(X_{ij})}{\text{Max}(X_{ij}) - \text{Min}(X_{ij})} \quad (1)$$

where X_{ij} denotes the raw indicator values for each dimension; gbe_{ij} represents the standardized values of each evaluation indicator; subscript i refers to the observed sample

value for each prefecture-level city in a given year; and j corresponds to the index number of the evaluation indicator.

$$e_{ij} = -K \sum_{i=1}^m gbe_{ij} \ln gbe_{ij} \quad (2)$$

The constant K in the formula is functionally related to the system's sample size m . Since the samples in this study are in a completely disordered distribution state, $K = 1/\ln m$, $0 \leq e_{ij} \leq 1$. We performed further calculations of the information utility value of each indicator:

$$d_j = 1 - e_j \quad (3)$$

$$w_j = d_j / \sum_{j=1}^n d_j \quad (4)$$

Finally, based on the weightings of each indicator, the GBE level of a Chinese city is calculated using the following formula:

$$GBE = \sum_{j=1}^n w_j \times gbe_{ij} \quad (5)$$

3.1.2. Dependent Variable: UCR

Existing studies have utilized a diverse range of methodological approaches to assess urban resilience, including the hybrid weighting methods [70], the Delphi method [71], the coupling coordination model [72] and the entropy weight method [73]. While the choice of models varies, these approaches consistently adopt a multidimensional assessment framework encompassing economic, social, infrastructural, and environmental aspects. In line with the definition of climate resilience, and drawing on established indicator systems [27], this study categorizes UCR into four key dimensions: defensive capacity, restorative capacity, adaptive learning capacity, and organizational capacity. UCR is then quantified using the entropy weight method, following the same procedure applied to the GBE index. The detailed indicator composition is shown in Table 2. Among the indicators, the Public Environmental Concern Index is constructed following the approach of Li et al. [74], using the annual average of the Baidu Search Index for the keywords “environmental pollution” and “smog” to reflect public attention to environmental issues.

Table 2. UCR indicator system.

The First Indicators	The Second Indicators	The Third Indicators	Indicator Types
Defensive capability	Ecological endowment	Percentage of wetland area (%)	+
		Percentage of forest area (%)	+
	Ecological load	Industrial wastewater discharge volume (1000 tons)	—
		Industrial dust emissions (tons)	—
		Regional per capita GDP (yuan)	+
	Economic strength	End-of-year savings balance of urban and rural residents (CNY 10,000)	+
		Coverage rate of basic old-age insurance for urban employees (%)	+
	Social stability	Percentage of employees enrolled in basic medical insurance (%)	+
		Per capita park green space area (square meters)	+
	Green service	Green coverage rate of built-up area (%)	+

Table 2. *Cont.*

The First Indicators	The Second Indicators	The Third Indicators	Indicator Types
Recovery capability	Ecological management	Rate of harmless treatment of domestic waste (%)	+
	Economic vitality	Per capita retail sales of consumer goods (CNY)	+
	Infrastructure supply	Total water supply (in millions of cubic meters)	+
		Per capita road area (square meters)	+
Learning capability	Innovative output	Number of patent authorizations (pieces)	+
	Innovative input	Percentage of fiscal expenditure on science and technology (%)	+
		The number of students enrolled in regular higher education institutions	+
Organizational capability	Risk prevention	Fixed asset investment completed for municipal public facilities construction (CNY 10,000)	+
	Risk learning	Public Environmental Concern Index	+

3.1.3. Mediating Variable: GI

The count of green patents is commonly employed as a proxy indicator for regional GI performance [15]. Among them, green invention patents are more technically complex and difficult to obtain than green utility model patents, and thus make a more substantial marginal contribution to regional innovation capacity [75]. Therefore, this study employs the annual count of authorized green invention patents as a proxy measure for GI at the prefecture-level city scale. To facilitate the interpretation of regression coefficients, the number of patents is expressed in units of thousands.

3.1.4. Moderating Variable: CPU

This study adopts the CPU Index developed by Gavriilidis [76], using the monthly average values as the annual indicators [22,77]. The index is constructed based on keyword searches of articles from eight major U.S. newspapers and reflects the frequency of climate-policy-related terms in news media. Given the increasing interconnectedness brought by globalization and the broad, transboundary nature of climate change impacts, this index serves as a reasonably valid proxy for global climate policy volatility, making it suitable for climate-policy-related research in the Chinese context.

3.1.5. Control Variables

Following the study by Argyroudis et al. [78] and drawing upon the climate resilience assessment framework proposed by Tyler et al. [79], this paper incorporates a series of control variables that may influence UCR but are not explicitly included in the main indicator systems. Specifically, the selected variables include gross regional product [80], the share of secondary industry in GDP, the ratio of fiscal expenditure to GDP [81], the urbanization rate of the permanent population [82], the number of internet users [83], and the normalized difference vegetation index (NDVI) [27]. Among these, both gross regional product and the number of internet users are log-transformed to address potential heteroscedasticity and improve model interpretability. The NDVI is derived by averaging monthly observations over the course of a year, reflecting the overall vegetation coverage and ecological condition of each city.

3.2. Sample Selection and Data Sources

This study selects cities at the prefecture-level and above in China from 2009 to 2023 as the research sample. Following the exclusion of cities with substantial data gaps, a final panel dataset comprising 272 cities and 4056 observations was obtained. The data

required for constructing the GBE and UCR indicators are primarily sourced from the China City Statistical Yearbook and various provincial statistical yearbooks. The index of local government fiscal transparency is obtained from the Research Report on Fiscal Transparency of Chinese Municipal Governments. Data on wetland and forestland areas are drawn from the National Land Survey Data Sharing and Application Service Platform of China. Green patent data are retrieved from the CNRDS database, while the NDVI is derived from the MOD13A3 dataset released by NASA. For a limited number of missing values, this study applies linear interpolation and moving average methods to perform data imputation.

3.3. Model Construction

To study the impact of GBE optimization on UCR, this paper constructs the following model:

$$UCR_{i,t} = \alpha_0 + \alpha_1 GBE_{i,t} + \gamma Controls_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (6)$$

where $UCR_{i,t}$ represents the degree of UCR; $GBE_{i,t}$ represents the level of the GBE; $Controls_{i,t}$ represents a series of control variables; α_0 represents the intercept term; μ_i represents the individual fixed effect; δ_t represents the year fixed effect; $\varepsilon_{i,t}$ represents the random error term; the subscripts i and t represent the sample cities and years, respectively. When α_1 is significantly positive, Hypothesis 1 holds.

To study the mediating effect of GI, this paper draws on the mediation effect testing method proposed by Wen and Ye [84] to construct models (7) to (9).

$$GI_{i,t} = \beta_0 + \beta_1 GBE_{i,t} + \gamma Controls_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (7)$$

$$UCR_{i,t} = \theta_0 + \theta_1 GI_{i,t} + \gamma Controls_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (8)$$

$$UCR_{i,t} = \eta_0 + \eta_1 GBE_{i,t} + \eta_2 GI_{i,t} + \gamma Controls_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (9)$$

Subsequently, this paper adds the interaction term $GBE_{i,t} \times CPU_{i,t}$ to the benchmark model (6) to explore the moderating role of CPU, as shown in model (10).

$$UCR_{i,t} = \lambda_0 + \lambda_1 GBE_{i,t} + \lambda_2 CPU_{i,t} + \lambda_3 GBE_{i,t} \times CPU_{i,t} + \gamma Controls_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (10)$$

where $GBE_{i,t} \times CPU_{i,t}$ represents the interaction term between the GBE and UCR. To avoid multicollinearity issues, this paper performs decentralization processing on the core explanatory variables, each moderator variable, and their interaction terms. When λ_3 is significantly positive, Hypothesis 3 holds. Based on this, moderated mediation path testing models (11) and (12) are constructed.

$$GI_{i,t} = \zeta_0 + \zeta_1 GBE_{i,t} + \zeta_2 CPU_{i,t} + \zeta_3 GBE_{i,t} \times CPU_{i,t} + \gamma Controls_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (11)$$

$$UCR_{i,t} = \xi_0 + \xi_1 GBE_{i,t} + \xi_2 CPU_{i,t} + \xi_3 GBE_{i,t} \times CPU_{i,t} + \xi_4 GI_{i,t} + \xi_5 GI_{i,t} \times CPU_{i,t} + \gamma Controls_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (12)$$

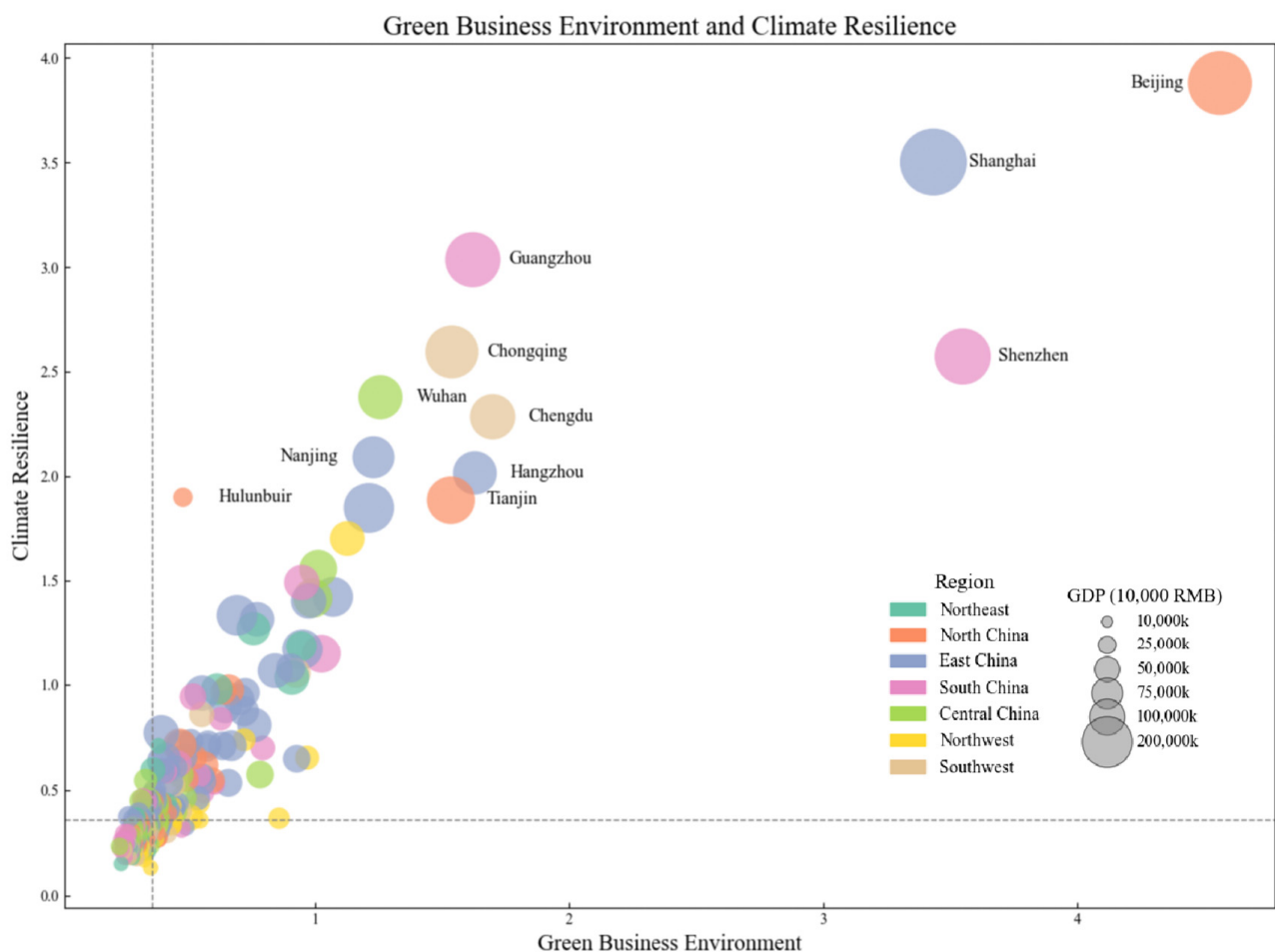
3.4. Descriptive Statistics

Table 3 reports the descriptive statistics results. The mean value of UCR is 0.538, with a standard deviation of 0.551. The observed maximum and minimum values are 4.816 and 0.081, respectively, indicating substantial variation in climate resilience levels across cities. The GBE index exhibits a similar distribution, with a mean of 0.487, a standard deviation of 0.466, and a range from 0.120 to 5.999, reflecting substantial cross-city variation. The distribution characteristics of the data for control variables align with the prior literature and are thus not elaborated upon here.

Table 3. Main variable descriptive statistics.

Symbol	Variable Name	Obs	Mean	SD	Min	Max	VIF
UCR	Urban climate resilience	4056	0.538	0.551	0.081	4.816	-
GBE	Green business environment	4056	0.487	0.466	0.120	5.999	2.41
IND2	Value added of the secondary sector as a percentage of GDP	4056	0.453	0.109	0.163	0.714	1.80
UR	Urbanization rate of resident population	4056	0.569	0.148	0.267	0.953	1.76
NDV	Normalized difference vegetation index	4056	0.511	0.135	0.067	0.748	1.22
FIN	Fiscal expenditure as a percentage of GDP	4056	0.190	0.084	0.075	0.492	2.44
GDP	Gross regional product	4056	16.65	0.943	14.00	19.97	9.53
INT	Number of Internet users	4056	13.50	1.003	10.52	17.76	6.66
GI	Number of green invention patents granted	4056	0.102	0.449	0.000	11.76	-
CPU	Climate policy uncertainty	4056	1.460	0.538	0.776	2.254	-

To more intuitively illustrate the locational and economic heterogeneity across cities, this study plots the sample mean values of each city in Figure 2. The horizontal axis represents the GBE, while the vertical axis represents UCR. Overall, the two variables exhibit a generally positive correlation, suggesting that cities with a higher level of GBE tend to demonstrate stronger climate resilience.

**Figure 2.** Bubble map of locational heterogeneity.

The size of each bubble reflects the city's GDP scale. Most cities are concentrated in the lower-left quadrant—those with both low GBEs (below 1) and low UCR (below 1.5). A small number of mega-cities are located in the upper-right quadrant. Among them, Beijing and Shanghai, as China's political and economic centers, respectively, show clear

advantages in both GBEs and UCR. This implies that economically developed regions are more capable of integrating environmental technologies and green investments, thereby demonstrating greater capacity to withstand climate risks.

Bubble colors indicate regional classifications. Cities in East and South China exhibit a distinct “high GBE–high UCR” pattern, reflecting a strong synergy between green economic development and climate resilience governance. In contrast, North China shows significant internal variation, with the capital’s agglomeration effects standing out. Cities in Central and Southwest China display a “low GBE–high UCR” pattern, suggesting that the role of the green economy in supporting climate governance has yet to be fully realized. Meanwhile, cities in Northeast and Northwest China generally fall into the “low GBE–low UCR” category, highlighting how regional development disparities are constraining climate adaptation capacities.

In addition, several outliers are worth noting. Shenzhen exhibits a significantly higher GBE index than Guangzhou and Chongqing, despite having similar UCR levels, indicating that its innovation-driven industrial structure may provide underlying advantages and stronger green economic dynamism. Conversely, Hulunbuir shows a low GBE but very high UCR, which may be attributed to its unique natural geography—grassland ecosystems with strong climate buffering and regulatory capacities.

Based on the above results, the heterogeneity in urban climate adaptation capacity can be attributed to the combined influence of structural, institutional, and environmental factors. First, cities in eastern and southern China benefit from stronger economic foundations and ongoing industrial upgrading, which enhance their fiscal capacity and environmental governance infrastructure. These conditions allow for better coordination between GBE optimization and climate adaptation efforts. Second, local institutional capacity plays a critical role: cities with higher administrative status—such as municipalities and provincial capitals—tend to possess greater autonomy and resources to implement integrated climate and environmental policies, thereby exhibiting higher levels of both GBE and UCR. Third, natural endowments and geographical features may independently shape adaptation outcomes. For instance, cities endowed with rich ecological resources—such as forests, wetlands, or grasslands—often enjoy inherent ecosystem-based buffering effects against climate risks, which helps explain why some regions with relatively low green economic development still demonstrate high levels of UCR. Finally, path dependence in historical development trajectories also matters. Many cities in northeastern and northwestern China are resource-dependent and face dual challenges in green innovation and climate governance due to aging infrastructure and the slow pace of industrial transformation, which contributes to their relatively low performance in both the GBE and UCR dimensions.

4. Analysis of Empirical Results

4.1. Baseline Regression Analysis

Table 4 presents the baseline regression results. Columns (1) and (2) report the results from random effects models, while columns (3) and (4) display the results from fixed effects models. Column (4) further incorporates control variables, as well as year and city fixed effects, building upon the specifications in the previous columns. Across all model specifications, the estimated coefficients of the GBE on UCR are consistently significant at the 1% level and positive, indicating that improvements in the GBE significantly enhance UCR. These results provide strong empirical support for Hypothesis 1.

Table 4. Results of baseline regression analysis.

	(1)	(2)	(3)	(4)
	UCR	UCR	UCR	UCR
GBE	1.047 *** (0.009)	0.683 *** (0.011)	0.773 *** (0.124)	0.696 *** (0.113)
IND2		−0.390 *** (0.040)		−0.266 ** (0.106)
UR		0.460 *** (0.029)		−0.144 (0.149)
INT		−0.118 *** (0.008)		−0.077 *** (0.016)
NDV		0.136 *** (0.027)		−0.325 * (0.187)
FIN		0.413 *** (0.061)		−0.020 (0.108)
GDP		0.318 *** (0.011)		0.283 *** (0.037)
Year FE	No	No	Yes	Yes
City FE	No	No	Yes	Yes
Constant	0.029 *** (0.006)	−3.730 *** (0.114)	0.095 ** (0.043)	−3.082 *** (0.542)
N	4056	4056	4056	4056
R ²	0.781	0.857	0.633	0.681

Note: Robust standard errors are in parentheses. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

4.2. Endogeneity Test

4.2.1. Instrumental Variable Approach

To address potential endogeneity concerns, this study employs a two-stage least squares (2SLS) regression model using an instrumental variable (IV) approach. Specifically, the average GBE of the three other prefecture-level cities within the same province whose GDPs are closest to that of the target city (denoted as Near_GBE) is used as an instrument for the city's own GBE.

In terms of relevance, economic scale is a fundamental basis for business environment optimization. As discussed in the descriptive analysis, cities with higher GDP levels tend to have better GBE performance. Furthermore, provincial-level policies are generally uniform across cities within the same province. Cities with similar GDP levels are also likely to have undergone similar stages of development. Therefore, the GBE of GDP-similar cities within the same province is highly correlated with that of the target city.

Regarding homogeneity, the GBE of nearby cities with similar GDP levels is unlikely to directly affect the target city's UCR. On one hand, cities with favorable business environments tend to generate agglomeration effects that attract green investment and enhance their resilience, although such spillover effects on neighboring cities are limited. On the other hand, UCR is a highly endogenous outcome shaped by a combination of natural endowments, historical development, and long-term planning, and is therefore unlikely to be influenced by the GBE of surrounding cities. Thus, the chosen instrument satisfies both the relevance and exclusion restrictions.

For municipalities directly under the central government and provinces with only one eligible city sample, the original GBE values of those cities are retained in the regression.

The two-stage regression models are specified as follows:

$$GBE_{i,t} = \sigma_0 + \sigma_1 \text{Near_GBE}_{i,t} + \gamma \text{Controls}_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (13)$$

$$UCR_{i,t} = \varphi_0 + \varphi_1 \text{hat_GBE}_{i,t} + \gamma \text{Controls}_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (14)$$

where $\text{Near_GBE}_{i,t}$ denotes the instrumental variable for the GBE of a city; $\text{hat_GBE}_{i,t}$ represents the fitted value of $\text{GBE}_{i,t}$ obtained from the first-stage regression. Table 5 reports the 2SLS estimation results based on this specification. In column (1), the coefficient on Near_GBE is significantly positive, indicating a strong correlation with the endogenous regressor. The first-stage F-statistic is 178.06, well above the conventional threshold of 10, confirming the relevance and strength of the instrument. Column (2) presents the second-stage regression results, showing that the GBE significantly improves UCR, thereby confirming the robustness of the baseline estimates. In addition, the results at the bottom of Table 5 indicate that issues of under-identification and weak instruments have been ruled out. Therefore, the 2SLS estimates can be considered statistically valid and reliable.

Table 5. Instrumental variable regression results.

	(1)	(2)
	GBE	UCR
Near_GBE	0.746 *** (0.056)	
hat_GBE		0.865 *** (0.091)
Control variables	Yes	Yes
Year FE	Yes	Yes
City FE	Yes	Yes
N	4056	4056
Kleibergen–Paap rk LM statistic	14.000 ***	13.998 ***
Cragg–Donald Wald F statistic	2252.480	2252.478
Kleibergen–Paap Wald rk F statistic	178.060	178.058
Stock–Yogo bias critical value	16.380 (10%)	16.380 (10%)

Note: Robust standard errors are in parentheses. *** $p < 0.01$.

4.2.2. PSM-DID Model

This paper further conducts an endogeneity test by using the propensity score matching combined with the difference-in-differences method (PSM-DID). Considering that the formation of a GBE may not be completely exogenous, factors such as the geographical conditions, economic foundation, or fiscal capacity of the city may affect the GBE level and UCR performance. The PSM method can achieve comparability between the treatment group and the control group at the observed variable level, and then combine DID to estimate the dynamic differences in policy impacts, thereby enhancing the credibility of causal identification [85].

Specifically, the State Council of China first published the “Regulations on Optimizing the Business Environment” in 2019 [86]. Therefore, this paper takes 2019 as the shock time point for policy identification. The cities with GBE indices higher than the national average in that year are set as the treatment group, while the rest are the control group. All the control variables used in this paper are taken as covariates. Due to the small sample size of the treatment group, to avoid information loss, we conduct a 1:2 nearest-neighbor matching with a 0.01 margin as the measuring scale. After obtaining the matching samples, a panel

dataset after matching is constructed, and the causal impact of the GBE on UCR is evaluated through DID regression. The model is set as follows.

$$UCR_{i,t} = \omega_0 + \omega_1(\text{treat}_i \times \text{post}_t) + \gamma \text{Controls}_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (15)$$

where treat_i indicates whether city i belongs to the treatment group; and post_t indicates whether the time is within the policy implementation period. The interaction term of these two variables is the key explanatory variable. ω_1 captures the net marginal impact of the green business environment on the city's climate resilience.

The matching results in Table 6 show that the standard deviations of the covariates are all less than 10%, and the t-test results all indicate that the null hypothesis—of no systematic difference between the treatment group and the control group—cannot be rejected. The balance test is passed. Table 7 presents the PSM-DID regression results, indicating that the main conclusion of this paper still holds after considering potential endogeneity issues.

Table 6. The results of the PSM balance test.

Variable	Unmatched	Mean		%Reduct		t-Test		V(T)/ V(C)
	Matched	Treated	Control	%Bias	Bias	t	$p > t $	
IND2	U	0.473	0.473	0.2		0.04	0.972	0.95
	M	0.475	0.472	3.1	−1192.1	0.44	0.657	1.14
UR	U	0.596	0.588	6.5		0.95	0.345	1.15
	M	0.595	0.587	7.5	−15.5	1.09	0.276	1.67 *
INT	U	13.589	13.342	29.6		4.33	0.000	1.09
	M	13.532	13.497	4.2	85.7	0.62	0.535	1.24 *
NDV	U	0.508	0.531	−18.0		−2.65	0.008	1.60 *
	M	0.512	0.507	4.3	76.3	0.59	0.557	1.74 *
FIN	U	0.162	0.174	−15.0		−2.18	0.030	0.96
	M	0.163	0.165	−3.2	78.7	−0.47	0.637	1.48 *
GDP	U	16.82	16.576	32.6		4.74	0.000	0.92
	M	16.778	16.736	5.7	82.6	0.84	0.401	1.17

Note: * $p < 0.1$.

Table 7. PSM-DID test results.

	(1)	(2)
	UCR	UCR
treat × post	0.041 * (0.023)	0.045 ** (0.018)
Control variables	No	Yes
Year FE	Yes	Yes
City FE	Yes	Yes
Constant	0.302 *** (0.010)	−2.389 *** (0.448)
N	855	855
R ²	0.77	0.83

Note: Robust standard errors are in parentheses. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

4.3. Mediating Role of GI

Table 8 tests the mediating effect of GI in the relationship between GBEs and UCR. In column (1), the regression coefficient of GBE on GI is 1.537, and in column (2), the coefficient of GI on UCR is 0.323; both are statistically significant at the 1% level, providing empirical support for Hypotheses 2a and 2b and confirming the validity of both paths in the mediation process. Column (3) includes both GBE and GI as explanatory variables for UCR.

The coefficients for GBE and GI are 0.331 and 0.237, respectively, and both remain significant at the 1% level. Compared with the results in the previous columns, the reduction in the magnitude of the GBE's coefficient in the presence of GI suggests the existence of a partial mediation effect. Taken together, these findings indicate that the GBE enhances UCR in part by promoting GI, confirming Hypothesis 2.

Table 8. The mediating role of GI.

	(1)	(2)	(3)
	GI	UCR	UCR
GBE	1.537 *** (0.388)		0.331 *** (0.080)
GI		0.323 *** (0.085)	0.237 ** (0.094)
Control variables	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Constant	−0.978 (0.686)	−2.893 *** (0.519)	−2.850 *** (0.498)
N	4056	4056	4056
R ²	0.493	0.727	0.750
Sobel's Z		8.789 ***	

Note: Robust standard errors are in parentheses. ** $p < 0.05$; *** $p < 0.01$.

4.4. Moderating Role of CPU

Table 9 reports the regression results examining the moderating effect of CPU on the GBE-GI-UCR pathway. We first test whether CPU moderates the direct effect of GBE on UCR, as shown in column (1). The coefficient of the interaction term (i.e., λ_1 in model (10)) is 3.870 and is significant at the 1% level, indicating that CPU positively moderates the direct relationship between the GBE and UCR. In other words, under greater climate policy volatility, the effect of a GBE on improving UCR becomes more pronounced—thus confirming Hypothesis 3.

Table 9. The moderating role of CPU.

	(1)	(2)	(3)
	UCR	GI	UCR
GBE	3.870 *** (0.979)	7.155 ** (3.290)	0.779 (0.730)
CPU	−0.004 (0.053)	−0.029 (0.072)	−0.022 (0.046)
GBE_CPU	2.241 *** (0.733)	5.970 *** (0.621)	3.147 *** (0.439)
GI			0.462 *** (0.110)
GI_CPU			−0.400 *** (0.051)
Control variables	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Constant	−2.932 *** (0.492)	−0.742 (0.668)	−2.945 *** (0.465)
N	4056	4056	4056
R ²	0.741	0.670	0.797

Note: Robust standard errors are in parentheses. ** $p < 0.05$; *** $p < 0.01$.

Based on the presence of a significant moderating effect on the direct path, we further estimate models (11) and (12) to test the moderation of the mediation pathway. The results are shown in columns (2) and (3). In model (11), the coefficient for GBE is 7.115, and the interaction term ($GBE \times CPU$) is 5.970, both significant at the 1% level. In model (12), the coefficient for GI is 0.462, also significant at the 1% level, indicating that CPU positively moderates the first half of the mediation process—that is, CPU reinforces the effect of a GBE on GI. However, the coefficient of the $GI \times CPU$ interaction term is significantly negative ($\beta = -0.400, p < 0.01$), suggesting that CPU negatively moderates the second half of the pathway, i.e., under high CPU, GI is less likely to be translated into improved climate resilience. Since the interaction terms in both models (11) and (12) are significant, the results confirm that CPU moderates both segments of the mediation pathway, supporting Hypothesis 4.

The economic implications of these findings are as follows. First, CPU strengthens the effect of a GBE on GI. On the one hand, in the context of frequent climate policy adjustments, firms face rising policy adaptation costs and investment risk premiums. A well-structured GBE, by providing financial support and market-based incentives, helps mitigate institutional and resource pressures, thereby fostering sustained investment in green innovation. In such scenarios, firms that already engage in GI increasingly rely on GBEs to hedge against the risks posed by CPU. On the other hand, from the perspective of strategic adaptation, firms facing a volatile climate policy environment are likely to seek proactive and adaptive responses. GBEs provide a stable institutional and policy framework that sustains GI activities, helping firms build competitive advantages through green technologies in an uncertain policy context.

Second, CPU inhibits the effect of GI on UCR. CPU transmits ambiguous policy signals, creating uncertainty regarding the market potential and policy support for green innovations. This may weaken the willingness of both firms and local governments to commit to long-term investments, making them more cautious about deploying and scaling green technologies. As a result, GI projects may face institutional barriers and inadequate policy follow-up, hindering their effective application. Although GI holds technical potential to address climate change, its real-world impact on resilience building may be constrained by high levels of CPU.

Nevertheless, the regression results suggest that the positive moderating effect of CPU on the direct GBE-UCR link outweighs the negative moderation in the mediation path. This indicates that, overall, CPU still plays a facilitating role in the process of GBEs enhancing climate resilience. However, its inhibitory effect on the translation of innovation into resilience outcomes should not be overlooked.

4.5. Robustness Checks

This study conducts four robustness checks. First, we replace both the explanatory variable and the mediating variable with alternative measures. Specifically, we substitute the GBE with environmental regulation intensity, denoted as ER, as shown in column (1) of Table 10. ER is proxied by a city's investment in pollution control. Due to the limited availability of pollution control data at the prefecture level, we scale provincial-level pollution control investment according to the ratio of each city's fiscal expenditure to the total provincial fiscal expenditure, thereby constructing a proxy for city-level environmental regulation strength. At the same time, we replace the mediating variable with the total number of authorized green invention patents and green utility model patents, denoted as TGI, to reflect broader GI output. The results using TGI are reported in columns (2) to (4) of Table 10. Second, we employ a dynamic panel model to incorporate the policy lag effect. Given that there is usually a time delay in enterprises' responses, technological innovation, and system

changes, the mechanism by which a GBE affects UCR may exhibit a policy transmission lag. Therefore, this paper further incorporates the time structure changes in the dependent variable and conducts regressions of t -period GBE on UCR for periods $t + 1$, $t + 2$, and $t + 3$ (denoted as F1_UCR, F2_UCR, and F3_UCR, respectively), and the results are shown in Table 11. Third, to account for the potential omission of province-level unobserved heterogeneity, we introduce province fixed effects and province-by-year interaction fixed effects into the regression models. The corresponding results are reported in columns (1) and (2) of Table 12, respectively. Fourth, for robustness regarding CPU, we exclude observations from years with globally significant climate policy fluctuations—specifically, 2015, the year of the Paris Agreement, and 2020, marked by the COVID-19 pandemic. The estimation results excluding these years are shown in columns (3) to (5) of Table 12. Across all robustness tests, the results remain valid.

Table 10. Robustness test based on variable substitution.

	(1)	(2)	(3)	(4)
	UCR	TGI	UCR	UCR
ER	0.666 *** (0.209)			
GBE		4.020 *** (0.638)		0.147 *** (0.053)
TGI			0.151 *** (0.011)	0.136 *** (0.011)
Control variables	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Constant	−35.718 *** (7.056)	−3.439 (2.099)	−2.619 *** (0.385)	−2.612 *** (0.384)
N	4056	4056	4056	4056
R ²	0.554	0.550	0.834	0.839

Note: Robust standard errors are in parentheses. *** $p < 0.01$.

Table 11. Robustness test based on dynamic panel model.

	(1)	(2)	(3)
	F1_UCR	F2_UCR	F3_UCR
GBE	0.782 *** (0.134)	0.758 *** (0.148)	0.665 *** (0.154)
Control variables	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Constant	−3.063 *** (0.508)	−2.924 *** (0.534)	−2.825 *** (0.577)
N	3776	3506	3238
R ²	0.70	0.68	0.64

Note: Robust standard errors are in parentheses. *** $p < 0.01$.

Table 12. Other robustness test results.

	(1)	(2)	(3)	(4)	(5)
	UCR	UCR	UCR	GI	UCR
GBE	0.696 *** (0.113)	0.703 *** (0.183)	3.606 *** (1.011)	6.176 * (3.178)	0.504 (0.740)
CPU			−0.002	0.008	−0.028

Table 12. Cont.

	(1)	(2)	(3)	(4)	(5)
	UCR	UCR	UCR	GI	UCR
GBE_CPU			(0.055) 2.528 *** (0.790)	(0.074) 7.250 *** (0.756)	(0.047) 3.267 *** (0.463)
GI					0.508 *** (0.117)
GI_CPU					−0.453 *** (0.058)
Control variables	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	No	No	No	No
Province_year FE	No	Yes	No	No	No
Constant	−3.082 *** (0.542)	−4.195 *** (1.017)	−2.969 *** (0.504)	−0.480 (0.733)	−2.995 *** (0.474)
N	4056	4056	3512	3512	3512
R ²	0.681	0.743	0.749	0.706	0.803

Note: Robust standard errors are in parentheses. * $p < 0.1$; *** $p < 0.01$.

5. Conclusions and Policy Implications

5.1. Research Conclusions

This study selects cities at the prefecture-level and above in China from 2009 to 2023 to empirically examine the impact of the GBE on UCR and the underlying mechanisms. The key findings are as follows:

First, this study systematically evaluates the levels of GBE and UCR across Chinese cities. Descriptive statistics show a generally positive correlation between the two but also reveal significant regional heterogeneity. Specifically, cities in East and South China exhibit relatively high levels of both GBE and UCR, while those in Northeast and Northwest China perform comparatively poorly. The Central region shows considerable internal variation. This spatial heterogeneity highlights the importance of GBEs in shaping a city's capacity to cope with climate risks.

Second, using composite indices and linear regression analysis, this study finds that the GBE has a significant positive effect on UCR, with GI playing a partial mediating role. That is, when cities adopt environmentally friendly economic development strategies, enterprises and research institutions are incentivized to accelerate green technology development and its application, thereby enhancing the city's resilience to climate-related risks.

Third, this study introduces CPU as a moderating variable and finds bidirectional effects. On the one hand, frequent shifts in climate policy increase economic actors' sensitivity to institutional stability, making the GBE more effective at stimulating GI under high uncertainty. On the other hand, high policy uncertainty can hinder the transformation of innovation outputs into resilience outcomes, thereby weakening the second half of the GBE-GI-UCR pathway. Nevertheless, the overall effect of CPU is still positive in terms of enhancing the direct impact of GBEs on UCR, confirming that CPU plays a conditional yet mostly facilitating role.

5.2. Policy Implications

First, given the significant role of GBEs in promoting UCR, governments should focus on both short-term incentives and long-term institutional design to build a resilient

green policy framework. On the one hand, short-term measures—such as tax reductions, innovation subsidies, and temporary financial incentives—can provide immediate support for firms engaging in GI. On the other hand, long-term strategies should include the enactment of legislation to formalize green development strategies and action plans, ensuring consistency and predictability through legal and institutional arrangements. In addition, market mechanisms should be improved by developing a robust green finance system that offers diverse funding channels for GI and climate adaptation projects. Green certification systems and environmental performance ratings can also serve as longer-term market-oriented tools to guide enterprises in upgrading their environmental technologies.

Second, since GI functions as the mediating mechanism between GBEs and UCR, its effectiveness depends on the continuous enhancement of innovation capacity. In the short run, governments should expand support for green R&D and industrialization through direct fiscal subsidies, temporary tax incentives, and targeted green credit programs, encouraging firms to invest in forward-looking technological reserves. In the longer term, a stable innovation ecosystem should be fostered by institutionalizing public–private partnerships, improving intellectual property protection, and promoting cross-regional technology cooperation. To address regional disparities, innovation-leading cities should be encouraged to drive industrial spillovers and share best practices, thereby promoting the diffusion of GI outcomes and enhancing regional climate resilience at the city cluster level.

Third, given the dual regulatory role of the CPU, the associated risks must not be overlooked. As a short-term response, policymakers should conduct policy uncertainty assessments and develop contingency plans during the early stages of GI project planning to ensure the continuity of innovation activities. In the longer term, efforts should focus on institutionalizing mechanisms to reduce policy volatility, such as improving policy feedback loops and accountability systems. At the transformation stage, emphasis should be placed on deepening industry–academia–research integration to ensure seamless connections between R&D and market deployment. When introducing new climate policies, attention should also be given to policy transparency and communication effectiveness. Through public consultations and expert reviews, stable and predictable signals should be sent to market participants to mitigate panic and investment withdrawal caused by uncertainty.

Finally, in light of the pronounced regional heterogeneity in both GBEs and UCR, climate adaptation strategies should be tailored to local characteristics. According to the descriptive bubble chart analysis, we put forward the following policy suggestions. In economically advanced eastern regions, efforts should focus on upgrading green industries and building globally competitive green industrial clusters. In central regions, leading cities should be supported to drive regional governance, while targeted support should be provided to underperforming areas to promote internal coordination and balanced development. In northeastern and northwestern regions, greater central fiscal transfers should be directed toward foundational green infrastructure, laying the groundwork for resilient development.

5.3. Discussion

This study provides valuable contributions both theoretically and practically. Theoretically, first, this paper reveals how GBEs promote urban resilience governance through the GI mechanism, bridging the gap between the economic policy environment and resilience governance, and providing a novel analytical perspective. The path to enhancing urban resilience has gradually become a focus of academic attention, with numerous studies on traditional urban resource endowments such as human resources [28], infrastructure [29] and technological capabilities [32]. Studies based on sustainable [33,36,37] or digital perspectives [34] are also increasing. However, this paper, by introducing the comprehensive

indicator of business environment, further integrates the concept of green economy and supplements previous studies that mainly focused on a single aspect of the city.

Secondly, this research enriches the ongoing theoretical discussion on the impact of CPU. By uncovering the dual moderating role of CPU—facilitating the positive effect of the GBE on green innovation while impeding the effective translation of innovation into resilience outcomes—this study reconciles previously one-sided views on the either positive [22–24] or negative [20,21] impacts of CPU, and advances theoretical understanding of the complex ways in which policy dynamics influence adaptive governance.

Thirdly, through a systematic assessment of GBEs and UCR, and taking into account geographical differences, this study demonstrates the significant role that regional context plays in shaping institutional effectiveness, and thereby emphasizes the necessity for local governments to formulate differentiated governance frameworks based on their urban development conditions.

Practically, the findings offer evidence-based guidance for governments in formulating green transition policies and building resilient cities, while also providing strategic references for enterprises facing climate risks and policy fluctuations. Ultimately, this study calls for collaborative efforts across society to jointly tackle climate risks and advance toward the shared goal of sustainable development.

However, we also acknowledge limitations in spatial coverage and indicator design. Specifically, this study is constrained to Chinese cities due to data availability, and the generalizability of the conclusions to other national contexts remains to be tested. Additionally, although the indicator design of a GBE draws on the existing literature, future research could further refine it by incorporating local policy implementation data and media-based perception indicators. Cross-national comparative studies are also encouraged to validate and expand the applicability of the findings.

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Data Availability Statement: The original data presented in this study are publicly available in the EPS database and provincial and municipal statistical yearbooks, at <https://www.epsnet.com.cn/index.html#/Index> (accessed on 23 January 2025); land use data can be obtained from the Shared Application Platform for Land Survey Results, at <https://gtdc.mnr.gov.cn/Share#/thirdSurvey> (accessed on 11 January 2025); normalized vegetation index data can be obtained from the NASA official website, at <https://search.earthdata.nasa.gov/search> (accessed on 14 February 2025); green patent data can be obtained from the Chinese Research Data Service Platform, at <https://www.cnrds.com/Home/Login> (accessed on 5 January 2025).

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