Extreme Heat Risk and Corporate Green Investment: Evidence from Chinese High-Carbon Firms

Bingcheng Tang*

North China Electric Power University, Beijing, 102206, China

*tangbingsheng0802@163.com

Abstract. This paper seeks to examine the correlation between severe temperatures and the extent of corporate green investment. We examine a group of high-carbon enterprises listed on China's A-share market from 2010 to 2022, with data on very high temperatures in the cities housing these firms. Extremely high temperatures markedly increase the level of enterprises' green investment. The results undergo a number of rigorous tests, encompassing alternate indicators, the instrumental variables method, and propensity score matching methodology. The findings from the mechanism tests demonstrate that executives possessing strong green perceptions and elevated corporate ESG ratings can amplify the influence of extreme heat on the extent of firms' green investment. Furthermore, the effect of extreme heat on firms' green investment is more significant for non-state-owned enterprises, those with high equity concentration, and firms located in central and western cities. These findings elucidate the process by which extreme climate influences corporate green investment behavior from many viewpoints.

Keywords: Extreme heat, Corporate green investment, Executive green perceptions, ESG

1 Introduction

In the past few years, the concept of greenhouse gases has come to be as a substantial obstacle to the expansion of the global economy.[1]. Global warming has resulted in the increased prevalence of exceedingly high temps, exceedingly low temps, and substantial rain. Severe climate conditions present a substantial risk to the ecosystem, essential for the purpose of human survival, public health, and the actual economy[2]. First and foremost, extreme heat results in substantial economic losses, and these impacts are direct and easily recognizable[3]. According to the information released by the World Bank and OECD organizations, during the 2022 heat wave in India, the average daily working hours in agriculture and construction were reduced by 2 hours, which directly led to a GDP loss of about US$350 million; and the annual cost of repairing transportation infrastructure due to high temperatures globally was as high as US$12 billion, which accounted for 30% of the climate-related infrastructure losses[4]. Second, high temperatures are frequent in some parts of China, and there are few remedies available for such meteorological disasters, making it difficult to recover from the damage

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caused; in 2023, high temperatures and droughts in China's Yangtze River Basin led to a shortage of hydropower and a 30% reduction in production by aluminum smelters due to power restrictions, and an 18% increase in global aluminum prices. Alongside the evident physical hazards posed by extreme weather, there are also micro-level implications for company development. In times of severe weather, business earnings and revenue experience a decline, and balance sheets deteriorate. The financing limitations and cash holdings of firms are impacted by extreme heat risks, which may result in liquidity issues and potentially increase the rates of loan defaults. Consequently, the theoretical and practical implications of studying the economic repercussions of extreme heat, reducing the physical events, and addressing the danger of extreme heat are immense.

It is impossible to disregard the economic consequences of extreme heat on enterprises. Does extreme heat have an impact on company green investment, given that existing studies have identified the detrimental effects of extreme heat on their company growth, financing limitations, and liquidity? Corporate green investment refers to enterprises' investment of funds into projects or technologies that can improve environmental performance and promote sustainable development, aiming to achieve the dual goals of economic and environmental benefits[5]. Research on the motivation of corporate green investment shows that it mainly comes from policy regulation motivation, corporate strategy motivation, and technological innovation motivation. Scholars who support the policy regulation motive believe that environmental regulations and government policies have a mandatory and guiding effect on corporate green investment, which in turn leads to corporate green investment[6]. Scholars who support corporate strategic motives believe that enterprises can develop green technology patents through green investment, form environmental brand reputation and other resources that are difficult to imitate and thus form a long-term competitive advantage, which leads to corporate green investment behavior[7]. Current research predominantly investigates the determinants influencing corporate green investment, emphasizing external macroeconomic and Firm-specific internal factors. Macroeconomic factors that are external to, such as green economy policies and regulations[8], market demand[9], and international trade cooperation[10], influence the level of corporate green investment. Firm-specific internal factors, Like the magnitude of the company[11], firm strategic positioning[12], and technological innovation capability[13], also influence the level of green investment. The external macro-factor that impacts firms is extreme heat, and its physical and transformational risks have an impact on firms, which in turn affects their decision-making. Nevertheless, there is a scarcity of research on the influence of climate extremes on the green investment behaviors of firms, as well as a lack of analysis of the heterogeneity and impact mechanisms of this relationship. Consequently, we investigate the internal mechanisms through which firms' green investments are influenced by severe heat, an external factor, in reaction to extreme heat shocks.

There are several reasons why this paper chooses Chinese high-carbon firms as the focus of the study of the impact of extreme heat. First, since 1961, there have been more high-temperature days on average each year in China, especially during over the previous decade. There has also been an increase in extreme heat events, with the extreme heat index increasing by 0.21°C per decade since 1961.20 In 2022, the Yangtze River Basin suffered an extreme heat and drought lasting more than 30 days and affecting

more than 900 million people, with an average number of high-temperature days across the country amounting to 5.3 (the most in the same period since 1961). Extremely high temperatures have become a focus of concern in China, so it is appropriate to use China as a study subject for extremely high temperatures, which is important for the study of global climate change.

Second, as the biggest investor in renewable energy and carbon emitter in the world, China has more than 2,200 enterprises participating in the Chinese carbon trading market, far exceeding the number of the European Union, so the climate risk and green transition pressure faced by its high-carbon enterprises is globally representative. The transition risks to enterprises created by the carbon pricing, green credit, and other policies enacted by China have significantly forced high-carbon enterprises to increase their R&D investment in green technologies. Taking the iron and steel industry as an example, Baosteel, due to the rise in carbon prices, has increased its R&D investment by 23% year-on-year in 2024, with 60% of it invested in hydrogen-rich steelmaking and other low-carbon technologies, so the study of the level of green investment by China's high-carbon enterprises is representative of China's green investment level. Considering these factors, we attempt to address the aforementioned queries by investigating how China's high temperatures affect the amount of green investment in high-carbon companies. In summary, the results of this study can be used to pinpoint similarities between China's climate change and the climate change worldwide, as well as to offer guidance on how both rich and developing nations should adapt to the changing environment.

We empirically investigate the effects of extremely high temperatures on the green investment actions of Chinese firms using 9,307 firm-year observations covering 1,587 Chinese A-share firms that were listed between 2010 and 2022. To quantify extremely high temperatures, we use the quantity of extreme high temperature days per year in 370 cities as a proxy variable. The baseline regression results show that extremely high temperatures increase the level of firms' green investment. This relationship is consistent across a variety of tests, including the instrumental variables approach, the PSM method, the exclusion of less influential samples, and the switching of explanatory and interpreted variables. In addition, the mechanism analysis shows highlights the favorable correlation between extreme high temperatures and firms' green investment levels is more significant in firms with strong green perceptions of corporate executives and high ESG scores, Verifying our theory. These results are in agreement with our hypothesis. To deepen our study, we conducted a number of experiments to investigate the diverse impacts of extreme heat. At the firm level, the positive association between extreme heat and firms' green investment levels is more pronounced among non-state-owned firms and firms with higher equity concentration. On a regional scale, the favorable association between extreme temperatures and corporate green investment behavior is more pronounced in central and western cities.

The following are some ways that this paper adds to the literature. First, the study corpus on the economic effects of climate extremes is expanded in this work. The economic effects of excessive heat have been examined in the past from the viewpoints of both large and small firms. Extreme heat has a macro-level impact on supply and demand[15], as well as trade in goods from and to [14]in different regions. Extreme weather

has a micro-level impact on businesses' capital market performance[16], resilience[17], performance, and return on assets[18].

And, We contribute to the corpus of information about the variables influencing the amount of green investment made by businesses. Prior studies have shown that external internal factors influence the level of corporate green investment. External factors including green economy policies and regulations[8], market demand[9] and international trade cooperation[10] affect the amount of corporate green investment. Extreme climate belongs to exterior environmental elements. We explore the impact of extreme heat on the amount of corporate green investment and extend the understanding of how the external surroundings has an effect on the amount of corporate green investment.

Nevertheless, there is a scarcity of empirical evidence from China, and there have been few studies that have examined the effects of exceptionally high temperatures on the level of green investment of firms. In light of this scarcity, we investigate and analyze the reasons why extreme heat impacts the amount of green investment of firms in prefecture-level cities in China. We suggest two channels of influence: the green perceptions of corporate executives and the ESG performance of firms. This proposal aims to broaden the relevant scope of the study and give factual proof. of the impact of extreme heat on China from a micro perspective. We have discovered that the level of corporate ecological investment is significantly increased by extreme heat. The results of mechanism testing indicate that corporate executives who possess high ESG scores and high green perceptions can amplify the influence of extreme temperatures on corporate green investment.

Our presentation includes certain constraints that necessitate additional investigation. Initially, our future research should focus on the exploration of machine learning algorithms to enhance accuracy, given the growing abundance of data. Secondly, the comprehensiveness of the climate change in a region may not be completely captured by our utilization of extreme climate data from Chinese county-level cities. Consequently, our future research should also focus on the identification of more representative microdata and the examination of the correlation between corporate financialization and climate extremes. Third, the identification of firms' green investment level is relatively uniform. Despite the fact that financial data is employed to determine the extent of corporate green investment, it is possible that other judgments are disregarded or incorrect. Further investigation is required to determine how to reduce the impact of episodic and cyclical factors and improve the accuracy of identification.

This is how the remainder of the paper is structured. Part 2 describes the theoretical framework, literature review, and hypothesis formulation. Part 3 describes the research design and data sources for the indicators of interest; Part 4 presents the empirical results, endogeneity tests; Part 5 describes the mechanism tests and heterogeneity tests; Part 6 describes the robust tests; and Part 7 provides results and policy suggestions.

2 Literature Review and Hypothesis Formation

2.1 Extreme Heat Risk

At the level of the macro, Regional economies are significantly impacted by extreme temperatures, which affects the supply-chain stability, demographics, and demand and supply. The yields of crops and food production are adversely affected by extreme weather, with a particular emphasis on low-income countries and main producing regions[19]. In addition, high temperature extremes increase mortality rates; however, colder regions are less affected by high temperature extremes, while warmer areas are less impacted by low temperature extremes, resulting in variations in the effects of climate extremes[2]. In addition, extreme climate negatively affects supply chain stability, with supply chain networks facing a critical situation of cascading effects from upstream to downstream due to increased peak loads under extreme climatic conditions[20]. On the contrary, extreme climates can stimulate innovative capacity and improve energy efficiency[1]. Furthermore, extreme climate risks are characterized by regional variations, which result in varying effects on regions with varying components of resources.

At the level of the micro, climate extremes have a lot effect on the performance, resiliency, capital market operation, and return on assets of firms. Initially, it has a direct effect on the production of firms, which in turn effects the overall productivity of factors and the return on assets. Factor reallocation is impeded by extreme heat, which also reduces firm productivity[16]. Firms' infrastructure, distribution networks, and consumer demand are all impacted by climate extremes. It is imperative for businesses to acknowledge the risks associated with climate change and to proactively devise strategies to confront these obstacles[21]. In order to endure extreme heat environments, these endeavors are indispensable. The capital markets of firms are also affected by extreme temperatures. The asset allocation of enterprises is influenced by the increase in risk-based capital ratios that banks experience during extreme weather shocks[22].

2.2 Corporate Green Investments

Firstly, companies may be influenced to make green investments by external macro forces. Within the appropriate range, increased economic policy uncertainty is unlikely to lead to increased green investment, and economic policy uncertainty inhibits green investment through the dual path of increased financing constraints and management risk aversion[23]. In addition, corporate green investment decisions can be reshaped through financial support, institutional optimization and spatial synergy, and policy-making needs to be tailored to implement precise interventions in response to differences in resource endowments, such as strengthening financial regulation in resource-based cities and optimizing the ecology of market competition in technology-intensive regions[24]. Yan, Almandoz and Ferraro[25] found that green investment efficiency improves more when the logic of the policy is compatible with the strategy of the firm. When policy logic is compatible with corporate strategy, green investment efficiency

improves more; while conflicting logic leads to a decrease in investment efficiency, and this effect is particularly significant in heavily polluting industries.

Second, a firm's internal governance is an important factor influencing its level of green investment. Among them, the characteristics of corporate executives is an important factor, the study found that Executives' environmental background is significantly positively correlated with the intensity of green investment, but need to be combined with sustainable management tools (such as the CSR Committee) in order to effectively drive the investment[26]; the probability of green investment in enterprises that employ executives with environmental backgrounds is increased by 18.7% has a greater increase, and the greater the management autonomy, the stronger the attraction to the green investor[27]. In addition, the board of directors set up a green investment committee of the enterprise, green technology R & D investment intensity is higher, the establishment of internal incentives, such as green funds and other incentives will significantly enhance the degree of employee participation[25].

2.3 Hypothesis Development

Nordhaus, a pioneer in the field of climate change economics, established the theoretical framework for the examination of the relationship between the actual economy and climate-induced physical changes. Transition risk and physical risk are the two primary categories of risks associated with climate change[28]. Transition risk is the risk that is linked to the policies that the government has implemented in order to mitigate the effects of climate change. For instance, in order to mitigate greenhouse gas emissions, the government implements emission reduction policies, establishes pertinent laws and regulations, and motivates businesses to invest in renewable energy. Consequently, high-carbon industries are susceptible to transition risks. Physical risk is the term used to describe the direct harm that climate change causes to economic activities, including health risks and harm to public infrastructure, as previously mentioned. Nordhaus proposes that the climate is a "asset"[29], that is increasing in value. Consequently, it is imperative for the state, enterprises, and individuals to make efforts to mitigate its adverse effects. The expansion of non-performing assets necessitates that organizations implement modifications to mitigate the adverse effects of risks.

The effect of extreme heat on corporate green investment is evident. Initially, excessive heat presents a transformational risk to businesses, which in turn induces corporate green investment. One example of the laws and frameworks that governments worldwide have established to address severe climate change is the Kyoto Protocol. This international agreement, which is intended to prevent global warming and limit the release of greenhouse gases in developed nations, was ratified by delegates from 149 countries and territories on February 16, 2005[30].The Paris Agreement, which was agreed on by 178 parties at the Paris Climate Change Conference, is another significant agreement. The Paris Agreement shapes the global climate governance landscape for the post-2020 period, with a long-term goal of limiting the increase in 2°C increase in the average global temperature over pre-industrial levels, setting an ambitious target of limiting the increase to 1.5°C[31]. The emergence of carbon markets has become a sig-

nificant trend in order to accomplish the objectives of the climate agreement. Companies are either obligated or voluntarily committing to reduce emissions of greenhouse gases. China's national strategy to combat climate change encompasses the implementation of a greenhouse gas trading management system, as evidenced by the National Carbon Market and the Pollution Emissions Trading System (PETS), which were respectively launched in 2002, and the National Carbon Market (NCM), which will be officially launched in 2021. With the implementation of carbon emission control policies, high-carbon companies are under tremendous pressure to transform. This trend has pushed enterprises to make green investments[32]. The main motivation of corporate green investment is categorized into three types: policy regulation motivation and corporate strategy motivation. Scholars who support the policy regulation motive believe that environmental regulations and government policies have a mandatory and guiding effect on corporate green investment, which in turn leads to corporate green investment. Scholars who support corporate strategic motives believe that enterprises can develop green technology patents through green investment, form environmental brand reputation and other resources that are difficult to imitate and then form long-term competitive advantage, which leads to corporate green investment behavior[6]. Furthermore, enterprises' financial indicators, including cash flow and profitability, may be indirectly impacted by extreme weather events, such as elevated transportation and raw material expenses. Firms integrate the potential consequences of extreme change in the climate and extreme weather events into their strategies and procedures for making decisions due to the hazards associated with extreme climate events. To this end, firms may adapt by relocating from high-risk areas such as extreme drought and extreme precipitation[33]. To cope with the impacts of extreme heat, firms will accelerate their low-carbon transition and application of energy-efficient technologies, optimize their production processes and increase their investment in renewable energy projects, thereby increasing their level of green investment.

In accordance with the theoretical analysis, we suggest the subsequent empirical hypothesis1.

Hypothesis1: Extreme heat risk has a facilitating effect on firms' green investment levels.

Extreme heat, as a significant climate risk signal, strengthens the environmental crisis awareness of executives with high green perceptions, who are more inclined to interpret extreme heat as a long-term environmental threat rather than a short-term operational disruption, and this cognitive difference leads to an increase in green investment to cope with systemic risks. Moreover, executives with environmental protection background will prioritize resource allocation to green technology research and development after extreme weather events[26], executives with high green cognition are more inclined to view environmental problems as opportunities rather than costs, and enhance competitiveness through green technology investment or supply chain optimization[34], and executives with strong green cognition are able to more keenly identify the long-term threat of climate change to their enterprises, and thus lay out a plan for a Low-carbon transition, which in turn improves the level of corporate green investment. Extreme high temperatures intensify stakeholders' environmental expectations of firms, and executives with high green perceptions are more sensitive to such pressures and

increase green investment maintenance, especially in firms with high analyst attention[25].

In accordance with the theoretical analysis, we suggest the subsequent empirical hypothesis2.

Hypothesis2: The level of corporate green investment is positively correlated with extreme high temperatures as the level of green awareness of business executives increases.

High ESG-rated firms have a stronger awareness of environmental risks, and when faced with extreme high temperatures, they will see it as a strategic transformation opportunity rather than an operational threat, thus triggering preventive green investments, a rise in the climate risk index, and a higher improvement in the return on clean energy investments for high ESG firms than for ordinary firms[35], Secondly, firms with top ESG ratings usually have established a sound green governance structure, and such firms will proactively adjust capital expenditures to green technologies through the carbon pricing internalization mechanism under high temperature shocks[26], in addition to this, high ESG firms face stronger stakeholder oversight, and their corporate ESG committees cause R&D investments to improve the elasticity of response to high temperatures, and this effect is amplified with the increase in ESG scores[25].

In accordance with the theoretical analysis, we suggest the subsequent empirical hypothesis3.

Hypothesis3: As firms' ESG scores increase, the positive relationship between their green investment levels and extreme high temperatures increases.

3 Research Methodology

3.1 Construction of Models

To test the above hypotheses, we constructed a fundamental regression model:

$$EIR_{it} = \alpha_0 + \alpha_1 ExtremeHeat_{it} + \sum \alpha_2 Controls_{it} + \mu_i + \lambda_i + \varepsilon_i \quad (1)$$

Where, for firm i and year t, EIA_{it}denotes a proxy variable for the degree of green investment by firms, and $ExtremeHeat_{it}$ denotes an indicator of extreme heat. $Controls_{it}$denotes a series of control variables, $\mu_i$denotes individual fixed effects of firms, $\lambda_i$denotes time fixed effects, and ε_i denotes residual term.

3.2 Definition of Variables

3.2.1 Corporate Green Investment.

We adopt the measurement method proposed by Zhang Qi, Zheng Yao and Kong Dongmin[36], and select enterprise green investment (EIR) as a proxy variable for enterprise green investment. The calculating approach involves aggregating the data pertaining to investment expenditures associated with pollution control, ecological management, and sustainable production, To obtain the enterprise's green investment expenditure data for the year, divide it by the overall revenue at the end of the period for

standardization. This includes desulfurization and denitrification, the procurement of energy-saving equipment, and cleaner production in the construction schedule in progress. Compared with international standards (e.g., GRI, ISO14031), this method relies more on voluntary disclosure by enterprises, and suffers from the defects of data availability and geographical applicability, while the method of Zhang Qi, Zheng Yao and Kong Dongmin[36] is applicable to the disclosure norms of listed companies in China, and has strong data verifiability.

3.2.2 Extreme Heat.

Referring to the study of Pankratz, Bauer and Derwall[18],this study uses ExtremeHeat as a proxy variable to represent the extreme climate risk and conducts empirical tests based on this variable. The defining standard of China Meteorological Administration (CMA) is used to refer to high temperature when the maximum temperature reaches or exceeds 35°C. The value of ExtremeHeat days in the prefecture-level city where each business is located is calculated by adding up the number of days in a month when the daily maximum temperature reaches or surpasses 35°C. This allows one to determine the extent of the impact of the extreme weather conditions.

Persistent hot weather significantly exacerbates the operational pressure of energy enterprises, with surging power demand leading to rising grid loads and the risk of power restrictions in some areas[37]; photovoltaic (PV) module output power attenuation due to high temperatures, and reduced cooling efficiency in thermal and nuclear power[38]; and high energy-consuming enterprises are forced to reduce production due to tense power consumption or power restriction policies, while high-temperature environments exacerbate equipment wear and tear, and increase maintenance costs[39]. In view of this relevant empirical tests on high-carbon enterprises in China.

3.2.3 Control Variable.

We cite the research on corporate green investing and comprehensively adopt the methodology of Cui[40],and Sun, Wen, Jiang and Zhang[41] on the setting of control variables, and select firms' age at listing (Age), ratio of fixed assets (Fixed), ratio of intangibles (Int), ratio of net profit on total assets (ROA), ratio of research and development (R&D) to operating income (RD), ratio of book-to-market value (PM), ratio of top ten shareholders (Top10), and ownership attributes (SOE) as control variables. revenue ratio (RD), book-to-market ratio (PM), The shareholding ratio of the top 10 shareholders (Top10), firm size (Size), and ownership attributes (SOE) as control variables.

The definitions of the reference variables and their estimation methods are shown in **Table 1**.

Table 1. Definition table for the primary variable.

Variable type	Variable name	Variable identification	Definition
Dependent variable	Corporate green investment	EIR	(Expenditure on pollution prevention + expenditure on ecological environment management + expenditure on investment in green production)/total assets
Independent variable	Extreme heat	Extreme-Heat	Extreme high temperature days in the enterprise's location
Control variables	Age of firms going public	Age	Age of enterprise listing
	Fixed Assets Ratio	Fixed	Fixed Assets/Total Assets
	Intangible assets ratio	Int	Intangible assets/total assets
	Net profit margin on total assets	ROA	Net profit/total assets
	R&D investment to revenue ratio	RD	R&D investment/revenue
	Book-to-market value ratio	PM	Net assets/market capitalization
	Shareholding ratio of top ten shareholders	Top10	Number of shares held by top ten shareholders/total shares
	Company Size	Size	Total assets of enterprise take logarithm
	Ownership Attributes	SOE	Non-state-owned businesses = 0; state-owned businesses = 1.

3.3 Sample Selection and Data Sources

In this study, 9,307 financial data of high-carbon enterprises listed in A-share market from 2010 to 2022 are selected. This study intends to use extreme high temperature to measure extreme climate risk, similar to Pankratz, Bauer and Derwall[18], which is obtained from Data from the National Meteorological Service Center of China, while the data of corporate green investment and control variables are obtained from the National Bureau of Statistics of China, CSMAR database, Wind database and so on. And the sample data are processed as follows: (1) data of ST, *ST, and PT companies during the sample period are excluded; (2) data of listed companies other than those in the energy industry are excluded; and (3) all continuous variables are shrink-tailed at the before-and-after 1% level.

4 Empirical Results and Analysis

4.1 Descriptive Statistics

Table 2 presents the descriptive statistics of the primary variables utilized in the benchmark regression. The variable EIR exhibits a mean of 15.457 and a standard deviation of 8.979. The maximum green investment level among Chinese energy companies is 45.992, while the minimum is 1.875. The sample companies demonstrate varying degrees of green investment, with notable disparities among them. The greatest extreme high temperature duration is 66 days, the minimum is 0 days, the mean is 20.172 days, and the standard deviation is 16.662 days, indicating significant variability in severe high temperature days among the sampled enterprise sites. The remaining variables align with prior research and will not be reiterated here.

Table 2. Descriptive statistics

VarName	Obs	Mean	SD	Min	Max
EIR	9307	15.457	8.979	1.854	45.992
ExtremeHeat	9307	20.172	16.662	0.000	66.000
Age	9307	9.961	7.541	0.000	27.000
FIXED	9307	0.247	0.140	0.032	0.667
INT	9307	0.051	0.044	0.003	0.280
ROA	9307	0.049	0.039	0.001	0.192
RD	9307	3.787	2.753	0.040	15.820
PM	9307	0.651	0.240	0.152	1.189
Top10	9307	0.431	0.192	0.135	0.900
size	9307	22.490	1.319	20.170	26.324
SOE	9307	0.358	0.479	0.000	1.000

4.2 Corporate Green Investment

Table 3 displays the outcomes of the base regressions, with column (1) showing findings without control factors and column (2) presenting results with firm control variables, both accounting for firm and year fixed effects. The findings indicate that the coefficient for exceptionally high temperatures remains considerably positive, irrespective of the inclusion of control variables. The findings indicate that the predicted coefficient for extreme heat is 0.014, suggesting that for every additional day of extreme heat, corporate green investment rises by an average of 0.014%. The growth in extreme high temperature days elevates demand for energy and climate risk exposure, hence fostering the green investment decisions of energy companies, thereby substantiating hypothesis 1 of this paper.

Table 3. Extreme heat and corporate green investment: benchmark regression results

	(1) EIR	(2) EIR
Extreme Heat	0.016***	0.014***
	(2.84)	(2.65)
Age		-0.066
		(-0.20)
FIXED		0.824
		(0.71)
INT		17.131***
		(5.08)
ROA		-21.371***
		(-7.02)
RD		0.937***
		(10.87)
PM		1.261**
		(2.25)
Top10		-1.278
		(-1.62)
size		-2.063***
		(-7.04)
SOE		-0.262
		(-0.39)
Constant	15.909***	57.959***
	(45.91)	(8.95)
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observation	9307	9307
R2	0.328	0.426

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

4.3 Endogeneity Test

4.3.1 Instrumental Variable Approach.

Referring to Poudel, Cuo, Ding and Gyawali[42], it can be seen that the frequency and intensity of extreme high temperatures are significantly lower in high altitude regions than in low altitude regions due to the stability of the atmospheric circulation and the radiation balance characteristics of the surface, and that offshore regions are exposed to the risk of heatwave-extreme sea level composite events, which makes extreme high temperatures more likely to occur in offshore regions[43], and that such geographic variables are strictly exogenous as they only have an impact through pre-determined climatic or historical channels and are not directly related to contemporary economic factors[44]. So we choose the altitude (Altitude) and the closest distance to the coastline

(Distance) of the company's location as instrumental variables, which are logarithmically valued in order to better explain the realistic characteristics of the nonlinear relationship between the explanatory variables.

Table 4, column (1) shows the regression results of the first stage, and it is found that the regression coefficient of the company's location altitude is significantly negative at the 1% level, and the regression coefficient of the company's location nearest distance to the coastline is significantly positive at the 1% level, which is in line with the expectations of the previous section, and it indicates that the instrumental variable selection satisfies the principle of relevance. In addition, the value of Cragg-Donald Wald F statistic is 100.617, which is significant at 1% level, and the value of Sargan statistic is 1.925, which is not significant, indicating that there is no problem of weak instrumental variables or over-identification in instrumental variables selection.

Table 4, column (2) presents the findings of the second stage regression, revealing that the regression coefficients for extreme high temperatures and corporate green investment are significantly positive at the 10% level, suggesting that extreme high temperatures substantially enhance corporate environmental investment. The estimated coefficients and their signs derived from the instrumental variable estimation method are largely congruent with the standard regression outcomes, indicating the robustness of the regression results presented in this study.

Table 4. Endogeneity Tests - Instrumental Variable Approach

	(1) ExtremeHeat	(2) EIR
Altitude	-11.908***	
	(-5.30)	
Distance	8.396***	
	(3.11)	
ExtremeHeat		0.090*
		(1.72)
Controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observation	9307	9307
R2	0.371	0.426
Cragg-Donald Wald F	100.617 (0.000)	
Sargan	1.925 (0.165)	

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

4.3.2 PSM Approach.

PSM considerably lessens the correlation between observable variables and treatment parameters. We thus use the Propensity Score Matching (PSM) approach for robustness testing in order to address problems associated with missing variables and sample selection bias. Based on the mean value of very high temperatures, the observed data are first split into two groups. The experimental group is made up of the top one-

third of the firms, while the control group is made up of the lowest one-third of the companies. Second, the aforementioned control variables are chosen as the foundation for matching, and regression tests are performed on the matched samples using 1:2 caliper matching and 1:1 closest neighbor non-return matching.

The regression results obtained from the PSM analysis are shown in **Table 5**. At the 1% level, the regression coefficients for corporate green investment and severe high temperatures are considerably positive, indicating that corporate environmental investment is greatly increased by extreme high temperatures. This supports the validity of the study findings and is consistent with earlier findings.

Table 5. Endogeneity Tests - PSM Approach

	(1)1:2 Caliper Matching	(2) 1:1 Nearest Neighbor Matching
	EIR	EIR
ExtremeHeat	0.022***	0.022***
	(3.03)	(3.03)
Controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observation	5657	5657
R2	0.439	0.439

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

5 Mechanism Tests and Heterogeneity Tests

5.1 Mechanism Tests

5.1.1 Executive Green Perceptions.

According to previous hypothesis 2, corporate executive perceptions reinforce the impact of extreme weather on corporate green investment. We test this mechanism using an interaction term regression, specifically, we draw on Fang and Li[45] and test the moderating effect of executive green perceptions on the baseline regression by using the ratio of executive green perceptions word frequency to the total number of words in the annual report multiplied by 10,000 as a proxy variable for executive green perceptions. The results in **Table 6**(1) show that the regression coefficient of the interaction term between extreme high temperatures and executives' green perceptions is significantly positive at the 5% level, suggesting that extreme high temperatures exacerbate stakeholders' expectations of firms' environmental protection, and that executives with high green perceptions are more sensitive to such pressures, and increase the maintenance of green investments. Executives with high green perceptions are more sensitive to recognizing the long-term threat of climate change to enterprises, so that they can lay out low-carbon transformation in advance, reconstruct the risk of extreme heat into transformation opportunities, and coordinate internal and external resources to mitigate the impacts of high temperatures, which will in turn promote enterprises to take the initiative to make green investments and develop green technologies.

5.1.2 Company ESG Performance.

According to Hypothesis 3, ESG performance is a comprehensive measure of corporate ESG practices, which reflects the effect of a firm's internal and external resource integration capabilities on its green strategy and enhances the positive impact of extreme weather on green investment. Drawing on Zhu, Tan and Xin[46], we examine the moderating effect of firms' ESG performance on the benchmark regression by using the ESG score of firms published by CSI divided by 100 as a proxy variable for firms' ESG performance. The results in **Table 6**(2) show that the regression coefficients of the interaction term between extreme high temperature and firms' ESG performance are significantly positive at the 5% level, indicating that firms with high ESG scores usually have a well-established green governance structure and have easier access to low-cost green funding, as well as a stronger awareness of environmental risks when facing extreme high temperatures. When faced with extreme heat, they will see it as an opportunity for strategic transformation rather than an operational threat, thus triggering precautionary green investment, which can respond to the tightening of corporate financing constraints when extreme heat risks are unexpected, and thus ensure that companies can still safeguard their investment capacity and release more funds for green transformation under climate shocks.

Table 6. Mechanism Tests

	(1) EIR	(2) EIR
ExtremeHeat	0.007	-0.027*
	(1.14)	(-1.76)
EGR	-0.176	
	(-0.99)	
EH*EGR	0.014***	
	(2.72)	
ESG		-0.297**
		(-2.43)
EH*ESG		0.011***
		(2.81)
Controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observation	9307	9307
R2	0.326	0.327

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

5.2 Heterogeneity Tests

5.2.1 Heterogeneity in the Ownerships of Enterprises.

Because of their distinct makeup, state-owned businesses have distinct advantages in the credit market and are more likely to receive official loans from banks and other

sources. These businesses also have more access to resources and state support, so natural disasters have less of an effect on them. In contrast, private businesses frequently struggle with size and ownership discrimination during the financing process and are unable to secure enough funding.[47]. Therefore, the heterogeneity of the nature of business ownership was analyzed. As shown in **Table 7**, The findings show that extreme high temperature has a positive effect on corporate green investment in both SOEs and private enterprises, but the coefficient of extreme high temperature on SOEs is 0.05 and insignificant, and the coefficient on private enterprises is 0.15 in line with the benchmark regression and significant. Private enterprises, unlike state-owned enterprises, lack state recognition and have tighter cash flow. Consequently, in contrast to state-owned businesses, private businesses are less resilient in the face of external risks and crises, and extreme heat has a greater impact on them, forcing them to increase green investment to improve risk resistance.

Table 7. Heterogeneity in the ownerships of enterprises.

	(1)SOE	(2)Non-SOE
	EIR	EIR
ExtremeHeat	0.005	0.015**
	(0.63)	(2.48)
Controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observation	3149	5905
R2	0.850	0.858

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

5.2.2 Heterogeneity at the Level of Equity Concentration.

In this paper, the enterprises whose top ten shareholders' the equity ratio exceeds the median. are classified as enterprises with high degree of equity concentration, and the rest are enterprises with low degree of equity concentration, and the regression results of the grouping are shown in **Table 8**. The impact of extreme high temperature on green investment in enterprises with high and low equity concentration is positive, but extreme high temperature significantly promotes “investment prevention” green investment in enterprises with high equity concentration, while the impact on enterprises with low equity concentration is not significant. This is because when the degree of equity concentration is low, the majority shareholder's supervision and control of the enterprise is weak, at this time the enterprise is prone to more serious principal-agent problems, the management out of their own reputation and the post to obtain the maximum benefit considerations, it is more likely to invest the enterprise's funds into the short term to bring economic benefits to the enterprise's field, and thus at this time on the impact of green investment in the enterprise concern is not significant[48].When the degree of equity concentration is high, the supervision and control of the enterprise by the major shareholders of the enterprise is strengthened, the principal-agent problem is

weakened, and the interests of the enterprise management and the interests of the shareholders are closer to each other, and thus for the long-term development of the enterprise, the enterprise will allocate more resources to the enterprise's green investment. The above results confirm the heterogeneity of extreme high temperatures on corporate green investment in terms of equity concentration, indicating that extreme high temperatures are more likely to attract the attention of enterprises with high equity concentration.

Table 8. Heterogeneity at the level of equity concentration.

	(1) high level of equity concentration. EIR	(2) low level of equity concentration. EIR
ExtremeHeat	0.018***	0.010
	(2.75)	(1.49)
Controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observation	4416	4420
R2	0.860	0.872

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

5.2.3 Heterogeneity of City Locations.

China is a vast country with varying levels of economic development in various regions, so the impact of climate extremes on the degree of green investment by enterprises is also regionally heterogeneous[49], which is worthy of in-depth exploration. China's territorial space is categorized into eastern, central, and western areas based on general division criteria, since the swift growth of the economy in the eastern region has led to a concentration of firms establishing themselves there. Despite the upward tendency in the center and western regions, a significant disparity remains with the east. We refer to the study of YAN-MEI D[50], who categorized the Midwest as a group. According to **Table 9**'s regression results for regional categorization, extreme high temperatures have a negative and negligible impact on eastern cities while having a positive and significant impact on central and western cities. Additionally, the central and western cities' corporate green investment levels are significantly impacted by extreme high temperatures. China's eastern area has a greater percentage of tertiary industry and a better degree of economic development than its central and western regions, the service industry is more developed, can reduce the loss of high-temperature stoppages through flexible office, the urgency for the green transformation of the enterprise is not strong, and reduces the necessity of green investment. The central and western regions, on the other hand, are concentrated in many high energy-consuming industries, and the extreme high temperature will directly lead to a decline in productivity and a surge in energy demand, forcing enterprises to develop environmentally friendly technologies to reduce operational risks through green investment. The above results confirm the regional heterogeneity of extreme heat on green investment of enterprises, indicating

that extreme heat is more likely to cause the accumulation of risks in areas with weak regional economic development.

Table 9. Heterogeneity of city locations.

	(1)Eastern cities	(2)Midwest cities
	EIR	EIR
ExtremeHeat	-0.002	0.037***
	(-0.35)	(4.32)
Controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observation	6125	3178
R2	0.831	0.818

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

6 Robustness Tests

6.1 Using Subsamples

Since China has a large geographic range and substantial regional climate variations, the impact of climate extremes on some areas may be negligible[51], for this reason, Inner Mongolia Autonomous Region, Tibet Autonomous Region, Qinghai Province, Yunnan Province, Guizhou Province, and Heilongjiang Province are not included in the analysis of extreme high temperatures. The results are displayed in **Table 10**, and the fact that the effects of extreme high temperatures on businesses' green investments remain significant even after these samples are removed further supports the validity of the research findings.

Table 10. Using subsamples

	(1)	(2)
	EIR	EIR
ExtremeHeat	0.016***	0.014***
	(2.84)	(2.65)
Controls	No	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observation	9090	9090
R2	0.328	0.426

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

6.2 Replacing Dependent Variable

To validate the robustness of the conclusions derived from the benchmark regression, we perform a substitution test for the substitute variables of green investment. To rigorously assess the influence of extreme weather on corporate green investment, we utilize the environmental investment asset ratio (EIA) as a proxy indicator. This ratio is derived by aggregating investment expenditures associated with pollution prevention, ecological management, and green production from the construction-in-progress schedule, including expenditures on desulphurization, denitrification, energy-saving equipment, and cleaner production. This total is then divided by the sum of all assets at the end of the period for standardizing purposes. The results presented in **Table 11** align with those of the standard regression. This discovery further substantiates the influence of climate extremes on firms' green investment decisions, and the conclusion remains unaffected by the measurement of green investment, hence augmenting the reliability of the study's conclusions.

Table 11. Replacing Dependent variable

	(1) EIA	(2) EIA
ExtremeHeat	0.025**	0.023**
	(2.41)	(2.28)
Controls	No	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observation	9307	9307
R2	0.020	0.184

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

6.3 Replacing Independent Variable

In the previous chapter, we used the number of days in which the maximum temperature of the city at the prefecture level in which we are located exceeds 35°C as a proxy variable for extreme high temperatures, and with reference to the study of Galstyan, Kocharyan and Khan[52], we replaced the proxy variable for extreme high temperatures by constructing the extreme high temperature intensity (HWI) as a proxy variable, which was calculated in the following way:

$$HWI = \frac{1}{N}\sum_{i=1}^{N}\left(T_{max,i} - 35\right) \tag{2}$$

where HWI is the extreme high temperature intensity, N is the total number of days with daily maximum temperatures ≥35°C during the study period, and $T_{max,i}$ is the actual maximum temperature on the ith high temperature day. The intensity due to actual thermal shock can be well considered using HWI. The regression results are shown in **Table 12**, which are consistent with the baseline regression results, and can prove that extreme high temperatures will have a significant positive impact on corporate green

investment, a finding that further validates the facilitating effect of extreme climate on corporate green investment decisions, and enhances the reliability of the research conclusions.

Table 12. Replacing Independent variable

	(1) EIR	(2) EIR
HWI	0.088	0.129***
	(1.60)	(2.61)
Controls	No	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observation	1960	1960
R2	0.015	0.201

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

7 Conclusion

Extreme heat is a significant obstacle to global economic development; we conducted a theoretical analysis of the unbalanced panel data about extreme heat and Chinese energy listed companies from 2010 to 2022, we empirically investigated the impact of extreme heat on corporate green investment from the perspective of green investment and conducted a mechanism analysis, we analyzed the green perceptions of corporate executives and the firm's ESG performance moderating role in the impact of extreme high temperatures on corporate green investment, while also considering the heterogeneity of corporate nature, corporate equity concentration and geographic location. The empirical study finds that extreme heat significantly enhances the level of corporate green investment, especially for private firms, firms in central and western cities, and firms with high equity concentration.

This paper's conclusions offer significant empirical evidence about the influence of high heat on corporate green investment and carry policy implications. Governments should develop effective climate policies and enhance investment in climate governance to alleviate the effects of climate extremes. Simultaneously, the awareness of businesses and the public regarding the risks associated with excessive heat can be heightened, and the transparency of information concerning these risks can be augmented. Augment the environmental awareness of company executives to thoroughly evaluate ecological aspects and the repercussions of excessive heat occurrences. Enhance the capacity of organizations to amalgamate internal and external resources, while implementing proactive risk control and management strategies in advance.

An insurance sector focused on extreme heat events can be developed to directly alleviate economic losses incurred by businesses during such conditions and to mitigate the effects of extreme heat. Specific support and recompense can be offered to affected regions and enterprises, with the objective of lessening the negative consequences of extreme heat and fostering the growth of the real economy. Eradicate discrimination in

corporate credit and alleviate the financial limitations faced by private firms. Eradicate size and ownership-based discriminatory practices encountered by private firms in the loan market. Enhance the business climate in central and western cities to further advance the growth of the real economy for small and micro firms. Formulate tailored climate policy reflecting China's specific circumstances. China ought to establish diverse policies for addressing extreme climatic threats, tailored to the specific location and scale of various cities. The government's involvement in resource allocation, particularly in urban areas significantly impacted by excessive heat hazards, should be properly leveraged. Policies could be modified to more effectively mitigate the negative consequences of extreme heat hazards.

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