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# Impact of risk-taking on enterprise value under extreme temperature: From the perspectives of external and internal governance

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## ABSTRACT

Climate change leads to the frequent occurrence of extreme weather, which has become an important risk factor for enterprises. Based on panel data of Chinese A-share manufacturing enterprises from 2000 to 2019, this study examines the impact and influence mechanism of extreme temperature on risk-taking and enterprise value. The results reveal that risk-taking level increases under extreme temperatures but does not enhance enterprise value. Further analysis shows that the endowment effect of risk-taking level plays an important role: when the existing risk-taking is below the optimal level, the extreme temperature increases the enterprises' risk-taking, which then increases the market value; otherwise, the extreme temperature reduces risk-taking and has a negative impact on enterprise value. The mechanism test reveals that external supervision by market participants aggravates the negative market reaction to an increase in risk-taking under extreme temperatures and reduces enterprise value, whereas good internal governance of enterprises enhances their market value. This study expands the literature on the effect of extreme weather on the risk behavior of listed companies, provides micro-empirical evidence that extreme weather risks transmit to the capital market and impair enterprise value, and serves as an empirical reference for enterprise climate risk management.

## 1. Introduction

Risk-taking under uncertainty is an important decision to ensure the sustainable and healthy development of enterprises. According to the Global Risk Report released by the World Economic Forum (WEF, 2022), extreme weather events are prominent risks facing human society. In 2021, extreme weather events occurred around the world. In China, Henan province was hit by the heaviest rain in a thousand years, with daily rainfall exceeding record highs. North America continues to experience high temperatures, with the daily average exceeding 40 °C in various places. In its latest scientific assessment of climate change in 2021, the United Nations Intergovernmental Panel on Climate Change (IPCC) said that climate crises are becoming worse; global warming is inevitable; the probability and severity of extreme weather events have increased, and the intensity and frequency of extreme temperature are rising at a

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rapid rate. Extreme heat is one of the greatest threats to humanity (National Weather Service, 2020). The number of extremely high-temperature days has increased in all regions of China, whereas the number of extremely low-temperature days has decreased. Moreover, the intensity of extreme temperature events is increasing. The forecast results also indicate that, in the future, extremely high-temperature events in China will continue to rise, whereas low-temperature events will decrease (Chen & Zhai, 2017; Li et al., 2017; Li et al., 2019).

China's manufacturing sector is weather-sensitive, and the total value of the economy exposed to weather risks is high (Weatherbill, 2008). Since 2021, a number of listed manufacturing companies have issued interim reports about the possible impact of the torrential rains in Henan province on production, operation, and performance. Extreme weather is an important risk factor for listed manufacturing enterprises. And, it poses a substantial risk to assets that are difficult to measure accurately and forces the economy and society to shift toward a green and sustainable development path that is conducive to risk mitigation. Higher risk prevention and risk-taking capacity requirements are put forward for economic agents, and resource allocation is optimized according to the transition direction. Both China's 14th Five-Year Plan and the Outline of the 2035 Long-term Goals stress the need to accelerate the green transition of China's development model. Achieving China's "3060" carbon peak and carbon-neutral goal requires arduous efforts. Moreover, China's manufacturing industry's carbon emissions accounted for more than half of the total carbon emissions (IPCC, 2019). Therefore, green transition has become a must for manufacturing enterprises.

Risk-taking reflects the risk preference of enterprises in making investment, innovation, and other decisions. Appropriate risk-taking helps to achieve the goal of maximizing the value and shareholder wealth of enterprises and is the cornerstone of business survival and development (John, Litov, & Yeung, 2008). In the uncertain natural environment that experiences frequent and severe extreme weather events, enterprise risk-taking is an adaptive behavior to deal with changes. However, the process of "creative destruction," such as green transition, requires enterprises to make more investments in technological transformation and R&D and pursue more innovation strategies, which lead to higher adjustment costs and uncertainty. This requires companies to take higher risks (Basco et al., 2020).

Value-enhancement of listed companies is the core issue that shareholders are concerned about. The global impact of temperature shocks on the cost of equity can be as high as 2.8% per year, implying a global GDP loss of \$2.2 trillion per year (Gregory, 2021). Capital markets around the world are increasingly tightening the disclosure requirements of climate change risks. In June 2021, the Guidelines for the Format of Annual Reports issued by the China Securities Regulatory Commission stressed that firms need guidance to pay more attention to environmental protection and carbon reduction. Changes in business operation, the possibility of assets being stranded, and the depth and process of participating in the transformation are all mechanisms of enterprises' risk-taking. Investors are also gradually paying more attention to new factors other than traditional ones when assessing asset risk and making investment decisions, among which climate risk is an important component (Bolton & Kacperczyk, 2021; Hong et al., 2019; Huynh et al., 2020).

Therefore, whether a manufacturing enterprise can reasonably take risks under extreme weather is not only related to the ultimate goal of listed enterprises to enhance their market value but also essential for promoting China's green transition and achieving high-quality economic development. Therefore, this study examines whether extreme weather affects the risk-taking behavior of Chinese manufacturing listed companies and determines the difference between the effects of different levels of risk-taking. Regarding listed firms' value management, this study explores how extreme temperature affects enterprise value through risk-taking and the mechanisms that can exacerbate or mitigate the effect. These are the main problems that this study aims to solve.

## 2. Theoretical analysis and literature review

### 2.1. Theoretical analysis

Knight (1921) first proposed the relationship between environmental uncertainty and enterprise risk-taking behavior. Because the distribution of its potential impacts is unpredictable, environmental uncertainty cannot be measured. Therefore, it is often the perceived risks that affect organizational decision-making. The increase in extreme temperature events is one of the typical impacts of climate change. On the one hand, it increases the risk exposure of physical assets, and on the other hand, it exposes the social and economic system to urgent pressure of low-carbon transition and increases the uncertainty of the business environment. Based on the relevant research on environmental uncertainty and risk-taking, the risk attributes of extreme temperature events, and the risk characteristics of enterprises, this study analyzes the theoretical rationale of the impact of extreme temperature on enterprise risk-taking behavior.

#### 2.1.1. Effect of physical risk perception

Climate change risks affect enterprises through two types of paths—physical risk and transition risk. Physical risk refers to the risk associated with the physical impacts of climate change (TCFD, 2017). In his integrated risk framework, Miller (1992) extended the scope of uncertainty to the natural environment and proposed that the uncertainty of the natural environment affects organizational performance. Climate change is a good example of the uncertainty of the natural environment. Extreme temperature is an event-driven acute physical risk, which may have financial impacts on enterprises, such as direct asset damage and the indirect effects of supply chain disruptions, which affect enterprises' perception of climate risks (IPCC, 2021; Lewis & Harvey, 2001). Moreover, the thick-tailed nature of climate risk means that when the temperature exceeds a certain threshold, the risk will increase sharply (Weitzman, 2014, 2020). Therefore, extreme temperature aggravates the risks related to the physical assets of enterprises. However, as it is impossible to accurately predict the losses that may be caused, they take risk and reduce the risk exposure of physical assets, such as business premises, supply chain, transportation, and employees.

### 2.1.2. Expectation effect of transition risk

The transition to a low-carbon economy may require extensive changes in policy, law, technology, markets, and reputation (Dietz, Bowen, Dixon, & Gradwell, 2016; McGlade & Ekins, 2015; TCFD, 2017). Climate policy requires companies to reduce carbon or adapt to climate change, including pricing climate externalities, increasing the use of low-carbon energy, and adopting energy-saving strategies, thereby increasing the risk of high-carbon assets stranding. Improving and innovating low-carbon and energy-saving technologies affect the competitiveness of some enterprises, so the timing of the development and deployment of new technologies constitutes an uncertainty factor. Moreover, climate change may lead to changes in the legal, reputational environment, and market supply and demand structures. The intensification and frequent occurrence of extreme temperatures increase the expectations of enterprises toward the speed and depth of low-carbon transition. The uncertainty of the transition expectation leads to innovation and growth opportunities, and enterprises may regard the uncertainty as a potential development "opportunity," prompting them to take risks (Chen J.X, 2019; Roper & Tapinos, 2016; Segal et al., 2015), invest in R&D, and even engage in mergers and acquisition or split.

### 2.1.3. Enterprise risk endowment effect

The risk behavior of economic entities has an endowment effect (Koszegi & Rabin, 2007; Sprenger, 2015; Anagol et al., 2018). Risk behavior usually begins in an original risk state, whereas individual risk attitudes and risk choices, such as investment and innovation, are affected by existing risk levels (Clist et al., 2021; Lin & Jiang, 2012). Although extreme temperature increases enterprises' perception of climate risk, the original risk state of enterprises affects their risk preference and risk behavior during climate risk exposure. Enterprises with a lower initial level of risk-taking have a stronger ability to deal with it, tend to seize the opportunities brought by "creative destruction" (Segal et al., 2015), choose to bear large fluctuations in the rate of return, and pursue investment and innovation that will help them deal with climate change to seek possible returns and long-term sustainable development. Enterprises with a higher initial level of risk-taking may choose a more conservative path of stability under external shocks to retain the original level of growth, reduce volatility, and avoid more risks.

## 2.2. Literature review

### 2.2.1. Extreme weather and enterprise risk-taking

Studies have revealed that weather and temperature affect risk-taking willingness (Bassi et al., 2013; Chang et al., 2017; Kamstra et al., 2003). Kamstra et al. (2003) found that less sunlight in winter leads to depression, which reduces risk-taking behavior. Bassi et al. (2013) recognized that individuals are more risk-tolerant on sunny days, and bad weather reduces risk-taking among the participants. Chang et al. (2017) pointed out that heat exposure increases risk-taking behavior.

Other studies have revealed that extreme weather makes the business environment more complex and changeable. For instance, frequent and intense heatwaves, droughts, cold spells, and extreme precipitation expose agricultural activities to climate risks and thus influence the risk appetite and risk-taking behavior of farmers and agricultural enterprises (Hunt, 2015; Burke & Emerick, 2016; Doherty et al., 2021). Extreme temperature also impacts manufacturing enterprises. High temperatures reduce working hours, increase absenteeism, and reduce enterprise or total factor productivity, leading to lower output and economic losses (Cachon, Gallino, & Olivares, 2012; Graff & Neidell, 2014; Zhang et al., 2018; Somanathan et al., 2021). Cai et al. (2018) demonstrated that there is an inverse U-shaped relationship between temperature and worker productivity, with either too high or too low temperature having a negative effect on production.

### 2.2.2. Extreme weather, risk-taking, and enterprise value

In the market value management of listed companies, the influence of weather factors has long been an academic concern. For example, a negative correlation has been found between cloud cover, temperature, and stock returns (Cao & Wei, 2005; Hirshleifer & Shumway, 2003; Peillex et al., 2021; Saunders, 1993). Studies on capital markets in China have also found that temperature, humidity, visibility, wind speed, and extreme weather have significant effects on firms listed on the A-share stock market (Huang et al., 2020; Lu & Chou, 2012). Recent studies have focused on the direct impact of temperature and extremely high temperature on asset value (Griffin et al., 2019). Griffin et al. (2019) found that the average market capitalization of American listed companies fell by approximately 0.5% in a month after an extremely high-temperature event, but the market underestimated the risk.

Furthermore, enterprise risk-taking is an important channel for enterprises to create value. A willingness to pursue high-risk, i.e., high-margin investment opportunities, is a source of long-term growth of enterprise value (He et al., 2019; John et al., 2008; Knight, 1921). Few studies have found that risk-taking reduces enterprise value (Bromiley, 1991). Segal et al. (2015) pointed out that only "good" uncertainty can promote growth and raise asset prices. In addition, the rationality of risk-taking is equally important (Chen & Miller, 2007; Wright et al., 1996). Taking too much risk will aggravate the financial burden of the economic subject and even lead to a business crisis. However, the lack of risk-taking may make them miss opportunities for development.

### 2.2.3. Impact mechanism of risk-taking on enterprise value under extreme weather

Weather factors affect enterprise value, in which the degree of investor sentiment or risk preference is an important mechanism. Among other things, extreme weather and air pollution can trigger negative investor sentiment or risk aversion, causing stocks to underperform or fluctuate depending on weather conditions (Chang et al., 2008; Goetzmann et al., 2015; Kamstra et al., 2003; Lepori, 2016). Such conditions also make analysts reduce their earnings forecasts due to pessimism, which is reflected in changes in enterprise share prices (Dong et al., 2021).

As the issue of climate change continues to receive increasing attention, businesses face pressure from stakeholders and investors to

assume greater responsibility for climate and environmental governance, improve relevant responsibility performance, and undertake more green innovations (Amore & Bennedsen, 2016; Berrone et al., 2013). Enterprises' management of climate-related risks also enhances enterprise value. Aggarwal and Dow (2012) found that the measures taken by enterprises to address climate change can reflect their ability of enterprise governance, help them to gain market recognition or rewards, and maximize their value. Harjoto and Laksmana (2018) found that good environmental responsibility performance can reduce deviation from the relative optimal level of enterprise risk-taking and thus enhance enterprise value. Therefore, the present study assumes that to a certain extent, the value effect of risk-taking under extreme temperatures is moderated by the supervision pressure of market participants and enterprise governance.

The existing articles on the impact of extreme weather on enterprises mainly focus on business performance, such as labor force, output, and productivity, without considering the impact on the risk situation of enterprises from the perspective of climate change. Moreover, they only regard risk-taking as an important way for extreme weather to affect personal risk preference, and only focus on the psychological level. There is no research on whether the risk-taking behavior and results of enterprises are affected by exposure to extreme weather. Therefore, it is not clear whether extreme temperature, which is a typical manifestation of climate risk, has an impact on the risk-taking behavior of enterprises. This raises the following questions: "Under the influence of extreme temperature, can enterprises take risks to increase enterprise value?" "What factors help enterprises to enhance their value?" This study helps to clarify how climate risk is transmitted to enterprises, and it will be of great significance to the risk management of listed companies and the healthy development of China's capital market. However, this area of research has not been the concern of scholars.

The marginal contributions of this study are as follows. First, this study clarifies the theoretical mechanism of the impact of extreme weather on enterprise risk-taking. Second, it enriches the empirical evidence of the influence of natural environmental uncertainty on micro-enterprise behavior and pays attention to the rationality of the risk-taking behavior of enterprises. In the existing literature, there is little analysis of the impact of extreme weather conditions on the level of risk-taking from the perspective of climate risk. This study finds that it does not only significantly affect the risk-taking behavior of listed companies but also has significantly different effects on enterprises with different risk-taking endowments. Third, it expands the research on enterprise risk-taking and its economic impacts and provides new empirical evidence on the effect of climate risk on financial markets. Although the impact of climate change on the financial system has received considerable attention from policymakers and academia, the existing literature focuses on the risk of stranding high-carbon assets and the transmission of natural disaster losses in the financial system (Alok et al., 2020; Dafermos et al., 2018). As climate risk has become an important exogenous risk factor for enterprises, it is essential to study how it affects China's capital market through enterprise risk-taking. Finally, this study is not only concerned about the climate risk management of listed enterprises but also closely related to China's response to climate change; the change in the development model; perfection of capital market regulation; environmental, social, and governance (ESG) investment; etc. All these factors have important policy and practical significance.

### 3. Method

#### 3.1. Models

##### 3.1.1. Baseline model

Following Zhang et al. (2018), we model risk-taking using the regression model in Eq. (1). In Eq. (1),  $r$  represents enterprises;  $c$  represents cities;  $i$  represents industries, and  $t$  represents years. The explained variable is measured by the volatility of the enterprise's return on assets (ROA), which is measured by the ratio of net profit to assets. For every observation period of three years ( $T-1$  to  $T+1$ ), the industry-adjusted standard deviation is calculated on a rolling basis. This index is multiplied by 100, which is consistent with the approach of Faccio et al. (2011) and He et al. (2019). The dimension treatment does not affect the significance of the test.

$$Risktaking_{r,t+i} = \alpha_0 + \sum_m \alpha_1^m Tbin_{rt}^m + \alpha_2 Weather_{rt} + \mu_c + \lambda_i + \gamma_t + \varepsilon_{rt} \quad (1)$$

Following Zhang et al. (2018) and Chen X (2019),  $Tbin_{rt}^m$  denotes the number of days in year  $t$  on which daily average temperatures fall into the  $m^{th}$  temperature bin in the city where firm  $r$  is located. The temperature information is obtained by matching the gridded temperature data with the geographical information of Chinese prefecture-level cities and areas where the headquarters of the sampled enterprises are located. The average daily temperature is divided into 11 bins with a length of 6 °C. The first temperature bin is less than -18 °C, and the second is [-18 °C, -12 °C). By analogy, the 11th temperature bin is greater than 36 °C. To avoid multicollinearity problems, we select [12 °C, 18 °C) as the omitted category. In addition, this study controls for three weather variables-annual average precipitation, 2 m dew point temperature, and air pressure-which are represented by  $Weather_{rt}$ . Moreover,  $\mu_c$ ,  $\lambda_i$ , and  $\gamma_t$  represent the fixed effects of the city, industry, and year, respectively.  $\varepsilon_{rt}$  is an error term that captures the effects of other factors that are not included in Eq. (1). Standard errors in the baseline regressions are clustered within cities.

##### 3.1.2. Model for the deviation from the optimal risk-taking level

$$Risktaking_{r,t} = \alpha_0 + \alpha_1 areturn_{rt} + \alpha_2 gdp_{gth}_{rt} + \alpha_3 ebit_{r,t-1} + \alpha_4 btm_{r,t-1} + \alpha_5 lev_{r,t-1} + \mu_c + \lambda_i + \gamma_t + \varepsilon_{rt} \quad (2)$$

The optimal managerial risk-taking level is estimated using the regression model of Barger et al. (2010). The explanatory variables include macroeconomic factors and enterprise characteristics.  $areturn_{rt}$  denotes the annual return of the A-share stock market;  $gdp_{gth}_{rt}$  is the national GDP growth rate;  $ebit_{r,t-1}$ ,  $btm_{r,t-1}$ , and  $lev_{r,t-1}$  represent the earnings before interest and tax, book-to-market ratio,

and the asset–liability ratio, respectively. The macro-economic and enterprise characteristics variables are the current and previous values, which are selected to control for possible endogenous problems.

The value of residuals measures the deviation from the optimal risk-taking level. In this study, the risk-taking endowment of an enterprise is measured using a dummy variable *opt\_rt*, which has a value of 1 if the enterprise’s risk-taking level is greater than the optimal level, that is, excessive risk-taking; and it has a value of 0 if the enterprise’s risk-taking level is less than the optimal level, that is, insufficient risk-taking.

3.1.3. Model for the impact of risk-taking on enterprise value under extreme temperature

$$Intq_{r,t+1} = \alpha_0 + \sum_m \alpha_1^m Tbin_r^m + \sum_m \alpha_2^m Tbin_r^m * Risktaking_{rt} + \alpha_3 Risktaking_{rt} + \alpha_4 Weather_{rt} + \mu_c + \lambda_i + \gamma_t + \varepsilon_{rt} \tag{3}$$

This study also examines the effect of risk-taking on an enterprise’s market value under extreme temperatures. The above model is constructed based on the work of [Qian and Yin \(2017\)](#). The explained variable is the market value of the enterprise for the current and following year, which is measured using the Tobin Q. On the right side,  $\sum_m \alpha_2^m Tbin_r^m * Risktaking_{rt}$  is the interaction term of temperature bins and risk-taking. If the coefficient is significant, it implies that risk-taking has a significant effect on enterprise value.

3.1.4. Model for the impact mechanism of risk-taking on enterprise value under extreme temperature

$$Intq_{r,t+1} = \alpha_0 + \sum_m \alpha_1^m Tbin_r^m + \sum_m \alpha_2^m Tbin_r^m * Risktaking_{rt} + \sum_m \alpha_3^m Tbin_r^m * Risktaking_{rt} * X_{rt} + \alpha_4 Risktaking_{rt} + \alpha_5 X_{rt} + \alpha_6 Weather_{rt} + \mu_c + \lambda_i + \gamma_t + \varepsilon_{rt} \tag{4}$$

Based on [Eq. \(3\)](#), a triple interaction term  $\sum_m \alpha_3^m Tbin_r^m * Risktaking_{rt} * X_{rt}$  is added, where  $X_{rt}$  represents the impact mechanism. We analyze it from two perspectives and six indicators, in which analyst attention (*ana\_att*), analysts’ report attention (*rep\_att*) and independent institutional investors’ shareholding ratio (*indins*) represent external supervision; and environmental responsibility score (*env*), executive team average age (*age*), and executive team female proportion (*gdr*) represent internal governance, respectively. Due to the characteristics of collaborative governance on climate and environmental issues ([He et al., 2019](#)) and as the data on the climate responsibility performance of listed companies are not available, we follow the method in the existing literature ([Ramelli et al., 2018](#)) and use the enterprise environmental responsibility score as the proxy variable for climate responsibility performance. If the triple interaction coefficient in [Eq. \(4\)](#) is significantly positive, then risk-taking through this mechanism has a significant and positive moderating effect on market value; otherwise, the effect is negative.

3.2. Data and samples

The sample of this study covers the data of A-share manufacturing enterprises from 2000 to 2019. In this study, the manufacturing industry is divided by two-digit codes, and the sampled industries with only one company are removed. The calculation of enterprise risk-taking requires a three-year window period, but the data can be obtained from 1999 to 2020. Thus, the observation year is from 2000 to 2019. Financial and insurance companies and enterprises with missing variables are excluded. Finally, an unbalanced panel is

**Table 1**  
Summary statistics.

Var_Name	Obs	Mean	SD	Min	P25	Median	P75	Max
Risktaking	17458	2.722	3.268	0.003	0.926	1.67	3.04	28.7
T_bin1	17477	0.908	4.941	0	0	0	0	66
T_bin2	17477	2.579	9.193	0	0	0	0	83
T_bin3	17477	6.524	14.452	0	0	0	3	103
T_bin4	17477	18.216	23.882	0	0	3	36	119
T_bin5	17477	37.580	23.719	0	21	41	55	100
T_bin6	17477	51.513	23.517	0	39	54	67	124
T_bin7	17477	62.464	16.098	0	52	62	71	151
T_bin8	17477	85.556	19.764	0	74	84	95	234
T_bin9	17477	87.456	47.706	0	63	79	97	248
T_bin10	17477	12.414	13.024	0	0	9	20	68
T_bin11	17477	0.004	0.103	0	0	0	0	3
opt_rt	15296	0.300	0.458	0	0	0	1	1
Intq	17187	103.745	31.325	14.2	81.1	95.4	118	425
ana_att	12202	9.772	9.859	1	2	6	14	75
rep_att	12333	18.990	23.945	1	3	10	25	253
indins	3365	9.014	7.503	0.066	3.32	6.96	12.4	57.8
env	10846	1.954	5.457	0	0	0	0	30
age	17376	46.314	3.900	31.8	43.7	46.4	49	60.8
gdr	17378	0.127	0.117	0	0	0.111	0.2	0.833

obtained, with 17,477 observations of 1868 companies.

The data sources are as follows. (1) The temperature and other weather data are from the ERA5 reanalysis dataset of the European Centre for Medium-Range Weather Forecasts. The horizontal resolution of the data is  $0.25^\circ \times 0.25^\circ$  (latitude  $\times$  longitude), and the temporal resolution is one hour. The surface temperature is 2 m, and the weather data in the control variables include 2 m dew point temperature, total precipitation, and surface pressure. (2) The environmental responsibility score data are derived from the environmental responsibility score in the social responsibility scoring system of Hexun. (3) The remaining data are from the CSMAR database. All continuous variables are winsorized at the top and bottom 1% levels.

### 3.3. Descriptive statistics

Table 1 presents the descriptive statistics of the main variables. The average and median risk-taking levels are 2.722 and 1.666, respectively, which indicates that listed manufacturing enterprises in China are quite different in this regard with a significant right deviation. For temperature distribution, the daily average indicates that the overall figures are consistent with the normal distribution. However, the number of days in the high-temperature bins is higher than that in the low-temperature bins, which is consistent with the climatic characteristics of China. The temperature of the north and south has a large difference in winter but is commonly high in most areas during summer. The risk-taking endowment variable *optm\_rt* indicates that most of the sampled companies have lower risk-taking levels. The mean of *env* is 1.954, whereas the median and 75% percentile are both 0, which reveals that disclosure of environmental responsibility information is not common among listed companies in China. The proportion of women in the executive team is generally low in China, with an average of 0.127 and a 75% percentile of 0.2. The descriptive statistical results of the other variables are consistent with those of the existing literature, and they are all within a reasonable range.

## 4. Empirical analysis

### 4.1. Baseline regression results

This study empirically tests the effect of extreme temperature on enterprise risk-taking using Eq. (1), and the results are presented in Table 2. Column 1 does not include control variables, whereas three weather variables, precipitation, dew point temperature and air pressure, are gradually added in columns 2–4, respectively. The results reveal that both bins with extremely low temperature (less than  $-18^\circ\text{C}$ ) and extremely high temperature (more than  $36^\circ\text{C}$ ), with significant and positive effects on enterprise risk-taking. Moreover, compared with that of the extremely low-temperature bin, the economic importance of the extremely high-temperature bin is much higher by approximately 10 times under the same 1% statistical significance level. On the one hand, high temperatures lead to a slowdown in manufacturing production; on the other hand, more importantly, compared with cold weather, extremely high temperature weather events are a more direct and easily recognized manifestation of global warming. It not only has a significant impact on manufacturing production, but also has an extensive impact on people's daily life and outdoor activities, which directly leads to the expectation of social and economic low-carbon transition, thus increasing the risk-taking behavior of enterprises from the perspective of physical risk and perception and expectation of transition risk.

The parameter estimates of *T\_bin1* and *T\_bin11* are statistically significant at the 1% level, suggesting that risk-taking increases with extreme temperatures. For each additional day of extremely high and low temperature, the ROA fluctuation of the firm increases by 0.00028 and 0.00297,<sup>1</sup> respectively. As the explained variable in this study is a standard deviation, we pay more attention to the relative degree of its variation. For instance, in a day with an average temperature of  $12\text{--}18^\circ\text{C}$ , an additional day at  $36^\circ\text{C}$  can lead to an increase in risk-taking by approximately 10.9%, whereas risk-taking increases by 1.03% with an additional day at  $-18^\circ\text{C}$ , holding all other things constant. The results suggest that the increase in risk-taking due to an increase in extreme temperature is quite large, especially in extremely high temperatures.

The division of extremely high-temperature bins and the significance and magnitude of the estimated coefficients for all temperature bins are generally consistent with those of previous studies (Graff & Neidell, 2014; Chen X, 2019; Peillex et al., 2021).

### 4.2. Robustness tests

#### 4.2.1. Changing omitted temperature bin

In the baseline regression, ( $12^\circ\text{C}$ ,  $18^\circ\text{C}$ ) is selected as the omitted category. This rationality is explained by using nine bins outside the extreme temperature as the omitted category. Table 3 presents the results.

The observations are as follows. First, when the enterprise is in the two extremely high-temperature bins, risk-taking is significantly high and the coefficient is more stable, which implies that the choice of temperature bin has little influence on the baseline results. Second, when the enterprise is in the extremely low-temperature bin of less than  $-18^\circ\text{C}$ , the statistical significance of the test results varies from 1% to 10%, and the economic significance is generally smaller than when it is in the extremely high-temperature bin. This result indicates that extremely low temperature has less influence on enterprises' risk-taking, which is consistent with the conclusion of the baseline regression. Because of these results, we pay greater attention to the effect of extremely high temperature on risk-taking

<sup>1</sup> Taking into account the dimensions of the calculation of risk-taking above, we reduce them in the interpretation of the coefficients.

**Table 2**  
Baseline regression results.

	(1)	(2)	(3)	(4)
	Risktaking	Risktaking	Risktaking	Risktaking
T_bin1	0.02746 (3.191)***	0.02717 (3.183)***	0.02771 (3.216)***	0.02813 (3.190)***
T_bin2	0.00581 (0.539)	0.00553 (0.510)	0.00663 (0.604)	0.00672 (0.605)
T_bin3	0.00880 (1.091)	0.00857 (1.059)	0.00993 (1.192)	0.01011 (1.190)
T_bin4	0.00538 (0.959)	0.00516 (0.921)	0.00596 (1.029)	0.00609 (1.032)
T_bin5	0.00358 (0.932)	0.00363 (0.941)	0.00416 (1.053)	0.00422 (1.063)
T_bin6	0.00243 (0.807)	0.00234 (0.774)	0.00280 (0.952)	0.00280 (0.950)
T_bin8	0.00581 (1.536)	0.00594 (1.590)	0.00566 (1.505)	0.00564 (1.504)
T_bin9	-0.00229 (-0.439)	-0.00181 (-0.357)	-0.00208 (-0.410)	-0.00209 (-0.411)
T_bin10	0.00111 (0.198)	0.00205 (0.359)	0.00167 (0.294)	0.00166 (0.291)
T_bin11	0.28696 (4.622)* **	0.28856 (4.646)* **	0.29643 (4.666)* **	0.29710 (4.648)* **
precip		26.62216 (0.580)	12.63870 (0.261)	12.76779 (0.264)
d2m			0.06349 (0.716)	0.06029 (0.706)
sp				-0.00020 (-0.176)
Year_FE	Y	Y	Y	Y
Ind_FE	Y	Y	Y	Y
City_FE	Y	Y	Y	Y
Cluster	City	City	City	City
N	17456	17456	17456	17456
r2_a	0.074	0.074	0.074	0.074

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

and other economic outcomes. Finally, the regression coefficients of each temperature bin reveal that when  $T_{bin7}$  is omitted, the coefficients of other regions are positive, but only those of  $T_{bin1}$ ,  $T_{bin8}$ , and  $T_{bin11}$  are significant. Compared with the two extreme temperature bins, the coefficient of  $T_{bin8}$  has a quantitative difference that only appears in Column 6. However, there may be a small range of fluctuations in the effect of temperature on the level of enterprise risk-taking, which is reasonable. In summary, when the enterprise location is in the temperature bin of (12 °C, 18 °C), which is the bin with the relatively minimum level of risk-taking. The results are consistent with the selection criteria of the omitted category.

#### 4.2.2. Changing temperature bin length

In the baseline regression, the temperature bin length is set as 6 °C, which contains a strong implicit assumption that a one-day increase of different temperatures in the same bin has a homogeneous effect on enterprise risk-taking. To avoid the interference of this assumption, we reduce the length of the temperature bin to 3 °C for the robustness test. Table 4 presents the empirical results. The omitted temperature bins of Columns 1–2 and 3–4 are [12 °C, 15 °C) and [15 °C, 18 °C), respectively, and are tested with and without weather control variables.

The baseline conclusion of this paper is not affected by the artificially set bin length. In addition, the results of Columns 2 and 4 reveal that the corresponding *p* values of  $tb_{in19}$  regression coefficient for the [33 °C, 36 °C) temperature bin are 0.153 and 0.160, respectively, indicating a relatively large economic significance. Therefore, the effect of high temperature on enterprises' risk-taking occurs gradually, but the effect increases sharply at extremely high temperatures.

#### 4.2.3. Changing fixed effects and standard errors

In the baseline regression, the fixed effects of the city, industry, and year are controlled, but non-observation factors at the enterprise level may be missing. Therefore, we first include time-invariant enterprise fixed effects that are used to control for the unobserved characteristics that are unique to enterprise *r*, and allow us to identify the causal effect of extreme temperature using random and exogenous variation in the distribution of temperature around each firm's mean exposure. As unobserved factors that are common to all enterprises in a given year may differ across industries, such as the introduction of new production technology or changes in trade policies that are specific to industry *i*, we also introduce industry\*year fixed effect; Columns 1 and 2 of Table 5 present the results. The significance levels of the coefficients of extremely low and high temperature are similar to those in the baseline regression, whereas the

**Table 3**  
Robustness test: changing omitted temperature bin.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Risktaking	Risktaking	Risktaking						
T_bin1	0.02142 (1.813)*	0.01802 (2.456)**	0.02205 (3.043)**	0.02391 (3.087)**	0.02533 (3.074)**	0.03023 (2.784)**	0.02249 (2.326)**	0.02813 (3.190)**	0.02648 (2.426)**
T_bin2		-0.00340 (-0.459)	0.00063 (0.078)	0.00249 (0.263)	0.00392 (0.390)	0.00881 (0.728)	0.00108 (0.093)	0.00672 (0.605)	0.00506 (0.397)
T_bin3	0.00340 (0.459)		0.00403 (0.725)	0.00589 (0.861)	0.00731 (1.014)	0.01221 (1.205)	0.00447 (0.490)	0.01011 (1.190)	0.00846 (0.792)
T_bin4	-0.00063 (-0.078)	-0.00403 (-0.725)		0.00186 (0.467)	0.00329 (0.684)	0.00818 (1.022)	0.00045 (0.064)	0.00609 (1.032)	0.00443 (0.523)
T_bin5	-0.00249 (-0.263)	-0.00589 (-0.861)	-0.00186 (-0.467)		0.00143 (0.439)	0.00632 (0.987)	-0.00142 (-0.264)	0.00422 (1.063)	0.00257 (0.381)
T_bin6	-0.00392 (-0.390)	-0.00731 (-1.014)	-0.00329 (-0.684)	-0.00143 (-0.439)		0.00489 (0.995)	-0.00284 (-0.659)	0.00280 (0.950)	0.00114 (0.200)
T_bin7	-0.00881 (-0.728)	-0.01221 (-1.205)	-0.00818 (-1.022)	-0.00632 (-0.987)	-0.00489 (-0.995)		-0.00773 (-2.122)**	-0.00209 (-0.411)	-0.00375 (-1.073)
T_bin8	-0.00108 (-0.093)	-0.00447 (-0.490)	-0.00045 (-0.064)	0.00142 (0.264)	0.00284 (0.659)	0.00773 (2.122)**		0.00564 (1.504)	0.00398 (0.859)
T_bin9	-0.00672 (-0.605)	-0.01011 (-1.190)	-0.00609 (-1.032)	-0.00422 (-1.063)	-0.00280 (-0.950)	0.00209 (0.411)	-0.00564 (-1.504)		-0.00166 (-0.291)
T_bin10	-0.00506 (-0.397)	-0.00846 (-0.792)	-0.00443 (-0.523)	-0.00257 (-0.381)	-0.00114 (-0.200)	0.00375 (1.073)	-0.00398 (-0.859)	0.00166 (0.291)	
T_bin11	0.29038 (4.542)**	0.28699 (4.466)**	0.29101 (4.549)**	0.29288 (4.583)**	0.29430 (4.594)**	0.29919 (4.684)**	0.29146 (4.589)**	0.29710 (4.648)**	0.29544 (4.579)**
Weather	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year_FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ind_FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
City_FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cluster	City	City	City						
N	17456	17456	17456	17456	17456	17456	17456	17456	17456
r2_a	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074

t statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

coefficient of T\_bin1 increases slightly.

Standard errors are clustered within the city level in the baseline regression. However, the standard errors at the prefecture-level city in the same province may also be related. Therefore, the standard errors are further clustered within the provincial level in the robustness test. As presented in Column 3 of Table 5, the baseline conclusions are not affected by the change.

#### 4.2.4. Substituting explained variables

Three substitutes are used for the explained variables. First, the logarithm of the risk-taking is taken to form *lnRisktaking*; second, the range of ROA in three years, which is represented by *Risktaking2*, is constructed; third, as the sample is listed companies, the standard deviation is calculated based on return on equity (ROE) to form *Risktaking\_roe*. Based on Eq. (1), only the explained variables are replaced in Columns 1–3 of Table 6; Columns 4–6 further control for enterprise and industry-year fixed effect, and the standard errors are clustered within provinces. The effect of extreme temperature on risk-taking is significantly positive. After comparing the three alternative variables, we find that the coefficient of *Risktaking2* is slightly larger than that of the baseline estimation, which is consistent with previous findings (He et al., 2019). The ROE-based standard deviation, which is related to the characteristics of the sampled listed enterprises, is also more affected by extreme temperature. The coefficient obtained by using the standard deviation calculated based on ROE is relatively larger, which is due to the particularity of the samples as listed enterprises. Thus, in the following content, we focus on the market value of listed companies as the economic returns of increasing risk-taking at extreme temperatures and pay attention to the influence of market participant supervision and enterprise governance on economic returns.

#### 4.2.5. Excluding alternative explanations: impacts of daily maximum and minimum temperatures

In the baseline regression, extreme temperature is measured by the daily average. Although the duration of the impact of daily maximum and minimum temperature on enterprises is short, it is closely related to the former. A possible alternative explanation is that the effect of extreme temperatures on risk-taking is caused by daily maximum and minimum temperatures. Therefore, from the hourly data of the ERA5 dataset, we process the daily maximum and minimum temperatures. Similar to the method in the baseline regression, 11 temperature bins are constructed and [12 °C, 18 °C) is selected as the omitted category; the results are presented in Table 7. Whether the weather control variables are added, the fixed effects are used, or the standard errors are clustered within or not, the extreme temperature bins obtained by daily maximum and minimum temperatures have an insignificant coefficient. Thus, the baseline results are not caused by maximum or minimum temperatures.

**Table 4**  
Robustness test: changing temperature bin length.

	(1)	(2)	(3)	(4)
	Risktaking	Risktaking	Risktaking	Risktaking
tbin1	0.03156 (2.627)* **	0.03213 (2.561)* *	0.03244 (2.504)* *	0.03273 (2.363)* *
tbin2	0.00504 (0.275)	0.00593 (0.317)	0.00592 (0.318)	0.00654 (0.336)
tbin3	0.00878 (0.452)	0.00970 (0.482)	0.00966 (0.485)	0.01030 (0.491)
tbin4	0.01793 (1.183)	0.01880 (1.194)	0.01881 (1.187)	0.01940 (1.159)
tbin5	0.00658 (0.501)	0.00803 (0.591)	0.00746 (0.550)	0.00863 (0.597)
tbin6	0.01189 (1.215)	0.01239 (1.187)	0.01277 (1.161)	0.01300 (1.075)
tbin7	0.00556 (0.637)	0.00621 (0.682)	0.00644 (0.676)	0.00682 (0.660)
tbin8	0.00860 (1.178)	0.00898 (1.158)	0.00948 (1.117)	0.00959 (1.016)
tbin9	0.00223 (0.335)	0.00292 (0.426)	0.00311 (0.400)	0.00352 (0.424)
tbin10	0.00529 (0.861)	0.00542 (0.876)	0.00616 (0.922)	0.00602 (0.843)
tbin11	0.00201 (0.338)	0.00230 (0.394)	0.00289 (0.448)	0.00290 (0.428)
tbin12			0.00088 (0.245)	0.00061 (0.154)
tbin13	-0.00088 (-0.245)	-0.00061 (-0.154)		
tbin14	0.00559 (1.224)	0.00543 (1.176)	0.00647 (1.169)	0.00603 (0.992)
tbin15	0.00891 (2.248)* *	0.00855 (2.271)* *	0.00978 (2.122)* *	0.00915 (1.952)* *
tbin16	0.00050 (0.081)	0.00052 (0.084)	0.00138 (0.188)	0.00113 (0.147)
tbin17	0.00122 (0.212)	0.00095 (0.168)	0.00210 (0.343)	0.00156 (0.244)
tbin18	0.00095 (0.216)	0.00110 (0.233)	0.00183 (0.361)	0.00171 (0.338)
tbin19	0.01626 (1.306)	0.01852 (1.433)	0.01713 (1.307)	0.01913 (1.410)
tbin20	0.24344 (3.405)* **	0.24944 (3.447)* **	0.24432 (3.410)* **	0.25005 (3.437)* **
Weather	N	Y	N	Y
Year_FE	Y	Y	Y	Y
Ind_FE	Y	Y	Y	Y
City_FE	Y	Y	Y	Y
Cluster	City	City	City	City
N	17456	17456	17456	17456
r2_a	0.074	0.074	0.074	0.074

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

#### 4.3. Further discussion: endowment effect of risk-taking

The risk-taking behavior of enterprises differs due to the varying levels of original risk-taking, revealing the endowment effect. In this study, according to the relative optimal risk-taking level deviation obtained by Eq. (2), a dummy variable  $opt\_rt$  is constructed. Based on this dummy variable, grouping tests are performed on the sample using different risk-taking endowments; the results are presented in Table 8. Columns 1 and 2 list enterprises whose original risk-taking level is less than the optimal level, that is, insufficient risk-taking. This group experienced an increase in the level of risk-taking under extremely low and high temperatures, and the effect of extremely high temperature is still high. In Columns 3–4, the original risk-taking level is greater than the optimal level, that is, excessive risk-taking. In this group, extremely high temperature significantly reduces risk-taking; the enterprises demonstrate apparent risk aversion, whereas extremely low temperature has no significant effect. Among them, Columns 1 and 3 control the fixed effects of year, industry, and city levels, and standard errors are clustered within cities. The robustness of the results is tested; Columns 2 and 4 control enterprise and industry-year fixed effect, and standard errors are clustered within provinces.

**Table 5**  
Robustness test: changing fixed effects and standard errors.

	(1)	(2)	(3)
	Risktaking	Risktaking	Risktaking
T_bin1	0.03727 (4.115)* **	0.03833 (4.256)* **	0.03833 (2.932)* **
T_bin2	0.00874 (0.766)	0.00403 (0.351)	0.00403 (0.313)
T_bin3	0.01498 (1.675)*	0.01321 (1.512)	0.01321 (1.231)
T_bin4	0.00764 (1.229)	0.00565 (0.973)	0.00565 (0.826)
T_bin5	0.00417 (1.050)	0.00392 (0.951)	0.00392 (0.780)
T_bin6	0.00174 (0.596)	-0.00023 (-0.081)	-0.00023 (-0.093)
T_bin8	0.00550 (1.294)	0.00242 (0.588)	0.00242 (0.646)
T_bin9	-0.00453 (-0.880)	-0.00703 (-1.399)	-0.00703 (-1.460)
T_bin10	0.00142 (0.257)	0.00069 (0.123)	0.00069 (0.139)
T_bin11	0.29398 (4.605)* **	0.29791 (4.175)* **	0.29791 (3.366)* **
Weather	Y	Y	Y
Year_FE	Y	Y	Y
Enterprise_FE	Y	Y	Y
Indyr_FE	N	Y	Y
Cluster	City	City	Prov
N	17332	17316	17316
r2_a	0.256	0.283	0.283

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

## 5. Influence of risk-taking on enterprise value under extreme temperature

### 5.1. Main impact

Based on Eq. (3), we examine the impact of risk-taking on enterprises' market value under extreme temperatures; Columns 1–2 of Table 9 present the results. The explained variables in Columns 1–2 are enterprises' Tobin Q in the current and following years, respectively. First, the increase in risk-taking under extremely low temperatures has a significant and negative effect on market value, which may be caused by the following reasons. On the one hand, extremely low temperature is often accompanied by adverse weather or disasters, such as rain, snow, or freezing. For example, the large-scale ice storm that occurred in China from January to February 2008 severely affected transportation, water supply, and power supply in the short term, having a double blow on production and sales. These events eroded the ability of enterprises to take risks. The baseline regression results reveal that the increase in risk-taking at extremely low temperatures is much smaller. On the other hand, disasters accompanied by extremely low temperatures lead to an increase in negative sentiment and risk aversion in the market, which also affect market concerns about the impacts of the increase in risk. These concerns are reflected in the reduction in investors' valuation of listed companies. Second, risk-taking under extremely high temperature significantly reduces enterprise value in the following year. Extremely high temperature has a considerable effect on labor productivity and may also reduce working hours and thus the output of enterprises. However, the impact of extremely high temperature on transportation and water supply is relatively small. Although power supply pressure can be relieved by planned alternating power outages, enterprises arrange production in advance; thus, the negative effect may appear in the following year. Finally, by comparison, the lagging effect of risk-taking on enterprise value under extremely high temperature is greater than that under extremely low temperature in the current period, which may be related to the fact that most listed enterprises in China are located in high-temperature areas. In the context of climate change, high-temperature events are also more likely to attract investor attention.

### 5.2. Heterogeneity analysis based on risk-taking endowment

The above results demonstrate that an enterprise's risk behavior under extreme temperatures is related to its existing risk-taking endowment, which may lead to the heterogeneity of economic returns. Based on the dummy variable  $opt_{rt}$ , we further test the effect of enterprise risk-taking on enterprise value in the current and following years under extreme temperatures; the results are presented in Columns 2–3 and 5–6 of Table 9. Enterprises with insufficient risk-taking can enhance their value through their risk-taking behavior under extremely high temperature, which is also significant in the following year. However, extremely high temperature has no significant effect on the value of enterprises with excessive risk-taking in the current period but has a negative effect in the following

**Table 6**  
Robustness test: substituting explained variables.

	(1)	(2)	(3)	(4)	(5)	(6)
	lnRisktaking	Risktaking2	Risktaking_roe	lnRisktaking	Risktaking2	Risktaking_roe
T_bin1	0.00589 (3.315)* **	0.05388 (3.257)* **	0.06368 (2.085)* *	0.00772 (3.555)* **	0.07465 (2.932)* **	0.09277 (2.722)* *
T_bin2	0.00161 (0.851)	0.01246 (0.598)	0.04425 (1.678)*	0.00128 (0.705)	0.00854 (0.356)	0.04163 (1.380)
T_bin3	0.00279 (1.882)*	0.01968 (1.249)	0.03997 (1.858)*	0.00328 (1.710)	0.02624 (1.330)	0.04789 (1.674)
T_bin4	0.00122 (1.119)	0.01223 (1.140)	0.03076 (1.665)*	0.00116 (0.957)	0.01220 (0.984)	0.02882 (1.286)
T_bin5	0.00091 (1.248)	0.00834 (1.143)	0.00793 (0.605)	0.00081 (0.910)	0.00770 (0.830)	0.00988 (0.586)
T_bin6	0.00055 (0.932)	0.00562 (1.033)	0.01045 (1.128)	-0.00003 (-0.062)	-0.00003 (-0.007)	0.00556 (0.646)
T_bin8	0.00093 (1.266)	0.01065 (1.519)	0.00972 (0.828)	0.00012 (0.147)	0.00441 (0.626)	0.00284 (0.253)
T_bin9	0.00006 (0.057)	-0.00344 (-0.361)	-0.01481 (-0.834)	-0.00111 (-1.213)	-0.01311 (-1.453)	-0.02119 (-1.359)
T_bin10	0.00048 (0.425)	0.00238 (0.223)	-0.01029 (-0.549)	0.00009 (0.094)	-0.00002 (-0.002)	-0.00777 (-0.423)
T_bin11	0.11492 (7.321)* **	0.58712 (4.855)* **	0.37375 (2.219)* *	0.10229 (5.829)* **	0.58491 (3.514)* **	0.43245 (2.414)* *
Weather	Y	Y	Y	Y	Y	Y
Year_FE	Y	Y	Y	Y	Y	Y
Ind_FE	Y	Y	Y	N	N	N
City_FE	Y	Y	Y	N	N	N
Enterprise_FE	N	N	N	Y	Y	Y
Indyr_FE	N	N	N	Y	Y	Y
Cluster	City	City	City	Prov	Prov	Prov
N	17456	17474	17378	17316	17316	17238
r2_a	0.075	0.077	0.085	0.289	0.284	0.316

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

**Table 7**  
Excluding of alternative explanations: effects of daily maximum and minimum temperatures.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Risktaking							
Tmx_bin1	0.01345 (0.399)	0.01456 (0.432)	0.11946 (1.049)	0.13106 (1.137)				
Tmx_bin11	-0.00067 (-0.084)	-0.00043 (-0.055)	-0.00280 (-0.215)	-0.00275 (-0.211)				
Tmn_bin1					0.00970 (0.934)	0.01017 (0.922)	0.00434 (0.464)	0.00508 (0.539)
Tmn_bin11					-0.00370 (-0.906)	-0.00412 (-0.990)	-0.00271 (-1.058)	-0.00313 (-1.171)
Weather	N	Y	N	Y	N	Y	N	Y
Year_FE	Y	Y	Y	Y	Y	Y	Y	Y
Ind_FE	Y	Y	N	N	Y	Y	N	N
City_FE	Y	Y	N	N	Y	Y	N	N
Enterprise_FE	N	N	Y	Y	N	N	Y	Y
Indyr_FE	N	N	Y	Y	N	N	Y	Y
Cluster	City	City	Prov	Prov	City	City	Prov	Prov
N	17456	17456	17306	17306	17456	17456	17316	17316
r2_a	0.074	0.074	0.292	0.292	0.074	0.074	0.282	0.283

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

year. It may also have a negative effect on the market value in the following year in the full sample test. The above results demonstrate that the warning effect of extreme weather in enhancing enterprises' awareness of climate hazards and leading them to take risks more actively is not universal but is only effective in enterprises with a smaller risk-taking endowment. Only such an increase in risk-taking can attain market recognition and achieve value enhancement; enterprises with larger original risk-taking tend to avoid risks, which restrain the market value.

**Table 8**

Further discussion: endowment effect of risk-taking.

	(1) opt_rt= 1	(2) opt_rt= 1	(3) opt_rt= 0	(4) opt_rt= 0
	Risktaking	Risktaking	Risktaking	Risktaking
T_bin1	0.01955 (0.557)	0.03969 (1.112)	0.00225 (0.584)	0.00178 (0.367)
T_bin2	0.01754 (0.754)	-0.02000 (-0.764)	-0.00068 (-0.151)	0.00018 (0.044)
T_bin3	0.00746 (0.485)	-0.00772 (-0.385)	0.00384 (1.414)	0.00357 (1.123)
T_bin4	0.01609 (1.109)	0.00510 (0.358)	-0.00029 (-0.125)	-0.00141 (-0.593)
T_bin5	0.01871 (1.969)*	0.01109 (1.097)	0.00091 (0.718)	-0.00036 (-0.264)
T_bin6	0.00980 (1.382)	0.00144 (0.235)	0.00049 (0.508)	-0.00034 (-0.426)
T_bin8	0.00483 (0.604)	-0.00567 (-0.825)	-0.00105 (-0.823)	-0.00266 (-2.271)* *
T_bin9	-0.00401 (-0.403)	-0.01340 (-1.461)	-0.00154 (-0.957)	-0.00254 (-1.432)
T_bin10	-0.00578 (-0.449)	-0.00732 (-0.450)	-0.00039 (-0.201)	-0.00133 (-0.810)
T_bin11	-0.30087 (-2.399)* *	-0.55720 (-2.370)* *	0.13171 (6.373)* **	0.07978 (2.457)* *
Weather	Y	Y	Y	Y
Year_FE	Y	Y	Y	Y
Ind_FE	Y	N	Y	N
City_FE	Y	N	Y	N
Enterprise_FE	N	Y	N	Y
Indyr_FE	N	Y	N	Y
Cluster	City	Prov	City	Prov
N	4576	4215	10707	10535
r2_a	0.290	0.629	0.196	0.319

t statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ **Table 9**

Influence of risk-taking on enterprise value under extreme temperature: main impact and heterogeneity analysis.

	(1)	(2) optm_rt= 0	(3) optm_rt= 1	(4)	(5) optm_rt= 0	(6) optm_rt= 1
	lntq	lntq	lntq	lead_lntq	lead_lntq	lead_lntq
T_bin1RT	-0.00057 (-4.378)* **	-0.00151 (-2.912)* **	-0.00107 (-7.320)* **	0.00010 (0.363)	-0.00106 (-1.741)*	-0.00024 (-1.271)
T_bin11RT	-0.00165 (-0.348)	0.03000 (2.030)*	0.00033 (0.051)	-0.00336 (-2.001)*	0.02822 (3.761)* **	-0.02726 (-2.101)* *
Weather	Y	Y	Y	Y	Y	Y
Year_FE	Y	Y	Y	Y	Y	Y
Enterprise_FE	Y	Y	Y	Y	Y	Y
Indyr_FE	Y	Y	Y	Y	Y	Y
Cluster	Prov	Prov	Prov	Prov	Prov	Prov
N	17025	11859	4698	15679	10916	4360
r2_a	0.592	0.629	0.630	0.624	0.659	0.609

t statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ 

Note: in order to show the robustness of the results, the regression control the fixed effects of the enterprise, year and industry-year level, and cluster the standards within the provincial level; for the sake of brevity of the results, only the coefficients of interaction items that are of concern in the test are listed; same as below.

### 5.3. Mechanism analysis

We further analyze the mechanism of how risk-taking affects enterprise value under extreme temperature from two dimensions, which are external supervision and internal governance. The effect of extremely high temperature is more significant, and its resulting risk-taking has a significant influence on enterprise value in the following years. Therefore, in the mechanism analysis, the interpreted variable is the Tobin Q value in the following year. According to Eq. (4), if the coefficients of the triple interaction terms are significantly positive, the factor has a value-enhancing effect, but if it is otherwise, it has a value-inhibiting effect.

## 5.4. External supervision: value-inhibiting effect

Extreme temperature affects the sentiment and risk preference of market participants. By comparison, analysts and institutional investors have higher information sharpness than ordinary investors and serve as an important external supervision mechanism. Analysts who track and launch research reports can transmit effective data of listed companies to the market and alleviate information asymmetry (Bushman & Smith, 2001; Arya & Mittendorf, 2007). Institutional investors also have a relatively stronger ability to collect and analyze information, whereas compared with non-independent institutional investors, independent institutional investors pay more attention to the sustainable development ability and long-term prospects of enterprises (Oh et al., 2011; García-Sánchez et al., 2020). However, when a company is faced with the effect of negative events, analysts and institutional investors may, under the influence of negative sentiment, significantly reduce enterprise valuations, which will affect their investment decisions, resulting in considerable fluctuations or falls in the company stock price (Lang et al., 2004).

This study examines the mechanism of external supervision by selecting three indicators—analysts' attention, research reports' attention, and independent institutional investors' shareholding ratio. Table 10 presents the results. Columns 1–3 are based on Eq. (4), and the three variables are treated as triple interaction items. The estimation coefficients are significantly negative, indicating that under the pressure of analyst tracking, in-depth interpretation of research reports, and supervision of independent institutional investors, extreme temperature increases risk-taking, thereby reducing enterprise value. Thus, for enterprises facing extreme temperature risk, analysts and independent institutional investors play the role of external supervision, which has an inhibitory effect on enterprise value. This finding is similar to those of previous studies. Makridis (2018) found that investors are more likely to be

Table 10

The influence of risk-taking on enterprise value under extreme temperature: mechanism analysis.

	(1)	(2)	(3)	(4)	(5) (att_2 =1) & (env>0)	(6) (att_2 =1) & (env<0)	(7)	(8)
	lead_lntq	lead_lntq	lead_lntq	lead_lntq	lead_lntq	lead_lntq	lead_lntq	lead_lntq
T_bin1RT	-0.00008 (-0.225)	-0.00023 (-0.654)	-0.00184 (-2.99)* **	0.00098 (0.970)	-0.00127 (-1.332)	-0.00152 (-1.92)*	0.00309 (2.338)* *	0.00010 (0.374)
T_bin11RT	0.00337 (1.511)	0.00342 (1.697)	0.00048 (0.091)	-0.00171 (-0.980)	0.03237 (2.583)* *	-0.01015 (-2.99)* **	0.04021 (2.198)* *	-0.00444 (-1.908)*
T_bin1RTanaatt	-0.00003 (-1.019)							
T_bin11RTanaatt	-0.00080 (-6.18)* **							
T_bin1RTrepatt		-0.00000 (-0.224)						
T_bin11RTrepatt		-0.00027 (-4.35)* **						
T_bin1RTindpins			0.00001 (0.236)					
T_bin11RTindpins			-0.00070 (-2.025)*					
T_bin1RTenv				0.00000 (0.073)				
T_bin11RTenv				0.00038 (1.733)*				
T_bin1RTage							-0.00006 (-2.43)* *	
T_bin11RTage							-0.00087 (-2.26)* *	
T_bin1RTgdr								0.00089 (0.248)
T_bin11RTgdr								0.02461 (1.688)*
Weather	Y	Y	Y	Y	Y	Y	Y	Y
Year_FE	Y	Y	Y	Y	Y	Y	Y	Y
Enterprise_FE	Y	Y	Y	Y	Y	Y	Y	Y
Indyr_FE	Y	Y	Y	Y	Y	Y	Y	Y
Cluster	Prov	Prov	Prov	Prov	Prov	Prov	Prov	Prov
N	10952	11076	2666	10547	1827	3775	15694	14021
r2_a	0.674	0.675	0.708	0.683	0.735	0.711	0.603	0.629

t statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

pessimistic in extreme weather, which affects capital asset pricing and increases non-fundamental risks in capital markets at extreme temperatures below 15°F and above 85°F, which is approximately equal to below  $-9^{\circ}\text{C}$  and above  $30^{\circ}\text{C}$ .

#### 5.4.1. Internal governance: value-enhancing effect

5.4.1.1. *Climate responsibility score.* Using Eq. (4), we form a triple interactive term based on the enterprise environmental responsibility score, which is the proxy variable for climate responsibility performance. Column 4 of Table 10 presents the result, which is as expected. The coefficient is significantly positive, and better climate responsibility performance has a value-enhancing effect on risk-taking at extreme temperatures.

Furthermore, this study examines whether better enterprise climate responsibility performance alleviates the negative assessment of enterprise valuations by market participants in extreme weather. A sub-sample test is carried out, and Columns 5–6 present the results. First, according to the median of analysts' attention, the samples are divided into two groups—enterprises with high and low attention. Then, according to the distribution of enterprise environmental responsibility score, taking the 0 value as the dividing line, enterprises are divided into those with good and poor climate responsibility performance. The results reveal that among enterprises that receive greater attention from analysts, those with poor climate responsibility performance are affected by the value-inhibiting effect of risk-taking. Moreover, the good climate responsibility performance of enterprises has a positive effect on market value through increased risk-taking. A possible reason for this result is that for the latter group, analysts are less biased by pessimism, which is conducive to the reasonable pricing of listed companies. Therefore, increasing climate risk awareness and governance is an effective means for listed companies to maintain or even improve their market performance under extreme temperature shocks.

5.4.1.2. *Personal characteristics of executives.* Enterprise decision-making is fundamentally influenced by the individual traits of the executive team (Chatterjee & Hambrick, 2007; Quigley et al., 2019). The personal characteristics of executives, such as age and gender, affect enterprises' performance and social responsibility behavior. For example, the age of senior executives affects their empirical cognition and values and thus influences enterprise decision-making, whereas that of managers affects their morality and values and thus influences their judgment on the performance of social responsibility (Cucari et al., 2018). The gender of senior managers influences their attention to corporate social responsibility (CSR), which may lead to differences in actual performance (Elmagrhi et al., 2019; McGuinness, Vieito, & Wang, 2017).

Therefore, this study examines the moderating effect of the age and gender of the executive team on an enterprise's risk-taking and value under extreme temperatures. The coefficients of the triple interaction terms are tested using Eq. (4); the results are presented in Columns 7–8 of Table 10. In extremely low and high temperatures, a younger senior management team can help enterprises enhance market value through risk-taking. A possible reason for this is that young executives are more risk-seeking and innovative, have greater learning and resilience, and are more likely to add value to the enterprise (Bantel & Jackson, 1989; Serfling, 2014). In addition, younger executive teams also pay more attention to climate and environmental issues and even shareholder concerns (Elmagrhi et al., 2019; Katmon et al., 2019; Giannarakis et al., 2020). This attention also increases the value-enhancing effect of risk-taking when enterprises face extreme weather risks.

A higher proportion of women in executive teams can help reduce the negative impact of enterprise risk-taking on enterprise value at extreme temperatures. The possible reasons for this are that women are more empathetic and empathic than men, and the presence of women in executive teams enables companies to increase the awareness of their relationships with their environment. In addition, women are better at CSR (Boulouta, 2013; McGuinness et al., 2017), which helps companies improve their ability to cope with extreme weather and increase their market value through risk-taking.

## 6. Conclusions and policy implications

### 6.1. Conclusions

This study collates the daily average temperature data of 243 prefecture-level cities in China from 2000 to 2019, constructs a temperature interval variable with a length of  $6^{\circ}\text{C}$ , and matches this with the enterprise risk-taking level expressed by profit fluctuation. We use this firm-level panel to assess the causal effect of extreme temperature on enterprise risk-taking, and enrich the research on the influence of the uncertainty of the environment on the risk-taking of enterprises. Our results suggest that extreme temperature shock increases the earnings volatility of listed manufacturing enterprises, that is, the level of risk-taking significantly increases, and the effect of extremely high temperature is stronger than that of extremely low temperature, the former is about 10 times that of the latter. This finding suggests that industrial firms in China may be more vulnerable to extreme heat, which is consistent with the reality that extremely high temperature has a greater impact on manufacturing production time and productivity, as well as a more direct impact on climate risk perception. The results are insensitive to how temperature variables are constructed.

We further explore the value effect and mechanisms of extreme temperature on risk-taking of listed manufacturing enterprises, and find that in the value influence mechanism of risk-taking in extreme temperature, internal governance has a value-enhancing effect, whereas external supervision has a value-inhibiting effect. This finding expands the channels through which extreme weather affects asset values. At the same time, this negative impact also illustrates the impact of climate risk on capital markets.

This paper also finds that, for enterprises with small risk-taking endowments, extreme temperature shocks awaken their awareness of climate hazards, encourage them to take risks, and turn such events into opportunities to enhance value. However, enterprises with

large risk-taking endowments may suffer a double blow on their risk activities and market value. This heterogeneity proves that the risk endowment effect is an important mechanism of extreme temperature affecting enterprise risk-taking, and also shows the importance of comprehensive consideration of climate risk in the risk management system.

## 6.2. Policy implications

In determining the influence of extreme temperature on enterprises' risk-taking and market value, this study provides empirical evidence on the impact of extreme temperature on China's capital market from the perspective of risk-taking. The findings have the following policy implications.

First, listed companies should improve their climate resilience and manage climate-related risks. In particular, they should be aware that extremely high temperature has a greater impact, and this impact will be more prominent due to the increase in the frequency and intensity of it predicted by scientific research. Enterprises should raise awareness of climate risks and the increase in the concerns for such issues, and implement a strong governance structure to clarify the responsibility and oversight of the board of directors on the risks and opportunities of climate change, such as choosing younger or female executives. It is also important to proactively disclose climate and environmental information to shareholders and stakeholders, including risks and actions taken, which is the most direct way to communicate climate concerns to the public.

Second, the rationality of the risk-taking level should be a more critical factor in the risk management of listed companies. Enterprises with insufficient risk-taking should be aware of the advantages of risk endowment during the green transition period of economic development, and actively carry out investment, innovation, and other risk activities that are conducive to dealing with climate change and extreme weather shocks. Thus, they may achieve a win-win situation of fulfilling climate and environmental responsibilities and enhancing enterprise value by increasing risk-taking in this regard. Those with excessive risk-taking must focus on controlling risk levels to prevent extreme weather from reducing their market performance.

Third, market participants, especially analysts and institutional investors, can play a better role in the external supervision of enterprise risk management and pay more attention to extreme weather and enterprise-related risk exposure. Moreover, greater attention should be paid to the substantial effect of enterprise risk-taking on value-enhancing activities, such as R&D and innovation, and accurately assess the climate and extreme weather risks and market value of enterprises, avoid bias in corporate valuation due to the negative emotional magnification effect of extreme weather.

Finally, the climate information disclosure system must be strengthened for China's capital market. Supervisors can encourage their enterprises to publish information, such as the impact of climate change and the measures they have taken to address such concerns. Under the framework of the Task Force on Climate-Related Financial Disclosures, enterprises should better identify, assess, and manage climate change-related risks and opportunities. The ESG criteria of listed companies can be improved as a guide to enhance enterprise internal governance to better fulfill climate and environmental responsibilities and thus further create a conducive atmosphere for responsible investment.

The research in this paper still leaves some limitations for future improvement. Due to the lack of data and the scope of this paper, it is difficult for us to analyze the impact of extreme temperature on risk-taking from the two aspects of physics and transformation in the theoretical mechanism. In addition, given that extreme weather events are mixed with multiple disasters, although we have controlled the effects of precipitation, humidity and air pressure, we can not eliminate the mixed effects of other extreme weather disasters. However, it is because the losses of natural disasters are usually more magnified, it is of great significance to study them for risk-taking. If there is a better development of data availability, the above issues are worth further studying in the future.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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