Journal of International Money and Finance 149 (2024) 103198

Contents lists available at ScienceDirect

Journal of International Money and Finance

journal homepage: www.elsevier.com/locate/jimf

Green vs. brown: Climate risk showdown – who's thriving, who's diving?

Dongyang Zhang [a], Dingchuan Bai [a], Yizhi Wang [b,*]

[a] School of Economics, Capital University of Economics and Business, Beijing 100070, China
[b] Cardiff Business School, Cardiff University, Aberconway Building, Cardiff CF10 3EU, United Kingdom

ARTICLE INFO

Keywords:
Climate risk
Green firms
Brown firms
Cash flow

ABSTRACT

Increasingly complex climate change poses unprecedented risks and challenges. We attempt to analyze the strategic responses of firms in dealing with climate risk and whether green firms outperform brown firms by exploring the relationship between climate risk and firms' cash flow. To this end, this paper uses the high-dimensional fixed-effects model for empirical analysis based on panel data of Chinese listed firms from Q1 2010 to Q4 2022. We find that firms have the motivation to hold more cash in the face of climate risk, and that brown firms will be more proactive in cash flow management compared to green firms. In addition, there are significant industry and seasonal effects of climate risk on firms' cash flow. Mechanism tests find that climate risk prompts firms to increase cash flow by forcing them to reduce financial leverage and erode operating costs, as well as by inducing increased media attention to the firm. Heterogeneity analysis shows that the positive effect of climate risk on cash flow is more significant among low digital transformation firms, high financial constraints firms, firms with low managerial myopia, and SOEs. An analysis of the economic consequences shows that climate risk leads firms to be more aggressive in capturing market share, increasing productivity and strengthening ESG performance. The above findings help to enlighten firms on how to manage their risk exposures and adjust their internal governance structures as a way to maintain stable operations in an environment of intensified uncertainty. In brief, this paper highlights the differentiated financial decisions that green and brown firms make in response to climate risk, providing empirical evidence and policy implications for advancing the green transformation of firms.

1. Introduction

Climate change is seen as one of the toughest tests of global economic development. The Paris Agreement, adopted by the United Nations at the Paris Climate Change Conference on December 12, 2015, is the current international consensus on global climate governance. Through this agreement, governments commit themselves to working together with the goal of limiting the increase in global average temperature to 2 °C in the 21st century. This is despite the fact that various countries and regions have taken a series of policy measures to mitigate the potential harms of climate change, for example, China, as the world's leading economy, has put forward the strategic goals of achieving carbon peak and carbon neutrality by 2030 and 2060, respectively. However, there is still some disagreement and controversy about the urgency of climate change and specific strategies to address climate risk (Ardia et al., 2023).

* Corresponding author.
E-mail addresses: zhangdongyang@cueb.edu.cn (D. Zhang), 12023030026@cueb.edu.cn (D. Bai), wangy510@cardiff.ac.uk (Y. Wang).

https://doi.org/10.1016/j.jimonfin.2024.103198

Available online 24 September 2024
0261-5606/© 2024 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Especially since 2020, "green" and "development" have begun to run counter to each other as a result of the continuing impact of the epidemic coupled with the downward pressure on the economy (Zhang et al., 2024). The choice between growth or transformation in the post-pandemic era is caught in a dilemma against the backdrop of the growing complexity and uncertainty of climate change. Therefore, the governance style and selective preferences of firms, as micro-entities that promote high-quality economic development (Li et al., 2023; Chen et al., 2024; Zhang et al., 2024), in their response to climate risk are particularly important.

The existing literature has demonstrated the dampening effect of climate risk on business activities, including negative impacts on revenue (Pankratz et al., 2023), financing costs (Huynh et al., 2020), and total factor productivity (Zhang et al., 2018). However, there has been little scholarly discussion on the financial decisions that firms will take to manage and mitigate climate risk. Pástor et al. (2021) present a theoretical framework that predicts that green firms outperform brown firms when climate risk is elevated. Ardia et al. (2023) empirically test the theory by demonstrating that financial institutions and investors have a stronger preference for green firms when firms are exposed to climate risk, which results in higher returns for green firms than for brown firms. In addition, Pástor et al. (2021) argue that firms' cash flow expectations are the main source of investor confidence. To this end, this paper uses firms' cash reserves as an entry point to analyze whether firms manage their cash flow to cater to investors as well as to protect against climate risk? Are the response mechanisms of green firms to be superior to those of brown firms? Exploring these issues in depth can help seek deterministic behaviors and preferences of firms from uncertainty, and is also of great significance to guide firms to actively respond to climate change and thus promote green transformation.

Based on this, this paper examines the extent to which climate risk affects firms' cash flow and the differentiated strategies of green firms and brown firms in dealing with climate risk, using panel data of Chinese listed firms from Q1 2010 to Q4 2022. We find that firms have an incentive to hold more cash in the face of climate risk in order to maintain sound day-to-day operations. Green firms are better able to cope with risk than brown firms. In other words, brown firms will be more proactive in cash flow management. After utilizing a series of robustness tests, such as propensity score matching (PSM), instrumental variable method, alternative variable index and sample elimination, the conclusion is still valid. In addition, climate risk has strong industry and seasonal effects on firms' cash flow. The regression coefficients are higher for brown firms compared to green firms in most industries, and the willingness of firms to hold cash in response to climate risk rises gradually from the first to the fourth quarter. In the mechanism analysis, climate risk can induce firms to reduce financial leverage and operating costs as well as inducing increased media attention to the firm, thus allowing firms to increase cash flow to maintain operational stability. Further, we find that the positive effect of climate risk on cash flow is more significant among low digital transformation firms, high financial constraints firms, firms with low managerial myopia, and SOEs. Finally, this paper explores the possible economic consequences of climate risk and finds that firms are more proactive in enhancing their market competitiveness in the face of climate risk, in terms of capturing market share, increasing productivity and strengthening ESG performance.

By answering how climate risk triggers firms' cash flow anomalies, the differentiated strategic decisions of green versus brown firms, and the possible risk linkage mechanisms between parent firms and subsidiaries, this paper attempts to make research contributions to the existing body of knowledge in the following three areas.

First, the current mainstream literature on climate risk at home and abroad focuses on its induced environmental consequences (Short and Neckles, 1999; D'amato and Cecchi, 2008), health problems (McMichael and Haines, 1997; Haines and Patz, 2004), and economic losses (Tol, 2009; Huang et al., 2020; Kotz et al., 2024), among others. Some scholars have attempted to introduce climate risk into the field of micro-individual studies to explore how climate risk affects the behaviors of firms, households, or individuals (Zhang et al., 2018; Sinha et al., 2018; Desbordes and Eberhardt, 2024). On this basis, this paper expands the research perspective to the strategic decision-making of micro subjects when coping with climate risk, and analyzes the impact mechanism of climate risk on firms' cash flow from the dual dimensions of theory and empirical evidence. This underpins how firms can build effective risk control systems in an environment of heightened uncertainty and fills the literature on the factors influencing climate risk.

Second, while scholars have begun to discuss the financial decisions that firms make when responding to climate risk (Engle et al., 2020; Ginglinger and Moreau, 2023), these studies do not go further to analyze the differentiated behaviors of green versus brown firms. Ardia et al. (2023) classify U.S. firms into green and brown firms based on carbon intensity. However, due to the limited access to carbon emission data for Chinese firms (Ma et al., 2023a), this paper utilizes the environmental scores in the quarterly CSI ESG Index for classification. By assessing the ability of green and brown firms to cope with climate risk, we can more effectively identify the sustainability performance of firms in the context of increased risk volatility. Green firms will generally have a higher social responsibility profile relative to brown firms, helping to gain a competitive advantage in the marketplace and thus reducing potential losses when exposed to risk. In this regard, this paper conveys a key message to firms' managers in emerging market countries similar to China, that "greening" is an important factor for firms to manage their risk exposures. At the same time, this paper will also help the government to formulate more precise and efficient policy measures to promote the sound growth of green firms and the green transformation of brown firms.

Third, the existing literature has not paid sufficient attention to the study of the transfer mechanism between parent firms and subsidiaries, and most of the studies have only superficially explored the transmission mechanism of the firms (Chen et al., 2024; Lai et al., 2024). To this end, in exploring the mechanisms by which climate risk acts on firms' cash flow, we examine whether the mechanisms in question trigger linkage effects of sub-parent firms. The research in this paper finds that the parent firms of brown firms tend to take on higher financial leverage and will have more sophisticated cost response mechanisms relative to their subsidiaries. This finding not only emphasizes the importance of decentralization for firms' risk management, but also provides new ideas to the literature on the characteristics of firms' internal governance structures.

The rest of our research is designed as follows. Section 2 gives the theoretical analysis and presents the research hypotheses. Section 3 describes the research design of the paper, giving the econometric model, variable selection, and the treatment and description of the sample data. Section 4 provides the results of the empirical analysis of the paper, including results from benchmark regressions, industry effects, and seasonal effects. Section 5 and Section 6 show the regression results of mechanism analysis and heterogeneity analysis, respectively. Section 7 gives the results of the robustness tests. Section 8 analyzes the economic consequences of climate risk. Finally, we give the conclusion and implications of this paper in Section 9.

2. Theoretical analysis and research hypotheses

2.1. Climate risk and firms' cash flow

Uncertainties such as extreme weather events, natural disasters, and ecosystem damage caused by climate change are the main causes of climate risk. The main form of climate risk is dominated by physical risk, but it is not limited to this and also covers aspects such as policy risk. Physical risk is typically the combined effects of interacting physical processes at multiple spatial and temporal scales (Zscheischler et al., 2018), which can trigger chemical pollution (Noyes et al., 2009), species extinction (Zandalinas et al., 2021), sea level rise (Haines and Patz, 2004), and frequent storm surges (Takayabu et al., 2015), among other environmental events. Relatively speaking, the risk of policy volatility, represented by climate policy uncertainty, has more important economic effects. Ren et al. (2022) find that climate policy risk will significantly reduce the total factor productivity of firms, and the impact on low-productivity firms is greater than that on high-productivity firms.

Cash is regarded as a relatively stable and low-risk asset, which is the "blood" of firms' production and operation activities, and plays a vital role in the healthy development of the firms. In addition, cash flow expectations are one of the important criteria for institutional investors to judge stock selection (Pástor et al., 2021). Real options theory states that firms have the flexibility to adjust their investment decisions to maximize the potential value of options in an uncertain environment (Kellogg, 2014). For this reason, firms may choose to reduce the uncertainty associated with climate risk by reducing investment activity and increasing the level of cash holdings as a way of restoring investor confidence. According to the above discussions, we derive our first hypothesis.

H1. Climate risk can force firms to increase cash flow to maintain day-to-day operations.

2.2. Green versus brown firms

The differences between green and brown firms are mainly in their business philosophy and production processes. From the perspective of business philosophy, green firms are centered on sustainable development, focusing on the balance of environmental protection, social responsibility and economic benefits. Their goal is to make profits without harming the environment and to promote long-term social and economic development. Brown firms, on the other hand, follow the traditional business model, focusing more on short-term economic benefits and neglecting environmental protection and social responsibility. In terms of the production process, green firms will proactively adopt cleaner production technologies to optimize the use of resources and reduce waste and emissions. Brown firms rely on high energy consumption and pollution-intensive production techniques with less regard for environmental impacts. Globally, green firms are gaining more importance with the continuous pursuit of low-carbon economy and sustainable development. However, brown firms are actively advocated to undergo a green transition in order to reduce their burden on the environment.

Rising climate risk could trigger a series of knock-on effects such as reduced business profitability, increased operational risk and production disruptions. Given the unique attributes of brown firms, they are often under more severe transformational pressures to address climate risk. In addition, existing literature demonstrates that sustainable investors raise the cost of capital for brown firms relative to green firms (Chava, 2014; Hartzmark and Shue, 2022). This has led to a stronger investment preference for green firms among financial institutions and investors in the context of heightened uncertainty in the climate environment (Ardia et al., 2023), allowing green firms to demonstrate greater resilience and adaptability even in the face of climate risk without the need for additional implementation of complex risk control measures. On the contrary, due to the lack of investment, brown firms may need to carry out corresponding cash flow management to meet their liquidity needs. Based on these arguments, we propose the second hypothesis.

H2. Green firms outperform brown firms in responding to climate risk, i.e., the impact of climate risk on cash flow of brown firms is more significant compared to green firms.

3. Research design

3.1. Model specification

In order to validate the above research hypotheses, this paper examines the impact of climate risk on firms' cash flow and the differentiated financial decisions made by green and brown firms in response to climate risk by employing a high-dimensional fixed-effects model. The specific model setup is as follows:

$$Cashflow_{it} = \alpha_0 + \alpha_1 CPU_{it} + \beta X_{it} + \lambda_{ind} + \mu_t + \lambda_{ind}{}^*\mu_t + \varepsilon_{it} \tag{1}$$

where $Cashflow_{it}$ represents the cash flow of firm i in period t; CPU_{it} represents the climate risk faced by firm i in period t; X_{it} is a series of firm-level control variables, including firm size, return on equity, Tobin's Q, operating income growth rate, and shareholding of the largest shareholder; λ_{ind} denotes industry fixed effects; μ_t denotes time fixed effects; $\lambda_{ind}{}^*\mu_t$ denotes industry-time fixed effects, which capture trends in industry heterogeneity over time; ε_{it} is the random error term. In order to mitigate possible problems such as autocorrelation and heteroskedasticity, the standard errors of the regression coefficients in the model are clustered at firm level in this paper.

3.2. Variables selection

3.2.1. Outcome variables

Considering that operating income is the most important source of cash flow from operating activities, this paper adopts "cash inflow from operating activities / operating income" to measure firms cash flow. According to the hierarchy theory (Myers and Majluf, 1984), firms tend to finance themselves from internally generated resources rather than resorting to the market. In this case, firms with large cash flow will maintain higher levels of cash (García-Teruel et al., 2009). Therefore, this paper expects that firms with larger cash flow indicator will hold more cash. In addition, this indicator can directly reflect the gap between the cash received and the revenue recognized by the enterprise, which helps stakeholders to understand the cash flow status of the enterprise, and also helps to identify the credit risk and liquidity risk that the enterprise may have in the sales process. The cash flow indicator is from the CSMAR database.

3.2.2. Explanatory variables

In recent years, policy uncertainty has become an important research field (Baker et al., 2016). Firms' investment and financing maturity mismatches caused by confinement to external policy uncertainty can amplify firms' financial risks. With the increasing severity of the global climate change problem, firms are becoming more and more sensitive to climate policies. However, most current scholars measure climate policy uncertainty indices at the national level, which are not locally representative (Gavriilidis, 2021; Lee and Cho, 2023). To this end, we aim to validate more precisely how climate policy risks affect corporate strategies by looking at them at the city level.

In this paper, we choose the climate policy uncertainty index calculated by Ma et al. (2023b) to measure the climate risk of prefecture-level cities in China. Following the principles of Baker et al. (2016), they comprehensively construct climate policy uncertainty indices at different levels of China's country, provinces, and cities based on 1,755,826 articles in six mainstream Chinese newspapers from 2000 to 2022, combined with artificial auditing and the MacBERT model. Since the index provides monthly data, we average the climate risk index for the three months of each quarter to represent the CPU of that quarter. Then, by matching the CPU data of prefecture-level cities to firms, we finally obtain the quarterly CPU index of firms.

3.2.3. Control variables

We make the model setting more accurate by controlling for relevant firm economic characteristic variables. Firm size (Size) is expressed as the natural logarithm of the firm's current total assets; return on equity (Roe) is expressed as "net profit / average balance of shareholders' equity"; Tobin's Q (TobinQ) is calculated by "(market capitalization of outstanding shares + number of shares of non-outstanding shares × net assets per share + book value of liabilities) / total assets"; growth rate of operating income (Growth) is calculated as "operating revenue of the current quarter / operating revenue of the previous quarter − 1"; shareholding ratio of the largest shareholder (Top1) is expressed as "number of shares held by the largest shareholder / total number of shares". Control variables data are obtained from the CSMAR database.

3.3. Data preprocessing and summary statistics

This paper selects the panel data of Chinese listed firms from Q1 2010 to Q4 2022 as the research sample. This time span covers a number of climate events with major international impact, such as the 2012 Doha UN Climate Change Conference and the signing of the Paris Agreement. At the same time, China has experienced various climate events during this period, including extreme heat, drought, heavy rainfall, typhoons and cold waves. As a result, data from this period not only adequately reflect the impacts of climate change on firms and the economy, but also have the timeliness to capture the latest trends in climate risk. Further, listed firms play a crucial role as leaders in various industries. They are not only the engines of economic growth, but also the promoters of technological innovation and industrial upgrading. The size and influence of listed firms make them pivotal in the economic system, and their business strategies, risk control and responses to challenges will largely affect the direction of the industry and the job market. Therefore, the study and analysis of these firms are of great significance in understanding the economic development trend and formulating relevant policies. In addition, listed firms are required to disclose financial reports and related business information on a regular basis in order to meet regulatory requirements, which provides investors, researchers and regulators with the conditions to assess their climate risk exposures and management more accurately. Consequently, the selection of listed firms as the research sample is justified. Compared to cross-sectional and time-series data, our choice of panel data structure allows us to better control for individual heterogeneity and time trends, and helps to understand the dynamic process of policy uncertainty over time.

Before conducting the empirical analysis, we clean the data with a view to obtaining a qualified sample. First, we exclude incorrect values that violate accounting principles or that have been recorded incorrectly, such as negative or zero assets and fixed assets that are greater than total assets. Second, we eliminate the influence of outliers on regression results by winsorizing the upper and lower 0.5 percentiles of the distribution of variables included in the regressions.

After imposing the above restrictions, we obtained the cleaned sample. Table 1 Panel A reports the descriptive statistics of the variables, including the observations, mean, standard deviation, minimum, maximum, skewness and kurtosis for each variable. As can be seen from the table, the mean value of the cash flow indicator is 1.014, and the minimum and maximum values are 0.275 and 4.028, respectively, indicating that there are obvious fluctuations in the firms' cash flow. The standard deviation of the climate risk indicator is 0.590, ranging from 0 to 5.230, with the skewness and kurtosis of 0.750 and 5.111, respectively, indicating significant heterogeneity in the climate risk faced by firms. In addition, the description results of the remaining variables also show that these indicators exhibit obvious distributional heterogeneity among firms. Table 1 Panel B reports the results of the mean T-test for each variable in green and brown firms. From this table, there are significant differences in the mean values of all variables for green firms relative to brown firms. This provides a basis to further analyze the differential strategies of green and brown firms when facing climate risk.

4. Empirical analysis

4.1. Linear relationship test

Whether there is a linear or non-linear relationship between the variables needs to be considered before conducting empirical tests, otherwise the model setting and estimation results may be biased. To this end, we first validate the relationship between climate risk and firms' cash flow using binned scatterplots. In contrast to statistical tests, it provide a nonparametric estimation way to visualize linear and nonlinear relationships between variables without pre-assuming a specific link between variables.

Fig. 1 (a) presents a binned scatterplot of the fitted relationship between climate risk and firms' cash flow for the overall sample. As can be seen from the figure, there is a positive correlation between climate risk and firms' cash flow, i.e., as climate risk increases, firms' cash flow increases. In addition, this paper utilizes the median environmental score from the quarterly CSI ESG index as a benchmark to classify green and brown firms, with firms scoring above the 0.5 percentile defined as green firms and brown firms otherwise. Fig. 1 (b) shows the relationship between climate risk and cash flow of green firms, and Fig. 1 (c) gives the relationship between climate risk and cash flow of brown firms. As shown in the figure, the positive relationship between climate risk and cash flow is stronger in brown firms, while the correlation between climate risk and cash flow is not obvious in green firms.

4.2. Benchmark regression

Based on Model (1), Table 2 reports the results of the benchmark regression of climate risk on firms' cash flow for the overall sample, where Column (1) controls for industry fixed effects only. The results show a significant positive correlation between climate risk and firms' cash flow, indicating that higher climate risk is associated with higher firms' cash flow. Columns (2) and (3) incorporate time fixed effects and industry-time fixed effects on the basis of Column (1), respectively. It can be seen from the table that neither the coefficients nor the significance of CPU have changed significantly. According to the R-squared values, we take the estimates in Column (3) as a benchmark. The regression coefficient of climate risk is 0.014, which is significant at 1 % level. This suggests that climate risk significantly enhances firms' cash flow, which is consistent with the expectation of H1. This can be attributed to the increase in extreme weather events leading to higher climate risk, making firms more risky in their day-to-day operations. Firms respond to climate risk by proactively managing their cash flow and increasing their liquidity as a way to ensure sound operations (Huang et al., 2018).

Table 3 presents the regression results of climate risk on cash flow of green versus brown firms. There is no significant relationship between climate risk and cash flow in green firms, while climate risk has a significant positive effect on cash flow in brown firms. This validates H2. This suggests that brown firms are more motivated to increase their cash flow in response to the negative impacts of

Table 1
Descriptive statistics.

Panel A: Overall sample							
Variable	Obs.	Mean	Std.dev.	Min.	Max.	Skew.	Kurt.
Cashflow	144,997	1.014	0.316	0.275	4.028	2.796	20.117
CPU	134,640	1.138	0.590	0	5.230	0.750	5.111
Size	146,958	22.139	1.332	18.932	26.832	0.741	3.528
Roe	146,003	0.0420	0.072	−0.473	0.360	−0.973	11.301
TobinQ	140,836	2.000	1.186	0.868	8.886	2.356	9.882
Growth	144,551	0.133	0.537	−0.848	4.448	2.761	16.096
Top1	149,386	33.622	14.242	8.437	74.401	0.502	2.555

Panel B: Green vs. Brown					
Variable	Green firms		Brown firms		Mean T-test
	Obs.	Mean	Obs.	Mean	Green − Brown
Cashflow	76,215	1.008	68,782	1.020	−6.740***
CPU	70,830	1.134	63,810	1.142	−2.263**
Size	77,438	22.347	69,520	21.907	64.166***
Roe	77,466	0.045	68,537	0.039	15.193***
TobinQ	74,379	1.875	66,457	2.140	−42.155***
Growth	76,276	0.126	68,275	0.140	−4.886***
Top1	79,324	33.870	70,062	33.342	7.153***

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

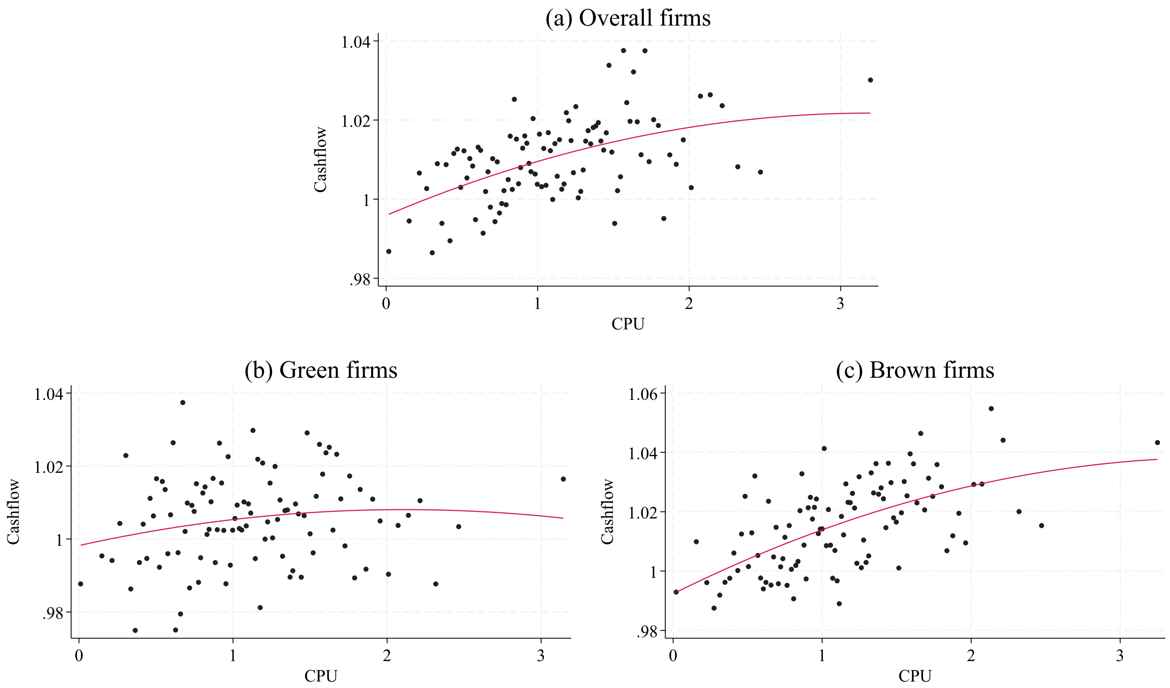

Fig. 1. Binned scatterplot of the fitted relationship between climate risk and firms' cash flow.

Table 2
Benchmark regression results.

Variables	Cashflow		
	(1)	(2)	(3)
CPU	0.009***	0.013***	0.014***
	(0.003)	(0.004)	(0.004)
Constant	0.868***	0.898***	0.888***
	(0.049)	(0.051)	(0.051)
Controls	YES	YES	YES
Industry fixed effects	YES	YES	YES
Time fixed effects	NO	YES	YES
Industry-time fixed effects	NO	NO	YES
Observations	117,356	117,356	117,086
R-squared	0.102	0.107	0.151

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The standard errors are clustered at firm level.

Table 3
Benchmark regression results of green vs. brown firms.

Variables	Cashflow					
	(1)	(2)	(3)	(4)	(5)	(6)
	Green			Brown		
CPU	0.003	0.007	0.007	0.015***	0.018***	0.019***
	(0.004)	(0.005)	(0.005)	(0.004)	(0.005)	(0.005)
Constant	0.783***	0.804***	0.783***	0.984***	1.028***	1.032***
	(0.059)	(0.061)	(0.061)	(0.066)	(0.070)	(0.071)
Controls	YES	YES	YES	YES	YES	YES
Industry fixed effects	YES	YES	YES	YES	YES	YES
Time fixed effects	NO	YES	YES	NO	YES	YES
Industry-time fixed effects	NO	NO	YES	NO	NO	YES
Observations	60,178	60,178	59,834	57,177	57,177	56,755
R-squared	0.116	0.120	0.181	0.093	0.101	0.160

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The standard errors are clustered at firm level.

climate change when facing with high climate risk. In contrast, such motivations are less pronounced for green firms. This may be due to the fact that green firms will generally have a lower cost of capital than brown firms, as well as the fact that green firms have a positive net present value, which leads to a higher level of investment relative to their size than brown firms (Ardia et al., 2023). As a result, green firms are better able to cope with risk than brown firms during periods of poorer climatic conditions.

In Table 4, we report the estimation results when using alternative thresholds (the 0.4–0.6, 0.25–0.75, and 0.1–0.9 quantiles of the environmental scores in the quarterly CSI ESG Index) to define green and brown firms. In these three cases, climate risk has no significant impact on the cash flow of green firms, while the regression coefficients of CPU are significantly positive in brown firms. This is consistent with the results in Table 3, and the estimates of CPU for brown firms in Panel C (firms with environmental scores above the 0.9 quantile are defined as green firms, and those below the 0.1 quantile are defined as brown firms) are slightly larger than the estimates for brown firms under the other classification criteria. This proves that the browner firms have stronger incentives to increase their own cash flow in response to climate risk, in line with the expectations of this paper.

4.3. Industry effects

Since financial institutions and investors have selective investment preferences for certain industries (Bolton and Kacperczyk, 2021), the degree of response to climate risk may vary across industries. For this purpose, we divided the industries according to the National Economic Industry Classification and Codes (GB/4754–2011) and excluded industries with little sample. Fig. 2 illustrates the regression coefficients and their 95 % confidence intervals of CPU for overall, green and brown firms in different industries. From the figure, the regression coefficients of brown firms are larger than those of green firms in most industries, which is consistent with the previous results. Only the mining (B), electricity, heat, gas and water production and supply (D), real estate (K), rental and business services (L), and water conservancy, environment and public facilities management (N) do not show this trend. This is because the return potential of such industries is greater in scenarios of higher climate risk. Therefore, it may reverse the risk management strategies of brown firms, making their willingness to hold cash relatively low.

4.4. Seasonal effects

Firms' strategic objectives may be adjusted in different quarters, while firms may have differences in sensitivity to temperature due to their own attributes (Addoum et al., 2023). Therefore, it is necessary to explore the seasonal effects of climate risk on firms' cash flow. Fig. 3 illustrates the regression coefficients and their 95 % confidence intervals of CPU for overall, green and brown firms under

Table 4
Estimation results of alternative thresholds.

Variables	Green			Brown		
	Cashflow					
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: 0.4–0.6 quantiles						
CPU	0.002	0.006	0.007	0.014***	0.016***	0.017***
	(0.004)	(0.005)	(0.005)	(0.004)	(0.005)	(0.005)
Constant	0.733***	0.753***	0.728***	1.019***	1.074***	1.080***
	(0.064)	(0.066)	(0.067)	(0.077)	(0.081)	(0.083)
Observations	49,117	49,117	48,724	46,051	46,051	45,540
R-squared	0.118	0.122	0.183	0.088	0.097	0.159
Panel B: 0.25–0.75 quantiles						
CPU	0.001	0.004	0.004	0.016***	0.016***	0.017***
	(0.005)	(0.006)	(0.006)	(0.005)	(0.006)	(0.006)
Constant	0.741***	0.770***	0.747***	0.951***	1.009***	1.007***
	(0.075)	(0.078)	(0.080)	(0.092)	(0.098)	(0.103)
Observations	32,371	32,371	31,889	28,691	28,691	28,209
R-squared	0.111	0.116	0.192	0.087	0.097	0.179
Panel C: 0.1–0.9 quantiles						
CPU	0.002	0.005	0.005	0.021***	0.018**	0.017*
	(0.007)	(0.008)	(0.009)	(0.008)	(0.009)	(0.009)
Constant	0.642***	0.634***	0.604***	0.906***	1.013***	1.040***
	(0.004)	(0.005)	(0.005)	(0.007)	(0.007)	(0.007)
Observations	15,863	15,863	15,187	11,338	11,338	10,815
R-squared	0.099	0.105	0.208	0.088	0.103	0.258
Controls	YES	YES	YES	YES	YES	YES
Industry fixed effects	YES	YES	YES	YES	YES	YES
Time fixed effects	NO	YES	YES	NO	YES	YES
Industry-time fixed effects	NO	NO	YES	NO	NO	YES

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The standard errors are clustered at firm level.

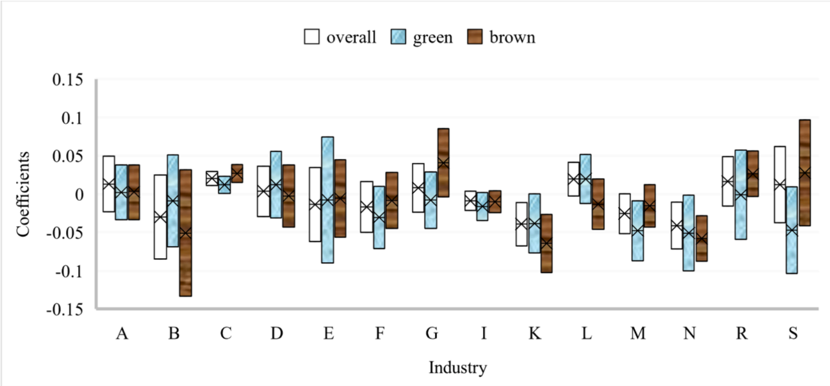

Fig. 2. Industry effects of climate risk on firms' cash flow. Note: The middle symbol of each box represents the coefficient of CPU, with the upper border representing its upper 95% confidence interval value and the lower border representing its lower 95% confidence interval value. A: Agriculture, forestry, animal husbandry and fishery; B: Mining; C: Manufacturing; D: Electricity, heat, gas and water production and supply; E: Construction; F: Wholesale and retail trade; G: Transportation, warehousing and postal services; I: Information transmission, software and information technology services; K: Real estate; L: Rental and business services; M: Scientific research and technological services; N: Water conservancy, environment and public facilities management; R: Culture, sports and recreation; S: Public administration, social security and social organizations.

four quarters. The effect of climate risk on firms' cash flow in the first quarter is not significant either among green or brown firms. On the contrary, the effect of climate risk on firms' cash flow in the fourth quarter is significantly positive in all types of samples, but the regression coefficients and significance of CPU for brown firms are higher than those of green firms. The second and third quarters are similar, with insignificant coefficients of CPU for green firms and significant positive coefficients of CPU for brown firms. In addition, the overall trend shows that firms do not have a strong desire to increase cash flow in response to climate risk in the first quarter, while firms have the highest incentive to hold cash in the fourth quarter. This is mainly due to the fact that firms will formulate the annual capital budget and capital demand plan at the beginning of the year, and the first quarter is the period when firms invest capital for equipment renewal, technological transformation or market expansion, thus holding less cash. However, at the end of the financial reporting period, such as the fourth quarter, firms hold more cash to ensure financial soundness or to guard against potential tax payment needs.

5. Mechanism analysis

The above analysis suggests that climate risk has an incentive effect on firms' cash flow, and that this effect is mainly concentrated in brown firms. However, the mechanisms between climate risk and firms' cash flow need to be further verified. To this end, this paper examines the mechanism in the following three dimensions.

5.1. Leverage mechanism

In this section, this paper analyzes the mechanism of firms' leverage. We use the asset-liability ratio as a proxy for financial leverage (Lev), specifically measured by "total liabilities / total assets". Table 5 reports the specific regression results. As shown in Panel A, climate risk pushes firms to reduce their own financial leverage, thus forcing them to increase their cash flow to maintain daily

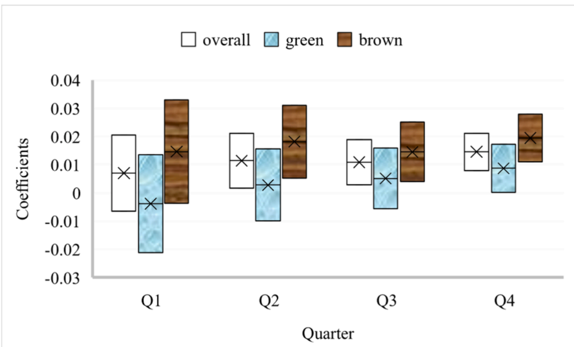

Fig. 3. Seasonal effects of climate risk on firms' cash flow. Note: The middle symbol of each box represents the coefficient of CPU, with the upper border representing its upper 95% confidence interval value and the lower border representing its lower 95% confidence interval value.

operations. This is somewhat parallel to the research of Ginglinger and Moreau (2023). This mechanism is particularly evident among brown firms, suggesting that green firms typically have stronger risk coping capabilities. In addition, we further explore whether there is an interaction between parent firms and subsidiaries in addressing climate risk. Panel B and Panel C show the regressions results of the leverage mechanism for parent firms and subsidiaries, respectively. It can be seen that subsidiaries of brown firms will reduce their financial leverage more in response to climate risk relative to their parent firms. This may be due to the fact that the parent firms of brown firms will diversify their risk through the diversified portfolio, while the subsidiaries will be assigned specific brown operations, causing them to take on higher financial leverage in pursuit of higher returns. However, it also increases the vulnerability of subsidiaries to climate risk. With the growing importance of Corporate Social Responsibility (CSR), parent firms tend to push subsidiaries to reduce financial leverage in order to demonstrate their commitment to environmental responsibility and avoid negative public relations and potential financial losses.

5.2. *Cost mechanism*

We explore the cost mechanism of climate risk in this section. In this paper, the operating cost ratio is used as a proxy for cost of a firm. Specifically, it is measured using “operating cost / operating revenue”. Table 6 reports the regression of climate risk on firms’ costs. As shown in Panel A, the regression coefficients of climate risk are significantly negative. It indicates that climate risk drives firms to reduce operating costs as a way to enhance their cash holdings. Consistent with the previous conclusions, the cost-driven effect of brown firms is greater than that of green firms. Further, this paper explores the cost response mechanism of parent firms and subsidiaries. As Panel B and Panel C show, parent firms will have more incentives to reduce costs compared to subsidiaries. This may be due to the fact that the parent firms are usually at the core of the group’s strategic decision-making, with a strong ability to integrate resources and a high level of risk-taking. As a result, they are able to actively promote cost-control measures to address climate risk from a long-term perspective. In contrast, subsidiaries are more focused on the short-term business operations and profit maximization, resulting in their lack of subjective initiative in adopting cost reduction strategies.

5.3. *Media attention mechanism*

In this section, we analyze the media attention mechanism for climate risk. In this paper, media attention (MA) is defined as online media attention. We measure MA using the natural logarithm of the total number of online media reports for each firm plus one. Table 7 reports the relevant regression results. From Column (1), climate risk has a significant positive effect on media attention. This indicates that climate risk increases media attention to firms, and that firms will engage in risk control and increase cash holdings in

Table 5
Estimation results of the leverage mechanism.

Variables	Lev		
	(1)	(2)	(3)
Panel A: Consolidated statement	Overall	Green	Brown
CPU	−0.010***	−0.005	−0.013***
	(0.003)	(0.004)	(0.004)
Constant	−1.279***	−1.219***	−1.395***
	(0.042)	(0.047)	(0.058)
Observations	117,939	60,845	56,594
R-squared	0.439	0.471	0.430
Panel B: Parent firms	Overall	Green	Brown
CPU	−0.006	−0.003	−0.008*
	(0.004)	(0.005)	(0.005)
Constant	−0.813***	−0.803***	−0.771***
	(0.056)	(0.067)	(0.074)
Observations	106,805	54,107	52,191
R-squared	0.258	0.284	0.254
Panel C: Subsidiaries	Overall	Green	Brown
CPU	−0.024*	−0.011	−0.040**
	(0.013)	(0.016)	(0.019)
Constant	−0.597***	−0.547***	−0.705***
	(0.162)	(0.200)	(0.245)
Observations	105,866	53,614	51,744
R-squared	0.038	0.062	0.056
Controls	YES	YES	YES
Industry fixed effects	YES	YES	YES
Time fixed effects	YES	YES	YES
Industry-time fixed effects	YES	YES	YES

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The standard errors are clustered at firm level.

Table 6
Estimation results of the cost mechanism.

Variables	Cost		
	(1)	(2)	(3)
Panel A: Consolidated statement	Overall	Green	Brown
CPU	−0.013***	−0.011***	−0.014***
	(0.003)	(0.003)	(0.004)
Constant	0.411***	0.462***	0.349***
	(0.038)	(0.041)	(0.055)
Observations	117,740	60,179	57,056
R-squared	0.428	0.432	0.450
Panel B: Parent firms	Overall	Green	Brown
CPU	−0.021***	−0.018***	−0.023***
	(0.004)	(0.004)	(0.005)
Constant	0.467***	0.565***	0.413***
	(0.063)	(0.073)	(0.083)
Observations	97,234	49,391	47,320
R-squared	0.292	0.301	0.308
Panel C: Subsidiaries	Overall	Green	Brown
CPU	−0.016	−0.021	−0.013
	(0.014)	(0.018)	(0.019)
Constant	−0.535**	−0.788***	−0.279
	(0.212)	(0.280)	(0.292)
Observations	94,625	48,237	45,858
R-squared	0.042	0.059	0.061
Controls	YES	YES	YES
Industry fixed effects	YES	YES	YES
Time fixed effects	YES	YES	YES
Industry-time fixed effects	YES	YES	YES

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The standard errors are clustered at firm level.

Table 7
Estimation results of the media attention mechanism.

Variables	MA		
	(1)	(2)	(3)
	Overall	Green	Brown
CPU	0.037***	0.028	0.042**
	(0.014)	(0.018)	(0.017)
Constant	−4.346***	−4.801***	−3.407***
	(0.255)	(0.318)	(0.274)
Controls	YES	YES	YES
Industry fixed effects	YES	YES	YES
Time fixed effects	YES	YES	YES
Industry-time fixed effects	YES	YES	YES
Observations	116,512	59,242	56,780
R-squared	0.427	0.469	0.408

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The standard errors are clustered at firm level.

order to enhance their public image and meet investor expectations. The regression results in Columns (2) and (3) show that the media attention mechanism exists only in brown firms. It suggests that reports of brown firms are more attractive to the media in the context of heightened climate risk. This is largely in response to growing public concern about environmental issues and the monitoring of firms' environmental performances as a means of promoting the green transformation of society and markets.

6. Heterogeneity analysis

The above analysis confirms the mechanisms by which climate risk affects firms' cash flow and the differences in the sensitivity of green and brown firms to climate risk. In this part, we explore the heterogeneity effects of firms based on the degree of digitization, financial constraints, managerial myopia, and the nature of ownership.

6.1. Heterogeneity across digital transformation

Digital transformation (DT) helps to improve the productivity and competitiveness of companies, while also contributing to their long-term sustainability. We use the frequency of digital transformation words in firms' annual reports to proxy for the degree of digital transformation. If the degree of digital transformation is above the median level, it is defined as a high digital transformation firm, otherwise it is a low digital transformation firm. Table 8 reports the heterogeneity of the impact of climate risk on firms' cash flow at different levels of digitization in overall, green and brown firms, respectively. Under the overall sample, the regression coefficients of CPU for high digital transformation firms are significantly positive, but they are smaller than those of low digital transformation firms. This is consistent with the brown firms. The coefficients of CPU for green firms are not significant in either category. It shows that as the degree of digital transformation of brown firms increases, their motivation to hold cash in response to climate risk diminish. Green firms, on the other hand, are not affected by the heterogeneity of the degree of digital transformation. This may be due to the penetrating nature of digital technology, which can break down the spatial and temporal constraints on the flow of production factors through the various sectors and reduce production costs, thus enhancing firms' ability to withstand risks (Du et al., 2023). At the same time, digital technology facilitates information sharing within the firm and with supply chain partners. Through cloud-based platforms, real-time data analytics and online collaboration tools, firms can achieve real-time monitoring of risks and increase transparency to better manage and respond to climate-related risks. In addition, digital tools help firms more accurately forecast market demand and optimize inventory management, thereby reducing the risks of raw material price fluctuations and supply disruptions caused by climate events.

6.2. Heterogeneity across financial constraints

The degree of financial constraints (FC) is one of the most important factors influencing firms' decision-making. Low financial constraints mean that firms have easy access to external financing, which supports investment and production expansion. To avoid endogenous disturbances that may arise from the use of the financial expense to debt ratio to measure financial constraints, we use the SA index as a measure of financial constraints. Hadlock and Pierce (2010) classify the types of financial constraints based on firms' financial reports, and then construct the index using only two variables, firm size and firm age, which do not change much over time and are highly exogenous. The specific construction formula is shown as follows:

$$SA = -0.737*Size + 0.043*Size^2 - 0.04*Age \tag{2}$$

where $Size$ is the firm size, Age is the listed years of the firm. The value of this index is generally negative, with larger absolute values implying stronger financial constraints. If the SA index is above the median level, it is defined as a firm with low financial constraints, otherwise it is a firm with high financial constraints.

Table 9 reports the impact of climate risk on firms' cash flow under different financial constraints. As shown in Columns (1) and (2), the coefficients and significance of CPU for firms with high financial constraints are greater than those of firms with low financial constraints. Columns (5) and (6) show that the regression results of brown firms are consistent with the overall. Columns (3) and (4) give the regression results of green firms, where the coefficients of CPU are significantly positive under high financial constraints, while they are not significant under low financial constraints. The above results suggest that financial constraints further weaken firms' risk resilience and increase their risk sensitivity. Under high financial constraints, brown firms will increase their cash reserves more significantly in response to climate risk, and even green firms will do something to cope with the crisis.

6.3. Heterogeneity across managerial myopia

Managerial myopia (MM), in which managers have a shorter decision horizon, indicates that managers are more inclined to

Table 8
Estimates of heterogeneous effect across digital transformation.

Variables	Cashflow					
	(1)	(2)	(3)	(4)	(5)	(6)
	Overall		Green		Brown	
	High DT	Low DT	High DT	Low DT	High DT	Low DT
CPU	0.012***	0.015***	0.008	0.004	0.015**	0.023***
	(0.004)	(0.005)	(0.006)	(0.007)	(0.006)	(0.007)
Constant	0.926***	0.848***	0.800***	0.758***	1.094***	0.986***
	(0.062)	(0.069)	(0.073)	(0.085)	(0.093)	(0.098)
Controls	YES	YES	YES	YES	YES	YES
Industry fixed effects	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES
Industry-time fixed effects	YES	YES	YES	YES	YES	YES
Observations	59,608	56,938	30,849	28,393	28,192	27,953
R-squared	0.154	0.183	0.183	0.225	0.183	0.189

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The standard errors are clustered at firm level.

Table 9
Estimates of heterogeneous effect across financial constraints.

Variables	Cashflow					
	(1)	(2)	(3)	(4)	(5)	(6)
	Overall		Green		Brown	
	High FC	Low FC	High FC	Low FC	High FC	Low FC
CPU	0.017***	0.011**	0.011*	0.005	0.023***	0.016**
	(0.005)	(0.005)	(0.007)	(0.007)	(0.007)	(0.006)
Constant	0.989***	0.866***	0.862***	0.795***	1.118***	0.998***
	(0.085)	(0.057)	(0.101)	(0.069)	(0.112)	(0.083)
Controls	YES	YES	YES	YES	YES	YES
Industry fixed effects	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES
Industry-time fixed effects	YES	YES	YES	YES	YES	YES
Observations	59,842	56,710	30,632	28,554	28,535	27,519
R-squared	0.158	0.179	0.194	0.227	0.185	0.185

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The standard errors are clustered at firm level.

maximize the benefits of immediate gratification as opposed to focusing on the future development of the firm (Stein, 1989). However, the act of increasing cash flow tends to make firms reduce certain investment activities in the short term, which means that short-term profits of the firm need to be sacrificed to some extent. To this end, we verify whether managerial myopia has a heterogeneous effect on firms' behavior when facing climate risk. In this paper, we calculate the word frequency of "short-term horizon" in MD&A as a proxy for managerial myopia. The larger the value of this indicator is, the more short-sighted the manager is. Based on the median of the indicator, we divide the sample into firms with high managerial myopia and firms with low managerial myopia. Table 10 reports the specific regression results. Climate risk has a significant positive effect on cash flow for firms with low managerial myopia, while firms with high managerial myopia have weaker motivations to hold cash flow in response to climate risk. This finding holds true for overall, green and brown firms. This is mainly because the consequences of climate risk may not be immediately apparent. Short-sighted managers may seek current economic returns while ignoring the costs of climate risk in the long term, such as production disruptions, loss of assets and reputational damage due to extreme climate events. In addition, with the focus on short-term financial performance, short-sighted managers may lack awareness of the severity and urgency of climate risk and therefore not prioritize climate risk response strategies in their strategic planning.

6.4. *Heterogeneity across ownership types*

In China's unique political system and business environment, the type of ownership significantly affects the production activities of firms (Zhang, 2023). For this reason, we divide the sample into two sub-samples of state-owned enterprises (SOEs) and non-state-owned enterprises (Non-SOEs), and explore the heterogeneous effects of climate risk on firms' cash flow under different ownership natures. Table 11 reports the specific regression results. The coefficients of CPU in SOEs are larger than those in Non-SOEs under the overall, green and brown samples. This is because SOEs play a central role in the country's economic and social structure and need to ensure stable operations and profitability as a means of maintaining social stability and public interest. Meanwhile, SOEs are often regarded as the "face of the nation" and are expected to be more socially responsible. They need to play an exemplary role in environmental protection and sustainable development, and respond positively to national policies and guidelines on climate change. As a result, SOEs will face multiple responsibilities and considerations when addressing climate risk. In order to achieve these goals, SOEs will tend to hold higher cash reserves as a buffer against potential climate-related risks, ensuring operational continuity and social

Table 10
Estimates of heterogeneous effect across managerial myopia.

Variables	Cashflow					
	(1)	(2)	(3)	(4)	(5)	(6)
	Overall		Green		Brown	
	High MM	Low MM	High MM	Low MM	High MM	Low MM
CPU	0.009*	0.021***	0.002	0.016**	0.014**	0.025***
	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.007)
Constant	0.931***	0.845***	0.836***	0.729***	1.082***	0.988***
	(0.063)	(0.063)	(0.075)	(0.079)	(0.092)	(0.090)
Controls	YES	YES	YES	YES	YES	YES
Industry fixed effects	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES
Industry-time fixed effects	YES	YES	YES	YES	YES	YES
Observations	66,169	50,456	33,627	25,596	31,865	24,188
R-squared	0.160	0.176	0.200	0.213	0.177	0.196

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The standard errors are clustered at firm level.

Table 11
Estimates of heterogeneous effect across ownership types.

Variables	Cashflow					
	(1)	(2)	(3)	(4)	(5)	(6)
	Overall		Green		Brown	
	SOEs	Non-SOEs	SOEs	Non-SOEs	SOEs	Non-SOEs
CPU	0.020***	0.012***	0.019**	0.006	0.019**	0.017***
	(0.007)	(0.005)	(0.009)	(0.006)	(0.009)	(0.006)
Constant	0.715***	0.880***	0.661***	0.785***	0.780***	1.022***
	(0.102)	(0.068)	(0.120)	(0.083)	(0.138)	(0.092)
Controls	YES	YES	YES	YES	YES	YES
Industry fixed effects	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES
Industry-time fixed effects	YES	YES	YES	YES	YES	YES
Observations	37,066	79,469	19,063	40,060	17,449	38,710
R-squared	0.200	0.155	0.223	0.198	0.246	0.165

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The standard errors are clustered at firm level.

responsibility during turbulent times.

7. Robustness tests

To verify the reliability of the research design and empirical results in more depth, we implemented a series of robustness tests.

7.1. Difference-in-differences (DID) method

We use the median of climate risk indicator as the grouping criterion to divide the sample into high and low climate risk groups to implement the DID analysis. In this setting, the high climate risk group is considered as the treatment group, while the low climate risk group serves as the control group. We estimate by constructing the following DID model:

$$Cashflow_{it} = \alpha_0 + \alpha_1 DID_{it} + \beta X_{it} + \lambda_{ind} + \mu_t + \lambda_{ind}{}^{*}\mu_t + \varepsilon_{it} \quad (3)$$

where DID_{it} is a dummy variable that equals 1 if firm i is exposed to high climate risk, and 0 if otherwise; the remaining parameters are defined in accordance with Model (1).

Columns (1) − (3) of Table 12 show the estimation results of Model (3). The coefficients of the DID variable of the overall and brown firms are significantly positive at the 1 % level, while the DID variable of the green firms has no significant impact on firms' cash flow. This is consistent with the implications of the above findings, and validates the validity of the regression results in this paper.

7.2. PSM-DID method

Based on the DID method, this paper uses the control variables as covariates and firms' cash flow as outcome variables, and matches them using the 1: 1 nearest neighbor matching method with put-back. Fig. 4 illustrates the differences between the high and low climate risk groups before and after sample matching. As shown, there is a large gap between the treatment and control groups in each covariate before matching, while the gap is significantly reduced after matching. The matched data are then used for causal identification of the baseline regression, the results of which are shown in Columns (4) − (6) of Table 12. The coefficients of CPU are significantly positive in overall and brown firms, while there is no significant relationship between CPU and cash flow in green firms. It indicates that the regression results in this paper are still robust after mitigating the endogeneity problem of sample selection bias.

7.3. IV estimates

To further mitigate the endogeneity problem, this paper uses the latitude of the city where the firm is located to construct instrumental variables. The latitude of the city in which a firm is located may have an impact on the local climate change, but as an objective physical variable, it does not directly affect firms' behavior. Therefore, this variable satisfies the correlation and exogeneity conditions of instrumental variables. Since the research sample in this paper is firm-quarter level panel data, and the latitude of the city where the firm is located is the variable that does not change over time. For this purpose, we refer to Nunn and Qian (2014) for the treatment of two-dimensional instrumental variables. Given that temperature is one of the most important factors to measure climate change, this paper adopts the quarterly average temperature of the city where the firm is located to capture the time-varying nature of the instrumental variable. Specifically, we use the interaction between the latitude of the city where the firm is located and the quarterly average temperature as the instrumental variable (IV) of climate risk. In this paper, the 2SLS method is adopted as the instrumental variable method, and the estimation results are shown in Table 13. Columns (1), (3) and (5) show the estimation results of the first stage, where the coefficient of IV is statistically significant, indicating that IV is significantly associated with climate risk. In addition, the magnitude of the KP F-statistic (Kleibergen-Paap Wald rk F-statistic) for weak identification in the first stage are above

Table 12
Estimation results of DID and PSM methods.

Variables	Cashflow			Cashflow		
	(1)	(2)	(3)	(4)	(5)	(6)
	Overall	Green	Brown	Overall	Green	Brown
DID	0.014***	0.008	0.018***			
	(0.004)	(0.005)	(0.005)			
CPU				0.012***	0.006	0.017***
				(0.004)	(0.006)	(0.006)
Constant	0.895***	0.786***	1.044***	0.915***	0.818***	1.069***
	(0.051)	(0.061)	(0.071)	(0.055)	(0.066)	(0.077)
Controls	YES	YES	YES	YES	YES	YES
Industry fixed effects	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES
Industry-time fixed effects	YES	YES	YES	YES	YES	YES
Observations	117,086	59,834	56,755	64,829	33,107	31,068
R-squared	0.150	0.181	0.160	0.166	0.202	0.185

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The standard errors are clustered at firm level.

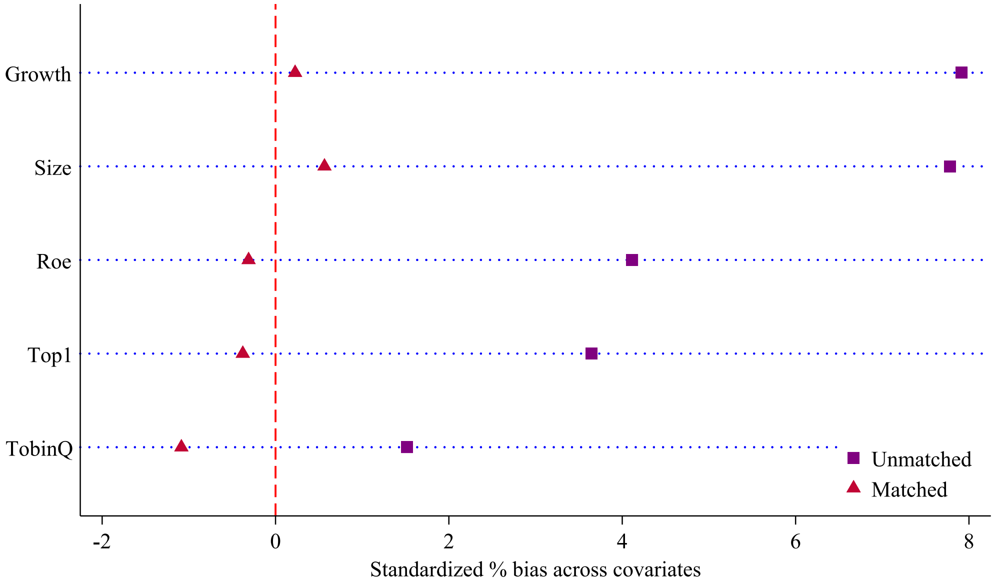

Fig. 4. Differences before and after sample matching.

Table 13
Estimation results of 2SLS method.

Variables	CPU	Cashflow	CPU	Cashflow	CPU	Cashflow
	(1)	(2)	(3)	(4)	(5)	(6)
	Overall		Green		Brown	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
IV	0.001***		0.001***		0.001***	
	(0.000)		(0.000)		(0.000)	
CPU		0.043		−0.075		0.132**
		(0.058)		(0.092)		(0.066)
Controls	YES	YES	YES	YES	YES	YES
Industry fixed effects	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES
Industry-time fixed effects	YES	YES	YES	YES	YES	YES
KP F-statistics	66.294		34.636		51.460	
Observations	109,281	109,281	55,031	55,031	53,779	53,779

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The standard errors are clustered at firm level.

Stock-Yogo's 10 % maximal bias threshold of 16.38, indicating that the IV is not a weak instrumental variable (Kleibergen and Paap, 2006). Columns (2), (4) and (6) give the results of the second stage. Climate risk has no significant effect on cash flow of green firms, while the coefficient of CPU for brown firms is significantly positive at the 1 % level. This is consistent with the results in Table 3, which once again verifies the robustness of the research conclusions in this paper.

7.4. Other robustness tests

To further ensure the robustness of the empirical results in this paper, the standard errors are clustered at city level to deal with the potential correlation in the error term. The relevant regression results are reported in Columns (1) – (3) of Table 14. The coefficients and significance of CPU for overall, green and brown firms are highly consistent with the above results, which verifies the validity of the regression results in this paper.

Second, by drawing on the setting of Hong et al. (2019), we use the degree of volatility of quarterly average temperature at the prefecture level (CPUr) as a proxy to replace the climate risk indicator. Specifically, this paper measures the degree of volatility of temperature by standardizing the quarterly average temperature of prefecture-level cities. Standardization is a common approach of dimensionlessness, and standardized quarterly average temperatures satisfy both the requirement for horizontal comparability and the ability to portray the degree of volatility of temperature. Generally, as the degree of volatility of temperature rises, so does the climate risk. The corresponding results are shown in Columns (4) – (6) of Table 14. The results remain robust to the baseline estimates, indicating the validity of our identification.

Finally, this paper excludes single-situation groups with only one observation, which is common when multiple levels of fixed effects are introduced in regressions (Qi et al., 2023). Columns (7) – (9) of Table 14 show that the regression results after excluding the single-situation groups remain consistent with the benchmark regression in this paper. The above results provide additional evidence for our findings.

8. Economic consequences

The above demonstrates that climate risk have a positive impact on firms' cash flow and the differentiated decision-making of green and brown firms when dealing with climate risk. However, how does this positive influence and differentiated decision-making affect a firm's industrial chain discourse and market competitiveness? To answer this question, we set up the following regression model.

$$\text{Consequence}_{it} = \alpha_0 + \alpha_1 CPU_{it} + \beta X_{it} + \lambda_{ind} + \mu_t + \lambda_{ind}{}^{*}\mu_t + \varepsilon_{it} \quad (4)$$

where Consequence_{it} develops the argument from three perspectives: market share (Mar_share), total factor productivity (TFP_LP), and ESG performance, respectively. The remaining parameters are defined in accordance with Model (1). Specifically, the market share indicator is obtained by using the industry share of the firms' operating revenue; the total factor productivity of firms is calculated using the LP method (Levinsohn and Petrin, 2003); the quarterly CSI ESG index is used to measure firms' ESG performance. Table 15 reports the results of the economic consequences. As can be seen from the table, climate risk has a significant positive impact on firms' market share, total factor productivity and ESG performance, and the extent of the impact is stronger for brown firms relative to green firms. This suggests that brown firms are more motivated to increase their market competitiveness by seizing market share, improving productivity and strengthening their ESG performance in the face of the growing threat of climate risk.

Table 14
Estimation results of other robustness tests.

Variables	Cashflow			Cashflow			Cashflow		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Overall	Green	Brown	Overall	Green	Brown	Overall	Green	Brown
CPU	0.014***	0.007	0.019***				0.014***	0.007	0.019***
	(0.005)	(0.005)	(0.006)				(0.004)	(0.005)	(0.005)
CPU_r				0.007***	0.003	0.011***			
				(0.003)	(0.004)	(0.003)			
Constant	0.888***	0.783***	1.032***	0.868***	0.754***	1.017***	0.888***	0.784***	1.032***
	(0.054)	(0.069)	(0.066)	(0.053)	(0.064)	(0.072)	(0.052)	(0.061)	(0.071)
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Industry fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Industry-time fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	117,086	59,834	56,755	109,281	55,031	53,779	116,999	59,753	56,749
R-squared	0.151	0.181	0.160	0.151	0.183	0.161	0.151	0.182	0.160

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The standard errors of Columns (1) – (3) are clustered at city level. The standard errors of Columns (4) – (9) are clustered at firm level.

Table 15
Estimation results of economic consequences.

Variables	Mar_share			TFP_LP			ESG		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Overall	Green	Brown	Overall	Green	Brown	Overall	Green	Brown
CPU	0.003***	0.002	0.003***	0.041***	0.027*	0.057***	0.002*	0.003**	0.004***
	(0.001)	(0.001)	(0.001)	(0.012)	(0.014)	(0.016)	(0.001)	(0.001)	(0.001)
Constant	−0.495***	−0.503***	−0.431***	−6.276***	−6.133***	−6.551***	4.039***	4.122***	4.173***
	(0.027)	(0.029)	(0.030)	(0.164)	(0.188)	(0.225)	(0.016)	(0.016)	(0.019)
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Industry fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Industry-time fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	117,933	60,253	57,176	104,545	51,974	52,045	114,147	56,147	57,490
R-squared	0.506	0.532	0.531	0.726	0.756	0.701	0.172	0.225	0.210

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The standard errors are clustered at firm level.

9. Conclusion and implications

Against the backdrop of the growing climate change problem, identifying the differences in the performance of green and brown firms in the face of climate risk is of great significance in guiding the transition from the pursuit of “profit maximization” to the practice of “green development” strategies. To this end, based on the quarterly-level panel data on listed firms, this paper empirically analyzes how climate risk affects firms’ cash flow, and the heterogeneity of green and brown firms’ preferences for cash flow in response to climate risk. We draw the following conclusions. First, climate risk has a significant positive impact on firms’ cash flow. This effect is primarily driven by brown firms, and no similar phenomenon is observed among green firms. Second, by exploring the industry and seasonal effects of climate risk on firms’ cash flow, this paper finds that the coefficients of brown firms are higher than those of green firms in most industries; firms’ incentives to increase their cash flow to cope with climate risk are weaker in the first quarter, while firms’ willingness to hold cash is higher in the fourth quarter. Third, climate risk will force firms to reduce their financial leverage and operating costs, as well as increase media attention on firms as a way to increase cash flow to sustain day-to-day operations. Fourth, the positive effect of climate risk on cash flow is more significant in low digital transformation firms, high financial constraints firms, firms with low managerial myopia and SOEs. Finally, this paper further finds that climate risk will drive firms to enhance their market competitiveness. Specifically, it has practical significance for the three dimensions of capturing market share, increasing productivity and strengthening ESG performance.

In line with the conclusions above, we propose the following policy implications. First, brown firms should strengthen climate risk management, including establishing robust risk control systems, developing adaptation and mitigation strategies, and improving their ability to respond to extreme climate events. In addition, governments and regulators should provide tax breaks, financial subsidies or other incentives for firms to promote green transformation and investment to mitigate the uncertainties associated with climate risk. Second, encourage firms to maintain reasonable levels of financial leverage and implement cost-benefit analyses, and adopt regulatory measures to ensure that firms remain financially sound in addressing climate risk, as well as increase their resilience to climate risk. At the same time, we advocate strengthening the role of informal systems, such as the media, in firms’ risk management, promoting increased transparency and public participation, and utilizing social pressure and public attention to prompt firms to pay more attention to climate risk. In this way, we will be able to build a virtuous circle mechanism for multi-party participation and joint response to climate risk. Third, digital transformation is not just a technological upgrade, but also a profound change in the management process and organizational structure of firms. By deepening the system of integration of industry, academia and research in order to build a cooperation platform for digital transformation, governments can lower the threshold and difficulty of digital transformation for firms and increase their willingness to do so, thereby improving operational efficiency and the ability to cope with risks. Fourth, firms should establish a reasonable mechanism to restrain the managerial myopia. On the one hand, when hiring senior management personnel, firms should focus on the examination of their time-cognitive qualities and awareness of sustainable development; on the other hand, firms should improve internal control and optimize the shareholding structure, so as to make the interests of controlling shareholders and the long-term development of firms organic combination. Finally, this paper provides perspectives and methodologies for risk identification and assessment for firms in countries with a similar level of climate risk as China, helping them to understand and anticipate the possible impacts of climate risk on their operations and supply chains. In addition, our research provides strategies for different types of firms to adapt and cope with climate risk. As global climate governance strengthens, this could also provide ideas for firms in countries where the level of climate risk differs significantly from that of China. Corresponding firms can take the initiative to explore and develop green financial products and services, such as climate bonds, green loans, green insurance, etc., through which they can accelerate their own green transformation process in order to effectively avoid potential financial risks and ensure long-term sustainable development.

CRediT authorship contribution statement

Dongyang Zhang: Writing – original draft, Visualization, Supervision, Software, Resources, Methodology, Data curation, Conceptualization. **Dingchuan Bai:** Writing – review & editing, Software, Resources, Methodology, Data curation, Conceptualization. **Yizhi Wang:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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.

Data availability

Data will be made available on request.

Acknowledgements

This paper acknowledges the financial support of the National Key R&D Program of China (2023YFA1009204), the National Natural Science Foundation of China (72103147), and the Project of Cultivation for Young Top-motch Talents of Beijing Municipal Institutions (BPHR202203184).

References

Addoum, J.M., Ng, D.T., Ortiz-Bobea, A., 2023. Temperature shocks and industry earnings news. J. Financ. Econ. 150 (1), 1–45.
Ardia, D., Bluteau, K., Boudt, K., et al., 2023. Climate change concerns and the performance of green vs. brown stocks. Manag. Sci. 69 (12), 7607–7632.
Baker, S.R., Bloom, N., Davis, S.J., 2016. Measuring economic policy uncertainty. Q. J. Econ. 131 (4), 1593–1636.
Bolton, P., Kacperczyk, M., 2021. Do investors care about carbon risk? J. Financ. Econ. 142 (2), 517–549.
Chava, S., 2014. Environmental externalities and cost of capital. Manag. Sci. 60 (9), 2223–2247.
Chen, H., Deng, J., Lu, M., et al., 2024. Government environmental attention, credit supply and firms' green investment. Energy Economics 134, 107547.
Chen, W., Liu, Y., Liu, S., et al., 2024. The governance effects of social media engagement on M&A outcomes: Evidence from China. Journal of International Financial Markets, Institutions and Money 91, 101946.
D'amato, G., Cecchi, L., 2008. Effects of climate change on environmental factors in respiratory allergic diseases. Clin Exp Allergy 38 (8), 1264–1274.
Desbordes, R., Eberhardt, M., 2024. Climate change and economic prosperity: Evidence from a flexible damage function. J. Environ. Econ. Manag. 125, 102974.
Du, J., Shen, Z., Song, M., et al., 2023. Nexus between digital transformation and energy technology innovation: An empirical test of A-share listed enterprises. Energy Econ. 120, 106572.
Engle, R.F., Giglio, S., Kelly, B., et al., 2020. Hedging climate change news. Rev. Financ. Stud. 33 (3), 1184–1216.
García-Teruel, P.J., Martínez-Solano, P., Sánchez-Ballesta, J.P., 2009. Accruals quality and corporate cash holdings. Account. Finance 49 (1), 95–115.
Gavriilidis K. Measuring climate policy uncertainty. Available at SSRN 3847388, 2021.
Ginglinger, E., Moreau, Q., 2023. Climate risk and capital structure. Manag. Sci. 69 (12), 7492–7516.
Hadlock, C.J., Pierce, J.R., 2010. New evidence on measuring financial constraints: Moving beyond the KZ index. Rev. Financ. Stud. 23 (5), 1909–1940.
Haines, A., Patz, J.A., 2004. Health effects of climate change. JAMA 291 (1), 99–103.
Hartzmark S M, Shue K. Counterproductive sustainable investing: The impact elasticity of brown and green firms. Available at SSRN 4359282, 2022.
Hong, H., Li, F.W., Xu, J., 2019. Climate risks and market efficiency. J. Econ. 208 (1), 265–281.
Huang, H.H., Kerstein, J., Wang, C., 2018. The impact of climate risk on firm performance and financing choices: An international comparison. J. Int. Bus. Stud. 49, 633–656.
Huang, K., Zhao, H., Huang, J., et al., 2020. The impact of climate change on the labor allocation: Empirical evidence from China. J. Environ. Econ. Manag. 104, 102376.
Huynh, T.D., Nguyen, T.H., Truong, C., 2020. Climate risk: The price of drought. Finance 65, 101750.
Kellogg, R., 2014. The effect of uncertainty on investment: Evidence from Texas oil drilling. Am. Econ. Rev. 104 (6), 1698–1734.
Kleibergen, F., Paap, R., 2006. Generalized reduced rank tests using the singular value decomposition. J. Econ. 133 (1), 97–126.
Kotz, M., Levermann, A., Wenz, L., 2024. The economic commitment of climate change. Nature 628 (8008), 551–557.
Lai, J., Ke, J., Lin, S., et al., 2024. Business environment optimization and labor income share of enterprises: Evidence from China. Research in International Business and Finance 71, 102491.
Lee, K., Cho, J., 2023. Measuring chinese climate uncertainty. Int. Rev. Econ. Financ. 88, 891–901.
Levinsohn, J., Petrin, A., 2003. Estimating production functions using inputs to control for unobservables. Rev. Econ. Stud. 70 (2), 317–341.
Li, J., Lian, G., Xu, A., 2023. How do ESG affect the spillover of green innovation among peer firms? mechanism discussion and performance study. J. Bus. Res. 158, 113648.
Ma, F., Cao, J., Wang, Y., et al., 2023a. Dissecting climate change risk and financial market instability: Implications for ecological risk management. Risk Anal.
Ma, Y.R., Liu, Z., Ma, D., et al., 2023b. A news-based climate policy uncertainty index for china. Sci. Data 10 (1), 881.
McMichael, A.J., Haines, A., 1997. Global climate change: the potential effects on health. BMJ 315 (7111), 805–809.
Myers, S.C., Majluf, N.S., 1984. Corporate financing and investment decisions when firms have information that investors do not have. J. Financ. Econ. 13 (2), 187–221.
Noyes, P.D., McElwee, M.K., Miller, H.D., et al., 2009. The toxicology of climate change: Environmental contaminants in a warming world. Environ. Int. 35 (6), 971–986.
Nunn, N., Qian, N., 2014. US food aid and civil conflict. Am. Econ. Rev. 104 (6), 1630–1666.
Pankratz, N., Bauer, R., Derwall, J., 2023. Climate change, firm performance, and investor surprises. Manag. Sci. 69 (12), 7352–7398.
Pástor, Ľ., Stambaugh, R.F., Taylor, L.A., 2021. Sustainable investing in equilibrium. J. Financ. Econ. 142 (2), 550–571.
Qi, Y., Zhang, J., Chen, J., 2023. Tax incentives, environmental regulation and firms' emission reduction strategies: Evidence from China. J. Environ. Econ. Manag. 117, 102750.
Ren, X., Zhang, X., Yan, C., et al., 2022. Climate policy uncertainty and firm-level total factor productivity: Evidence from China. Energy Econ. 113, 106209.
Short, F.T., Neckles, H.A., 1999. The effects of global climate change on seagrasses. Aquat. Bot. 63 (3–4), 169–196.
Sinha, P., Caulkins, M.L., Cropper, M.L., 2018. Household location decisions and the value of climate amenities. J. Environ. Econ. Manag. 92, 608–637.
Stein, J.C., 1989. Efficient capital markets, inefficient firms: A model of myopic corporate behavior. Q. J. Econ. 104 (4), 655–669.
Takayabu, I., Hibino, K., Sasaki, H., et al., 2015. Climate change effects on the worst-case storm surge: A case study of typhoon haiyan. Environ. Res. Lett. 10 (6), 064011.

Tol, R.S.J., 2009. The economic effects of climate change. J. Econ. Perspect. 23 (2), 29–51.
Zandalinas, S.I., Fritschi, F.B., Mittler, R., 2021. Global warming, climate change, and environmental pollution: Recipe for a multifactorial stress combination disaster. Trends Plant Sci. 26 (6), 588–599.
Zhang, D., 2023. Can environmental monitoring power transition curb corporate greenwashing behavior? J. Econ. Behav. Organ. 212, 199–218.
Zhang, D., Bai, D., Wang, C., et al., 2024. Distribution dynamics and quantile dynamic convergence of the digital economy: Prefecture-level evidence in China. International Review of Financial Analysis 95, 103345.
Zhang, P., Deschenes, O., Meng, K., et al., 2018. Temperature effects on productivity and factor reallocation: evidence from a half million chinese manufacturing plants. J. Environ. Econ. Manag. 88, 1–17.
Zhang, D., He, Y., Lu, M., 2024. Is energy firms' investment behavior more sensitive on corporate perception of monetary policy? Energy Economics 136, 107749.
Zscheischler, J., Westra, S., Van Den Hurk, B.J.J.M., et al., 2018. Future climate risk from compound events. Nat. Clim. Chang. 8 (6), 469–477.