Does Carbon Risk Affect Corporate Cash Holdings?

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Abstract: Against the backdrop of increasingly severe climate change issues, reducing corporate carbon emissions and promoting green transformation has become an important research topic at present. This research examines the impact mechanism of carbon risk has on corporate cash holdings, using the sample of Chinese A-share listed companies in Shanghai and Shenzhen from 2011 to 2021. We find that a significant positive correlation between carbon risk and corporate cash holdings. The mechanism analysis shows that companies with higher carbon risk will hold more cash to cope with more challenging financing constraints and higher transaction costs, due to preventive and transactional motives. Additional analyses indicate that the positive effect of carbon risk has on cash holdings is more pronounced in high-carbon emitting industries; in carbon emission trading cities, regions with high levels of financial development, and areas with high public environmental attention, the increasing effect of carbon risk on corporate cash holdings will be suppressed. Overall, our findings enrich the literature on economic effects of carbon risk on the firm level, and provide reference for policy makers, industry development, and corporate green transformation in the context of carbon risk.

Keywords: Carbon Risk; Cash Holding; Preventive Motive; Transactional Motive

1. Introduction

With the continuous rise of global temperatures, climate change has surpassed the scope of environmental issues and become a global challenge that affects national security, economic prosperity, and even human survival rights. The signing of the Paris Agreement in 2016 sent a signal to strengthen carbon emissions regulation, posing new conflicts and more risk challenges for businesses in coordinating growth and carbon reduction. The uncertainty impact of changes in carbon related policies and regulations on future cash flows of enterprises is known as carbon risk (Hoffmann and Busch, 2010), which includes compliance risk, technological risk, credit risk, and reputation risk.Currently, carbon risk is included as a key factor in the valuation system of corporate capital investment. Companies must effectively address the safety hazards caused by carbon risk while maintaining the necessary rate of return for shareholders, in order to achieve the coordinated goals of “development” and “safety” of the enterprise.

Previous studies have shown that carbon risk can have an impact on financial behaviors such as corporate financing costs (Nguyen and Phan, 2020), green investment (Shen and Zhou , 2017), dividend distribution (Balachandran and Nguyen, 2018), corporate mergers and acquisitions (Zhang and Tan, 2024), information disclosure (Cheng et al., 2024), risk management (Guo et al., 2024), and audit pricing (Wang et al., 2022). Carbon risk can have negative or positive impacts on a company’s financial performance, such as reducing dividend payout ratios, lowering audit fees, exacerbating financial difficulties, lowering investment efficiency, increasing capital costs, forcing companies to adopt proactive investment and financing policies, and promoting low-carbon innovation (Balachandran and Nguyen, 2018; Wang et al., 2022; Wang, 2020; Phan et al., 2022; Chava, 2014; Jia et al., 2023; Zhang et al., 2022).To effectively address carbon risks, companies will adjust their financial strategies to reduce the potential adverse effects on their sustainable development, such as introducing emission reduction technologies, inventing green patents , and increasing research and development expenditures. However, the proactive or passive adjustment of financial policies by enterprises may further bring about

new derivative risks, leading to inefficient or weak response strategies and seriously weakening the ability of enterprises to achieve safe and green transformation. Therefore, it is worth further exploring and researching the impact of carbon risk on corporate financial policies and the transmission mechanism. This article will answer this question from the perspective of the level of corporate cash holdings.

The reason for choosing the level of corporate cash holdings as the research entry point is mainly due to the fact that cash holding decisions, as one of the important daily financial policies of enterprises, can directly reflect the management's response strategy attitude based on carbon risk and indirectly reflect the governance efficiency of enterprises.Generally speaking, when facing the uncertainty brought by climate risks, enterprises tend to increase their cash holdings (Zhang et al., 2023), and excessively high cash holdings can also lead to lower investment efficiency.However, it is difficult to simply determine whether carbon risk constraints can guide companies to make better cash holding decisions to cope with external uncertainty and reduce risks.On the one hand, cash, as the “hub” to ensure the daily transaction needs of enterprises (Miller and Orr, 1966), can not only cope with operational risks caused by environmental instability, but also prevent enterprises from facing financial difficulties due to insufficient liquidity. It is also beneficial for enterprises to seize valuable investment opportunities in a timely manner (Opler et al., 1999). On the other hand, a higher level of cash holdings may result in higher agency costs for companies. When the corporate governance environment is poor, the company's free cash flow may become a tool for management or major shareholders to pursue control and personal gain, making it more prone to excessive consumption, embezzlement of funds, or inefficient investment, which can actually reduce the investment efficiency and market value of the company (Jensen, 1986). Therefore, it is necessary to conduct a systematic analysis of how and why corporate cash holding decisions change under carbon risk, and under what circumstances there are differences, in order to provide empirical evidence for the related research on the relationship between carbon risk and corporate cash holding, and also provide policy references for improving carbon policy system.

Based on this, this study takes Shanghai and Shenzhen A-share listed companies from 2011 to 2021 as the initial sample to study the impact mechanism of carbon risk on corporate cash holdings and the effect differences under different scenarios.

This paper differs from existing literature studies and will provide contributions in the following aspects:

(1) previous studies have mainly examined the impact of carbon risk on micro financial behavior of enterprises from the perspectives of dividend distribution (Balachandran and Nguyen, 2018), audit fees (Wang et al., 2022), investment and financing efficiency (Phan et al., 2022), and cost of capital (Chava, 2014). However, there is little research on whether and how carbon risk affects corporate cash holdings. This article takes corporate cash holdings as the starting point to explore the impact of carbon risk on corporate cash holdings, enriching the research results on the economic consequences of carbon risk at the micro level.

(2) existing literature mainly studies corporate cash holdings from preventive motives (Opler et al., 1999), transactional motives (Mulligan, 1997), agency motives (Jensen, 1986), speculative motives (Myers and Majluf, 1984), and tax motives (Foley et al., 2007). This article explores the impact of carbon risk on corporate cash holdings and enriches the relevant literature on corporate cash holdings; At the same time, it helps micro enterprises better measure their cash holding decisions in the context of carbon risk, in order to maximize value and provide reference for macro level policy formulation, meso level industry development, and micro level enterprise risk control and safe transformation.

2. Theoretical Analysis and Research Hypothesis

The academic community mainly divides the theories explaining the factors influencing corporate cash holdings into two categories: trade-off theory and agency theory (Myers and Majluf, 1984; Jensen, 1986). The reasons why companies hold cash can be specifically refined into preventive motivation (Opler et al., 1999), transactional motivation (Mulligan,

1997), speculative motivation (Myers and Majluf, 1984), agency motivation (Jensen, 1986), and tax avoidance (Foley et al., 2007). Carbon risk may have both promoting and inhibiting effects on corporate cash holdings. The specific analysis is as follows.

On the one hand, according to the theory of information asymmetry, due to the early stage of carbon risk management in Chinese enterprises, there are problems such as low quality of carbon information disclosure, difficulty in obtaining carbon data, and low reliability of carbon data. The existence of carbon risk may exacerbate the problem of information asymmetry among market participants (Faulkender and Wang, 2006), leading to greater difficulties for investors and external fund providers such as banks in evaluating the operating conditions of enterprises. Based on risk prevention considerations, external funding providers may reduce their credit scale or demand higher value collateral as collateral, thereby raising the financing costs and increasing the difficulty of financing for enterprises. In the situation where external funding supply is more difficult to obtain, corporate carbon risk leads to a lack of effective information exchange between the supply and demand sides of funds, exacerbating the financing constraints of enterprises and prompting them to hold more cash as a means of risk prevention (Cheng et al., 2023). At the same time, information asymmetry under carbon risk will also increase the external transaction costs faced by enterprises, such as the search costs incurred by enterprises in finding trading partners, the negotiation and negotiation costs incurred in signing contracts, as well as the supervision costs incurred in ensuring contract execution and the costs incurred by trading partner defaults (Zheng and He, 2024). In this case, based on preventive or transactional motives, companies with higher carbon risks may have a stronger demand and greater intensity to increase their cash holdings. In addition, under the promotion of the low-carbon economy concept by the whole society, the carbon risk of enterprises may have a negative impact on their reputation. In order to make up for the losses caused by carbon risk as much as possible, enterprises need to reserve more cash for public relations or advertising, or reduce carbon risk by adopting environmentally friendly materials, introducing energy-saving and environmental protection technologies, etc., to improve the reputation and sustainable competitive advantage of enterprises. These behaviors also increase the daily transaction demand of enterprises for cash (Chu et al., 2021).

On the other hand, Porter's hypothesis suggests that strict environmental regulations may increase compliance costs for businesses, but policies can force green technology innovation to gain new competitive advantages (Porter and Linde, 1995). Under the constraints of environmental regulations, due to the significant increase in production costs and emission reduction expenses caused by carbon risks, in order to achieve sustainable development of enterprises, they adopt technological upgrades and production transformations to improve production efficiency (Han et al., 2023), offset the negative consequences of “regulatory compliance costs” with “innovation compensation benefits”, and ultimately achieve the Porter effect. Technological upgrading and production transformation mean an increase in R&D expenditures and a reform of large-scale production methods for enterprises (Luo and Wu , 2023). This demand for transformation and reform will “consume” the cash assets held by enterprises. In order to actively promote the goal of reducing carbon emissions, China has not only improved regulations and systems such as environmental penalties, carbon trading policies, and green credit policies to limit the carbon emissions of enterprises (Guo et al., 2024); At the same time, government departments have also formulated a series of supportive policies, aimed at incentivizing enterprises to actively use cash for carbon reduction governance, low-carbon technology innovation, green production and other carbon reduction related resource allocation through policy subsidies and tax incentives (Zhou et al., 2023), thereby “squeezing” the cash assets held by enterprises.

Based on the above analysis, carbon risk may enhance the level of low-carbon governance and reduce the level of cash holdings while strengthening the precautionary and transactional motives of enterprises holding cash. Therefore, we propose the following competing hypothesis:

H1a. All other conditions being equal, the higher the carbon risk, the higher the level of cash holdings of the enterprise.

H1b. All other conditions being equal, the higher the carbon risk, the lower the cash holding level of the enterprise.

3. Research Design

3.1 Sample Selection and Data Sources

In 2011, China officially took the green economy and low-carbon economy as one of the strategic priorities of the "China's 12th Five-Year Plan". Therefore, this paper selects Shanghai and Shenzhen A-share listed companies from 2011 to 2021 as the sample, and excludes the missing observations of the financial and insurance sectors and related variables. The industry operating costs and total energy consumption data used in this article are sourced from the "China Industrial Economic Statistical Yearbook" and the "China Energy Statistical Yearbook", respectively. The public environmental attention data is manually compiled, while the remaining data comes from the China Securities Market and Accounting Research (CSMAR) Database and the Chinese Research Data Services Platform (CNRDS).

3.2 Definition of Main Variables

To investigate the impact of carbon risk on corporate cash holdings, the variables in this study are set as follows:

3.2.1 Dependent variables

Following Di et al. (2020), we measured cash holdings (*Cash1*) as the ratio of cash to total assets.For the sake of robustness, this article also selects *Cash2* as an alternative dependent variable, where *Cash2* is the ratio of cash to net assets.

3.2.2 Independent variables

Following Zhong and Ma (2022), we measured carbon risk (*CarbonRisk*) as the ratio of corporate carbon emissions to operating income. Enterprises' carbon emissions data are measured as shown in the endnotes.

3.2.3 .Control variables

Financial and operational risks, as important components of enterprise risk, can also have a certain impact on cash holdings. In order to eliminate the impact of financial and operational risks, this article uses *Lev* as a proxy indicator for corporate financial risk and the Z-index proposed by Atlman as a proxy indicator for corporate operational risk.The control variables are defined as shown in Table 1.

Table 1. Variables Definition

Variables	Definition
Cash1	The ratio of cash to total assets
Cash2	The ratio of cash to net assets.
CarbonRisk	The ratio of corporate carbon emissions to operating income
Size	The natural logarithm of book value of total assets
Lev	The book value of total debts divided by the book value of total assets
Zscore	Z-index=1.2 * (working capital/total assets) +1.4 * (retained earnings/total assets) +3.3 * (pre tax profit/total assets) +0.6 * (total market value of stocks/book value of liabilities) +0.999 * (sales revenue/total assets)
Capex	The ratio of capital expenses to total assets
Soe	A dummy variable that equals one if the firm is state-owned, and zero otherwise
ROA	Net income divided by total assets
Top1	The percentage of shares owned by the largest shareholder
Growth	The percentage change of sales from the previous one year
Age	The natural logarithm of one plus the time elapsed since the incorporation date of the firm
HHI	The product market competition is computed as the sum of squared market shares of all firms (by owner's equity) in a given 3-digit CSRC industry in each year

3.3 Regression Model

To verify how carbon risk affects corporate cash holdings, we estimated the following regression model to test this hypothesis:

$$Cash=\alpha_0+\alpha_1 CarbonRisk+\alpha_2 Size+\alpha_3 Lev+\alpha_4 Zscore+\alpha_5 Capex+\alpha_6 Soe+\alpha_7 ROA+\alpha_8 Top1+\alpha_9 Growth+\alpha_{10} Age+\alpha_{11} HHI+Industry+Year+\varepsilon \quad (1)$$

Where, *CarbonRisk* is the independent variable, and *Cash* is the dependent variable. Controls denote the control variables defined in Table 1. *Industry* is a industry fixed effect, *Year* is a year fixed effect, and ε is an error term.We winsorize all continuous variables at the 1st and 99th percentiles.

4. Empirical Analysis

4.1 Summary Analysis

Table 2 presents the results of the descriptive statistical analyses.The mean value of *Cash1* is 0.199, and the standard deviation is 0.149. In

addition, the maximum value of *Cash1* is 0.705 and the minimum value is 0, with a significant extreme and standard deviation, indicating a significant gap in cash holding among different firms. Similarly, the extreme difference and standard deviation of *Cash2* are also significant, again proving a gap between different firms' cash holding. The mean value of *CarbonRisk* is 0.001, and the standard deviation is 0.001. In addition, the maximum value of *CarbonRisk* is 0.004, and the minimum value is 0.000, indicating that due to the characteristics of the industry in which the enterprises operate, there are certain differences in the carbon risks faced by different enterprises in China.

Table 2. Descriptive Statistics of Variables

Variables	N	Mean	Sd	Min	Max
Cash1	34052	0.199	0.149	0.000	0.705
Cash2	34052	0.317	0.387	0.000	2.391
CarbonRisk	34052	0.001	0.001	0.000	0.004
Size	34052	22.060	1.400	15.580	28.640
Lev	34052	0.423	0.214	0.047	0.972
Zscore	34052	4.638	5.742	-0.069	36.070
Capex	34052	0.048	0.047	0.000	0.228
Soe	34052	0.319	0.466	0.000	1.000
ROA	34052	0.035	0.077	-0.370	0.214
Top1	34052	33.260	15.630	0.000	74.860
Growth	34052	0.397	1.087	-0.780	7.919
Age	34052	18.150	5.903	1.000	63.000
HHI	34052	0.142	0.132	0.032	0.744

Note: This table presents the descriptive statistics of interested variables in our model.

4.2 Baseline Regression

Table 3 reports the baseline results.Without including any control variables,columns (1) and (3) shows that the coefficients of the core explanatory variable *CarbonRisk* were significantly positive at the 1% level, indicating a meaningful relationship between carbon risk and the exaltation of cash holding.We included all the control variables in Column (2) and (4) to strengthen the analysis and account for potential confounding factors. This more comprehensive model shows that the coefficient of *CarbonRisk* remains statistically significantly positive at the higher confidence level of 1 %. This result proves that the higher the carbon risk, the higher the corporate cash holdings, thus validating Hypothesis H1a.

Table 3. Effect of Carbon Risk on Corporate Cash Holdings

	(1)	(2)	(3)	(4)
	Cash1	*Cash1*	*Cash2*	*Cash2*
CarbonRisk	0.056***(29.54)	7.660***(3.09)	0.248***(39.74)	32.723***(4.46)
Size		-0.001(-1.49)		-0.009***(-4.72)
Lev		-0.185***(-33.62)		-0.410***(-26.14)
Zscore		0.004***(19.91)		0.011***(16.54)
ROA		0.179***(15.46)		0.386***(12.50)
Capex		-0.341***(-22.83)		-0.994***(-25.92)
Soe		-0.007***(-4.17)		-0.022***(-5.14)
Top1		0.001***(23.05)		0.002***(18.07)
Growth		0.005***(5.80)		0.011***(4.85)
Age		-0.001***(-4.81)		-0.003***(-8.66)
HHI		0.013(1.32)		0.030(1.04)
Constant	0.267***(24.96)	0.290***(14.86)	0.530***(16.89)	0.703***(12.55)
Industy/Year	Yes	Yes	Yes	Yes
Observations	34,052	34,052	34,052	34,052
R-squared	0.125	0.303	0.108	0.262

Notes: The t-statistics are reported in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

4.3 Endogeneity Test

To address potential endogeneity issues in the research, this article conducted the following endogeneity tests.

4.3.1 Delayed handling of core explanatory variables.

Considering that the impact of carbon risk on corporate cash holdings may have a lag effect, and that both carbon risk and corporate cash holdings may be affected by certain unobservable variables, the variable *CarbonRisk* was lagged by one period and regressed again. The results are shown in Table 4. The estimated coefficient of *L.CarbonRisk* is still significantly positive at the 1% level, once again verifying hypothesis H1a.

4.3.2 Difference-in-differences(DID) test.

We utilize the quasi-natural experiment of the enactment of the Paris Agreement in 2016, to analyze the impact of carbon risk on corporate cash holdings. The paper employs the difference-in-difference approach by constructing differences on two dimensions: time and industry.The time-dimension is defined by the *Post* variable, where *Post* = 0 before the promulgation of the Paris Agreement and *Post* = 1 in the year of the promulgation of the Paris Agreement and thereafter.Following the approach of Wang et al. (2022), the industry dimension is based on the classification principle of high- and low-carbon-emitting industries. The sample of listed companies is divided into these two groups. If the enterprise belongs to the experimental group of high carbon emission enterprises,the value of *Treat* is 1, otherwise it is 0. The core independent variable *Treat* * *Post* is generated by multiplying *Treat* with *Post*. The coefficient of this variable indicates the impact of rising carbon risk on the corporate cash holdings. Eq. (2) represents the specific regression model constructed in this study.

$$Cash = \beta_0 + \beta_1 Treat * Post + \sum \beta_k Control + Industry + Year + \varepsilon \quad (2)$$

Table 4 shows the regression results of the DID model, where the coefficients of *Treat* * *Post* are significantly positive at the 1% level, indicating that compared to low-carbon emission enterprises, high carbon emission enterprises have significantly increased their cash holdings after the signing of the Paris Agreement.

4.3.3 Propensity score matching method (PSM).

The impact of carbon risk on corporate cash holdings is not a random selection process and may be influenced by external factors. Therefore, this article uses propensity score matching (PSM) to solve the problem of sample self selection.Specifically, high carbon emitting enterprises are considered as the treatment group, and the control variables in the baseline model are used as matching covariates. A 1:1 nearestneighbor matching is conducted on the samples to mitigate the bias. The regression results of the matched samples are shown in Table 4. The regression coefficient of *CarbonRisk* on corporate cash holdings is significantly positive at least at the 10% level, which is consistent with the previous results. This proves that the higher the carbon risk, the higher the corporate cash holdings.

4.3.4 Two-stage least squares method.

To enhance reliability and mitigate the endogeneity problem, we selected the same year and industry carbon dioxide emissions (*Industry_Carbon*) and the same year and region carbon dioxide emissions (*Area_Carbon*) as instrumental variables respectively, and by two-stage least squares method (2SLS) (Di et al., 2020; Hu et al., 2019). The results are reported in Table 5. The F-statistics reported in the first stage are 12.677 and 17.098, respectively, with F-values greater than 10, rejecting the weak instrumental variable hypothesis and indicating that the instrumental variables satisfy the correlation. There is currently no evidence to suggest that these two instrumental variables affect corporate cash holdings, and the corresponding p-values of the Hausman test are both less than 0.05, which also meets the exogeneity requirement. The results of the second stage regression show that the regression coefficients of corporate cash holdings are significantly positive at least at the 5% level. It indicates that after considering the potential endogeneity problem, the enhancement of carbon risk still leads to the enhancement of company's cash holdings, which is consistent with the previous results.

4.4 Robustness Test

4.4.1 Replacing the carbon risk measurement

method.

This paper remeasures carbon risk (*CarbonRisk1*) based on the sum of carbon emissions in Scope 1 and Scope 2 of the Greenhouse Gas Accounting System, and regresses Eq. (1). The coefficient of *CarbonRisk1* is significantly positive, indicating that different definitions of carbon risk do not affect the research conclusions, as shown in Table 6.

4.4.2 Quantile regression.

To prevent the impact of extreme data on the regression results of this article, quantile regression was used for the main research model of this article. The results are shown in columns (3) to (8) of Table 6. According to Table 6, the regression coefficients of *CarbonRisk* and *Cash* are significantly positively correlated at least at the 5% level, indicating that the research conclusions of this article are not greatly affected by extreme data.

Table 4. Endogeneity Tests

	(1)	(2)	(3)	(4)	(5)	(6)
	Cash1	*Cash2*	*Cash1*	*Cash2*	*Cash1*	*Cash2*
CarbonRisk					5.636*(1.77)	20.664**(2.36)
L.CarbonRisk	6.968***(3.51)	27.455***(4.95)				
*Treat*Post*			0.015***(3.90)	0.043***(4.46)		
Size	-0.000(-0.33)	-0.007***(-3.50)	-0.003(-0.96)	-0.016*(-1.81)	-0.004***(-4.07)	-0.016***(-5.75)
Lev	-0.137***(-24.57)	-0.265***(-17.58)	-0.226***(-19.80)	-0.483***(-15.33)	-0.166***(-19.33)	-0.349***(-15.05)
Zscore	0.005***(22.03)	0.013***(18.32)	0.001***(4.24)	0.004***(3.81)	0.004***(10.03)	0.009***(7.75)
ROA	0.163***(14.16)	0.329***(11.05)	0.091***(6.93)	0.136***(3.82)	0.201***(10.14)	0.395***(7.30)
Capex	-0.272***(-17.57)	-0.735***(-19.98)	-0.209***(-10.32)	-0.677***(-12.51)	-0.283***(-12.47)	-0.775***(-13.83)
Soe	0.001(0.67)	-0.003(-0.77)	-0.011(-1.54)	-0.006(-0.32)	-0.004(-1.44)	-0.011*(-1.76)
Top1	0.001***(20.11)	0.002***(16.06)	0.001***(8.08)	0.003***(6.56)	0.001***(11.24)	0.002***(9.87)
Growth	0.004***(4.48)	0.009***(3.90)	0.001(1.57)	0.004(1.62)	0.005***(3.53)	0.012***(3.26)
Age	0.000(0.18)	-0.001***(-2.81)	-0.005***(-5.01)	-0.017***(-6.47)	-0.000(-0.54)	-0.001(-1.47)
HHI	0.031***(3.13)	0.058**(2.43)	-0.006(-0.39)	-0.004(-0.09)	0.046**(2.50)	0.126**(2.55)
Constant	0.195***(10.94)	0.432***(9.52)	0.409***(6.11)	1.148***(5.72)	0.308***(9.79)	0.708***(8.43)
Industy/Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	29,245	29,245	34,052	34,052	12,251	12,251
R-squared	0.281	0.242	0.168	0.141	0.278	0.241

Notes: The t-statistics are reported in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 5. Results of Instrumental Variable Regression

	Industry_Carbon		*Area_Carbon*	
	Cash1	*Cash2*	*Cash1*	*Cash2*
CarbonRisk	348.428**(2.08)	960.308**(2.19)	405.213***(2.91)	892.585***(2.67)
Size	-0.000(-0.08)	-0.004(-0.48)	0.010***(2.86)	0.015*(1.72)
Lev	-0.012*(-1.68)	-0.028*(-1.71)	-0.300***(-7.64)	-0.644***(-6.79)
Zscore	0.009***(9.86)	0.022***(9.16)	0.004***(14.77)	0.011***(13.95)
ROA	0.012*(1.86)	0.036**(2.31)	0.015*(1.78)	0.038**(2.27)
Capex	-0.156***(-2.68)	-0.486***(-3.19)	-0.192***(-4.89)	-0.606***(-6.54)
Soe	-0.029***(-5.48)	-0.077***(-5.43)	-0.014***(-4.10)	-0.038***(-4.58)
Top1	0.002***(9.62)	0.003***(7.78)	0.001***(13.48)	0.003***(11.32)
Growth	-0.000(-0.80)	0.000(0.05)	-0.000(-0.88)	-0.000(-0.05)
Age	-0.001***(-4.40)	-0.004***(-5.65)	-0.001***(-2.63)	-0.003***(-5.36)
HHI	0.078***(2.78)	0.208***(2.69)	0.076***(2.97)	0.168***(2.67)
Constant	-0.968(-1.53)	-2.750*(-1.66)	-1.322**(-2.38)	-2.786**(-2.10)
Industy/Year	Yes	Yes	Yes	Yes
Observations	27,879	27,879	29,205	29,205
F statistics of first stage	12.677	12.677	17.098	17.098
Hausman test(p-value)	0.0038	0.0032	0.0000	0.0005

Notes: The t-statistics are reported in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 6. Robustness Tests

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Cash1	*Cash2*	*Cash1*	*Cash2*	*Cash1*	*Cash2*	*Cash1*	*Cash2*
	Standardized regression		Q50		Q75		Q90	
CarbonRisk			6.272** (2.40)	12.071*** (2.87)	9.928*** (2.82)	25.776*** (3.13)	15.761*** (3.15)	65.446*** (4.04)
CarbonRisk1	18.511** (2.57)	72.022*** (3.53)						
Size	-0.001** (-2.14)	-0.037*** (-15.91)	0.001 (1.60)	0.002 (1.43)	-0.004*** (-4.52)	-0.006*** (-2.77)	-0.012*** (-8.61)	-0.020*** (-4.35)
Lev	-0.183*** (-33.15)	-0.011 (-1.28)	-0.141*** (-25.79)	-0.178*** (-20.18)	-0.225*** (-30.40)	-0.327*** (-18.91)	-0.295*** (-28.04)	-0.546*** (-16.03)
Zscore	0.004*** (19.84)	0.004** (2.40)	0.005*** (30.82)	0.010*** (36.76)	0.006*** (26.79)	0.021*** (37.93)	0.005*** (15.65)	0.032*** (29.55)
ROA	0.171*** (14.93)	0.828*** (20.26)	0.157*** (13.11)	0.199*** (10.36)	0.190*** (11.76)	0.264*** (7.00)	0.247*** (10.76)	0.341*** (4.59)
Capex	-0.344*** (-23.06)	-1.083*** (-26.44)	-0.221*** (-11.85)	-0.305*** (-10.15)	-0.416*** (-16.53)	-0.709*** (-12.03)	-0.610*** (-17.06)	-1.245*** (-10.74)
Soe	-0.007*** (-4.28)	-0.041*** (-9.36)	-0.003 (-1.32)	-0.004 (-1.29)	-0.005* (-1.65)	-0.007 (-1.07)	-0.005 (-1.31)	-0.015 (-1.16)
Top1	0.001*** (22.65)	0.003*** (20.20)	0.001*** (15.72)	0.001*** (14.06)	0.001*** (13.82)	0.002*** (10.32)	0.001*** (8.39)	0.002*** (6.34)
Growth	0.005*** (5.87)	0.007*** (3.30)	0.003*** (4.15)	0.004*** (3.34)	0.004***(3.86)	0.007*** (2.70)	0.006*** (3.70)	0.012** (2.55)
Age	-0.001*** (-4.85)	-0.004*** (-9.84)	-0.000 (-1.56)	-0.000 (-1.50)	-0.001*** (-4.91)	-0.002*** (-3.97)	-0.001*** (-4.13)	-0.003*** (-3.52)
HHI	0.012(1.16)	0.032(1.08)	0.009(0.77)	0.008(0.41)	0.026*(1.67)	0.051(1.41)	0.039*(1.79)	0.137*(1.94)
Constant	0.326*** (18.86)	1.293*** (20.27)	0.181*** (8.86)	0.203*** (6.16)	0.470*** (17.06)	0.698*** (10.81)	0.798*** (20.35)	1.648*** (12.97)
Industy/Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	34,052	34,052	34,052	34,052	34,052	34,052	34,052	34,052
R-squared	0.303	0.205	——	——	——	——	——	——

Notes: The t-statistics are reported in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

4.5 Mechanism Analysis

4.5.1 Financing constraint mechanism

Financing constraints are one of the key factors affecting a company's cash holdings. Carbon risk essentially increases the degree of information asymmetry between companies and the outside world, thereby exacerbating the complexity of listed companies seeking credit support from financial institutions, deepening their financing difficulties, and highlighting the precautionary motivation of cash reserves. Drawing on the research of Fang and Hu (2023), adopts the *SA* index to measure the financing constraints of enterprises. The larger the absolute value, the more severe the financing constraint dilemma of the enterprise. In addition, this article uses the *WW* index instead of the *SA* index for robustness testing to analyze the impact of carbon risk on corporate financing constraints.

A large number of literature have verified the impact of financing constraints on corporate cash holdings (Opler et al., 1999), therefore, this article only reports the impact of carbon risk on financing constraints. As shown in columns (1) and (2) of Table 7, when the dependent variable is the *SA* index, the carbon risk coefficient is significantly positive at the 1% level; After replacing the dependent variable with the *WW* index, this conclusion remains unchanged, indicating that carbon risk will increase the degree of financing constraints for enterprises.

4.5.2 Transaction cost mechanism

Carbon risk will bring great uncertainty to the daily operations of enterprises. Increasing the demand for daily transactions and avoiding liquidity shortages, thereby increasing the transaction costs of enterprises, is another

important mechanism for carbon risk to increase the cash holdings of enterprises. In the process of increasing the amount of cash held by enterprises due to carbon risk, transactional motives may play a key role. This article will further analyze the effect of carbon risk on the transaction costs of enterprises. Following Zhang and Zhang (2021), using "period expenses/total assets" to measure the transaction costs of enterprises. Meanwhile, this article uses the sales expense ratio (*Fee*) to measure the transaction costs of enterprises for robustness testing, and analyzes the impact of carbon risk on enterprise transaction costs.

The impact of transaction costs on corporate cash holdings is evident (Miller and Orr, 1966), Therefore, this article only reports the results of carbon risk on transaction costs. As shown in columns (3) and (4) of Table 7, when the dependent variable is transaction cost, the Carbon Risk coefficient is significantly positive at the 1% level. After replacing the dependent variable with the sales expense rate (*Fee*), this conclusion remains unchanged.

Table 7. Mechanism Test of Financing Constraints and Transaction Costs

	(1)	(2)	(3)	(4)
	SA	*WW*	*Cost*	*Fee*
CarbonRisk	65.267***(8.26)	20.066***(4.13)	3.726***(3.06)	1.695***(2.68)
Size	0.100***(24.13)	-0.116***(-75.95)	-0.010***(-31.04)	-0.001***(-4.43)
Lev	-0.021(-1.16)	-0.225***(-18.94)	0.062***(25.60)	0.008***(4.35)
Zscore	0.015***(20.70)	-0.001**(-2.12)	0.000(0.85)	-0.000(-0.18)
ROA	-0.017**(-1.99)	0.186***(6.59)	0.029***(4.17)	0.064***(12.96)
Capex	-0.169**(-2.37)	-0.567***(-14.93)	-0.040***(-5.37)	-0.034***(-5.54)
Soe	-0.079***(-16.35)	0.006(1.37)	-0.005***(-6.48)	-0.006***(-9.87)
Top1	0.009***(30.11)	-0.000*(-1.81)	0.000**(2.33)	0.000***(4.83)
Growth	0.023***(12.56)	-0.006***(-3.56)	-0.003***(-10.13)	-0.002***(-7.65)
Age	0.050***(74.51)	-0.002***(-5.13)	-0.000(-1.43)	-0.000***(-4.82)
HHI	0.025(0.93)	0.050**(2.41)	0.007*(1.67)	-0.000(-0.01)
Constant	0.311***(2.76)	1.560***(39.38)	0.273***(30.75)	0.043***(6.82)
Industy/Year	Yes	Yes	Yes	Yes
Observations	34,052	34,052	34,052	29,668
R-squared	0.331	0.393	0.306	0.330

Notes: The t-statistics are reported in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

4.6 Further Analysis

We will further explore what factors play a moderating role in the process of carbon risk leading to an increase in corporate cash holdings.

Firstly, according to Balachandran and Nguyen's (2018) research, high carbon industries face higher carbon risks compared to low-carbon industries. On the one hand, in the face of strict environmental policies, high carbon industries may incur more carbon related management and accounting costs, such as clean-up costs, research and development costs, etc. (Clarkson et al., 2015). On the other hand, with the deepening of low-carbon awareness, investors may be more inclined towards low-carbon products (Pástor et al., 2021), making the financing constraints faced by high carbon emission companies more severe. Therefore, we predict that high carbon industries may face greater risks compared to low-carbon industries, which may further increase the company's cash holdings.

Secondly, carbon emissions trading policies may be one of the factors driving companies to reduce their cash holdings. As an environmental regulation, the core of carbon emission trading policy is to use carbon emissions as the trading object, regulate the capital flow of pilot enterprises through market mechanisms, promote low-carbon technology innovation, resource allocation optimization, and carbon emission reduction management of enterprises (Hu et al., 2020). The carbon emission trading policy may increase the costs related to the environment for enterprises and the cost of equity capital (Liu et al., 2024), and increase the environmental transformation pressure faced by local enterprises. In this situation, the cost and green investment of the enterprise will increase, therefore, the cash holdings of the enterprise may decrease.

Thirdly, previous studies have shown that the level of regional financial development can affect the degree of financing constraints faced

by enterprises (Ning et al., 2024). Firstly, financial development can reduce investment risks and transaction costs through diversified financial services, innovative financial products, and stable financial markets, providing more credit funds for enterprises (Rajan and Zingales, 1998). Secondly, financial development helps to improve market transparency, reduce information asymmetry, optimize capital allocation efficiency, and alleviate financing constraints for enterprises (Demirguckunt and Maksimovic, 1998). According to the above theoretical analysis, the higher the level of financial development in a region, the easier the financing constraints faced by enterprises may be, and thus their dependence on cash may be reduced.

Fourthly, as a regulatory tool, the public plays an effective supervisory role in the daily business activities of enterprises (Brown and Deegan, 1998). The production activities of enterprises need to comply with environmental legality. When enterprises harm the environmental welfare of the public, the public will force them to bear corresponding responsibilities (Luo and Wu, 2023). Therefore, in order to maintain legitimate operations in a low-carbon environment, enterprises will send a "legitimacy" signal to society by investing more funds in carbon risk management. That is to say, although carbon risk can increase a company's cash holdings, this situation will be suppressed when the public environmental concerns in the region where the company is located are high.

To test the moderating role of The above factors in the *CarbonRisk* affecting *Cash*, this paper constructs the following econometric model:

$$\begin{aligned} Cash = {} & \gamma_0 + \gamma_1 CarbonRisk + \gamma_2 Moderator + \gamma_3 CarbonRisk * Moderator \\ & + \gamma_4 Size + \gamma_5 Lev + \gamma_6 Zscore + \gamma_7 Capex + \gamma_8 Soe + \gamma_9 ROA + \gamma_{10} Top1 \\ & + \gamma_{11} Growth + \gamma_{12} Age + \gamma_{13} HHI + Year + \varepsilon \end{aligned} \tag{3}$$

$$\begin{aligned} Cash = {} & \gamma_0 + \gamma_1 CarbonRisk + \gamma_2 Moderator + \gamma_3 CarbonRisk * Moderator \\ & + \gamma_4 Size + \gamma_5 Lev + \gamma_6 Zscore + \gamma_7 Capex + \gamma_8 Soe + \gamma_9 ROA + \gamma_{10} Top1 \\ & + \gamma_{11} Growth + \gamma_{12} Age + \gamma_{13} HHI + Year + Industry + \varepsilon \end{aligned} \tag{4}$$

Among them, *Moderator* represents the four types of moderating variables mentioned above. (1) Enterprise characteristics (*High)*, this variable is a dummy variable that measures whether a company is a high carbon emission enterprise. If the company belongs to a high carbon emission enterprise, the value of *High* is 1, otherwise it is 0. This article refers to Wang et al. (2022) to construct this indicator. For details, please refer to the previous text. (2) Carbon emissions trading (*Pilot)*. Drawing on the research of Hu et al. (2023) , this variable is a dummy variable used to measure whether a company is in a carbon emission trading policy pilot city. If the company is in Guangdong, Hubei, Beijing, Shanghai, Tianjin, Shenzhen, Chongqing, and Fujian provinces and cities, the value is 1; otherwise, it is 0. (3) Financial Development Level (*Finance*). This variable is a continuous variable that measures the level of regional financial development. Drawing on the construction method of the regional financial development level indicator proposed by Ning et al. (2023), for a given province, this article measures its regional financial development level by the proportion of its total RMB deposit and loan balance to GDP. (4) Public environmental attention (*Attention*). Which is a continuous variable used to measure the level of public environmental attention in a region. Referring to the research of Tao et al. (2024), this article uses Python tools and the keyword search function of Baidu search engine to collect daily search volume data for the keywords "environmental pollution" and "haze" from the public in various cities across the country from 2011 to 2021. The index is constructed by adding them up and taking the natural logarithm. Among them, regulatory variable 1 uses Eq. (3) for regression, and the remaining regulatory variables use Eq. (4) for regression, and the results are presented in Table 8 below.

Table 8. The Impact of Carbon Risk on Corporate Cash Holdings: Various Moderating Effects

	(1) *Cash1*	(2) *Cash2*	(3) *Cash1*	(4) *Cash2*	(5) *Cash1*	(6) *Cash2*	(7) *Cash1*	(8) *Cash2*
CarbonRisk	-16.024***	-32.627***	8.891***	36.079***	9.867***	38.507***	-16.905***	-23.459***
	(-12.14)	(-9.50)	(3.52)	(4.86)	(3.56)	(4.87)	(-5.75)	(-2.85)
High	-0.038***	-0.077***(-						

	(-17.17)	14.52)						
CarbonRisk * *High*	15.623*** (8.69)	35.045*** (7.85)						
Pilot			0.013***(7.62)	0.037***(7.78)				
CarbonRisk * *Pilot*			-4.492*** (-2.66)	-12.256*** (-2.84)				
Finance					0.004***(10.01)	0.011***(9.86)		
CarbonRisk * *Finance*					-0.611* (-1.68)	-1.608* (-1.75)		
Attention							0.000*** (10.10)	0.000*** (8.33)
CarbonRisk * *Attention*							-0.009*** (-2.94)	-0.013* (-1.82)
Size	-0.003*** (-4.00)	-0.011*** (-5.94)	-0.001* (-1.83)	-0.010*** (-5.07)	-0.002*** (-2.64)	-0.011*** (-5.67)	-0.013*** (-13.42)	-0.037*** (-14.86)
Lev	-0.185*** (-34.78)	-0.411*** (-27.15)	-0.184*** (-33.44)	-0.406*** (-25.95)	-0.228*** (-31.80)	-0.521*** (-26.69)	-0.007 (-1.15)	-0.014 (-1.12)
Zscore	0.004*** (21.20)	0.012*** (17.59)	0.004*** (19.76)	0.011*** (16.42)	0.001** (2.41)	0.002*** (2.85)	0.001** (2.07)	0.004** (2.31)
ROA	0.156*** (13.67)	0.321*** (10.56)	0.179*** (15.54)	0.387*** (12.57)	0.191*** (16.36)	0.418*** (13.41)	0.005** (2.44)	0.017*** (3.78)
Capex	-0.395*** (-27.40)	-1.111*** (-29.78)	-0.342*** (-22.93)	-0.998*** (-26.03)	-0.356*** (-23.59)	-1.032*** (-26.60)	-0.301*** (-19.11)	-0.913*** (-23.13)
Soe	-0.007*** (-4.10)	-0.016*** (-3.90)	-0.007*** (-4.37)	-0.023*** (-5.36)	-0.008*** (-4.89)	-0.025*** (-5.86)	-0.019*** (-10.71)	-0.050*** (-10.98)
Top1	0.001*** (20.66)	0.002*** (15.98)	0.001*** (22.92)	0.002*** (17.94)	0.001*** (23.07)	0.002*** (18.28)	0.002*** (27.92)	0.003*** (23.01)
Growth	0.005*** (6.73)	0.013*** (6.40)	0.005*** (5.81)	0.011*** (4.85)	-0.000 (-1.42)	-0.000 (-0.51)	0.003*** (4.00)	0.008*** (3.45)
Age	-0.001*** (-7.86)	-0.004*** (-10.82)	-0.001*** (-5.00)	-0.003*** (-8.85)	-0.000*** (-3.33)	-0.003*** (-7.25)	-0.001*** (-8.01)	-0.004*** (-11.02)
HHI	0.001(0.22)	0.013(0.83)	0.013(1.28)	0.029(1.00)	0.011(1.10)	0.024(0.85)	0.019*(1.79)	0.042(1.41)
Constant	0.391*** (25.93)	0.932*** (21.99)	0.292*** (14.96)	0.708*** (12.65)	0.331*** (16.43)	0.805*** (14.00)	0.577*** (19.13)	1.366*** (17.39)
Industy/Year	No/Yes	No/Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	34,052	34,052	34,052	34,052	34,050	34,050	34,052	34,052
R-squared	0.274	0.238	0.305	0.264	0.294	0.253	0.202	0.183

Notes: The t-statistics are reported in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

In Table 8, the coefficient of *CarbonRisk * High* in column (1) is significantly positive at an average level of 1%, indicating that high carbon emitting enterprises hold more cash compared to low-carbon emitting enterprises when facing carbon risks; The coefficient of *CarbonRisk * Pilot* in column (2) is significantly negative at an average level of 1%, indicating that in the process of carbon risk leading to an increase in cash holdings of enterprises, being in a carbon emission trading city plays a restraining role; The coefficient of *CarbonRisk * Finance* in column (3) is significantly negative at an average level of 10%, indicating that when a company is located in a region with a higher level of financial development, it will suppress its cash reserves when dealing with carbon risks; The coefficients of the interaction term *CarbonRisk * Attention* in column (4) are significantly negative at the 1% and 10% levels, respectively. This result indicates that in the process of carbon risk causing an increase in corporate cash holdings, companies located in areas with high public environmental concern will suppress this phenomenon.

5. Conclusions and Policy Recommendations

Against the backdrop of increasingly severe climate change issues, reducing corporate carbon emissions and assisting in corporate green transformation have become important research topics at present. Based on the sample of A-share listed companies in Shanghai and Shenzhen from 2011 to 2021, this paper discusses the impact mechanism of carbon risk on corporate cash holdings and the difference

in effects under different scenarios. The study finds that there is a significant positive correlation between carbon risk and corporate cash holdings, that is, the greater the carbon risk, the higher the level of corporate cash holdings. After excluding endogenous problems and key indicator measurement errors, the research conclusion is still valid. Mechanism testing shows that when carbon risk is high, companies will hold more cash based on preventive and transactional motives to cope with more difficult financing constraints and higher transaction costs. Further analysis shows that compared to low-carbon emission enterprises, carbon risk has a more significant positive effect on cash holdings in high carbon emission enterprises; In carbon emission trading cities, regions with high levels of financial development, and areas with high public environmental awareness, the effect of carbon risk on the increase of corporate cash holdings will be suppressed.

Based on the research findings of this article, the following policy recommendations are proposed:

Firstly, as a policy provider, the government should take environmental regulation as the starting point, establish and improve the system for green economic development, perfect the carbon information disclosure system, and strengthen carbon emission supervision. Government departments should provide relevant publicity and education, policy guidance, and financial subsidies for enterprises, actively provide conditions for enterprises to seek investment and financing opportunities, and improve resource allocation efficiency. At the same time, we will strengthen the guidance of financial institutions to provide green credit to enterprises, accelerate the development of new quality productivity, and promote the green and sustainable development of the Chinese economy.

Secondly, as the main driving force, financial institutions should provide specialized green finance products and services to meet the financing needs of enterprises' green transformation, strengthen green investment guidance, encourage more social capital to flow into green industries and projects, and assist enterprises in their green transformation. At the same time, financial institutions should cooperate with government departments and industry associations to jointly develop green finance standards and norms, providing a better market environment for the green transformation of enterprises.

Thirdly, as important participants, enterprises should shift from being passive to being proactive and establish a carbon risk management system to assess, monitor, and manage their carbon assets. At the same time, enterprises should reduce their use of fossil fuels, actively disclose carbon emission information, strengthen employee green awareness training, and use green credit funds reasonably to reduce their carbon risks, accelerate green transformation, and achieve sustainable development.

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