Utrecht University

School of Economics

Master Thesis U.S.E.

The influence of carbon risk on cost of capital:
Empirical evidence from China[1]

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Date: 28th June 2024

[1] Acknowledgements: I acknowledge the helpful comments and suggestions from my supervisor and second supervisor.

Contents

Abstract

This study investigates the impact of carbon risk on corporate financing, with a particular focus on the cost of equity (CoE), cost of debt (CoD), and weighted average cost of capital (WACC) of Chinese companies. This study uses a sample of 499 companies in the S&P 500 China Index from 2015 to 2022 and uses carbon emissions as a proxy for carbon risk. The results show that the higher the carbon emissions, the lower the cost of capital (including CoE and CoD). In addition, carbon emissions have no significant impact on systemic risk, while ownership of high-emitting companies tends to be more dispersed. This study highlights the uniqueness of China's financial market, namely that environmental risks have not been fully incorporated into financial assessments. These insights highlight the need to strengthen environmental supervision and promote green finance in China to better internalize carbon risks and achieve sustainable development.

JEL-codes: G30, C12

Key words: Carbon Risk, Carbon Emissions, Cost of Capital, Cost of Equity, Cost of Debt, Panel Data

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1 Introduction

Since global warming is becoming a more significant issue due to greenhouse gas emissions from human activity, governments, corporate leaders, institutional investors, and the general people have come to realize how urgent it is to address climate change. Mitigation policy, as one of the important measures to deal with climate change, may bring transition risks to enterprises. Future cash flow concerns will depend, in particular, on how much carbon regulation and market changes would increase the cost of producing carbon-intensive goods. (Ansar et al., 2013). In financial markets and corporate finance, carbon emission related transition risks are called "carbon risks" and have become an increasing concern for investors (Dyck et al., 2019; Krüger et al., 2020; Trinks et al., 2022). The mainstream view is that the impact of carbon risk on a company's financial performance is reflected in the increase in cost of capital (Chava, 2014), specifically including the cost of equity capital (CoE) (Trinks et al., 2022) and the cost of debt capital (CoD) (Caragnano et al, 2020).

President Xi Jinping of China made a commitment on September 22, 2020, to attain carbon neutrality by 2060[2]. This commitment entails stricter guidelines for attaining carbon emissions zero and reaching the carbon peak as soon as feasible. China is required to take the lead in lowering carbon emissions and bolstering the response to global climate change because it is one of the biggest carbon emitters in the world, contributing approximately 30% of total

[2] https://www.climatechangenews.com/2020/09/22/xi-jinping-china-will-achieve-carbon-neutrality-2060/

emissions (Zhang, 2010; Xu et al., 2022). The motivation for this study is to provide strategic recommendations for companies by examining the impact of carbon risk on the financial costs of Chinese enterprises. This approach not only aids Chinese companies in addressing climate risk management but also promotes global environmental sustainability. Additionally, the research findings can offer insights into the current state of sustainable development in China's financial market.

This study examines the extent to which investors in the financial markets demand a premium for owning stock in companies that produce a lot of emissions, increasing these companies' cost of capital (including CoE and CoD). This article investigates 499 companies in S&P 500 China from 2015 to 2022, using the carbon emission data sources from Refinitiv Eikon. Furthermore, this study also uses the FactSet database as the source for "free float percentage" and "institutional ownership" data.

The results show that, contrary to common expectations, higher carbon emissions are associated with lower capital costs, including both CoE and CoD. Additionally, reducing carbon emissions does not currently affect the overall risk profile (systematic risk) of Chinese enterprises. It was also observed that high carbon-emitting firms tend to have more dispersed ownership, and CO2 emissions do not significantly impact the proportion of institutional ownership. These insights highlight the unique characteristics of the Chinese financial market, where environmental risks are not yet fully integrated into financial assessments.

Therefore, this study makes several significant contributions to the field of corporate finance and environmental economics. Firstly, it extends empirical research on the financial implications of environmental performance and corporate sustainability, offering new insights

into the relationship between corporate carbon emissions and the cost of capital in the Chinese context. Secondly, by focusing on the impact of carbon risk on the financing costs of Chinese listed companies, this study fills an important empirical gap, providing evidence from a region that has been underrepresented in previous research. Thirdly, the research employs a comprehensive analytical approach, using the cost of equity as the main moderator variable while also examining the cost of debt and the overall cost of capital. This holistic analysis provides a more detailed understanding of how carbon risk affects various components of capital costs. Lastly, this study adds to the body of knowledge by investigating two potential future pathways via which carbon risk could increase in risk (Dam and Scholtens, 2015), specifically systemic and non-systematic risk factors.

This paper proceeds as follows. Section 2 introduces existing literatures. Section 3 develops the main hypotheses from theories. Section 4 outlines the data and methods. The empirical analysis and results are presented in Section 5. Section 6 discusses the results and concludes.

2 Literature Review

2.1 Definition of Carbon Risk

Within the field of corporate finance, carbon risk primarily relates to the effects of society's transition to a sustainable economy on corporate value. This transition is driven by significant changes in laws, regulations, marketplaces, technology, and reputation (Dyck et al., 2019; Krüger et al., 2020; Trinks et al., 2022). Carbon risk is a transition risk among climate risks, rather than the direct physical risk caused by climate change to a company's economic

activities (for example, rising sea levels will cause damage to the production equipment of companies close to the sea).

Several studies define carbon risk in various ways. Hoffmann and Busch (2008) argue that, generally speaking, carbon risk is the term used to describe any business risk connected to the usage of fossil fuels or global warming. According to Ehlers et al. (2022), carbon risk is the possible financial consequence of tighter regulations pertaining to carbon emissions. As defined by Trinks et al. (2022), carbon risk is the commercial and regulatory risk brought on by high-emitting businesses as they switch from high-to low-carbon production systems. In the past, companies with high carbon emissions could shift the costs of these emissions to external parties, thus avoiding exposure to carbon risk. However, carbon risk is becoming a significant factor in business choices as a result of the increasing implementation of measures aimed at decreasing carbon emissions and the requirement for firms to internalize the cost of carbon emissions. (Chava, 2014).

Carbon emissions are employed to measure how carbon-intensive a company's production methods are. The primary sources of carbon emissions include the use of refrigerant gases, agricultural activities, deforestation, industrial production, and the burning of fossil fuels. According to the greenhouse gas (GHG) standard, a company's operations and economic activities determine whether carbon emissions are classified as direct or indirect. Direct emissions (Scope 1) occur from burning fossil fuels or processing minerals and chemicals from sources owned or controlled by the firm. Indirect emissions contain those from purchased power, steam, or heat (Scope 2) and extend to emissions from the full value chain, including product consumption, material purchases, outsourced services, and waste disposal (Scope 3).

As a result of shifting regulations and public expectations, companies now need to account for carbon risk in their strategic planning. This requires a comprehensive approach to managing carbon risk, highlighting its significance and urgency in contemporary business practices. In summary, comprehending the various definitions and sources of carbon risk is critical to appreciating its impact on corporate finance.

2.2 Carbon Risk and Cost of Capital

In academic research examining the impact of carbon hazards on capital costs, two factors are typically considered: the cost of equity (CoE) and the cost of debt (CoD). However, few scholars analyze the impact of a firm's environmental conditions on both its equity and debt capital costs simultaneously. According to Sharfman and Fernando (2008), enhancing environmental risk management can lower the cost of capital. Their study on 267 US businesses argues that their empirical data offers an alternative interpretation of the relationship between the environment and economic performance, which has traditionally been dominated by the notion that improved economic performance results from better resource utilization. Using the Implied Cost of Capital (ICC) derived from analyst earnings forecasts, Chava (2014) found that investors expect significantly higher returns from stocks excluded from green screening, such as those involved in hazardous chemicals, high emission levels, and sustainability issues, compared to businesses without environmental challenges. The research findings indicate that exclusive socially responsible investments and environmentally sensitive loans can significantly impact the cost of equity and debt capital for the firms involved (Chava, 2014).

In addition, a growing amount of research has examined the relationship between environmental performance and a company's overall capital structure. For example, Goss and

Roberts (2011) noted that companies with poor environmental performance typically incur higher debt costs as a result of lenders having to take on greater environmental risks; on the other hand, Eccles et al. (2014) found that companies with excellent environmental performance can both lower financing costs and increase their overall market value. However, some studies have reached the opposite conclusion. Delmas and Nairn-Birch (2011) pointed out that initiatives to reduce carbon emissions may lead to higher capital costs because they require large initial investments and operating expenses. Clarkson et al. (2011) also pointed out that while reducing carbon emissions has a positive impact on the environment, it may also lead to short-term financial pressures and higher capital costs. Jiraporn et al. (2014) found that environmental initiatives affect cash flow and financial flexibility, leading to higher capital costs.

Therefore, when formulating strategic plans, enterprises should fully consider the dual impact of carbon risk management on capital costs in order to balance and optimize environmental performance and economic performance. While these studies emphasize the importance of carbon risk management in reducing capital costs, they also illustrate that there may be some negative effects. Effective environmental risk management can help enterprises reduce financing costs, improve market competitiveness, and achieve long-term sustainable development. However, there are exceptions. Some studies have shown that efforts to reduce carbon emissions may lead to increased capital costs because of higher initial investment and operating expenses, as well as short-term financial pressures and capital market reassessment of corporate risks. Understanding the relationship between carbon risk and capital costs is essential to understanding the impact of environmental performance on corporate finance. This

is particularly relevant to this paper because it lays an empirical foundation for studying the financial impact of carbon emissions of listed companies in China. This understanding is the basis for the analysis and recommendations of this paper, which emphasizes the key role that carbon risk management plays in promoting sustainable development in financial markets. By studying the relationship between carbon risk and debt and equity costs, this study aims to shed light on the broader financial impact of environmental sustainability in the Chinese context. This study fills a major gap in the literature and provides insightful information for business and policy initiatives that can help support the sustainable development of China's financial industry and, in turn, contribute to global sustainable development.

2.2.1 Carbon Risk and Cost of Equity Capital

Some existing studies have examined the difference in investment returns between companies that emit CO2 and those that do not. Typically, investors want a return that is roughly equivalent to the level of risk they think they can accept. High-emission enterprises face growing regulatory and market risks as a result of the low-carbon shift throughout the economy. Financial investors seek compensation for these risks, which drives up the cost of equity for these companies (Trinks et al., 2022). Numerous empirical researches provide credence to this opinion. Oestreich and Tsiakas (2015) observed a carbon premium in the German equity market, with companies that obtained free carbon subsidies outperforming others. According to research by Bolton and Kacperczyk (2021), higher stock returns were also shown by American companies with more carbon emissions (and variations in emissions). This implies that the carbon premium cannot be explained by changes in unexpected profits or other widely recognized risk factors.

But there is not always proof of a carbon premium. When Bernardini et al. (2019) looked at European electricity companies, they discovered that between 2012 and 2016, positive returns adjusted for risk (alpha) were generated by investment portfolios comprising long-held, low-carbon firms and short-held, high-carbon enterprises.

A different set of research looked directly at the relationship between CoE and carbon risk. For instance, Kim et al. (2015) found a positive correlation between the cost of equity capital and carbon intensity, an indicator of carbon risk, using empirical analysis on a sample of 379 Korean enterprises from 2007 to 2011. This analysis was based on GHG emission data. Additionally, they found no difference in how carbon intensity affected the cost of equity capital between companies that voluntarily disclosed non-financial reports and those that did not. Trinks et al. (2022) showed in their study that the higher the carbon emission intensity, the higher the company's CoE, especially in industries with large emissions and industries subject to carbon pricing laws. In contrast, other studies have shown that efforts to reduce carbon emissions actually lead to higher equity costs. For example, Benlemlih and Girerd-Potin (2017) found that high upfront costs incurred to reduce carbon emissions may lead to higher equity costs because financial uncertainty and risk premiums are greater for investors. Liesen et al. (2017) also concluded that strict environmental regulations and compliance costs in the European market led to higher equity costs for companies that actively reduced their carbon footprint. Graham et al. (2005) pointed out that the large initial investments required for environmental technologies and upgrades can cause financial pressures, thereby increasing equity costs.

In summary, scholars in this field have used a variety of methods and indicators to study

whether investors consider carbon risk. Although most studies show that carbon risk significantly increases the cost of equity, there are still some differences in the results.

As concerns about climate change spread around the world, the impact of carbon risk on the cost of equity capital of companies has become increasingly significant. For companies, it is important to consider not only current carbon emissions, but also potential regulations for future carbon pricing and market reactions that may shift. In order to optimize capital structure and maintain competitive advantage, it is necessary to incorporate carbon risk management into strategic planning. In the future, research should focus on how the cost of equity capital in different markets and industries is affected by carbon risks, and how to reduce these potential risks by using effective carbon management techniques.

2.2.2 Carbon Risk and Cost of Debt Capital

Most studies on the relationship between debt costs and carbon risk are based on agency theory. According to the theory, agency risk may arise when borrowers and lenders have different expectations about carbon-intensive projects. More precisely, lenders will bear most of the costs of reducing carbon emissions, while shareholders will earn most of the profits from successful projects with high carbon footprints. Therefore, lenders must charge higher interest rates to companies with significant carbon risks to offset their increased default risk, reputational damage, and loss of unpredictable cash flows.

Many of the larger studies have explored the relationship between carbon risk and the cost of debt (CoD). For example, using data from the EuroStoxx 600 companies, Caragnano et al. (2020) found that lenders offset the impact of borrowers' greenhouse gas (GHG) emissions on their future cash flows (changes in borrowers' cash flows affect their ability to repay debts to

lenders) by charging higher debt financing fees to companies with higher carbon intensity. They also found that reducing carbon emissions on COD has a positive impact on both high- and low-emitting companies. Similarly, Palea and Drogo (2020) examined the relationship between debt financing costs and carbon emissions in a sample of Eurozone companies from 2010 to 2018. The findings showed that when carbon emissions rise, lenders want a higher risk premium. By combining borrower carbon intensity data from 567 distinct enterprises located in 31 countries with syndicated loan data, Ehlers et al. (2022) discovered a notable "carbon premium" following the Paris Agreement. Moreover, the loan risk premium linked to carbon intensity is seen in a number of industries and is more comprehensive than the risk premium produced by stranded assets resulting from the use of fossil fuels or other carbon-intensive industries alone.

An additional category of research is based on empirical investigations conducted at the national level. In their 2018 study, Jung et al. examined a sample of loan costs and carbon risk for Australian enterprises from 2009 to 2013. They found that for companies with higher levels of carbon awareness, the impact of carbon risk on debt costs is mitigated if not completely reversed. Zhou et al. (2018) conducted an empirical study from 2011 to 2015 on a sample of 191 Chinese A-share listed businesses participating in high-carbon industries, and found a U-shaped correlation between carbon risk and debt financing costs in China. Additionally, they think that positive media attention could be negatively moderating this association.

Furthermore, lowering carbon emissions has been linked to higher loan capital costs, according to certain research. Chava (2014) demonstrated, for instance, that although lowering carbon emissions enhances environmental performance, the high expenses of environmental

expenditures and technology advancements may lead to higher debt payments. According to Goss and Roberts (2011), businesses that actively reduce their carbon footprint incur greater financing costs as a result of the strict environmental rules and expensive compliance costs.

All in all, researchers who have studied the relationship between carbon risk and debt costs using a variety of criteria have mostly reached the same conclusion: Companies facing higher carbon risk also have higher loan costs. Nevertheless, another conclusion has also been confirmed: the large financial expenditures required for environmental upgrades in an attempt to reduce carbon emissions can sometimes lead to higher debt payments.

The effect of carbon risk on capital costs is often investigated in academic research using the cost of debt and the cost of equity. There are disparities in the results, even though numerous research has shown that carbon risk raises CoE, CoD, and total capital costs. This is due to the fact that investments in the environment might have large upfront costs and financial uncertainty. To cut carbon emissions, for instance, significant investments in new technology and procedures are frequently needed, which raises short-term debt and equity costs. Determining the financial effects of carbon emissions on Chinese enterprises requires an understanding of this dual impact. This serves as the cornerstone of the thesis, which examines how capital costs are impacted by carbon risk within the framework of Chinese businesses. Using data from China, this study attempts to confirm the link between carbon risk and cost of capital (both equity and loan expenses). Although this topic has been studied extensively worldwide, the Chinese market offers particular environmental and policy circumstances. This study offers fresh data to comprehend the particular expressions and consequences of carbon risk in Chinese companies' loan financing.

3 Theoretical Framework and Hypothesis Development

For two key reasons, a company's cost of capital is an important factor in determining its valuation. It first shows the expected rate of return that investors will receive for their investment in the company. The greater the rate of return that investors require in exchange for lending money to the business, the more expensive financing will be for the enterprise. The rate at which investors discount the company's future cash flows is known as the cost of capital, secondly. The present value of future cash flows for the corporation decreases as the cost of capital increases. Companies with lower capital costs are therefore valued higher than those with greater capital costs, all other things being equal, making them more appealing to investors.

In the finance and economics literature and practice, a widely debated issue is whether the capital markets reward corporate sustainability (Heinkel et al., 2001; Ferrell et al., 2016). Conventional theory holds that any activity not aimed at corporate value will eventually be destroyed by generating value for shareholders. (Berle and Means, 1933; Jensen and Meckling, 1976). Nonetheless, current theoretical research indicates a good correlation between a company's financial health and sustainability (Dam and Scholtens, 2015; Ferrell et al., 2016). One important underlying mechanism is that, similar to insurance, business sustainability protects cash flow (Trinks et al., 2022). Companies can lessen their exposure to and the effects of regulatory, reputational, and litigation-related risks by attending to the concerns of a wider range of stakeholders (Sharfman and Fernando, 2008). As a result, in the capital markets, sustainability (i.e. low carbon risk) can be rewarded through lower discount rates applied by investors to a company's cash flows, effectively reducing the cost of capital.

According to financial theory, systematic risk and screening are the two ways that carbon intensity may impact CoE (Trinks et al., 2022). Firstly, since the shift to high-carbon manufacturing processes would affect the whole economy, the market ought to compensate such performance improvements with lower CoE if the reduction in systematic risk brought about by improved carbon risk results in better financial performance. The second mechanism's theoretical foundation is based on the notion that investors should maximize utility for non-financial issues in addition to the mean and variance of returns (Fama and French, 2007). According to Heinkel et al. (2001) models, "green" investors only put their money into businesses that have effective environmental risk management, or that are more compliant. In contrast, "non-green" investors have little interest in environmental risk management and may not even participate in "green" businesses. As their shareholders grow, businesses with minimal carbon risk will have lower equity cost of capital (Sharfman and Fernando, 2008). Therefore, the following hypotheses will be tested in this study:

Hypothesis 1. *The CoE of Chinese enterprises is lower when their emissions of CO2 equivalent are reduced.*

Specifically, the expectation that low-emission enterprises have lower systemic risk can be supported by the following key arguments. First, low-emission enterprises generally prioritize environmental, social, and governance (ESG) factors, which have been shown to be associated with lower systemic risk. Research shows that enterprises with high ESG scores exhibit lower market volatility and risk premiums (Henisz et al., 2019). These enterprises'

commitment to environmental protection and sustainable development helps reduce the risks associated with regulatory changes and improves their reputation among investors. Second, low-emission enterprises generally exhibit higher operational efficiency and innovation capabilities. According to Porter and van der Linde (1995), environmental regulations can stimulate innovation, thereby improving resource utilization and competitiveness. These innovations reduce production costs and create new market opportunities, leading to reduced economic uncertainty and market volatility. Third, low-emission enterprises generally benefit from favorable financing conditions. Goss and Roberts (2011) found that enterprises with better environmental performance incur lower debt financing costs because lenders perceive them as having lower long-term risks and higher financial stability. Fourth, the development of the green bond market provides low-emission companies with new financing channels, further reducing their capital costs (Flammer, 2020). Finally, investors' increasing attention to environmental sustainability makes low-emission companies more attractive in the capital market. Eccles et al. (2014) found that companies with excellent environmental performance not only reduced financing costs, but also increased their overall market value because investors believed that these companies would be more sustainable and resilient in the future, thereby reducing risk premiums. Therefore, this study proposes the following sub-hypotheses:

Hypothesis 1a. *The systematic risk of Chinese enterprises is lower when their emissions of CO2 equivalent are reduced.*

The expectation that equity ownership is more widely dispersed among low-emission

companies is supported by several key arguments and literature findings. Firstly, companies that reduce carbon emissions are often seen as more socially responsible and sustainable, attracting institutional and retail investors who prioritize Environmental, Social, and Governance (ESG) standards in their investment choices. Dhaliwal et al. (2011) found that companies with higher levels of Corporate Social Responsibility (CSR) disclosure attract more institutional investors, leading to more dispersed ownership. Secondly, low-emission companies often achieve better financial performance and stability due to improved operational efficiency and innovation (Porter & van der Linde, 1995), making them less risky and more appealing to various investors, thus promoting a more dispersed ownership structure. Thirdly, regulatory pressures and market trends increasingly favor sustainable practices. Eccles et al. (2014) found that companies with strong sustainable practices tend to have higher valuation multiples and better long-term performance, making them attractive to a diverse range of investors. Lastly, the increasing popularity of green financial instruments, such as green bonds, further enhances the appeal of low-emission companies to a broad base of investors, as noted by Flammer (2021). Therefore, this study proposes the second sub-hypothesis as follows:

Hypothesis 1b. *The share ownership of Chinese enterprises is more dispersed when their emissions of CO2 equivalent are reduced.*

If the improvement in carbon risk reduces the default risk condition exhibited by companies in the debt market, then these debt markets should, in turn, reward the improved risk condition by lowering the required interest rates and subsequently reducing the cost of debt

capital. This leads to our second prediction:

Hypothesis 2. *The CoD of Chinese enterprises is lower when their emissions of CO2 equivalent are reduced.*

Most publicly traded companies typically use both debt and equity to finance themselves. As a result, the total cost of capital for the company is given by the weighted average of its debt and equity costs, known as the Weighted Average Cost of Capital (WACC):

$$r_{WACC} = \left(\frac{E}{D+E}\right) CoE + \left(\frac{D}{D+E}\right) CoD(1-T), \quad (1)$$

where

E = market value of the company's equity;

D = market value of the company's debt;

CoE = the company's cost of equity capital;

CoD = the company's cost of debt capital; and

T = the company's rate of corporate taxation.

Combining the above assumptions leads to a comprehensive prediction that improvements in carbon risk will reduce a company's WACC (See Equation (1)). This leads to the next hypothesis of this article:

Hypothesis 3. *The WACC of Chinese enterprises is lower when their emissions of CO2 equivalent are reduced.*

This paper will systematically analyze and investigate each prediction that links carbon risk with capital costs in the following sections.

4 Data and Methodology

4.1 Sample and Dataset

This paper needs a dataset of businesses that satisfies two requirements in order to verify the aforementioned hypothesis: firstly, the companies must be sufficiently large to be publicly traded and regularly access capital markets for accurate estimation of their cost of capital; secondly, the companies must disclose carbon emission data to measure their carbon risk. The S&P 500 China Index dataset meets these criteria as it comprises 500 of the largest and most liquid Chinese companies, representing a diverse range of industries in the broader Chinese stock market. Furthermore, not all listed companies in China currently disclose carbon emission data, particularly those listed on the mainland, but a significant portion of the constituents (499 companies) covered by the S&P 500 China Index dataset do disclose such data.

Considering that the companies in this dataset are listed on the Shenzhen, Hong Kong, and Shanghai stock exchanges, some companies are listed on multiple exchanges, resulting in an initial sample of 1,116 companies. Firstly, the Screening dataset reports carbon emission data for 546 companies. Secondly, for companies listed on multiple exchanges (a total of 47 companies), their disclosed data is consistent across all exchanges. Since these companies are all listed on the Hong Kong Stock Exchange, their data from this exchange was uniformly selected. The final sample consists of 499 listed companies in China. These companies belong

to various industries, including Real Estate Services, Online Services, Biotechnology & Medical Research, Iron & Steel, Natural Gas Utilities, among others, totaling 97 industries.

4.2 Variables Measurement

4.2.1 Dependent Variables

The Capital Asset Pricing Model (CAPM) estimates the expected investor return on holding corporate equity, which is equal to the CoE:

$$CoE_i = r_F + \beta_i(r_M - r_F) \quad (2)$$

where

r_F = the risk-free rate;

r_M = the return on the market portfolio; and

$\beta_i = \frac{Cov(CoE, r_M)}{Var(r_M)}$ measures the firm's systematic risk.

According to the database (Eikon), the estimation window and data frequency for calculating the CAPM Beta and CoE are defined as follows. The CAPM Beta is calculated based on data availability, following a prioritized sequence of look-back periods. The priority order for calculating Beta is as follows: 90-day daily returns, 180-day daily returns, 2-year weekly returns, 3-year weekly returns, and 5-year monthly returns. This approach ensures that the Beta reflects a relatively stable measure of systematic risk based on the best available data.

Similarly, the CoE for each year is calculated using the CAPM model, where the Beta applied in the calculation is based on the prioritized sequence as described above. This method aligns with the definition provided in the data item library, where the CoE is calculated by multiplying the equity risk premium of the market with the Beta of the stock plus an inflation-adjusted risk-free rate. This consistent use of the best available Beta data for CoE calculations

provides a reliable and robust measure of the company's cost of equity capital.

The cost of debt (CoD) represents the company's marginal borrowing cost. It is calculated by adding the weighted cost of short-term debt and the weighted cost of long-term debt based on the 1-year and 10-year points of an appropriate credit curve. The data is sourced from the Refinitiv Eikon database. The weighted average cost of capital (WACC) is calculated according to formula (1), which reflects the cost ratio of various types of capital in the company's financing structure. Shareholder concentration is measured using the indicator of the FactSet database, which returns the percentage of outstanding shares in the total outstanding shares in the month. This study selects data from December of each year from 2015 to 2022 as the shareholder concentration indicator for that year. The higher the percentage of outstanding shares, the more shares can be freely circulated in the market, and the lower the shareholder concentration. Institutional shareholding data also comes from the FactSet database, which indicates the percentage of securities held by institutions in the total market value. Analyzing the proportion of institutional investors' holdings helps to understand the company's equity structure and the influence of institutional investors.

4.2.2 Carbon Risk

This study uses company-level carbon emissions data from Refinitiv Eikon as a proxy for carbon risk. The specific data used is "Total CO2 Equivalent Emissions". This metric includes the total annual emissions of carbon dioxide (CO2) and its equivalent, measured in tonnes. Relevant gases included are CO2, methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorinated compounds (PFCs), sulfur hexafluoride (SF6), and nitrogen trifluoride (NF3). The total CO2 emissions consist of direct (Scope 1) and indirect (Scope 2) emissions.

4.2.3 Control Variables

Several commonly used variables to explain company characteristics are also used as control variables in this article. These variables include size (defined as the natural logarithm of total assets), leverage (measured as total debt over total assets * 100%), and book-to-market ratio (defined as the book value of common equity divided by its market value). According to related studies (Trinks et al., 2022; Chava, 2014; El Ghoul et al., 2011; Sharfman and Fernando, 2008), the collection of control variables is appropriate. Definitions of all relevant variables can be found in Appendix Table 1.

4.3 Descriptive Statistics and Data Processing

According to the descriptive statistics (see Table 1), the sample data spans from 2015 to 2022. The CO2 emissions data reveals significant variation among enterprises. The average Weighted Average Cost of Capital (WACC) is 8.34%, the cost of equity (CoE) is 10.5%, and the cost of debt (CoD) is 2.91%, indicating differences in capital costs. The average Beta is 1.071, suggesting slightly higher systematic risk than the market average. The average Book-to-Market Ratio is 0.803, the firm size is 15.68, and the leverage is 0.240, highlighting significant differences in size and financial leverage. The average percentage of floating shares (shareholder concentration) is 0.553, institutional ownership averages 0.187, indicating relatively dispersed ownership and a significant role of institutional investors. These statistics provide a solid foundation for subsequent empirical analysis.

Table 1: Descriptive statistics

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
Year	3,992	2,019	2.292	2,015	2,022

CO2 emissions	1,958	1.182e+07	1.755e+08	39.40	7.631e+09
WACC	3,487	0.0834	0.0309	-0.0292	0.296
CoE	3,487	0.105	0.0324	-0.0956	0.354
CoD	3,487	0.0291	0.0145	-0.00349	0.102
Beta	3,487	1.071	0.434	-1.368	4.358
Book to Market Ratio	3,440	0.803	0.899	-1.150	14.62
Size	3,839	15.68	1.924	9.464	22.47
Leverage	3,839	0.240	0.227	0	3.664
Free float percentage	3,238	0.550	0.232	0	1
Institutional ownership	3,482	0.187	0.149	0	0.918
Company_code	3,992	250	144.1	1	499

4.4 Methods

4.4.1 Hypothesis 1

The following panel regression with fixed factors is used in this paper to examine if carbon intensity has a substantial impact on CoE:

$$CoE_{i,t} = \alpha + \beta\ Carbon\ emissions_{i,t-1} + \gamma' Controls_{i,t-1} + \Lambda + \mu_i + \varepsilon_{i,t}, \qquad (3)$$

where $CoE_{i,t}$ is the measure of firm i's cost of equity at time t; α is the constant term; $Carbon\ emissions_{i,t-1}$ is firm i's carbon emissions at time $t-1$; $Controls_{i,t-1}$is a set of observed firm specific characteristics which are know to affect CoE; Λ is a vector of year and industry fixed effects to control for time trends and heterogeneity; μ_i is a vector of firm-specific, time-invariant unobserved variables; $\varepsilon_{i,t}$ is an error term.

To further examine the results of the cost of equity under two sub-hypotheses (Hypothesis 1a & 1b), beta regression, shareholder concentration, and institutional holdings regression are conducted.

4.4.2 Hypothesis 2

In order to determine whether carbon intensity has a significant impact on CoD, this research uses the following panel regression:

$$CoD_{i,t} = \alpha + \beta\ Carbon\ emissions_{i,t-1} + \gamma' Controls_{i,t-1} + \Lambda + \mu_i + \varepsilon_{i,t}, \quad (4)$$

4.4.3 Hypothesis 3

In order to determine whether carbon intensity has a significant impact on WACC, this research uses the following panel regression:

$$WACC_{i,t} = \alpha + \beta\ Carbon\ emissions_{i,t-1} + \gamma' Controls_{i,t-1} + \Lambda + \mu_i + \varepsilon_{i,t}, \quad (5)$$

5 Empirical Results

5.1 Correlation Analysis

To understand the impact of environmental performance on financial metrics, this study conducted a preliminary correlation analysis before performing regression, as shown in Appendix Table 2. Firstly, there is a strong positive correlation between CoE, WACC, and systematic risk (Beta), indicating that these financial metrics are closely linked. Specifically, higher equity costs are generally associated with higher overall capital costs and systematic risks. Companies should consider the interrelationships between these indicators when evaluating their financing costs. In addition, free float ratio is positively correlated with CoE, CoD, WACC, and Beta. This suggests that a higher free float ratio is associated with higher financial costs and risks, possibly because a higher free float ratio attracts more short-term investors, thereby increasing market uncertainty and risk.

However, the correlation between CO2 emissions and most financial indicators is weak, especially the relationship with CoE, CoD, and systemic risk is not significant. This suggests that in the current Chinese market environment, environmental performance may not yet be the main factor affecting these financial indicators. It is worth noting that there is a weak negative

correlation between CO2 emissions and WACC, which suggests that higher CO2 emissions may be associated with lower overall capital costs. This counterintuitive finding may reflect that China's financial market is not yet fully mature in terms of environmental risk pricing.

Finally, there is a strong positive correlation between institutional holdings and the proportion of shares outstanding, but weaker correlations with other financial indicators and CO2 emissions. This suggests that while institutional investors hold a significant position in shares outstanding, they may not yet fully incorporate environmental performance into their investment decisions. In the future, as global attention to sustainable development continues to grow and the Chinese market matures, the importance of environmental risks in financial decision-making may become more prominent.

These findings provide an overview of the relationships between financial metrics and CO2 emissions, indicating that while some financial metrics are interrelated, CO2 emissions currently may not significantly impact these financial performance measures. Since correlation analysis does not account for the influence of other variables, it has certain limitations. Therefore, regression analysis is needed to more comprehensively reflect the relationships between the variables.

5.2 Regression Analysis

This study employs a fixed effects model for empirical analysis, revealing significant relationships between CO2 emissions and various financial indicators, providing insights into the impact of environmental performance on the financial costs of Chinese firms. The following section will elaborate on the regression results presented in Tables 2 and 3.

Table 2: Hypothesis 1 (including 1a. & 1b.)

VARIABLES	(1) std_CoE	(2) Beta	(3) Free float percentage	(4) Institutional ownership
L.std_carbon	-0.003**	-0.000	0.006***	0.000
	(-2.15)	(-0.56)	(32.97)	(0.28)
L.Book to Market Ratio	-0.089*	-0.032	0.001	-0.017***
	(-1.84)	(-1.28)	(0.28)	(-3.22)
L.Size	0.105	0.104	0.067***	0.021
	(0.62)	(1.30)	(3.95)	(1.51)
L.Leverage	0.925*	0.406*	-0.084*	-0.054
	(1.91)	(1.85)	(-1.69)	(-1.38)
Constant	-2.015	-0.660	-0.463*	-0.079
	(-0.76)	(-0.52)	(-1.74)	(-0.36)
Observations	1,444	1,444	1,363	1,445
R-squared	0.185	0.038	0.062	0.047
Number of Company_code	426	426	420	427
F test	0	5.76e-08	0	5.91e-07
r2_a	0.179	0.0313	0.0556	0.0406
F	35.46	5.657	414.0	5.045

First, as seen in Table 2, there is a significant negative relationship between carbon emissions and the cost of equity. Specifically, the coefficient for std_carbon is -0.003 with a t-value of -2.15, which is significant at the 5% level ($p<0.05$). This indicates that for each standard deviation increase in carbon emissions, the CoE decreases by 0.3%. The empirical result refuses to accept Hypothesis 1, indicating that, in China, firms with higher carbon emissions still face lower equity financing costs. Additionally, the Book-to-Market Ratio also shows a significant negative relationship with the cost of equity, with a coefficient of -0.089 and a t-value of -1.84, significant at the 0.1 level ($p<0.1$). This suggests that firms with higher Book-to-Market Ratios tend to have lower equity costs, possibly because these firms are perceived as less risky. Other variables in the model, such as size and leverage, do not have significant effects on the cost of equity. The R-squared value for this regression is 0.185,

indicating that the model explains about 18.5% of the variance in the cost of equity.

Second, there is no significant relationship between carbon emissions and systematic risk. The coefficient for Beta's L.std_carbon is -0.000 with a t-value of -0.56, which is not significant ($p>0.1$). This indicates that reducing CO2 emissions does not significantly impact the systematic risk of Chinese firms, thus not supporting Hypothesis 1a. Other variables, including the Book-to-Market Ratio, size, and leverage, also show no significant relationship with Beta. The R-squared value for this model is very low at 0.038, indicating that the model only explains 3.8% of the variance in systematic risk.

Third, regarding shareholder concentration, there is a significant positive correlation between CO2 emissions and the percentage of free-floating shares. The coefficient for L.std_carbon is 0.006, with a t-value of 32.97, significant at the 1% level ($p<0.01$). This still rejects Hypothesis 1b, which posited that lower CO2 emissions would lead to more dispersed share ownership. On the contrary, the empirical results indicate that firms with lower CO2 emissions have more concentrated ownership. Additionally, firm size is significantly positively correlated with shareholder concentration, with a coefficient of 0.067 and a t-value of 3.95, significant at the 0.01 level ($p<0.01$). This implies that larger firms tend to have more concentrated ownership. On the other hand, leverage is negatively correlated with shareholder concentration, with a coefficient of -0.084 and a t-value of -1.69, significant at the 10% level ($p<0.1$), indicating that higher leverage may lead to more dispersed ownership. The R-squared value for this model is 0.062, indicating that the independent variables explain about 6.2% of the variance in shareholder concentration.

Fourth, regarding institutional investors, the empirical results do not show a significant

relationship between CO2 emissions and institutional ownership. The coefficient for L.std_carbon is 0.000 with a t-value of 0.28, which is not significant (p>0.1), indicating that changes in CO2 emissions currently do not have a significant impact on the institutional ownership of Chinese firms. However, the Book-to-Market Ratio is significantly negatively related to institutional ownership, with a coefficient of -0.017 and a t-value of -3.22, significant at the 1% level (p<0.01). This suggests that firms with higher Book-to-Market Ratios tend to have lower institutional ownership. Other variables, such as size and leverage, do not have significant effects on institutional ownership. The R-squared value for this model is 0.047, indicating that the model explains 4.7% of the variance in institutional ownership.

Table 3: Hypothesis 2 & 3

VARIABLES	(1) std_CoD	(2) std_WACC
L.std_carbon	-0.010***	-0.012***
	(-5.64)	(-9.39)
L.Book to Market Ratio	-0.069	-0.202***
	(-1.46)	(-4.13)
L.Size	-0.002	-0.188
	(-0.01)	(-1.08)
L.Leverage	0.233	-0.190
	(0.66)	(-0.44)
Constant	-0.069	3.075
	(-0.04)	(1.11)
Observations	1,444	1,444
R-squared	0.740	0.224
Number of Company_code	426	426
F test	0	0
r2_a	0.738	0.219
F	576.5	691.1

The verification results for Hypotheses 2 and 3 are shown in Table 3. The regression

results indicate the following: Firstly, CO2 emissions are significantly negatively correlated with the cost of debt. The coefficient for L.std_carbon is -0.010, with a t-value of -5.64, significant at the 1% level ($p<0.01$). This finding rejects Hypothesis 2, suggesting that enterprises with lower CO2 emissions still face higher debt financing costs. In the model, the Book-to-Market ratio has a coefficient of -0.069 and a t-value of -1.46 ($p>0.1$), indicating that the Book-to-Market ratio does not significantly impact the cost of debt. Similarly, firm size and leverage do not significantly impact the cost of debt. The R-squared value for this regression is 0.740, indicating that the model explains about 74.0% of the variance in the cost of debt.

Secondly, CO2 emissions are significantly negatively correlated with the weighted average cost of capital (WACC). The coefficient for L.std_carbon is -0.012, with a t-value of -9.39, significant at the 1% level ($p<0.01$). This indicates that for each standard deviation increase in carbon emissions, the WACC decreases by 1.2 standard deviations. This result does not support Hypothesis 3, suggesting that enterprises with higher CO2 emissions have lower overall capital costs. Additionally, the Book-to-Market ratio is significantly negatively related to WACC, with a coefficient of -0.202 and a t-value of -4.13, significant at the 1% level ($p<0.01$). This suggests that firms with higher book-to-market ratios tend to have lower WACC, possibly because these firms are perceived as less risky. Other variables such as firm size and leverage do not significantly affect WACC. The R-squared value for this regression is 0.224, indicating that the model explains about 22.4% of the variance in WACC.

Therefore, the empirical results lead to five main findings. First, in China, enterprises with higher carbon emissions still face lower equity financing costs. Second, carbon emissions currently do not have a significant impact on systematic risk. Third, high carbon-emitting firms

have more dispersed ownership. Fourth, CO2 emissions currently do not have a significant impact on institutional ownership. Fifth, CO2 emissions are negatively correlated with both debt costs and weighted average cost of capital.

In short, the empirical results reveal the complex relationship between CO2 emissions and the financial costs of Chinese enterprises. These findings reflect the unique characteristics of the Chinese market and the current status of sustainable development in China.

6 Discussion and Conclusion

6.1 Discussion

Combined with the empirical results, the possible reasons behind these results are explored next. First, the negative correlation between CO2 emissions and equity costs suggests that Chinese companies with higher carbon emissions tend to have lower equity financing costs. This may be due to factors specific to the Chinese context. For example, Chinese investors may prioritize short-term financial performance over long-term environmental risks, resulting in lower equity costs for high-emitting companies. Alternatively, China's regulatory environment may not yet fully punish high carbon emissions, allowing these companies to benefit from lower equity costs. As China continues to strengthen environmental regulation and promote green finance, this relationship may change, and companies with higher carbon emissions may face higher equity costs as environmental risks are internalized into financial assessments.

Second, the lack of a significant relationship between CO2 emissions and systemic risk suggests that reducing carbon emissions does not currently affect the overall risk of Chinese companies. This may be because systemic risk is affected by a variety of factors other than

environmental performance, such as economic conditions, market volatility, and political stability, which have a greater impact on systemic risk. As global attention to sustainable development continues to increase and the Chinese market matures, the degree to which environmental risks are incorporated into systemic risk assessments may further increase.

Third, CO2 emissions are positively correlated with the proportion of tradable shares, indicating that the equity structure of high-carbon emission companies is more dispersed. This finding may be attributed to (1) the market is less sensitive to environmental issues, and investors are less concerned about the environmental risks of high-carbon emission companies, resulting in a more dispersed equity structure. (2) High-carbon emission companies are often in traditional industrial fields, with higher short-term financial returns, attracting more short-term investors. (3) High-carbon emission companies are usually larger in scale and have higher market liquidity, while China's regulatory policies on high-carbon emission companies may not be fully mature, making these companies still attractive to small and medium-sized investors in the capital market. (4) In addition, these companies may have adopted a risk diversification strategy to attract more investors by increasing the proportion of tradable shares. With the improvement of corporate governance practices and the increase of investors' environmental awareness, the equity structure may change as companies shift from high emissions to low emissions.

Fourth, the results show that CO2 emissions have no significant impact on institutional ownership. This may reflect the current investment strategy of Chinese institutional investors, who may not have fully incorporated environmental standards into their decision-making process. However, as global investment trends shift toward sustainability and China's

regulatory framework continues to evolve to support green investments, institutional investors will place greater emphasis on environmental performance in the future, which may lead to changes in their ownership patterns.

Finally, the study found that CO2 emissions are negatively correlated with debt costs and weighted average cost of capital (WACC). This suggests that high-carbon emission companies have lower debt financing costs and total capital costs. This result may also be affected by the current state of China's financial markets, where environmental risks have not yet been fully factored into debt and capital costs. As China continues to develop its green finance initiatives, including the implementation of a carbon pricing mechanism and stricter environmental regulations, financial markets may begin to more accurately reflect environmental risks, which may increase the debt costs and WACC of high-emitting companies.

6.2 Conclusion

In order to achieve the carbon neutrality goal, more and more initiatives to reduce carbon emissions are being gradually implemented in China. Consequently, carbon risk is likely to become an important consideration in corporate decision-making. Numerous studies have previously explored how carbon risk affects corporate financing costs. However, there remains a lack of empirical research focusing on Chinese enterprises. This study conducts an empirical analysis using Chinese samples, which not only helps fill this gap in the literature but also provides insights into the current state of sustainable development in the Chinese financial market. This, in turn, can offer valuable guidance for the government and enterprises in achieving their sustainability goals.

This study examines the impact of carbon risk on the financial costs of 499 Chinese listed

companies from 2015 to 2022, focusing particularly on the cost of equity (CoE), cost of debt (CoD), and weighted average cost of capital (WACC).

The empirical results reveal several key findings: (1) In China, firms with higher carbon emissions currently enjoy lower capital costs, including both lower equity financing costs and debt costs. (2) Reducing carbon emissions does not currently affect the overall risk profile of Chinese enterprises. As global attention to sustainability increases and the Chinese market matures, environmental risks are expected to be better integrated into systematic risk assessments.(3) Firms with higher carbon emissions have more dispersed ownership. This may be due to the lower sensitivity of investors to environmental issues. Additionally, high-emission firms are often in traditional industrial sectors that offer higher short-term returns, attracting more short-term investors. (4) CO2 emissions do not significantly impact the proportion of institutional ownership, indicating that the current investment strategies of institutional investors in China do not fully incorporate environmental standards into their decision-making processes.

In summary, this study offers the following insights. Firstly, the current Chinese financial system is still in the early stages of achieving sustainable development goals (carbon neutrality). The regulatory policies for high-emission firms may not yet be fully mature, resulting in environmental risks not being fully reflected in financial instruments, and carbon risk not being completely internalized by enterprises. Secondly, individual investors have a low sensitivity to environmental issues, with most prioritizing short-term financial returns over long-term non-financial returns. Thirdly, institutional investors have not yet fully integrated carbon risk into their investment decision processes.

Therefore, to achieve carbon neutrality, the Chinese government should strengthen environmental regulations, establish effective carbon pricing mechanisms, support green innovation through incentives, promote renewable energy, enhance public awareness and education, and facilitate international cooperation. Chinese companies should integrate environmental risk management into their core strategies, invest in green technologies, improve transparency and reporting, optimize energy use, and make rational use of financial instruments such as green financing and carbon credits. These initiatives will work together to accelerate China's transition to a low-carbon economy and contribute to the global sustainable development goals.

This study provides valuable insights into the impact of carbon risk on the financial performance of Chinese companies, but it still has the following limitations. First, the dataset used in this study is limited to public data from Refinitiv Eikon and FactSet from 2015 to 2022. This time frame may not capture long-term trends and the changing impact of carbon regulations and market conditions on corporate finances. Future research could benefit from a longer time frame to better understand how carbon risk changes over time. Second, this study relies on carbon emissions data as a proxy for carbon risk. While this is a widely accepted measure, it may not fully capture the complexity of carbon risk and represent carbon risk. More comprehensive carbon risk measures, including forward-looking indicators, can provide a more nuanced understanding. Third, the findings may not be applicable to companies in other countries with different environmental regulations, market conditions, and investor preferences. Comparative studies across multiple countries can provide a broader perspective on the relationship between carbon risk and corporate finances. Fourth, this study mainly examines

direct financial costs associated with carbon risk, such as equity cost, debt cost, and weighted average cost of capital. However, indirect effects, such as reputational impacts, changes in consumer behavior, or changes in supply chain dynamics, are not considered. Future research that incorporates these broader impacts could provide a more complete understanding of how carbon risks affect corporate financial health.

China's unique economic, regulatory, and market conditions determine the relationship between carbon emissions and financial costs. As China progresses on its path towards sustainable development, strengthening environmental regulations, and promoting green finance, future research may observe different dynamics in the relationship between environmental performance and financial costs. Understanding these evolving dynamics is crucial for policymakers, enterprises, and investors in navigating the challenges and opportunities presented by the transition to a low-carbon economy.

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Appendix

Table 1: Variable definitions

Variable	Definition
Carbon emissions	Total CO2 emissions consist of direct (Scope 1) and indirect (Scope 2) emissions.
CoE	Cost of equity: (Risk-free rate + Beta * equity risk premium) * 100%.
CoD	Cost of debt : (weighted cost of short-term debt + weighted cost of long-term debt), based on the 1-year and 10-year points of an appropriate credit curve.
WACC	CoE * [Equity / (Debt + Equity)] + CoD * [Debt / (Debt + Equity)] * (1 - Tax)
Beta	CAPM Beta is calculated based on data availability. The priority order for calculating Beta is as follows: 90-day daily returns, 180-day daily returns, 2-year weekly returns, 3-year weekly returns, and 5-year monthly returns.
Size	Ln (total assets in 1,000 USD).
Book-to-Market ratio	Book value of common equity / Market value of common equity (the reciprocal of P/B).
Leverage	(Total debt / total assets) * 100%.
Shareholder concentration	Free float data as a percentage of shares outstanding.
Institutional holding	Percentage of institutional holders.

Table 2: Correlation results

CoE	CoD	WACC	Beta	Free float percentage	Institutional ownership	L.CO2 emission	
CoE	1						
CoD	0.0542*	1					
0.00140							
WACC	0.6968*	0.0308	1				
0	0.0691						
Beta	0.9696*	0.0493*	0.6555*	1			
0	0.00360	0					
Free float percentage	0.0910*	0.0396*	0.1196*	0.0760*	1		
0	0.0254	0	0				
Institutional Ownership	-0.0308	-0.0190	0.0934*	-0.0386*	0.5953*	1	
0.0726	0.267	0	0.0241	0			
L.CO2emission	-0.0258	-0.0188	-0.0606*	-0.0271	0.0324	-0.0335	1
0.323	0.471	0.0202	0.300	0.229	0.201		
L.Book to Market ratio	-0.000700	0.0522*	-0.3885*	0.0219	0.0448*	-0.0676*	0.0385
0.968	0.00470	0	0.236	0.0181	0.000200	0.143	
L.Size	-0.0491*	0.1284*	-0.4243*	-0.0354*	0.1102*	0.0304	0.0322
0.00630	0	0	0.0490	0	0.0904	0.217	
L.Leverage	0.1213*	0.1315*	-0.2785*	0.1294*	-0.0417*	-0.1595*	0.0683*
0	0	0	0	0.0245	0	0.00890	

L. Book to Market ratio	L.Size	L.Leverage
L. Book to Market ratio	1	

L.Size	0.4581*	1	
0			
L.Leverage	0.1993*	0.1659*	1
0	0		