The Paris Agreement Impact on the Cost of Equity Capital: Evidence from Heavy Polluting Industries

Abstract:

Climate governance has become a global issue. Employing a new measure of the cost of equity capital (CoE), this study examines the impact of the Paris Agreement (PA) on the relation between carbon risk and CoE using a sample composed of 24,520 listed companies in China from 2008 to 2021. The results in the difference-in-differences (DID) model show that the PA significantly increases the CoE for heavy polluting firms. Furthermore, this effect is stronger for state-owned enterprises, for firms with higher financing constraints, and headquartered in regions with stricter environmental monitoring. Various robustness tests support the main evidence. This study enriches the current research on the impact of the PA on the cost of capital and provides Chinese companies with important green policy suggestions.

Keywords: Carbon Risk; Paris Agreement; Cost of Equity Capital

1. Introduction

As the world's largest developing country, China has been playing a significant role in mitigating climate change. Despite of the policies implemented, and technologies developed to control environmental pollution, China's total carbon emissions in 2021 reached 10.523 billion tons, making it the world's largest emitter and accounting for 45% of global carbon emissions. One of the most significant actions that China has taken to address the challenge due to climate change was to join the Paris Agreement (PA) in 2016 along with over 170 countries. The core objective of the Paris Agreement is to establish a multilateral mechanism, wherein sovereign nations participate voluntarily, equally, and autonomously, ensuring their collective efforts are legally binding to address the real demands of global climate change (Liu et al., 2020; Savaresi, 2016; UNFCCC, 2015). Multiple studies endorse the significant impacts of the Paris Agreement in various domains, including global-regional climate policies, investors' valuation of low-carbon assets, and long-term total factor productivity (Li et al., 2017; Monasterolo and De Angelis, 2020; Pang et al., 2023). Some other studies, however, have questioned the flexibility of the agreement and its effectiveness (Diaz-Raineyl et al., 2021; Fahmy, 2022). In 2017, the United States withdrew from the PA, claiming concerns about the adverse effects of PA on economy and social structure.

One of the most important roles that financial markets take is to allocate capital. If the PA improves the financial markets' function in aligning investments with sustainability, the flexibility of the PA is not likely a concern. Lee et al. (2023) report that the passage of the PA significantly affects corporate financing decisions. The authors' arguments are mainly centered on the increased cost of debt due to the monitoring and compliance costs associated with the PA. Indeed, among existing studies on the impact of carbon risk on the cost of capital, fewer studies examine the cost of equity than the cost of debt (Wang, 2023).[1] Since stock markets and equity contracts usually react faster to external shocks, and the cost of equity financing from stock markets is harder to control directly by regulators, making it a more interesting topic to examine

[1] In the literature review of financial effects of carbon risk by Wang (2023), he found that there are more studies on the cost of debt than the cost of equity. For example, Kim et al (2015), Bui et al. (2020) and Gerged et al. (2021) study the cost of equity associated with carbon risk. The studies on the cost of debt and carbon risk include Jung et al. (2018), Zhou et al (2018), Caragnano et al. (2020), Palea and Drogo (2020), Ehlers et al. (2021), Kleimeier and Viehs (2021), and Morrone et al. (2021).

empirically.[2] If the PA increases the CoE due to carbon risk, carbon emission can be more costly and green investment will become more profitable, increasing the impact of PA on sustainable growth.

Using a sample of 24,520 listed companies in China from 2008 to 2021, this study examines the impact of PA on the CoE for heavily polluting firms. We use the Difference-in-Difference (DID) model to identify the causal relationship between carbon risk and corporates' equity capital costs. This model eliminates the interference of factors other than policy on the estimation results and resolves the issue of reverse causality. Our results show that the PA significantly increases the CoE for heavy polluting firms. Furthermore, this effect is stronger for state-owned enterprises, for firms with higher financing constraints, and headquartered in regions with stricter environmental monitoring. Various robustness tests support the main evidence.

Our study contributes to literature in the following three aspects. First, this study provides new evidence of the PA's impact on curbing carbon emission. If CoE significantly increases with the carbon risk in the post-PA period, the PA can be efficient in dealing with the climate change through the financial market's capital allocation function. Multiple studies endorse the significant impacts of the PA using evidence from various domains, including guiding global-regional climate policies, promoting green innovation, influencing corporate financing decisions, and impacting long-term consumption and labor force participation (Li et al., 2017; Pang et al., 2023; Lee et al., 2023; Shapiro et al., 2023). Lee et al (2023) find that the capital structure becomes more sensitive to firm size, the market-to-book ratio, and the business risk after the PA. Using a sample of Chinese companies, Wang and Sun (2021) report that carbon intensive firms significantly reduced financial leverage after the PA. Complementing these studies, our study shows that the PA could help to curb carbon emission through increased equity financing cost of carbon intensive firms.

Second, our study provides new evidence regarding the relation between carbon risk and the cost of capital. A stream of recent studies examines the effect of carbon risk on the cost of debt (Jung et al., 2018; Zhou et al, 2018; Li et al., 2014; Caragnano et al., 2020; Palea and Drogo, 2020; Ehlers et al., 2021; Kleimeier and Viehs, 2021; Morrone et al., 2021; Zhou et al., 2018;

[2] The green credit policy was formally enacted in 2007 in China to curb industrial pollution (Liu et al., 2019). In particular, the green credit policy directs commercial banks to consider corporate environmental behavior as an important consideration when granting loans (He et al., 2019; Zhang et al., 2011).

Kleimeier and Viehs, 2018; Maaloul, 2018; Pizzutilo et al, 2020; Mahmoudian et al, 2023; Xing et al, 2021).[3] In studying the association between carbon risk and CoE, fewer studies are found (Wang, 2023). Kim et al. (2015) find that Korean firms' CoE increases with carbon risk. Bui et al. (2020) employs a global sample and finds that CoE increases with carbon risk but reduces with carbon disclosure. Gerged et al. (2021) finds a U-shaped relation between carbon emission and CoE. Trinks et al. (2022) reports that carbon intensity is positively correlated with equity capital cost.

Prior studies on CoE mostly employ the CAPM model by Fama and French (1992). To overcome the bias in estimating beta and risk premium due to noisy historical return data, recent studies on CoE used the implied costs of capital (ICC) method to offer more accurate estimation results (Kim et al., 2015; Li et al., 2018; Hmiden et al., 2022, Ke, 2022). However, ICC estimation model requires strict assumptions for certain variables, such as growth rate assumptions and a fixed-term structure for discount rates (EPR, GGM, 1997), and ICC model necessitates predicting earnings for two to four years (GGM, 1997; CT, 2001; GLS, 2001; OJ, 2005; MPEG, 2004), which inevitably produces some degree of error, resulting in biased estimates. Ashton and Wang (2013) and Peng et al. (2022) therefore proposed another ex-ante implicit estimation method of CoE that neither relies on assumptions of growth rate and discount rate nor specifies a dividend policy and only requires one-year-ahead forecasted earnings and allows the cost of capital to change over time. Our paper is the first to use this more efficient measure of CoE to examine the impact of PA on curbing carbon risk.

2. Literature Review and Hypothesis Development

[3] Caragnano et al. (2020) and Morrone et al. (2021) find that GHG emission increases the cost of debt for EuroStoxx 600 companies and international energy enterprises, respectively. Palea and Drogo (2020) find similar results by examining carbon emissions' impact in the eurozone. Palea and Drogo (2020) and Morrone et al. (2021) also find that a higher environmental disclosure is negatively associated with the cost of debt. Kleimeier and Viehs (2021) report that in the global scope carbon emission increases the cost of bank loans. Zhou et al (2018) demonstrate a "U" shaped relationship between carbon risk and the cost of debt, especially for private companies. Kleimeier and Viehs (2018) and Maaloul (2018) find that carbon emissions have a positive and significant effect on loan spreads of UK and Canadian firms, respectively. Using companies listed on the Euro Stoxx 600 Index, Pizzutilo et al (2020) report that carbon risk increases the cost of debt. Mahmoudian et al (2023) find that details of companies' carbon management practices increase the credit risk rating. Xing et al (2021) find that firms with more green innovation but not environmental disclosure have better access to bank loans.

The traditional financial pricing model such as the Capital Asset Pricing Model (CAPM) argues that systematic risk increases investors' required rate of return. Recent studies find that firms' sustainability is associated with their systematic risk because it reduces the incidence and intensity of sustainability-related shocks (Bénabou and Tirole, 2010). For example, Albuquerque, Koskinen, and Zhang (2019) report that firms with higher CSR scores have lower betas. Battiston et al (2017) report that the direct and indirect exposures to climate-policy-relevant sectors represent a large portion of financial actors' equity holdings portfolios, which indicates the difficulty in diversifying the climate risk. As part of sustainability, environmental risk or carbon risk could increase the systematic risk. Trink et al (2022) argue that carbon intensity increases a firm's systematic risk because the transition away from high-carbon production systems will have economy-wide effects. Bolton and Kacperczyk (2021) find that investors across all three continents require a higher market-based premium for companies with higher levels of carbon emissions. Because of the increased systematic risk, the carbon risk increases CoE (Kim et al., 2015b; Trinks et al., 2022).

The PA increases the consensus on the importance of aligning finance to sustainability (UNEP-FI, 2018; HLEG, 2018). After the PA, governments and regulatory bodies are increasingly focused on carbon emissions, implementing stringent regulations and policies such as carbon emission limits and carbon taxation (Van der Ploeg and Rezai, 2020). Since such regulations are universal to all firms and across the whole market, carbon-intensive firms are more likely to bear higher systematic risk (Bolton and Kacperczyk, 2020).[4] Monasterolo and Angelis (2020) observe that the overall systematic risk for the low-carbon indices decreases consistently and the weight of the low-carbon indices within an optimal portfolio increases after the PA. If CoE is positively associated with the systematic risk, we expect that the PA increases CoE especially for firms with high carbon risk.

H_1: The PA increases the CoE especially for firms with high carbon risk.

The traditional financial pricing models do not consider the possibility of incomplete market and asymmetric information (Greenwald and Stiglitz, 1986). Studies find that the quality of a

[4] Bolton and Kacperczyk (2020) argue that carbon emissions could be a systematic risk factor if expected regulatory interventions to curb emissions apply uniformly to all emissions. For example, if a large federal carbon tax were to be introduced, this would be a systematic shock affecting all companies with significant emissions. On the other hand, technological improvements in the use of renewable energy could be mostly targeted to particular operations or sectors. In this case, one would not expect carbon emissions to be a systematic risk factor.

firm's information environment affects the required compensation from investors. For example, Bui et al (2020) find that the extent of carbon disclosure helps reduce the premium required by investors to compensate for poor carbon performance. Gerged et al (2020) find that the greenhouse gas information disclosure reduces the cost of capital for UK firms. In studying the CoE, Gupta et al (2018) find that it is negatively associated with the social capital of a firm's headquarters because of higher information quality. Misnawati et al. (2021) demonstrates that information asymmetry significantly increases CoE. A group of studies focuses on the sustainability associated information disclosure and CoE. For example, Dhaliwal et al (2011) and Hmiden et al. (2022) report that CSR information disclosure decreases CoE. Using a sample of Chinese listed firms, Li and Liu (2018) claim that the quality of the CSR disclosure is shown to be negatively related to CoE, especially for firms in environmentally sensitive industries. Botosan (1997) incorporated the information disclosure into the cost of equity financing and found that there was a negative correlation between the degree of information disclosure and the cost of equity financing.

The channel through which the PA affects CoE can also be from its impact on corporate information environment. Polizzi and Scannella (2023) find that PA increases European firms' environmental disclosure and firms belonging to the most polluting sectors are more likely to do so. Li and Liu (2018) find that CSR disclosure have a more negative impact to CoE for firms in environmentally sensitive industries. According to these studies, we expect that the PA could more likely to reduce the CoE for high carbon risk firms.

H_2: The PA reduces the CoE especially for firms with high carbon risk.

3. Research Design

The original sample uses all listed companies included in the CSMAR database from 2008 to 2021. We exclude firms in the financial and insurance industries, or those with ST or *ST designation. We also deleted observations when there is missing financial data. The final sample includes 24,520 firm-year observations. All variables are winsorized at the 1% level.

We establish the following Difference-in-Difference (DID) model to test the hypotheses. This model eliminates the interference of factors other than policy on the estimation results and resolves the issue of reverse causality.

$$R_{i,t} = \alpha_0 + \alpha_1 Carbon_i + \alpha_2 Post_t + \alpha_3 Carbon_i \times Post_t + \alpha_i \chi_{i,t} + \delta_i + \eta_t + \omega_{i,t} \quad (1)$$

where $R_{i,t}$ represents the equity capital cost of the firm i in the period t. We follow the newly proposed estimation method of CoE by Ashton and Wang (2013) and Peng et al. (2022). $Post_t$ is a dummy variable that equals one for years no earlier than 2016 when China signed the PA, and zero otherwise. $Carbon_i$ is a dummy variable that represents whether a firm belongs to the high-carbon industry based on its industry's carbon emission and energy consumption level (Wang and Sun, 2021).[5] We include time and individual fixed effects to alleviate the issue of omitted variables. The coefficient α_3 of the interaction term ($Carbon \times Post$) measures the impact of PA on the relation between carbon intensity and CoE. If α_3 is significantly positive, it supports the hypothesis H_1 that the PA increases the association between carbon risk and CoE. On the other hand, if α_3 is significantly negative, it suggests that the PA reduces the association between carbon risk and CoE, which supports the hypothesis H_2. Control variables are denoted as $\chi_{i,t}$. Following the studies on CoE, we include control variables such as net return on assets, pre-tax profit-to-total-assets ratio, debt-to-assets ratio, fixed assets ratio, revenue growth rate, cash recovery rate, dual-roles, firm size, book-to-market ratio, years of listing, independent director

[5] Following Zhou et al. (2018) and Yang & Zhang (2022), in conjunction with the Industry Management Catalog for Environmental Protection Verification, the "Regulations for the Administration of Listed Companies" issued by the General Office of the Ministry of Environmental Protection in 2008, the National Economic Industry Classification for Protected Industries GB/T 4754-2017, and the revised "Guidelines for Industry Classification of Listed Companies," as well as the "Notice on Conducting Carbon Trading Pilot Projects" issued by the State Council in 2011, the carbon-intensive industries include the coal mining and washing industry (B06), the petroleum and natural gas extraction industry (B07), the black metal ore mining and dressing industry (B08), the nonferrous metal ore mining and dressing industry (B09), the non-metallic mineral product mining and dressing industry (B10), the textile industry (C17), the wood processing and products of wood, bamboo, rattan, palm, and straw industry (C20), the papermaking and paper products industry (C22), the petroleum, coal, and other fuel processing industry (C25), the chemical raw materials and chemical products manufacturing industry (C26), the chemical fiber manufacturing industry (C28), the rubber and plastic products industry (C29 and C30), the non-metallic mineral product manufacturing industry (C31), the black metal smelting and rolling processing industry (C32), the nonferrous metal smelting and rolling processing industry (C33), the railway, shipbuilding, aerospace and other transportation equipment manufacturing industry (C37), the metal products, machinery, and equipment repair industry (C43), the electricity, heat production, and supply industry (D44), the gas production and supply industry (D45), the housing construction industry (D47), the civil engineering construction industry (E48), and the construction decoration, finishing, and other construction industry (E50). Other industries are considered as non-carbon-intensive industries.

ratio, the board size, top-five shareholders, and Beta (Trink et al, 2022; Kim et al, 2015; Bui et al, 2020). Variables δ_i and η_t represent firm and year fixed effects, respectively. Detailed variable definitions are provided in Appendix A.

4. Empirical Results and Analysis

4.1. Descriptive statistics

Table 1 presents the descriptive statistics of the main variables. The average of R is 0.103, with the standard deviation of 0.06. Our measure of CoE is comparable to those in Kim et al. (2015) and Bui et al (2020). The mean of Carbon is 0.296, denoting that 29.6% of the sample observations are from carbon intensive industries. The minimum, mean, and maximum values of Profit are -1.445, 0.0664, and 0.779, respectively, suggesting that companies experience both profit and loss, with the majority of the sample companies being profitable. The average leverage ratio is 0.423 and the average beta is 1.142, suggesting that an average firm has more equity financing than debt financing and it has a bit higher systematic risk than the market. These observations are consistent with Ke (2022).

Table 1 Descriptive Statistics

This table reports descriptive statistics of main variables the study. The sample includes 24,520 firm-year observations of publicly listed Chinese firms from 2008 to 2021. Detailed variable definitions are included in Appendix A. All continuous variables are winsorized at the 1% level.

Variable	N	Mean	SD	Min	Median	Max
CoE	24,520	0.103	0.0575	1.66e-05	0.095	0.697
Carbon	24,520	0.296	0.457	0	0	1
ROE	24,520	0.0929	0.122	-2.816	0.091	1.467
Profit	24,520	0.0664	0.0637	-1.445	0.061	0.779
DTA	24,520	0.423	0.202	0.00752	0.418	0.987
FA	24,520	0.216	0.164	0	0.181	0.971
Growth	24,520	1.045	96.06	-0.984	0.144	14883
CF	24,520	0.0530	0.0756	-0.742	0.520	0.664
Dual	24,520	0.266	0.442	0	0	1
Size	24,520	22.31	1.357	18.22	22.12	28.55

BM	24,520	0.966	1.229	0.0117	0.608	28.65
Age	24,520	1.994	0.881	0	2.198	3.466
IndpDir	24,520	0.373	0.0551	0	0.333	0.800
BrdSz	24,520	2.148	0.199	1.099	2.198	2.890
Block	24,520	54.87	15.25	9.510	55.12	99.23
Beta	24,520	1.142	0.393	-6.568	1.145	16.63

4.2. Univariate analysis

Table 2 shows the univariate analysis. Before the PA, the CoE of carbon-intensive firms is 0.0931, which is not significantly different from that of non-carbon-intensive firms of 0.0935. After the PA, the average CoE increased to 0.1244 in the carbon-intensive subsample and to 0.1078 in the non-carbon-intensive subsample. Both increases are statistically significant at the 1% level, suggesting that the PA increases CoE for all firms. Furthermore, the CoE increase in the carbon-intensive firms (0.0313) is 0.017 higher than that in the non-carbon-intensive firms (0.0143) and this difference is also statistically significant at the 1% level. After the PA, the CoE in the carbon-intensive firms therefore becomes significantly higher than that of non-carbon-intensive firms (the difference equals 0.0167 with the p-value less than 0.01). We also observe similar results in the medians of CoE comparing carbon-intensive and non-carbon-intensive firms before and after the PA. These preliminary results provide initial support for the hypothesis H_1.

Table 2 Univariate Analysis of CoE

This table reports univariate analysis on CoE (R). The sample includes 24,520 firm-year observations of publicly listed Chinese firms from 2008 to 2021. We split the sample into carbon-intensity companies (carbon = 1) and non-carbon-intensity (carbon=0) subsamples. We also split the sample period into post-PA (2016 – 2021) and pre-PA sub-periods (2008 – 2015). We report the difference in the averages of CoE for carbon-intensive and low-carbon-emission companies before and after the PA. Detailed variable definitions are included in Appendix A. All continuous variables are winsorized at the 1% level. *, **, and *** show the statistical significance at the 1%, 5%, and 10% levels.

Variable		Carbon = 1	Carbon = 0	Difference
Mean of CoE		(1)	(2)	(1) – (2)
Post = 1	(a)	0.1244	0.1078	0.0167**

Post = 0	(b)	0.0931	0.0935	-0.0004
Difference	(a) – (b)	0.0313^{***}	0.0143^{***}	0.0170^{***}
Median of CoE		(1)	(2)	(1) – (2)
Post = 1	(a)	0.1122	0.1048	0.0074^{***}
Post = 0	(b)	0.0815	0.0819	-0.0004
Difference	(a) – (b)	0.0307^{***}	0.0229^{***}	0.0078^{***}

4.3. Baseline regression

Table 3 reports the OLS regression results of the impact of carbon risk on CoE following equation (1). Heterogeneity robust standard errors are listed in the parentheses.[6] Column (1) shows the test results without adding control variables or considering time or individual fixed effects. The coefficients of Post and Carbon×Post are 1.43 and 1.70, respectively, both significant at the 1% level. These results are consistent with those from the univariate tests, that is, the PA increases CoE and the association between carbon risk and CoE. Time and firm-fixed effects are added to column (2), which significantly increases the R^2 of the regression from 0.0365 to 0.4313. The coefficient of Carbon×Post almost doubles from 0.0170 to 0.0216 and it keeps being statistically significant, confirming the positive impact of PA on the sensitivity of CoE to carbon intensity. Control variables are included in columns (3) and (4). We find that the coefficient of Carbon×Post barely changes. These consistent results support the hypothesis H1. We notice that the coefficients of Carbon are negative and significant in three models. Before the PA high carbon firms may enjoy lower production cost and higher firm performance that contribute to lower CoE. The coefficients of Post do not have consistent signs, suggesting that main impact of PA is on firms with high carbon risk rather than those with low carbon risk. Similar to Trink et al (2022), Kim et al (2015) and Bui et al (2020), we find that leverage and BM ratio increase CoE. Consistent with Ke (2022), our results show that size decreases CoE and growth increases CoE. Overall, the results in Table 3 provide supportive evidence that the PA increases the sensitivity of CoE to carbon risk. (why the coefficient of carbon is negative?)

Table 3 The effect of carbon risk on the cost of equity capital

[6] This article uses the DID model to study the dynamic economic effects of policies in different years, which needs to meet the parallel trend assumption and placebo test (please see ‘‘Appendix A.2 and A.3’’ for the verification).

This table reports the multivariate OLS regression results of carbon risk on CoE. The sample includes 24,520 firm-year observations of publicly listed Chinese firms from 2008 to 2021. Detailed variable definitions are included in Appendix A. All continuous variables are winsorized at the 1% level. Heterogeneity robust standard errors are listed in the parentheses. *, **, and *** show the statistical significance at the 1%, 5%, and 10% levels.

Variables	(1)	(2)	(3)	(4)
Carbon	-0.0004	-0.0066*	-0.0040***	-0.0086**
	(0.0014)	(0.0040)	(0.0013)	(0.0038)
Post	0.0143***	-0.0121***	0.0161***	0.0006
	(0.0009)	(0.0028)	(0.0009)	(0.0049)
Carbon×Post	0.0170***	0.0216***	0.0173***	0.0231***
	(0.0020)	(0.0025)	(0.0019)	(0.0024)
ROE			-0.0037	-0.0128
			(0.0090)	(0.0097)
Profit			0.0346*	-0.0339*
			(0.0180)	(0.0179)
DTA			0.0671***	0.0598***
			(0.0031)	(0.0053)
FA			-0.0048	0.0257***
			(0.0034)	(0.0065)
Growth			0.0000***	0.0000***
			(0.0000)	(0.0000)
CF			0.0981***	0.0592***
			(0.0068)	(0.0074)
Dual			-0.0011	0.0001
			(0.0009)	(0.0015)
Size			-0.0044***	-0.0092***
			(0.0006)	(0.0015)
BM			0.0025***	0.0006
			(0.0009)	(0.0013)
Age			0.0026***	-0.0002
			(0.0006)	(0.0016)
IndpDir			0.0184*	0.0179
			(0.0100)	(0.0137)
BrdSz			0.0037	0.0046
			(0.0027)	(0.0052)
Block			0.0000	-0.0001**
			(0.0000)	(0.0001)
Beta			-0.0053***	-0.0006
			(0.0010)	(0.0011)
Constant	0.0935***	0.1406***	0.1404***	0.2983***
	(0.0008)	(0.0024)	(0.0132)	(0.0321)
Observations	24,520	24,520	24,520	24,520
R-squared	0.0365	0.4313	0.0990	0.4488
Firm FE	NO	YES	NO	YES
Year FE	NO	YES	NO	YES

4.4. Further discussions on firm characteristics

Ownership affects a firm's access to financing resources in China. Due to the government endorsement, state-owned enterprises enjoy the government guarantee and financing facilities which non-state-owned enterprise cannot (Yang and Zhang, 2022).[7] However, since state-owned enterprises not only pursue economic profits but also bear more social responsibilities. After the Paris Agreement is signed, state-owned enterprises will be under stricter environmental regulations than non-state-owned enterprises. These state-owned enterprises will increase carbon risk more significantly in heavy polluting industries. If the PA affects the CoE mainly through the risk channel (H_1), we expect that the PA increases the CoE more significantly for state-owned enterprises with high carbon risk. On the other hand, Li and Liu (2018) find that state-owned enterprises in environmental sensitive industries are more likely to have a reduced CoE due to CSR disclosure. Therefore, if the PA affects the CoE mainly through the information transparency channel (H_2), we expect that the PA is more likely to reduce the CoE for high carbon risk firms when they are state-owned enterprises. We define the dummy variable SOE equals one for state-owned enterprises and zero for non-state-owned enterprises.

Financial constraint could also affect the impact of the PA on CoE of firms with high carbon risk. Firms with financial constraints bear more expensive external financing (Fazzari et al., 1988). Following the Kyoto Protocol ratification, polluting firms with financial constraints are more likely to incur higher cost of debt (Balachandran and Nguyen, 2018), and both their book and market leverage ratios reduce more significantly (Nguyen and Phan, 2020). Phan et al. (2022) find that financial constraints increase the probability of carbon-intensive firms to cut investment due to lack of resources (Phan et al., 2022). If PA increases CoE of polluting firms because of increased risk, this impact will be more pronounced for firms with financial constraints as these firms have less financing options for carbon efficient investments. We adopt the approach of Hadlock and Pierce (2010) and use the debt-to-assets ratio (DTA) to measure the

[7] For example, studies find that state-owned enterprises enjoy easier access to bank credit policy. It is often called "credit discrimination" of non-state-owned enterprises (Yang and Zhang, 2022). Wang and Sun (2021) find that state-owned enterprises and firms with financial constraint are more likely to reduce leverage after the PA.

degree of financial constraints. The dummy High-leverage equals one if a firm has higher-than-median DTA; otherwise, it equals zero.[8]

The intensity of environmental regulations due to environmental regulation compliance cost can be different across provinces. When a province's overall compliance cost is higher, polluting firms may face higher carbon risk due to stricter regulation and environmental violation monitoring. Following the literature (Gray, 1987; Bermanand Bui, 2001; Lanoie et al., 2008), we use the sample average ratio of the value of investment in pollution-control equipment to the total cost in an industry to proxy for the industry's intensity of environmental regulations. Firms headquartered in provinces with higher-than-average environmental regulations intensity are assigned with a dummy of stricter_regulation equal one; otherwise, this dummy equal zero.

Column (1) in Table 4 reports the results of the main regression model as shown in equation (1) and includes a dummy of state-owned enterprises (SOE) and its interaction terms with Carbon and Post. The coefficient of Carbon×Post×SOE is 1.71, significant at the 1% level. It suggests that state-owned enterprises are more likely to have a higher CoE due to the PA's impact on high carbon firms. This result echoes the evidence on the cost of debt that stricter environmental regulation increases the state-owned enterprises' cost of debt more significantly than non-state-owned enterprises in heavily polluting industries (Ren et al., 2023; Wang and Sun, 2021).[9] Column (2) tests the impact of financial constraint measured by the dummy of high leverage (D-Lev). The coefficient of Carbon×Post×High_leverage is 0.92, significant at the 5% level, suggesting that financial constraint further increases the CoE after the PA for firms with high carbon risk. Column (3) presents that in regions with high environmental regulation intensity, high carbon-emitting enterprises face higher CoE after the PA. The coefficient of Carbon×Post×High_regulation is 1.0, significant at the 5% level. Overall, all the evidence on firm characteristics as reported in Table 4 supports the argument that the PA increases the CoE of heavy polluting firms due to increased risk.

Table 4 Further Analysis by Firm Characteristics

[8] Phan et al. (2022) uses firm age to proxy for financial constraints, where older firms are less likely to have financial constraints. Our results stay qualitatively the same when using this measure.

[9] Ren et al (2023) find that state-owned corporations have higher debt financing cost after the low-carbon policies. Wang and Sun (2021) find that state-owned enterprises are more likely to reduce leverage after the PA, suggesting that the PA increases cost of debt for state-owned enterprises more significantly.

This table reports the multivariate OLS regression results of carbon risk on CoE by focusing on firm characteristics. SOE is a dummy of state-owned enterprises. High_leverage is a dummy variable that equals one for firms with higher-than-median debt-to-asset ratio; otherwise, it equals zero. High_regulation is a dummy variable that equals one if a firm is in a province with higher-than-median pollution fees. Control includes a list of control variables that are the same as in Table 3. Detailed variable definitions are included in Appendix A. All continuous variables are winsorized at the 1% level. Heterogeneity robust standard errors are listed in the parentheses. *, **, and *** show the statistical significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)
Carbon×Post	0.0160***	0.0170***	0.0174***
	(0.0030)	(0.0028)	(0.0031)
Carbon×Post×SOE	0.0171***		
	(0.0050)		
Carbon×Post×High_leverage		0.0092**	
		(0.0043)	
Carbon×Post×High_regulation			0.0100**
			(0.0042)
Carbon	-0.0060	-0.0070*	-0.0051
	(0.0049)	(0.0041)	(0.0040)
Post	0.0061	-0.0014	-0.0017
	(0.0053)	(0.0049)	(0.0049)
Carbon×SOE	-0.0035		
	(0.0062)		
Post×SOE	-0.0103***		
	(0.0024)		
Carbon×High_leverage		-0.0027	
		(0.0032)	
Post×High_leverage		0.0020	
		(0.0020)	
Carbon×High_regulation			-0.0064**
			(0.0029)
Post×High_regulation			0.0036**
			(0.0016)
SOE	-0.0022		
	(0.0048)		
High_leverage		-0.0024	
		(0.0020)	
High_regulation			-0.0023*
			(0.0013)
Control	YES	YES	YES
Constant	0.3075***	0.2979***	0.2995***
	(0.0329)	(0.0320)	(0.0320)
Observations	23,546	24,520	24,520
R-squared	0.4521	0.4493	0.4498
Company FE	YES	YES	YES
Year FE	YES	YES	YES

5. Robustness check

5.1. The PSM-DID model

The sample of companies' cost of equity capital in the experimental and control groups studied in this paper may be influenced by systematic differences at the individual level, leading to sample selection bias. To address the endogeneity issue, this robustness check employs the PSM-DID model. In the application of the PSM-DID model, all control variables in the main regression model (1) are selected as covariates, and a Logit model was used to calculate the propensity scores, indicating the likelihood of the firms in the sample being affected by the PA. Then, the nearest neighbor matching principle is applied in a 1:1, 1:2, 1:3, 1:4, and 1:5 ratio to match the samples based on the propensity scores, ensuring that different experimental group samples were not matched to the same control group sample. Similar or close scores indicate similar characteristics between the two samples. Finally, the obtained sample of firms is included in the regression analysis, and the results are presented in the first column of Table 5. The results are qualitatively the same as in Column (4) of Table 3.

5.2. Alternative measures of CoE

In this robustness check, the CoE estimated using the modified Ohlson model (Wang, 2021) and the average of the cost of equity capital estimated by the PEG model (Easton, 2004) and the OJ model (Ohlson et al., 2005), were used as dependent variables. The results are shown in the second and third columns of Table 5, respectively. The results indicate that our previous evidence is not sensitive to a particular measure of CoE.

Table 5 Robust Check

This table reports the regression results using the PSM-DID model in column (1), and the main regression results using the CoE measure based on the MOH model and the POJ model in columns (2) and (3) respectively. Detailed variable definitions are included in Appendix A. All continuous variables are winsorized at the 1% level. Heterogeneity robust standard errors are listed in the parentheses. *, **, and *** show the statistical significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)
VARIABLES	PSM-DID	MOH	POJ
Carbon	-0.0087**	-0.0055	-0.0038
	(0.0038)	(0.0042)	(0.0042)

Post	0.0004	-0.0187***	-0.0387***
	(0.0049)	(0.0051)	(0.0038)
Carbon*Post	0.0231***	0.0253***	0.0070***
	(0.0024)	(0.0026)	(0.0017)
Control	YES	YES	YES
Constant	0.2961***	0.2734***	0.1597***
	(0.0323)	(0.0353)	(0.0303)
Observations	24,501	22,976	17,005
R-squared	0.4487	0.4059	0.5249
Company FE	YES	YES	YES
Year FE	YES	YES	YES

6. Conclusion and Implications

Environmental protection has received unprecedented attention in this century. As the world's largest developing country, China has made significant contributions to mitigating climate change. In recent years, China has elevated green development to the height of its national development strategy, aiming to drive enterprises towards green development through environmental regulations. Since the establishment of the carbon emissions trading pilot program in 2011, China has been exploring and developing the carbon trading market. This signifies that carbon emissions have become a focal point for firms' development. Therefore, it is necessary to explore the impact of carbon risk faced by carbon-intensive enterprises on their cost of equity capital.

This study takes the Paris Agreement signed by China in 2016 as the policy background and uses a difference-in-differences model to test the impact of carbon risk on the cost of equity capital for firms. The research findings reveal that compared to low-carbon-emitting firms heavy polluting firms significantly increase their CoE after the signing of the agreement. Further examinations indicate that the impact of carbon risk on increasing the cost of equity capital is more significant for state-owned enterprises, firms with higher levels of financing constraints, and environmental regions with high regulatory intensity. This study provides new evidence regarding the impact of the PA on CoE and contributes to the equity financing literature.

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Appendix A: Variables Definitions

Variable Name	Symbol	Definition
Equity capital cost	CoE	Obtained by the model (Ashton et al., 2013; Wang et al., 2021)
Experimental group dummy variable	Carbon	Takes a value of 1 if a firm is in the carbon-intensive industry; otherwise 0
Time dummy variable	Post	Takes a value of 1 for the years 2016 and onwards, and 0 for years before 2016
Net return on assets	ROE	Net income divided by total equity
Profitability	Profit	EBIT / total assets
Debt-to-assets ratio	DTA	Total liabilities / total assets
Fixed assets ratio	FA	Net fixed assets / total assets
Revenue growth	Growth	% growth in revenue
Cash flow ratio	CF	Net cash flow from operating activities / total assets
Dual	Dual	Takes a value of 1 if the chairman and CEO positions are held by the same person, otherwise 0
Firm size	Size	Natural logarithm of total assets at year-end
Book-to-market ratio	BM	Book value of equity / market value of equity
Years of listing	Age	Natural log of the number of listing years
Independent director ratio	IndpDir	% of independent directors
Board size	BrdSz	Natural log of the number of directors
Equity concentration	Block	% shares held by the top five shareholders
Beta value	Beta	Beta coefficient estimated using