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Article

The effects of corporate carbon performance on financing cost-evidence from S&P 500

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Abstract: This study investigates the impact of corporate carbon performance on financing costs, focusing on S&P 500 companies from 2015 to 2022. Utilizing a fixed-effects regression model, the research reveals a complex U-shaped nonlinear relationship between carbon intensity (CI) and cost of debt (COD). The sample comprises 2896 firm-year observations, with CI measured by the ratio of Scope 1 and 2 greenhouse gas (GHG) emissions to annual sales. The findings indicate that companies with higher CI initially face increased COD due to heightened regulatory and operational risks. However, as CI falls below a certain threshold, further reductions in emissions can paradoxically lead to increased COD, likely due to the substantial investments required for advanced technologies. Additionally, a positive relationship between CI and cost of equity (COE) is observed, suggesting that shareholders demand higher returns from companies with greater environmental risks. These results underscore the importance of balancing short-term and long-term environmental strategies. The study highlights the need for corporate managers to communicate the long-term benefits of environmental efforts effectively to creditors and investors. Policymakers should consider these dynamics when designing regulations that incentivize lower carbon emissions.

Keywords: carbon intensity; cost of debts; cost of equity; environmental sustainability; creditors; shareholders

1. Introduction

Climate change is no longer a distant issue affecting the future; people worldwide are already experiencing or under its impact. As per the Intergovernmental Panel on Climate Change's (IPCC) sixth assessment report, there was a temperature increase of 1.09 degrees Celsius between 2022 and 2020 compared to the 1850–1900 baseline period (IPCC, 2021). Extreme weather events like droughts, floods, heatwaves, and storm surges increasingly affect agriculture and business activities, posing critical global challenges. These events have profound implications for economies, societies, and ecosystems, highlighting the urgency of addressing climate change.

In response to these challenges, the international community has taken significant steps to address climate change, as exemplified by the Paris Agreement adopted at COP21 in 2015. This landmark agreement, signed by 196 countries, aims to limit global temperature rise to between 1.5 and 2 degrees Celsius above pre-industrial levels (IPCC, 2023). Consequently, achieving carbon neutrality has become a central goal for nations and corporations alike, with many firms committing to ambitious carbon reduction targets. Firms with robust environmental practices can attract investments from socially conscious investors and environmental-friendly funds. According to the Climate Bonds Initiative (CBI), by the end of Q3 2023, the cumulative value of green, social, sustainability, sustainability-linked (SLB), and transition bonds (GSS+) had reached approximately $4.2 trillion (CBI, 2023). The International Energy Agency (IEA) reported that in 2023, nearly 90% of the investment in electricity generation is expected to be directed towards low-emission power sources. Solar energy plays a particularly crucial role, with daily investments projected to surpass US $1 billion, amounting to approximately US $380 billion for the year (IEA, 2024).

Within this context, corporate environmental performance, particularly carbon performance, has become a crucial factor influencing financial markets. Carbon performance refers to how efficiently a company uses and emits carbon (Hoffmann and Busch, 2008). CI and a key measure of carbon performance (He et al., 2013; Luo, 2019; Velte et al., 2020) refers to the GHG emissions produced per unit of economic activity (IEA, 2020). Lower CI indicates more efficient and less polluting energy use, whereas higher CI suggests more significant environmental impact and inefficiency. Meanwhile, COD represents the effective interest rate a firm pays on its borrowings, while COE reflects the returns that investors expect for their investment in the company. While the importance of environmental sustainability has been increasingly recognized globally, the research on the impact of corporate carbon performance on financing costs still has significant gaps. Most studies link better carbon performance to lower COE, but research on its impact on COD is limited and complex. Besides, few have explored the differing views of shareholders and creditors on environmental risks. This study addresses these gaps by examining the U-shaped relationship between CI and COD and its effect on COE.

Therefore, this study aims to examine the impact of carbon performance on COD and COE among S&P 500 companies from 2015 to 2022. Specifically, the research seeks to address the following questions:

1) How does carbon intensity influence the cost of debt among S&P 500 companies?

2) How does carbon intensity influence these companies' equity costs?

There are two hypotheses proposed in this study:

H1: A U-shaped nonlinear relationship existed between carbon intensity and the cost of debt financing.

H2: Carbon intensity is significantly positively related to its COE.

Based on previous research and the results of the F-test and Hausman test, this study chooses to employ a fixed effects regression model to analyze a sample of 2896 firm-year observations from S&P 500 companies. It particularly focuses on the differing perceptions of environmental risks between creditors and shareholders. Shareholders might be willing to accept higher risks for potentially higher returns in the long run, while creditors typically prioritize short-term financial stability and risk minimization. This difference in risk perception can significantly impact a company's cost of debt and equity. Understanding this discrepancy not only aids in comprehending market reactions to environmental performance but also guides companies in formulating their environmental policies and financing strategies. Furthermore, by examining data from S&P 500 companies between 2015 and 2022, this study deepens our understanding how environmental performance impacts corporate financing strategies. S&P 500 companies represent significant sectors of the

U.S. economy, making the study's findings highly relevant to global markets and policymakers. The findings of this study have significant implications for corporate managers, investors, and policymakers. Understanding the nonlinear effects of carbon intensity on financing costs for corporate managers can inform more effective environmental strategies that balance short-term financial pressures with long-term sustainability goals. Investors can use these insights to assess better the risks associated with carbon-intensive firms and adjust their portfolios accordingly. On the other hand, policymakers can leverage these findings to design regulations that incentivize better carbon performance without imposing undue financial burdens on companies.

2. Literature review

2.1. The effects of carbon performance on financing cost

While there is not enough research explicitly examining the link between corporate carbon performance and financing costs, the existing findings tend to be divergent. Among them, the majority confirmed a significant negative correlation (Palea and Drogo, 2020; Wang et al., 2021; Zhu and Zhang, 2023). However, some literature also supports the existence of no correlation or a U-shaped nonlinear relationship (Gerged et al., 2020; Görgen et al., 2018; Zhou et al., 2018). Many literatures propose that a corporation's carbon performance can alleviate financing constraints and diminish associated costs. Maaloul (2018) focused on Canadian companies and indicated that higher GHG emissions lead to an increase in the cost of debt for these firms. Specifically, there is an average increase of 11%–15% in COD for each extra tonne of GHG emissions. It suggests that lenders factor in the GHG emissions of firms in their decision-making process and impose financial penalties on firms with higher pollution levels. Kumar and Firoz (2018) revealed a positive and significant correlation between carbon emissions and the cost of debts in India. However, both Maaloul (2018) and Kumar and Firoz (2018) focus on single countries, limiting the generalizability of their findings. An examination of 4655 firm-year observations across 34 countries by Bui et al. (2020) revealed a positive correlation between the intensity of a company's GHG emissions and its cost of equity financing. None of the studies explicitly discuss sectoral differences, which could be a critical factor in how GHG emissions impact financing costs. These studies collectively suggest that GHG emissions and carbon risks are becoming increasingly significant factors in financial decision-making. However, the limitations regarding regional focus, sectoral analysis, and methodological differences highlight the need for further research.

On the other hand, the study by Zhou et al. (2018) investigates the relationship between carbon risk and the cost of debt financing among Chinese companies in high-carbon industries, focusing on the moderating effect of media attention. The study, covering 191 Chinese A-share listed firms from 2011 to 2015, finds a U-shaped relationship between carbon risk and the cost of debt, indicating that both very low and very high carbon risks can increase financing costs. However, the research focuses only on Chinese companies in high-carbon industries, which may limit the generalizability of the findings to other countries or industries. Besides, it covers a period from 2011 to 2015, which may not capture long-term trends or the impact of recent environmental policies. Gerged et al. (2020) examined the performance of FTSE 350 companies in the UK from 2011 to 2016 and discovered a U-shaped nonlinear correlation between GHG emissions and the cost of capital. In addition, Sun et al. (2018) investigated the relationship between corporate environmental management efforts and financial success by employing general Bayesian networks. Their findings indicate that there is no direct link between the two. Nollet et al. (2016) highlighted that the correlation between corporate social responsibility and financial performance could be non-linear or inconsequential. The studies collectively highlight the complex, often non-linear, relationships between environmental performance, CSR, and financial outcomes. They challenge linear assumptions and suggest that both extremely high and low levels of environmental performance can be associated with better financial results, while moderate levels might not. However, these findings should be interpreted with caution due to potential limitations in sectoral focus, measurement approaches, and the temporal relevance of the data. Future research could build on these insights by exploring these relationships in different contexts and over time.

2.2. The mechanism of the effects

Research consistently highlights the financial and operational risks faced by companies with high carbon hazards. These companies are more likely to encounter significant regulatory pressure, leading to increased costs for emissions reduction and compliance (Capasso et al., 2020; Kabir et al., 2021). Such regulatory challenges raise lending risks, prompting creditors to demand higher returns (Clarkson et al., 2013; Liu et al., 2019). Additionally, high carbon emissions can damage a company's reputation as stakeholders become more environmentally conscious, potentially leading to lower income and increased ownership costs (Clarkson et al., 2013). This reputational risk is especially pronounced for companies with significant Scope 3 emissions, which face reduced sales growth due to tightening climate legislation (Guastella et al., 2023).

Moreover, firms with higher carbon risks often rely on outdated technologies, exposing them to substantial operational difficulties and financial instability as they are forced to modernize (Batoon and Rroji, 2024; Kabir et al., 2021). This necessitates significant investments, further straining their financial resources. Jung et al. (2018) suggests that companies with greater carbon risk incur higher borrowing costs, but proactive management and disclosure of these risks can mitigate some of these expenses. The collective emphasis is on the critical role of investor perception and regulatory pressures in shaping the financial outcomes of high-carbon firms. The reviewed literature provides a comprehensive view of the financial and operational challenges faced by high-carbon firms, emphasizing the role of regulatory pressure, stakeholder perception, and technological obsolescence. However, the diversity in methodologies, geographic focus, and temporal relevance highlights the need for more integrated and up-to-date research that can offer a holistic understanding of carbon risk management in a rapidly evolving regulatory landscape.

2.3. Determinants of financing cost

Financing costs are a crucial consideration for firms when planning their capital structures. These costs can significantly influence corporate investment decisions, competitiveness, and long-term sustainability. The cost of debts representing the required return of creditors is influenced by several factors. The perceived credit risk of a firm significantly impacts its debt financing costs, with higher credit risks leading to higher interest rates due to the increased risk of default. Firms with better credit ratings and lower default risks enjoy reduced debt financing costs (Griffin et al., 2017). Traditional financial ratios such as leverage, profitability, and liquidity are critical, with high leverage increasing perceived risk and higher profitability and liquidity reducing costs (Clarkson et al., 2015). Broader economic conditions like inflation rates, central bank policies, and economic growth also play a role, with stable conditions leading to lower costs (El Ghoul et al., 2018). Additionally, larger firms and those in certain industries benefit from economies of scale, better credit ratings, and more stable cash flows, leading to lower debt financing costs (Clarkson et al., 2015; Misani and Pogutz, 2015). It also proposed that the better a company's corporate governance is, the lower its bank debt financing cost. Lou et al. (2022) used a fixed-effects regression model to analyze Chinese listed companies and found that firms with extensive carbon information disclosure experienced reduced financing costs. In their study, they controlled for variables such as firm size, leverage, profitability, liquidity, industry and year effects, growth opportunities, and corporate governance indicators to isolate the impact of carbon information disclosure on financing costs.

Equity financing costs, often represented by the expected return on equity, are influenced by several factors. Market risk and beta, measuring systematic risk, are primary determinants, with higher betas leading to higher equity costs due to increased volatility (Misani and Pogutz, 2015; Sun et al., 2018). Sun et al. (2018) confirmed that firms with greater market risks tend to have higher expected returns on equity, reflecting the premium investors demand for bearing additional risk. Strong growth prospects and stable earnings reduce perceived risk, leading to lower equity costs, whereas uncertain earnings increase costs. Nollet et al. (2016) examined this dynamic and found that firms with consistent earnings and robust growth prospects enjoy lower equity costs because investors perceive them as safer investments. This study emphasizes that predictable earnings and clear growth trajectories can significantly enhance investor confidence, thereby reducing the required return on equity. Consistent and high dividend payouts signal financial health, lowering equity costs. This finding is supported by El Ghoul et al. (2018), who found that consistent dividend policies contribute to lower perceived risk and, consequently, reduced equity financing costs. Finally, robust corporate governance practices enhance investor confidence and reduce equity costs by mitigating agency costs and ensuring better oversight. Liu and Qi (2020) further supported this by demonstrating that effective governance can lead to lower equity costs by improving transparency and accountability.

In summary, while the literature provides valuable insights into the relationship between carbon performance and financing costs, significant gaps remain. Most previous studies have focused on the relationship between carbon performance and COE, typically finding that better carbon performance is associated with lower equity financing costs. However, research on the impact of carbon performance on COD is relatively scarce, and the complexity of this relationship has not been fully explored. Additionally, there is a lack of research that examines the differing perceptions between shareholders and creditors when assessing companies' environmental risks from the perspective of corporate financing costs. Future research should address these gaps by exploring the specific mechanisms through which carbon performance influences COD and COE, considering industry-specific factors, and integrating the role of corporate governance. This would provide a more comprehensive understanding of how companies can manage their environmental performance to optimize their financing costs across different types of capital.

2.4. Hypothesis

Creditors typically have lower risk tolerance and are primarily concerned with a firm's ability to meet its debt obligations. High CI is perceived as a risk factor that could lead to regulatory penalties, environmental liabilities, and reputational damage (Clarkson et al., 2013; Liu et al., 2019; Kabir et al., 2021). Consequently, firms with high CI may be seen as higher-risk borrowers, prompting creditors to demand higher interest rates or stricter covenants, thereby increasing their debt financing costs. As CI further increases, the initial risk increment effect gradually diminishes. Beyond a certain critical point, the marginal utility of further emission reductions decreases, and the costs of achieving further reductions outweigh the benefits, forming a U-shaped relationship. From the empirical evidence, Misani and Pogutz (2015) identified that both very high and very low carbon intensities are associated with increased debt costs due to differing risk perceptions and returns. Sharfman and Fernando (2008) highlighted that better environmental performance typically lowers capital costs, but high carbon intensity increases default risk, while low carbon intensity may involve high initial sustainable investment costs. The stakeholder theory (Freeman, 1984) and the resource-based view (Hart, 1995) suggest balancing stakeholder interests and optimizing resource allocation to reduce debt costs. Market behavior studies (Clarkson et al., 2015; El Ghoul et al., 2018) and regulatory impacts further support this relationship, indicating that firms with moderate carbon intensity benefit from lower debt costs due to balanced risk and efficiency. Therefore, based on the above analyses and showed in **Figure 1**, this paper proposes:

H1: A U-shaped nonlinear relationship existed between carbon intensity and the cost of debt financing.

Shareholders generally have higher risk tolerance and focus more on a firm's long-term profitability and growth prospects. According to stakeholder theory, investors consider not only the economic benefits but also the social responsibilities and environmental factors of companies when making investment decisions (He, 2014). Good carbon performance can attract socially responsible investors and those seeking sustainable investment opportunities, thus lowering the equity financing costs of firms (Lemma, 2017). Furthermore, according to sustainability theory, good carbon performance can enhance a company's market reputation, competitive advantage, and business opportunities, thereby increasing the company's value and reducing equity financing costs (Broadstock et al., 2020; Dhaliwal et al., 2011; Giese et al., 2019).

Therefore, based on the above analyses and showed in **Figure 1**, this paper proposes:

H2: Carbon intensity is significantly positively related to its COE.

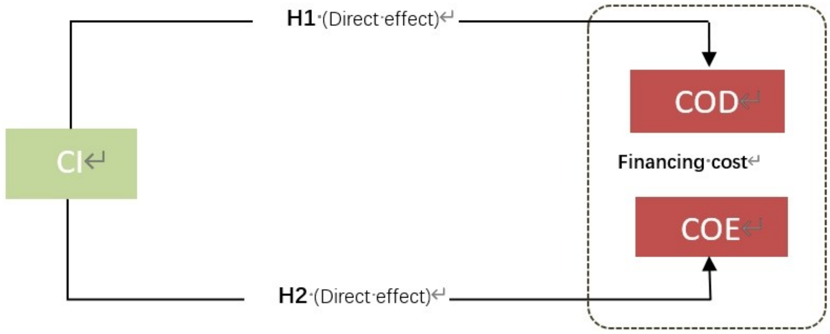

Figure 1. The conceptual framework.

3. Methodology and sample

3.1. Sample selection

The research sample is S&P 500 listed companies from 2015–2022. The environmental and financial information are both from the Bloomberg Professional database. The following selection criteria resulted in a preliminary sample of about 2896 observations:

a) Firms are on the S&P 500 list from 2015 to 2022.

b) Excluding firms without carbon emissions data (Scope 1 and 2) made public during 2015 and 2022.

c) Excluding firms without environmental disclosure scores in Bloomberg from 2015 to 2022.

d) Excluding firms unable to access the comprehensive information for the remaining variables.

The S&P 500 companies are selected as the research sample because, despite its relatively small size, it offers high representativeness and data quality. The S&P 500 encompasses a diverse range of industries, accounting for approximately 80% of the U.S. stock market capitalization, making it a comprehensive reflection of the broader U.S. economy and corporate behavior regarding environmental information disclosure (CEIC Data, 2024). Additionally, the focus on the period from 2015 to 2022 ensures consistent and high-quality data while capturing the market response to corporate carbon challenges following the Paris Agreement. By employing a fixed effects model, we derive robust conclusions from this small sample, which are valuable for providing practical insights to corporate managers and policymakers. However, it may inadvertently overlook the relevance of smaller companies, non-U.S. entities, and private firms, leading to some industry and geographical limitations. Additionally, factors such as company strategies or industry-specific regulations that were not fully considered could introduce a degree of bias in the relationship between carbon performance and financing costs.

3.2. The research methods

To determine the statistical method, the *F*-test and Hausman test will be carried out. The first step is to do an F-test, as the statistical analysis yields a P-value of 0, the result of **Table 1** indicating that the fixed effect method is superior to the mixed OLS model. In Step 2, a Hausman test is performed, yielding a P-value of 0. These findings indicate that the fixed effect model outperforms the random effect model. Therefore, the fixed effect model is selected as the reference model. Meanwhile, most existing studies have employed this method, including works by Siddique et al. (2021), Rehman et al. (2023), Bui et al. (2020), Luo (2019), Li et al. (2019) and Yu et al. (2020), among others. Building on the existing research methodology, to further test the stability of the model, this study will conduct a series of robustness checks will be performed to ensure the reliability and consistency of the research findings.

Table 1. The results of the F-test and Hausman test.

Test	**Statistic**	***P*-value**	**Conclusion**
F-test	17.02	0.000	The fixed effect method outperforms the mixed OLS model.
Hausman test	52.17	0.000	The fixed effect model outperforms the random effect model.

3.3. Research models

Regression models 1 and 2 are constructed to test research hypotheses 1 and model 3 are built to test hypotheses 2.

$$COD_{i,t} = \alpha_0 + \alpha_1 CI_{i,t-1} + \sum \alpha_j Control_{i,t} + Year\ Effect + \epsilon_{i,t} \tag{1}$$

$$COD_{i,t} = \alpha_0 + \alpha_1 CI_{i,t-1} + \alpha_2 CI_{i,t-1}^2 + \sum \alpha_j Control_{i,t} + Year\ Effect + \epsilon_{i,t} \tag{2}$$

$$COE_{i,t} = \alpha_0 + \alpha_1 CI_{i,t-1} + \sum \alpha_j Control_{i,t} + Year\ Effect + \epsilon_{i,t} \tag{3}$$

In the regression, $COD_{i,t}$ represents the cost of debts in period *t*; $COE_{i,t}$ represents the cost of equity in period *t*; $CI_{i,t-1}$ represents the carbon intensity in a year deferred value; $CI_{i,t-1}^2$ is the square value of *CI*. Control variables: $SIZE_{\mathrm{i,t}}, LEV_{\mathrm{i,t}}, BSIZE_{\mathrm{i,t,}}, ROA_{\mathrm{i,t}}, TURNOVER_{\mathrm{i,t}}, INCOV_{\mathrm{i,t}}, DPS_{\mathrm{i,t}}, EPS_{\mathrm{i,t}}$. α_0 indicates the constant term in the regression equation; α_j (*j* = 1, 2, 3, ..., 10) represents the regression coefficient of explanatory and control variables in the model. $\epsilon_{i,t}$ stands for the random error term.

3.4. Variables

3.4.1. Dependent variables

This study draws upon previous research by Palea and Drogo (2020), Wang et al. (2022) and Eliwa et al. (2021), which commonly measures an enterprise's debt financing cost using the ratio of interest expense to average debt. The cost of debt of a company in year t is shown below:

$$COD_{i,t} = \frac{\text{interest expense}_{i,t}}{\left[\frac{\text{total debt}_{i,t-1} + \text{total debt}_{i,t}}{2}\right]} \tag{4}$$

Total debt refers to the combined amount of financial liabilities, both short-term and long-term, that accumulate interest.

This study employs the CAPM model to calculate the enterprises' cost of equity, drawing on methodologies established in related literature by Trinks et al. (2022), Dhaliwal et al. (2014), Lins et al. (2017) and Ng and Rezaee (2015).

$$COE_{i,t} = R_f + \beta \times (R_m - R_f) \quad (5)$$

R_f represents risk-free interest rate; R_m represents market return rate; $(R_m - R_f)$ represent risk premium in equity market; β represents widely existing systematic risks in the market. All dependent variable is confined within both the 5% and 95% percentiles of its distribution.

3.4.2. Independent variable

Referencing previous literature, CI is chosen as the proxy for carbon performance (He, 2013; Luo, 2019; Velte, 2020). Based on past practices, most studies use a firm's total Scope 1 and Scope 2 GHG emissions divided by its total sales. This represents the efficiency of the firm's production processes.

$$CI_{i,t} = \frac{\text{Scope 1 and Scope 2 GHG emissions}}{\text{Total sales}} \quad (6)$$

3.4.3. Control variables

In line with the existing literature such as Long et al. (2023), Palea and Drogo (2020), Datt (2019), Siddique (2021), He (2013), and Kim (2015), this research included the following variables as control variables which are listed in the **Table 2**: Company Size (SIZE), Leverage (Lev), Return on Assets (ROA), Board Size (BSIZE), Asset Turnover (TURNOVER), Interest Coverage (INCOV), Dividend per share (DPS), Earnings per share (EPS), Industry (H_Polluted), Year (YEAR).

Table 2. Variable description.

Variables	Labels	Descriptions
Cost of debt	COD	(Interest expense/Total liabilities on average) × 100
Cost of equity	COE	Application of CAPM
Carbon intensity	CI	(GHG scope 1 + scope 2)/Annual sales using one-year deferred values
The company size	SIZE	Natural log of total assets at year-end
Gearing ratio	LEV	Total long-term liabilities/Total assets
Return on assets	ROA	(Net income/Total average assets) × 100
Board size	BSIZE	The natural log of the number of board members
Asset turnover	TURNOVER	Net sales/Total average assets
Interest coverage	INCOV	Earnings before interest and taxes/ Interest expense
Dividend per share	DPS	Total dividends paid/ Number of outstanding shares
Earnings per share	EPS	(Net income − preferred dividends)/average number of common shares outstanding
Industry	H_polluted	Dummy variable 1 if the sample is in materials, energy, utilities, or industrials according to GICS; Otherwise, 0
Year	YEAR	Control the effects of different macroeconomic circumstances each year

4. Results

4.1. Descriptive statistics and correlation analysis

The descriptive statistics and the correlation analysis are provided in **Tables 3** and **4**. It shows that COE is significantly higher than COD, reflecting the compensation demands of equity investors for higher risk. The average COD is 1.78%, standard deviation of 1.02%, range from 0.07% to 4.073%. These figures indicate a relatively low cost of debt financing among S&P 500 sample companies, possibly due to the high corporate credit ratings. The mean value of COE is 11.511%, with a standard deviation of 17.226% and a maximum of 46.6%. Regarding the independent variables of CI, it ranges from 0 to 2.65 indicating significant differences in environmental impact among different companies. Lower CI could indicate progress in reducing carbon emissions and improving energy efficiency.

Table 3. Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
COD (%)	3481	1.78	1.02	0.07	4.073
COE (%)	3523	11.511	17.226	4.82	46.6
CI	3966	0.185	0.525	0	2.65
CI2	3966	0.31	1.293	0	7.025
SIZE	4000	9.883	1.747	0	15.135
LEV (%)	3157	40.686	25.808	0	71.3
ROA (%)	3940	6.833	7.975	−2	20.886
BSIZE	3919	10.94	2.146	3	24
TOVER	3940	0.7	0.64	0.027	5.494
INCOV	3280	12.50	15.715	−0.982	63.91
DPS	3938	1.488	1.391	0	4.73
EPS	3940	4.825	4.325	−0.456	19.078

Table 4. Matrix of correlations.

	COD	COE	CI	CI2	SIZE	LEV	BSIZE
COD	1						
COE	0.0130	1					
CI	0.151***	−0.00500	1				
CI2	0.112***	−0.0150	0.963***	1			
SIZE	−0.196***	0.038**	0.108***	0.085***	1		
LEV	0.481***	0.0170	0.125***	0.092***	0.033*	1	
BSIZE	−0.111***	0.00700	0.075***	0.065***	0.511***	0.064***	1
ROA	−0.135***	−0.038**	−0.187***	−0.155***	−0.284***	0.00500	−0.130***
TURNOVER	−0.155***	−0.0130	−0.168***	−0.153***	−0.288***	−0.00900	−0.130***
INCOV	−0.552***	−0.042**	−0.186***	−0.151***	−0.156***	−0.376***	−0.076***
DPS	−0.00800	−0.037**	0.047***	0.041***	0.220***	0.163***	0.196***
EPS	−0.196***	−0.042***	−0.100***	−0.082***	0.169***	0.055***	0.113***

	ROA	TURNOVER	INCOV	DPS	EPS
ROA	1				
TURNOVER	0.329***	1			
INCOV	0.544***	0.241***	1		
DPS	0.036**	−0.045***	−0.046***	1	
EPS	0.323***	0.169***	0.200***	0.364***	1

Table 4 represents the correlation analysis of all variables in this study. Firstly, regarding the dependent variables COD and COE, COD shows almost no correlation with COE (0.013). COD is significantly positively correlated with CI (0.151***), suggesting that the cost of debt financing is positively related to the company's carbon intensity. It may indicate that CI is somewhat associated with the COD. COD generally shows significant relationships with other control variables. The correlation between COE and CI is weaker (−0.005), which may reflect different perspectives and risk assessments of investors and creditors regarding corporate environmental performance. The correlation matrix shows that the larger, more profitable companies with higher turnover, interest coverage, and earnings per share tend to have lower debt financing costs. On the other hand, COE has weaker correlations with these variables, showing a slight positive correlation with SIZE (0.038***) and TURNOVER (0.241***), but negative correlations with ROA (−0.038**), INCOV (−0.042***), and EPS (−0.042***), suggesting that equity financing costs are less influenced by these factors compared to debt financing costs.

Table 5 reports the stationarity of the main variables. Considering that the sample consists of unbalanced panel data at the firm level, this study employs the PP-Fisher test to estimate panel unit roots. It can be observed that among the tested variables, the smallest chi-square statistic is for COE, but it still has a value of 1186.4261, with the corresponding p-values all being less than 1%. Therefore, the equations are stationary at the same order, and there is no issue of spurious regression.

Table 5. The unit root analysis.

	Chi-Squares	***P*-value**
COD	2468.8588	0.0000
COE	1186.4261	0.0000
CI	2891.8096	0.0000
CI2	2948.8032	0.0000
SIZE	2150.0538	0.0000
LEV	2125.0573	0.0000
BSIZE	2556.9638	0.0000
ROA	2271.4275	0.0000
TURNOVER	1385.8646	0.0000
INCOV	2279.3741	0.0000
DPS	1291.4384	0.0000
EPS	2060.8783	0.0000

4.2. The impact of CI on COD

The results in **Table 6** show a U-shaped nonlinear relationship existed between CI and COD (model 2-3 coefficient of CI $\beta 1 = -0.589$, $t = -4.06$; coefficient of CI2 $\beta 2 = 0.286$, $t = 4.82$). Accepted H1: A U-shaped nonlinear relationship existed between carbon intensity and the cost of debt financing. Specifically in Model 1, the impact of CI on COD is not significant (coefficient of 0.066, t-statistic of 1.61). This suggests that CI has no linear impact on COD statistically. Model 2-1 to 2-3 results show a U-shaped nonlinear relationship between CI and COD. This finding is consistent with the research of Zhou et al. (2018); Gerged et al. (2021). means that CI has a significant positive effect on COD when CI is above a turning point, implying that a company's higher CI leads to higher COD. Firstly, high CI may lead to high regulatory risk (Capasso et al., 2020; Liu, 2019). Companies with high CI are more likely to face stricter regulations, potential penalties, or carbon taxes (Aggarwal et al., 2021; Davi and Cobb, 2010; Liu et al., 2019). The anticipation of these costs makes lending to such companies riskier, prompting creditors to demand higher returns for the increased risk. Besides, high CI may also lead to high reputational risk (Clarkson et al., 2013; Guastella et al., 2023; Kabir et al., 2021). Investors and consumers are increasingly concerned about sustainability. Companies with high carbon footprints may face consumer backlash or divestment from investors focused on green portfolios, leading to potential decreases in market value and increased financing costs (Gonzalez-Gonzalez and Ramírez, 2016; Lyon and Montgomery, 2015; Zheng et al., 2022). High CI may also lead to high operational risks (Batoon and Rroji, 2024; Busch and Hoffmann, 2007; Kabir et al., 2021). High CI often indicates reliance on outdated technologies or processes that may become obsolete as industries shift towards greener alternatives. Companies might then face substantial costs to upgrade or replace these systems to stay competitive, which affects their financial stability and creditworthiness. These potential environmental risks increase the investment risk for creditors, who demand higher returns.

However, when CI is below the turning point, CI negatively affects COD, implying that a company's lower CI leads to higher COD. This could be because when companies are at a non-high CI level, further reducing CI typically requires expensive technological improvements or process innovations (Gerged et al., 2020). When a company's carbon density decreases while its COD increases, although this may seem contrary to general expectations, it can be explained from several perspectives. When companies are at a relatively low carbon intensity level, further reducing carbon intensity typically requires expensive technological improvements or process innovations (Busch and Hoffmann, 2007; Clarkson et al., 2013; Gerged et al., 2021). This might lead to increased short-term financial pressures for the company, requiring more debt financing to support these investments (Bauer and Hann, 2010; Chava, 2014). Creditors might demand higher interest rates due to the increased short-term financial burden on the company, which to some extent indicates a myopic reaction in the market and creditors, who may underreact to the long-term benefits of reducing carbon emissions (Guenther et al., 2016; Zhou et al., 2018). Furthermore, a company's environmental actions, such as reducing carbon emissions or investing in environmental technologies, represent multiple possibilities for creditors. These include potential risks (like investment failure, immature technology, and low market acceptance) and benefits (like long-term cost savings, compliance advantages, and enhanced brand image) (Busch and Hoffmann, 2007; Clarkson et al., 2013; Choi, 2022). Creditors must weigh these factors to assess a company's financial health and repayment capability.

Regarding the control variables, SIZE is significantly negatively correlated with the COD, indicating that larger companies have lower debt financing costs. LEV is significantly positively correlated, meaning higher leverage increases debt financing costs. TOVER and DPS are both significantly negatively correlated, suggesting that higher turnover and dividends per share help reduce debt financing costs.

Table 6. The effect of CI on COD.

Variables	**Model 1**	**Model 2-1**	**Model 2-2**	**Model 2-3**
	COD	COD	COD	COD
CI	0.066	−0.466***	−0.507***	−0.589***
	(1.61)	(−3.80)	(−3.48)	(−4.06)
CI2		0.218***	0.285***	0.286***
		(4.61)	(4.76)	(4.82)
SIZE			−0.312***	−0.460***
			(−9.56)	(−11.78)
LEV			0.012***	0.008***
			(11.55)	(7.66)
BSIZE				0.008
				(0.81)
TURNOVER				−0.390***
				(−5.32)
INCOV				−0.000
				(−0.81)
ROA				−0.002
				(−1.06)
DPS				−0.030***
				(−3.11)
Year/Industry Fixed Effect	YES	YES	YES	YES
_cons	1.743***	1.770***	4.236***	6.135***
	(72.83)	(72.08)	(13.40)	(15.35)
N	3481	3481	2916	2825
r2_a	0.062	0.068	0.151	0.175
F	24.902	24.640	41.006	32.388

t-statistics in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.3. The impact of CI on COE

The results of Model 3 in **Table 7** show that CI significantly positively affects COE (model 3-3 coefficient of 0.58, *t*-statistic of 2.57). Accepted H2: Carbon intensity is significantly positively related to its COE. This indicates that as a company's CI increases, its COE also tends to increase. This conclusion is consistent with most of the existing studies, such as those by Wang et al. (2021), Zhu and Zhang (2023), Palea and Drogo (2020), Liu et al. (2019) and Aggarwal et al. (2021). This may reflect that investors have a higher risk assessment of high carbon emission companies, thus demanding a higher rate of return. Firstly, from risk perception, equity investors can perceive higher CI as a greater risk for multiple reasons, including potential regulatory changes, penalties, or the costs associated with transitioning to greener technologies. The elevated risks indicate a greater likelihood of future financial instability or reduced profitability, prompting investors to seek a higher rate of return as compensation for the augmented risk (Bolton and Kacperczyk, 2021; Ng and Rezaee, 2015). Secondly, high CI may also negatively impact brand and customer loyalty (Palea and Drogo, 2020). Companies with high CI may suffer from a damaged reputation as public awareness and preference for environmentally friendly practices grow. A tarnished brand can lead to customer churn and reduce brand loyalty, negatively impacting long-term profitability and increasing the COE as investors seek higher returns to offset these risks. Furthermore, there is growing evidence from financial performance that sustainability can correlate with financial performance (Zhu and Zhang, 2023). Companies that fail to adapt to environmental standards may face inefficiencies and increased operational costs, which can detract from their profitability. Investors anticipating lower returns due to these factors might require a higher COE to justify their investment. Lastly, high CI might restrict a company's access to specific markets or contracts, especially with governments and large corporations increasingly mandating lower carbon footprints. Companies lagging in sustainability may lose competitive advantage, prompting equity investors to require higher returns as compensation for these limitations.

Table 7. The effect of CI on COE.

Variables	**Model 3-1**	**Model 3-2**	**Model 3-3**
	COE	COE	COE
CI	1.458^{**}	4.186^{***}	3.896^{***}
	(2.17)	(4.43)	(4.09)
SIZE		−0.541	−0.898
		(−1.03)	(−1.51)
LEV		0.039^{**}	0.034^{**}
		(2.44)	(2.05)
BSIZE		−0.087	−0.087
		(−0.60)	(-0.59)
TURNOVER			−1.419
			(−1.38)
DPS			0.039
			(0.37)
EPS			−0.021
			(−1.13)
Year/Industry Fixed Effect	YES	YES	YES
_cons	1.336^{***}	5.545	10.401^{*}
	(3.58)	(1.14)	(1.73)
N	3966	3122	3106
r2	0.808	0.832	0.834
r2_a	0.779	0.807	0.809
F	1815.012	1223.414	969.793

t-statistics in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Additionally, LEV and SIZE significantly positively impact the COE. ROA has a significant negative impact. In summary, these results suggest that creditors and investors are sensitive to a company's carbon footprint and penalize companies with high CI regarding financing costs. This also indicates that with growing global concerns about climate change, a low-carbon economy and sustainable investment could become essential factors affecting a company's financing costs. However, the results of Model 1-2 suggest that creditors may underreact to the long-term benefits of reducing carbon emissions, focusing more on short-term financial performance and short-term operational risks.

4.4. The robustness checks

The robustness analysis results indicate that the U-shaped relationship between CI and COD, as well as the positive correlation between CI and COE, remain significant and consistent across different sample sizes and within both high-polluting and non-high-polluting industries. Specifically, the result of **Table 8** shows that only selected samples from 2016–2020, both models 2-3 and 3-3 remain robust. Besides, it shows that the U-shaped relationship between COD and CI remained unchanged in both heavily and non-heavily polluting companies. This means the observed effect or relationship holds even across different groups. Overall, these robustness checks reinforce the key conclusions of the study, demonstrating that the impact of CI on corporate financing costs is stable and reliable under various conditions.

Table 8. The results of robustness check.

	Change sample size	**Change sample size**	**Heavy polluting**	**Non-heavy polluting**
	COD	COE	COD	COD
CI2	0.311^{***}		0.202^{***}	0.569^{***}
	(3.77)		(3.38)	(3.99)
CI	-0.603^{***}	4.080^{***}	-0.478^{***}	-0.854^{**}
	(−3.05)	(3.21)	(−3.29)	(−2.43)
SIZE	-0.456^{***}	−0.874	-0.637^{***}	-0.396^{***}
	(−8.05)	(−0.91)	(−9.24)	(−8.17)
LEV	0.004^{***}	0.089^{***}	0.008^{***}	0.008^{***}
	(3.07)	(3.58)	(3.40)	(6.71)
BSIZE	0.007	−0.131	0.001	0.014
	(0.61)	(−0.65)	(0.09)	(1.17)
TURNOVER	-0.225^{**}	−1.293	-0.369^{***}	-0.395^{***}
	(−2.13)	(−0.75)	(−2.82)	(−4.42)
INCOV	−0.000		−0.000	−0.000
	(−0.08)		(−0.28)	(−0.75)
ROA	−0.002		-0.006^{*}	−0.001
	(−0.94)		(−1.91)	(−0.41)
DPS	−0.019	0.051	-0.046^{***}	−0.003
	(−1.14)	(0.35)	(−3.81)	(−0.19)

Table 8. (*Continued*).

	Change sample size	Change sample size	Heavy polluting	Non-heavy polluting
EPS		-0.087^{**}		
		(−2.08)		
Year/Industry Fixed Effect	YES	YES	YES	YES
_cons	6.207^{***}	19.698^{**}	8.061^{***}	5.367^{***}
	(10.51)	(1.99)	(11.44)	(10.81)
N	1766	1940	933	1892
r2_a	0.114	0.770	0.249	0.164
F	13.696	467.712	16.445	20.009

t-statistics in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5. Discussion

This study's findings carry significant implications for various stakeholders, including corporate managers, investors, creditors, and policymakers. The identified U-shaped relationship between CI and COD highlights the dual nature of environmental performance's impact on financing costs. Companies with high CI face higher debt costs due to increased regulatory, reputational, and operational risks (Clarkson et al., 2013; Guastella et al., 2023; Kabir et al., 2021). This suggests that companies in carbon-intensive industries must prioritize improving their environmental performance to mitigate financing costs and enhance their market competitiveness (Bui et al., 2020; Gerged et al., 2021). For corporate managers, the results emphasize the importance of balancing short-term financial pressures with long-term sustainability goals. While reducing carbon intensity can lead to higher immediate costs, these investments are crucial for ensuring long-term financial stability and reducing the overall cost of capital (Wang et al., 2020). Managers should communicate the long-term benefits of environmental initiatives to both shareholders and creditors to align their interests and secure more favorable financing terms.

Investors and creditors should recognize the nuanced impacts of environmental performance on financial outcomes. Shareholders might demand higher returns from companies with high CI due to perceived long-term risks, while creditors may focus on the short-term financial impacts of environmental initiatives (Bolton and Kacperczyk, 2021; Zhuo et al., 2018). Understanding these dynamics can help stakeholders make more informed decisions and better manage the risks associated with corporate carbon performance. Policymakers can use these insights to develop more targeted regulations that encourage companies to reduce their carbon emissions without imposing excessive financial burdens. By supporting corporate efforts to improve environmental performance, policymakers can contribute to a more sustainable economy and help reduce the overall cost of capital for businesses (Jung et al, 2018).

Future research should explore the broader financial impacts of corporate environmental performance beyond COD and COE. Investigating how carbon performance influences other financial outcomes, such as stock market performance, credit ratings, and firm valuation, could provide a more comprehensive understanding of the financial benefits of sustainability. Additionally, further research could examine the role of industry-specific factors and market conditions in shaping the relationship between environmental performance and financing costs, offering deeper insights into how different sectors can optimize their sustainability strategies. Moreover, expanding the scope of research to include companies outside the S&P 500 or in different geographical regions could validate the generalizability of these findings and provide a global perspective on the financial implications of corporate carbon performance.

6. Conclusion

In summary, this study underscores the significant impact of carbon performance on corporate financing costs, highlighting the differing considerations of creditors and shareholders in assessing corporate environmental risk. Creditors are primarily concerned with short-term financial stability and operational risk. Therefore, they demand higher debt costs for companies with high carbon intensity to mitigate potential risks. In contrast, shareholders focus on long-term investment returns and the sustainable growth of the company, hence requiring higher equity costs for companies with high carbon intensity to compensate for the uncertainties in their risk assessments. These findings emphasize the necessity of managing carbon performance to optimize financing conditions for companies. High carbon intensity can lead to higher financing costs, impacting the company's financial health and market competitiveness. For investors, the results suggest the importance of considering a company's environmental performance when making investment decisions. Investors should assess a company's ability to manage environmental risks and prioritize those excelling in sustainability to achieve more stable returns.

This study makes several key contributions to the literature on corporate environmental performance and financial costs. It provides empirical evidence supporting the existence of a U-shaped relationship between CI and COD, a relatively underexplored area in existing research. Furthermore, by focusing on the S&P 500, this study offers insights that are highly relevant to major sectors of the U.S. economy, highlighting the importance of managing carbon performance to optimize financing conditions. Despite its contributions, this study has certain limitations. The analysis is confined to S&P 500 companies, which, while representative, may not capture the full range of behaviors across different geographical regions or smaller firms. Additionally, the study period is limited to 2015–2022, which may not fully account for the long-term effects of carbon performance on financing costs. Future research should consider expanding the scope to include companies from different regions and of varying sizes to assess the generalizability of these findings. Additionally, exploring the impact of carbon performance on other financial outcomes, such as stock market performance, credit ratings, and firm valuation, would provide a more comprehensive understanding of the financial implications of environmental sustainability.

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