BORROWING ON A WARMING PLANET: CARBON RISK PREMIUMS IN CREDIT MARKETS

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ABSTRACT

This study examines the presence and magnitude of carbon risk premia in the Indian corporate bond market by evaluating credit spreads across firms in polluting and non-polluting industries. Using a comprehensive dataset of corporate bonds issued post-2008, the analysis deploys multivariate regression to assess the influence of carbon exposure alongside issuer- and bond-level characteristics. Results reveal that bonds from carbon-intensive firms carry significantly higher credit spreads, reflecting investor concerns over regulatory risks, future compliance costs, and reputational damage. Interestingly, in polluting industries, larger firms face wider spreads, suggesting that their scale intensifies perceived environmental liabilities. Traditional financial indicators such as leverage and profitability exhibit diminished significance, highlighting a shift in investor focus from classic credit metrics to climate-aligned considerations. Growth in operating income, particularly among polluting firms, is rewarded with tighter spreads, indicating market recognition of potential green transitions. The findings have important implications for investors, regulators, and policymakers: integrating carbon risk into investment decisions is not merely a value-based choice but a financially prudent necessity. The study underscores a paradigm shift in credit risk assessment, where environmental exposures increasingly shape borrowing costs, pushing firms toward transparency and strategic decarbonization.

Keywords: Carbon Risk, Credit Spreads, Corporate Bonds, India, Climate Finance.

INTRODUCTION

Global warming and its impact on the macro-economy has become a matter of considerable importance (Stern et al., 2006). This issue gained further prominence following the release of the Stern Review, which highlighted the financial risks associated with climate change. Post-Stern Review release, there's a high likelihood that investors started acknowledging the impact of climate change on their investments. This growing investor awareness is mirrored in the increased the volumes of searches across Google for the title 'climate change' as the search volume for "climate change" experienced an abrupt increase after the release of the 2006 UK Treasury–commissioned economic report (Stern Review), being significantly higher for every quarters relative to the quarters before the release. This abrupt increase in Google search volume implies a growing awareness towards the climate-change linked risks after the Stern Review's release (Marcus et al.,2020).

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Heightened emissions of greenhouse gases resulting from human actions have led to climate change across the globe, emerging as a major concern for all the international stakeholders. To mitigate these environmental impacts, the Paris Agreement was established, setting a global agenda for achieving carbon neutrality. The Paris Agreement prompted countries everywhere to prioritize achieving carbon neutrality. Achieving carbon neutrality necessitates that most industries progressively reduce their carbon emissions or even reach net zero. As a result, carbon-intensive industries are most affected by carbon-related policies.

Investor focus has been tied to volatility in share prices (Andrei et al., 2014), immediate returns (Da et al., 2011; Lou et al., 2014), and market responses to earnings news (Hirshleifer et al., 2011). As a result, the growing convergence between environmental sustainability concerns and financial market dynamics has significantly overlapped with the operation of financial markets. Growing awareness about the phenomenon of climate change and its impact on the economy has imposed the consideration of carbon risk in the financial markets.

Banks now price loans by emissions profile: highly polluting borrowers face costlier coupons to cover transition risk. Chava (2014) illustrates this trend, showing that companies with higher climate risks face increased demands for higher returns from investors, highlighting the significant financial implications. These companies either face reputation risk of being labelled as climate change indicators or face regulatory risks because the output will be affected by future regulation on climate change. Among physical, technological and policy risks, regulatory risk is considered by investors, policymakers, and others in the finance community to have the most immediate relevance (Kruger et al., 2020; Stroebel et al., 2021), particularly because environmental regulatory costs can significantly affect firms' operating costs and cash flows (Karpoff et al., 2005; Meng et al., 2017). This focus on regulatory risk underscores the broader challenge of climate policy uncertainty, which affects firms differently across the economy. We label the uncertainty firms encounter over carbon regulation as ‘Carbon Risk’ (Kim et al., 2015). High-carbon emitting firms face heightened uncertainty as they are most vulnerable to policies targeting emission reductions. Policies aimed at capping carbon emissions can result in significant operational distress (Litterman et al., 2016). Additionally, these firms might face funding difficulties in case of curbs imposed by banks due to climate-related capital requirements. With the advent of the shift towards a green environment, carbon risk has turned into one of the major underlying principles for analysing financial markets (Ravi et al., 2016). Due to the dynamic nature of the evolving financial market, carbon emissions have posed as a significant risk due to the intrinsic regulatory pressure. Accordingly, highly polluting firms can be subject to policy intervention, followed by negative investor sentiment which can further impair the company’s financial standing and performance (Wagner et al., 2015). This perception is further substantiated by the empirical findings of Krueger et al. (2020), who argued that institutional investors are increasingly aligning climate-related risk factors into their investment approach.

Credit risk from highly-polluting industries has been considerably greater than low-polluting industries, which has also been evidenced in options markets (Ilhan et al., 2021), credit markets (Delis et al., 2018), and equity markets (Chava, 2014; Kim et al., 2015.; Ferrell et al., 2016; Nguyen et al., 2020; Trinks et al., 2022), however, the effect on bond markets remains unclear (Duan et al., 2020; Seltzer et al., 2020). This paper explores the carbon risk premium hypothesis in the bond market, arguing that investors demand higher returns for holding corporate bonds issued by carbon-intensive firms (Hong et al.,2016) in India. Since predominantly, corporate bonds are held by institutional investors, who are typically sophisticated and likely to take carbon

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risks into account (Krueger et al.,2020), this study investigates whether the hypothesis remain valid in the Indian corporate bond market.

This study builds upon previous research works to examine the impact of carbon risk on corporate bond credit spreads by analysing the variation in credit spreads of polluting with non-polluting companies to assess how environmental risk perceptions are reflected in India's corporate bond market. These findings hold practical relevance for bond investors, as the synthesis of literature on carbon risk and credit spreads provides a framework for integrating emission intensity of the respective firms into investment strategies.

LITERATURE REVIEW

Carbon risk premia is influenced by numerous factors, including a firm's carbon footprint, regulatory changes, and market perceptions of climate-related risks. It has been argued in various research works that companies with higher carbon emissions have a higher cost of debt as they are perceived as riskier investments by investors and lenders (Kumar et al., 2018) which is in aligned with global trends, highlighting that companies with significant carbon footprints typically have worse credit ratings and higher yield spreads, especially in regions with more stringent regulatory enforcement.

The Indian corporate bond market offers a special case for analyzing how credit spreads are affected by carbon risk. Several studies have examined the factors concerning credit spreads in India, highlighting the role of macroeconomic variables like inflation, interest rates, and economic growth (Thakur et al., 2018), (Gupta et al., 2021). It is only in recent years that carbon risk has been identified as a determinant towards shaping credit spread behaviour.

According to a study on Indian companies reporting their carbon emissions data through the Carbon Disclosure Project (CDP), the cost of financing is positively and significantly correlated with the carbon-emissions coefficient (Kumar et al, 2018), suggesting that since lenders and investors expect a premium for exposure to carbon-related risks, businesses with higher carbon emissions face higher borrowing cost. The study also revealed that polluting companies had higher cost of debt than their counterparts, underscoring the significance of carbon risk in pricing for credit risk.

The impact of carbon risk on credit spreads is not uniform across sectors since highly polluting industries, such as mining, manufacturing, and power generation are more susceptible to the transition risks associated with a low-carbon economy. As a result, as lenders and investors increasingly take into account the risks associated with carbon-intensive operations, these sectors are probably going to experience greater credit spreads.

Carbon risk premia is mostly shaped by policy actions and regulatory changes, for instance, the Paris Agreement has been a shock to anticipated climate policies, resulting in adjustments to yield spreads and bond credit ratings (Seltzer et al., 2021).

It has been demonstrated that the implementation of carbon pricing regulations, like the Canadian carbon price system, increases credit risk for high-emitting industries (Oyegunle et al., 2023), similarly, the creditworthiness of businesses in carbon-intensive industries may be significantly impacted in India if comparable measures are implemented, emphasizing the criticality for financial institutions to include carbon risk in their frameworks for evaluating credit risk.

The rising awareness of investors and regulators regarding the risks associated with climate change is expected to have an impact on the carbon risk pricing in India. Empirical studies have indicated that issuers with financing constraints and those not undergoing a green transition are

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more affected by the pricing of carbon risk (Wu & Tian, 2022), underscoring the significance of firm-level efforts to reduce carbon risk.

The impact of rising interest rates further complicates the relationship between credit spreads and carbon risk, since high-carbon-emitting companies are anticipated to be significantly impacted by carbon risk, particularly in the context of rising interest rates (Batoon et al, 2024), this can have a significant impact on corporate bond markets in India, where the monetary policy framework is increasingly focused on managing inflation and maintaining financial stability.

The effect on credit spreads for the overall assets held by the bond-issuing firm is particularly noteworthy as the market perceives larger firms as stable because of lower credit spreads due to their greater asset base and financial resilience (Fama et al., 1993). However, certain industries are responsible for polluting at a significantly higher rate than their counterparts. Thus, a higher asset size can be considered as heightened operational risks and increased regulatory scrutiny by the investors, since a larger firm may have a significant operational footprint that exposes the firm to carbon related regulations, which amplifies compliance costs and creates liabilities. Chava (2014) indicated the relation associated with asset size and carbon risk can fundamentally alter the existing benchmark of credit spreads associated with a carbon intensive firm, and the interaction of these items should be further investigated. In addition, leverage, which is determined as the ratio of total debt to total assets- adds another layer of complexity to the relationship between carbon risk and credit spreads. Leverage is often associated with an increase in financial risk and wider credit spreads (Collin et al., 2001).

The relationship between profitability as represented by Return on Assets (ROA), and narrower credit spreads can be observed typically due to a firm's financial position and stability perceived by the creditors, as suggested by Kaplan and Urwitz (1979) and Blume et al. (1991).
Firm growth, which reflects changes in YoY change in operating income is traditionally seen as a positive signal of future potential and lower perceived risk; however, when carbon risk is a critical factor, this relationship becomes more complex. Growth often signals a positive outlook, leading to a reduction in perceived risk (Menz et al., 2010). Cash reserves and fixed assets owned by a firm are also situations assessed as part of risk and, as such, barriers to marginal capital. Companies with a lot of cash reserves are generally determined as less risky investments, yielding lower credit spreads (Acharya et al., 2012). Similarly, fixed assets used as collateral typically help create liquidity and are expected to contribute to lower credit spreads.

The status of a company as a Public Sector Undertaking (PSU) creates a further layer to the discussion of credit spread. Traditionally, since PSUs are viewed as having some backing from the government, they tend to experience smaller credit spreads (Chhaochharia et el., 2009) due to increased investor confidence in the timely obligation of the dues by the government backed entities. The credit ratings assigned to PSU's and non-PSUs are crucial for the understanding of the relationship between credit rating and credit spread, because they indicate the overall credit quality of the firm. One of the most prominent factor that is looked upon by the investors is a higher credit rating, as it typically translates into more favourable credit spreads, or lower risk, since the risk of default by the bond-issuing firm is perceived to be significantly decreased, as highlighted by Altman and Saunders (1998).

Bonds' maturity, or the time until the bond's principal is repaid, also affects credit spreads. Longer maturities usually contain more uncertainty and wider spreads (Longstaff & Schwartz, 1995). When carbon risk is factored in, bonds' maturity's impacts on credit spreads could be exacerbated in industries especially impacted by regulatory change. The joint impacts of carbon risk and maturity indicate to investors that firm longevity is a key concern regarding financial

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stability especially as we transition to a low-carbon economy. The proceeds from the bond sale, can also affect credit spreads. Larger bond issues can often take advantage of economies of scale to lower the spread. However, contextualized within the framework of carbon risk, the prospective use of proceeds may be evaluated, particularly when the proceeds are intended for carbon-heavy projects (Helwege et al.,1999).

Finally, the presence of guarantees, which indicate that bonds are secured by collateral, usually results in lower credit spreads due to the reduced risk for investors. Black and Scholes (1973) discussed the risk-decreasing nature of secured bonds, which typically lead to narrower spreads. In an industry with high carbon risk substantial value of the guarantees may not hold because the collateral is associated with assets that could be impaired or subject to restrictive regulation. For example, collateral of fossil fuel reserves or carbon-intensive infrastructure may lose value if future regulations restrict their applicability. Even if valuation is sensitive to regulatory risk, losing value based on environment exposure raised questions whether the guarantees would be more unreliable than investors consider based on their prudential assessment. Again, our consideration of the risks pertaining to investments associated with carbon regulation and low-carbon transitions leads to a demand for investors to reflect carbon risk in their surpass - a higher risk premium for corporate bonds consistent with carbon risk premium hypothesis. Overall, the risks associated with carbon regulations and low-carbon transitions encourage investors to incorporate carbon risk into their investment decisions and demand a higher risk premium for credit bonds.

RESEARCH METHODOLOGY

Data Description

The present research is based on corporate bonds issued in India after the year 2008, focussing on examining the influence of carbon risk on credit spreads, obtained by considering the starting year as 2009 to exclusively capture the perception of institutional investors on climate risk impact and its subsequent economic implication, following the publication of Stern Review in 2008. The uniform cutoff date has been considered as April 30, 2024 to ensure that the most recent data is included in this study.

The dataset comprises of 564 corporate bonds, which were classified into polluting and non-polluting industries using a two-step classification methodology by initially categorizing the bond issuers through the SEBI Standardized Industry Classification framework based on the firm's business/revenue generation model. Bond issuers were then classified into polluting and non-polluting industries categories based on the Ministry of Environment, Forest and Climate Change, Government of India, which identifies 17 high carbon risk industries, based on which these corporate bonds were categorised into 212 bonds from companies in high-carbon-risk industries (polluting) and 352 bonds from low-carbon-risk industries (non-polluting).

The required details of these corporate bonds including their ISIN, Company Name, Last traded prices (LTP), Coupon rate, Face value, Issue Date, Maturity Date, Payment Frequency, Last Interest payment date, Maturity Period, Bond issue size, Provision of Guarantee, and Credit Rating was sourced from the NSE, BSE, NSDL, and CDSL, while the information regarding the firm being state owned (PSU) or otherwise was validated through the company's official website. Similarly, details of Government Securities (G-Secs) were obtained from the RBI's publicly available database.

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Key financial data, including firm-level metrics such as Total Assets, Leverage, Return on Assets (ROA), Growth (Operating Profit), Cash holdings, and Fixed Assets were extracted from the annual financial reports of bond issuers for FY 2022-23 due to non-availability of the latest annual reports of these firms, based on the cutoff date of April 30, 2024.

Variable Description

Dependent Variable

- **Credit Spread**: Difference between the Yield to Maturity (YTM) offered by non-government securities of various maturities, issued by various firms and with different credit ratings, and the risk-free yield (YTM) on securities issued by the central government of similar maturity is commonly known as the credit spread, which can be used to capture the risk perception of the investors as it serves as a critical metric of credit risk of the firm.

Independent Variables

- **Carbon Risk (0/1)**: Based on the categorisation of industries and subsequently firms being labelled as polluting and non-polluting, a binary variable – **1**, indicating polluting firm, while **0**, indicating non-polluting firm were assigned to these bond issuing firms.

Issuer-Level Variables

- **Size**: This variable provides a measure of the bond issuer's firm size and is defined as the natural logarithm of the total assets.
- **Leverage**: A measure of the financial structure of the firm, it is defined as the ratio of Total Current & Non-Current Liability to the Total Assets of the firm, illustrating the extent to which a company relies on debt to finance its operations.
- **Return on Assets (ROA)**: A key profitability indicator, measured by dividing net operating earnings (EBIT) with the total assets, it reflects the efficiency of asset utilization for generating profits.
- **Growth**: The Year-on-Year change of percentage in operating income from the previous period i.e. from 2022 to 2023, indicates the expansion or contraction of the firm's core business over time.
- **Cash**: The proportion of cash and equivalents relative to total assets, indicating the firm's liquidity and ability to meet short-term obligations.
- **Property**: The ratio of net fixed assets to total assets, serving as an indicator of a firm's capital intensity or investment in physical infrastructure.
- **PSU (0/1)**: The ownership status of an organization, indicated by a binary variable, with 1 indicating a government owned-entity, while 0 indicating a privately owned entity.

Bond-Level Variables:

- **Credit Rating**: A numerical scale ranging from 1 (D) to 22 (AAA) assigned by the average rating assigned by the combination of the credit rating agencies- CRISIL, CARE, ICRA, BWR, ACUITE, IVR, IND, and FITCH to the bond issuing firm, signifying the issuer's creditworthiness.
- **Maturity (0/1)**: The time in number of years remaining until the bond's principal repayment to the investor by the borrowing firm.
- **Proceeds**: The natural logarithm of the amount of capital raised through the bond issuance, reflecting the scale of the funding, this standardization helps compare bonds of varying sizes.
- **Guarantee**: Provision of Guarantee/Partial Guarantee provided by the issuing firm, indicated using binary variable specifying Issuer Guarantee – 1 or otherwise – 0.

Research Methods

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Credit Spread Analysis

The objective of this analysis is to investigate the relationship between carbon risk and credit spreads in the Indian corporate bond market. The study employs a multivariate regression model to estimate the effects of carbon risk and a range of financial and bond-specific factors on credit spreads of polluting and non-polluting companies separately.

- **Regression Model**

The baseline regression model used in this study is specified as:

$$CS_{it}=\alpha+\beta_1 CarbonRisk_i + \beta_2 Size_i + \beta_3 Leverage_i + \beta_4 ROA_i + \beta_5 Cash_i + \beta_6 Property_i + \beta_7 PSU_i + \beta_8 Maturity_{it} + \beta_9 CreditRating_{it} + \beta_{10} Guarantee_{it} + \epsilon_{it}$$

Where:

- CS_{it} is the credit spread of bond i at time t.
- The coefficients β_1 through β_{10} represent the estimated impacts of carbon risk and the various control variables, while α is the intercept and ϵ_{it} is the error term.

The model accounts for both firm-specific and bond-specific variables, allowing for a comprehensive analysis of the determinants of credit spreads.

List of Hypotheses

Based on the theoretical considerations and existing literature, this study proposes the following hypotheses to examine the relationship between carbon risk and credit spreads, as well as the effects of issuer- and bond-specific characteristics. These hypotheses aim to provide insights into how different financial and structural factors influence the pricing of corporate bonds in the presence of environmental risks:

H_1: *Firms with high carbon risk (operating in polluting industries) exhibit higher credit spreads.*

H_2: *Larger firms (measured by total assets) exhibit lower credit spreads.*

H_3: *Firms with higher leverage (measured as the ratio of total debt to total assets) exhibit higher credit spreads.*

H_4: *Firms with higher profitability (measured by Return on Assets, ROA) exhibit narrower credit spreads.*

H_5: *Firms experiencing higher growth (measured by the percentage change in operating income) exhibit lower credit spreads.*

H_6: *Firms with higher liquidity (measured by the ratio of cash to total assets) exhibit narrower credit spreads.*

H_7: *Firms with a higher proportion of fixed assets (measured as the ratio of property to total assets) exhibit higher credit spreads.*

H_8: *Public Sector Undertakings (PSUs) exhibit narrower credit spreads than private firms.*

H_9: *Bonds with higher credit ratings exhibit narrower credit spreads.*

H_{10}: *Bonds with longer remaining maturities exhibit higher credit spreads.*

H_{11}: *Bonds with higher proceeds (measured by issuance size) exhibit higher credit spreads.*

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H_{12}: *Secured or guaranteed bonds exhibit narrower credit spreads.*

EMPIRICAL RESULTS

Descriptive Statistics

Table 1 presents the summary statistics for the main variables introduced in Table 2. The mean value of Carbon Risk is 0.375, indicating that 37.5% of the bond issuers in the sample are exposed to carbon risk. This statistic provides an essential foundation for analyzing the role of environmental risk in bond pricing. Particularly, the mean Credit Spread of 308.69 basis points underscores the risk premium that investors demand from corporate bonds, relative to government securities, in light of broader market uncertainties. Key financial metrics of the firms in the sample offer further insights into the characteristics of bond issuers. The mean Credit Rating of 20.606 suggests that the majority of bonds are highly rated, generally indicative of lower credit risk. However, the average Leverage of 70.5% reveals that many firms are significantly leveraged, potentially amplifying perceived risks, especially in the context of environmental liabilities. The mean Return on Assets (ROA) of 2.5% reflects relatively low profitability across the sample, a crucial factor when considering the financial health of these firms amid environmental scrutiny. Additional metrics such as Size (mean: 27.203), Growth (mean: 66.2%), Cash (mean: 4.4%), and Property (mean: 30.4%) highlight the structural diversity within the sample. These variables help assess bond issuers' ability to manage risk, particularly in the face of carbon exposure. The financial diversity observed across the sample offers a valuable basis to examine how these factors may influence credit spreads between polluting and non-polluting firms.

Table 1
VARIABLE DEFINITIONS

Variable	Label	Definition
Dependent Variable	Credit Spread	Corporate bond Yield to Maturity (YTM) relative to government bond yield (G-sec) of equivalent maturity
Independent Variable	Carbon Risk	Dummy variable equal to 1 if the issuer operates in any of the following carbon-intensive sectors: Aluminium, Cement, Chlor-Alkali, Fertilizers, Iron & Steel, Oil & Gas, Petrochemicals, Pharmaceuticals, Pulp & Paper, Thermal Power, Sugar, Tanneries, Zinc, Copper, Glass, Ceramics, or Textiles; otherwise 0
Issuer-level Variables	Size	Computed as the logarithmic transformation (natural log) of the firm's total asset value
	Leverage	Ratio of total liabilities to total assets, indicating the firm's financial leverage
	ROA	Earnings/total assets
	Growth	Year-over-year growth rate based on change in operating income relative to prior period
	Cash	Sum of cash and marketable securities divided by total assets.
	Property	Proportion of fixed tangible assets within the total asset base.
	PSU	Dummy variable assigned 1 for public sector undertakings (PSUs), else assigned 0.
Bond-level Variables	Credit Rating	Issuer's credit quality score mapped from D (lowest) to AAA (highest), scaled as 1 to 22.
	Maturity	Log-transformed value of the bond's maturity period (in years).

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	Proceeds	Log-transformed value of the total amount raised through the bond issuance.
	Guarantee	An indicator variable that equals 1 if the bonds are pledged, secured or guaranteed and 0 otherwise

Table 2
SUMMARY STATISTICS

	N	Mean	Median	Standard Deviation	Minimum	Maximum
Carbon Risk	563	0.375	0.00	0.48	0.00	1.00
Credit Spread	563	308.687	303.39	306.06	-676.31	1319.07
Size	563	27.203	27.34	2.23	13.68	30.41
Leverage	563	0.705	0.72	0.23	0.07	4.41
ROA	563	0.025	0.02	0.06	-0.91	0.30
Growth	563	0.662	0.18	3.04	-3.91	19.26
Cash	563	0.044	0.02	0.06	0.00	0.50
Property	563	0.304	0.02	0.34	0.00	0.88
PSU	563	0.481	0.00	0.50	0.00	1.00
Maturity	563	5.457	3.00	4.71	0.69	20.00
Proceeds	563	20.804	20.98	2.15	6.67	26.02
Guarantee	563	0.799	1.00	0.40	0.00	1.00
Credit Rating	563	20.606	21.67	2.34	0.00	22.00

Baseline Multivariate Regression and Two-Sample *t*-Test Results

Table 3 reports the multivariate regression estimates of how firm-level and bond-level attributes shape credit spreads for polluting versus non-polluting issuers. The coefficients reveal a consistent pattern: markets factor environmental risk directly into their assessment of credit risk.

Carbon Risk and Credit Spreads

Hypothesis (H1): Firms with high carbon risk (operating in polluting industries) exhibit higher credit spreads.

To evaluate H1, we first ran an *F*-test on the equality of variances between the two groups. The test did not reject the null of equal variances, so we applied a two-sample *t*-test under the equal-variance assumption.

The two-sample t-test revealed a statistically significant difference in the mean credit spreads between polluting and non-polluting firms, with polluting firms exhibiting significantly higher credit spreads at the 5% significance level. Consequently, the null hypothesis (H1) was accepted, confirming that the bond market differentiates between polluting and non-polluting firms, with the former facing higher credit spreads.

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Firm Size and Credit Spreads

Hypothesis (H2): Larger firms (measured by total assets) exhibit lower credit spreads.
Contrary to this hypothesis, the analysis reveals that within polluting industries, firm size is positively associated with credit spreads, significant at the 10% level. This finding suggests that larger firms in polluting sectors may face heightened environmental liabilities, leading to wider credit spreads. Conversely, in non-polluting industries, the relationship between firm size and credit spreads is negative but statistically insignificant, leading to the rejection of the hypothesis for both sectors.

Leverage and Credit Spreads

Hypothesis (H3): Firms with higher leverage (measured as the ratio of total debt to total assets) exhibit higher credit spreads.
Leverage is statistically insignificant for both polluting and non-polluting issuers, indicating that capital structure is not a key driver of credit risk premiums in either group.

Profitability (ROA) and Credit Spreads

Hypothesis (H4): Firms with higher profitability (measured by Return on Assets, ROA) exhibit narrower credit spreads.
ROA shows no significant effect in either sample, suggesting that profitability does little to sway market pricing of credit risk.

Growth and Credit Spreads

Hypothesis (H5): Firms experiencing higher growth (measured by the percentage change in operating income) exhibit lower credit spreads. Among polluting firms, growth is negatively and significantly (5 %) related to spreads—faster growers borrow more cheaply, reflecting investor optimism despite carbon risk. Growth is insignificant for non-polluters.

Liquidity (Cash) and Credit Spreads

Hypothesis (H6): Firms with higher liquidity (measured by the ratio of cash to total assets) exhibit narrower credit spreads. Liquidity is insignificant across both groups, implying that cash buffers do not materially affect credit risk assessments.

Fixed Assets (Property) and Credit Spreads

Hypothesis (H7): Firms with a higher proportion of fixed assets (measured as the ratio of property to total assets) exhibit higher credit spreads. Asset tangibility is insignificant in both sectors, indicating that fixed assets do not meaningfully influence credit spreads.

Public Sector Undertakings (PSUs) vs Private Firms and Credit Spreads

Hypothesis (H8): Public Sector Undertakings (PSUs) exhibit narrower credit spreads than private firms.

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Within polluting sectors, private firms enjoy significantly (5 %) narrower spreads than PSUs, hinting at perceived efficiency or agility advantages. No spread differential appears in non-polluting industries.
Conversely, in non-polluting industries, PSUs exhibit significantly narrower credit spreads, reflecting the market's perception of PSUs as more stable, with the relationship significant at the 1% level.

Credit Ratings and Credit Spreads

Hypothesis (H9): Bonds with higher credit ratings exhibit narrower credit spreads.
In polluting industries, credit ratings are significantly and negatively associated with credit spreads at the 1% level. However, a high Variance Inflation Factor (VIF) indicates multicollinearity, suggesting that credit ratings may be correlated with other factors. In non-polluting industries, credit ratings are statistically insignificant and free from multicollinearity concerns, suggesting that they are tied to traditional financial health in these sectors.

Maturity and Credit Spreads

Hypothesis (H10): Bonds with longer remaining maturities exhibit higher credit spreads. In fact, maturity is negatively related to spreads in both samples. Among polluting issuers the coefficient is significant at the 5 % level; among non-polluters it is significant at 1 %. Longer-dated bonds therefore trade at tighter spreads, suggesting investor confidence in the issuers' long-term stability.

Proceeds (Issuance Size) and Credit Spreads

Hypothesis (H11): Bonds with higher proceeds (measured by issuance size) exhibit higher credit spreads. Contrary to H11, issuance size is negatively and strongly (1 %) associated with spreads for both polluting and non-polluting firms. Bigger deals borrow more cheaply, consistent with greater market confidence in well-capitalised issuers.

Guarantees and Credit Spreads

Hypothesis (H12): Secured or guaranteed bonds exhibit narrower credit spreads. Evidence is mixed. In polluting sectors, non-guaranteed bonds price tighter at the 10 % level—possibly because only stronger polluters can issue unsecured debt. In non-polluting sectors, guaranteed bonds carry significantly (5 %) narrower spreads, aligning with the hypothesis.

Table 3
CARBON RISK AND BOND CREDIT SPREAD

Variable	Credit Spread	
	Polluting Firms	Non-Polluting Firms
Size	45.641*	-5.060383
	-1.78	(-0.51)
Leverage	-191.7	-116.5616
	(-1.26)	(-1.56)
ROA	522.417	-528.7457

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	-0.64	(-1.42)
Growth	-137.7703**	-5.309598
	(-2.07)	(-1.35)
Cash	2017.7	-191.6478
	-1.46	(-0.71)
Property	-109.8	100.71943
	(-0.52)	(-1.41)
PSU [0]	-65.23433**	120.82512**
	(-2.08)	(-4.28)
Maturity	-115.9074**	-15.60961**
	(-2.46)	(-4.32)
Proceeds	-65.20352***	-9.934664***
	(-6.8)	(-2.18)
Guarantee [0]	-70.20799**	47.152744**
	(-2.36)	(-2.48)
Credit Rating	-91.40167***	-5.232726
	(-3.01) *	(-0.69)
Constant	2744.4048***	936.60846***
	(-4.81)	(-3)

Note: *Multivariate regressions link carbon risk to bond credit spreads for polluting and non-polluting issuers. t-statistics (in parentheses) are based on firm-level clustered standard errors. Variable definitions appear in Table 1. ***, **, and * indicate significance at the 1 %, 5 %, and 10 % levels, respectively.*

DISCUSSION

The results point to a clear recalibration of credit-risk perception, with environmental exposure moving from a footnote to a headline concern. For borrowers entrenched in the carbon economy, scale turns out to be an ambivalent factor: while larger balance sheets usually signify stability, the evidence suggests that in carbon-intensive sectors greater size is linked with wider spreads, presumably because higher emissions footprint attracts tougher scrutiny, prospective carbon taxes, and litigation risk (Chava et al. 2014; Seltzer et al. 2020). In low-carbon emitting industries, the same size metric fades into statistical insignificance, reinforcing earlier work that highlights profitability, operating efficiency, and market position as the dominant signals of credit quality (Bauer et al. 2010).

Equally striking is the disappearing role of leverage. Traditional models treat high debt ratios as warning indicators, yet once contingent carbon costs enter the picture, investors appear to de-emphasize leverage considerations; the leverage coefficient is indistinguishable from zero across both samples, echoing Clarkson et al. (2011). The coefficient for Growth exhibits a distinct pattern relative to other variables. In carbon-heavy sectors, faster expansion—captured by the change in operating income—correlates with tighter spreads at the 5 % level. This finding lends weight to the idea that markets reward firms seen to be investing in cleaner technologies or operational upgrades that future-proof cash flows (Oestreich et al. 2015). The same variable is muted in low-carbon sectors, suggesting that investors there remain primarily focused on short-term fundamentals.

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Ownership structure is a statistically significant indication of investor perceptions. Private issuers in polluting industries borrow more cheaply than public-sector undertakings, a gap consistent with the view that privately managed firms can adjust more rapidly in response to policy shocks, whereas PSUs tend to face longer decision-making timelines due to the inherent bureaucratic nature of operations (Tashman et al. 2018). Outside the carbon core, that pattern reverses, as implicit state backing tempers the risk premium on PSU debt.

Bond characteristics reinforce this narrative shift. Longer tenors unexpectedly narrow spreads for both issuer groups, contradicting standard duration–risk logic but suggesting that investors believe firms have more time to adjust to evolving regulation when the maturity horizon is extended (Ehlers et al. 2017). Larger issue sizes likewise compress spreads, a pattern consistent with reputational signaling and the balance-sheet resilience typically associated with seasoned, high-volume borrowers. Guarantees complicate the picture: unsecured bonds from polluting firms sometimes trade at narrower spreads than secured issues, implying that only the strongest names can dispense with collateral, whereas in low-carbon sectors guarantees still perform their traditional role of tightening spreads. Credit-rating variables, meanwhile, confound financial and environmental channels in carbon-intensive industries, supporting Tang and Zhang's (2020) observation that environmental liabilities now filter directly into agency assessments.

Finally, the two-sample t-test confirms that average spreads remain materially higher for carbon-heavy issuers, signaling that the bond market is already charging a premium for future compliance costs and environmental liabilities. For firms intent on reducing their cost of capital, managing leverage alone will no longer suffice; articulating and executing credible decarbonization strategies has become an essential component of risk management and investor communication.

Implications

The evidence that borrowers with substantial carbon exposure pay a clear premium should prompt institutional investors to reevaluate their allocations. Large portfolio managers, tasked with balancing risk and return over long horizons, now confront the fact that firms carrying heavy environmental liabilities already face wider credit spreads and, by extension, higher funding costs (Chava 2014; Seltzer et al. 2020). Reallocating capital toward issuers with smaller carbon footprints—or toward firms that can document credible decarbonization plans—offers one practical safeguard. Flammer (2021) makes a similar point, showing that ESG-aware portfolios have begun to capture a valuation edge. Integrating climate metrics into the mainstream credit toolkit, rather than treating them as a ancillary disclosure, therefore resembles less a symbolic commitment and more like basic fiduciary duty.

Regulators, should take account of the market signal embedded in those wider spreads. When investors systematically penalize opaque environmental risks, the case for tougher disclosure rules almost makes itself. Better, more standardized climate reporting—along the lines advocated by the Task Force on Climate-Related Financial Disclosures—would shrink information gaps, allow prices to reflect risk with greater accuracy, and reduce the scope for sudden repricing shocks (Clarkson et al. 2011; Bauer & Hann 2010). SEBI and its counterparts thus have both the mandate and the market's tacit backing to tighten climate-risk guidelines.

Policy makers can influence capital-allocation decision through fiscal and regulatory instruments. Because the spread gap between polluters and non-polluters translates directly into borrowing-cost differentials, fiscal incentives that accelerate the shift to cleaner production—targeted tax credits, concessional loans, or public-private demonstration projects—can lower

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borrowing costs for firms willing to invest in abatement (Oestreich & Tsiakas 2015). Coordinated initiatives of this sort, Monasterolo and Raberto (2018) argue, not only mobilize private capital but also stabilize credit markets by mitigating tail-risk exposure associated with sudden regulatory changes.

Bond issuers, arguably encounter the most direct incentives. Carbon-intensive firms that ignore the price of environmental risk will experience elevated funding costs and their investor base shrink (Ginglinger et al., 2019). By contrast, issuers that disclose robust transition strategies, set verifiable emissions targets, or access capital markets via labelled green or sustainability-linked bonds increasingly attract a broader (and cheaper) pool of funds. These findings indicate that managing climate exposure has shifted from a reputational consideration to a determinant of debt market access (Tashman et al. 2018; Flammer 2021).

Credit markets are already putting a price on carbon. Throughout this study we found that bonds issued by carbon-intensive firms carry materially wider spreads than those of their low-carbon peers, a signal that investors are anticipating future regulation, potential carbon levies, and higher compliance costs. That premium, documented here for India, echoes a broader international pattern (Chava 2014; Seltzer et al. 2020) and confirms that environmental exposure has become a first-order credit concern rather than a peripheral non-financial risk. A closer look at firm characteristics further amplifies the context since in highly-emitting sectors, size—which traditionally indicates stability—now amplifies perceived risk. Larger polluters attract sharper regulatory scrutiny and are likely to incur higher costs as carbon-pricing regimes are implemented, so investors demand additional interest against the added risk. Our results dovetail with Clarkson et al. (2011) and extend them by showing that the same size effect disappears among low-carbon issuers, where conventional performance measures still dominate risk pricing.

The classic balance-sheet indicator of leverage exhibits a notably diminished effect. Debt ratios, long central to spread models, lose significance once environmental liabilities loom. Investors appear to view carbon exposure as an overarching risk factor that can overwhelm the incremental risk captured by leverage alone. Profitability too fades in explanatory power for polluters, reinforcing the notion that non-financial risks are crowding out some traditional metrics when credit committees price long-dated debt. Growth, however, deviates from this pattern. Within carbon-intensive industries, firms recording strong operating-income gains experience narrower spreads. Investors tend to reward revenue growth that stems from cleaner technologies or efficiency gains, interpreting it as evidence of a firm's capacity to adapt to evolving regulations. Oestreich and Tsiakas (2015) reach a similar conclusion, showing that growth often signals a forward-looking stance toward regulation. Our own results add that the spread gap is shaped not just by financial ratios but also by ownership structure and bond features.

Private issuers in polluting sectors borrow more cheaply than their public-sector counterparts, indicating that organisational agility and governance influence pricing when carbon policy is in flux. Longer tenors and larger issue sizes also attract tighter pricing, suggesting that investors view extended horizons and seasoned issuers as buffers against the buffers against the volatility associated with a low-carbon transition. Guarantees exert a bifurcated influence: they tighten spreads for clean-sector borrowers but, intriguingly, can be less valuable for high-carbon names—perhaps because only the strongest polluters forgo collateral. These findings matter for every corner of the market. Institutional investors must ensure that climate metrics anchor their credit screens. For asset managers, reallocating capital toward low-carbon or transition-ready issuers is driven primarily by risk-management considerations rather than ethical motives.

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Portfolios that ignore this shift may become over-concentrated in firms whose funding costs will rise as climate policy tightens.

Regulators assume a parallel responsibility. The market already discounts opaque environmental liabilities, but better disclosure would enhance that process and mitigate the likelihood of abrupt repricing events. India's own securities watchdog (SEBI) can accelerate adoption of robust frameworks such as the Task Force on Climate-Related Financial Disclosures, forcing issuers to quantify exposures and outline mitigation strategies. Transparent data transform climate risk from an estimated parameter into a quantified variable - one that ratings agencies, analysts, and investors can process quickly and consistently. Policy makers possess an important policy instrument as well: they can narrow the spread penalty by lowering the cost of cutting emissions. Targeted fiscal measures—such as tax credits, concessional loans, or public–private pilot projects—can mitigate the upfront expenditure of cleaner technology. Lowering that barrier mobilises private capital and reduces system-wide credit risk during the move away from carbon-intensive production. Monasterolo and Raberto (2018) add that such cooperation also cushions markets against abrupt shocks when new rules take effect.

For bond issuers—especially those with heavy carbon footprints— the implication is unambiguous. Ignoring climate exposure will become increasingly expensive. Firms that publish verifiable emissions targets, invest in abatement, and issue labelled green or sustainability-linked bonds can access broader pools of capital and secure more competitive pricing. Ginglinger and Moreau (2019) document this dynamic for European markets; our results suggest that the same logic holds true in the Indian context as well.
Looking forward, climate-adjusted credit modelling is likely to become increasingly sophisticated. Frameworks such as the EU's Sustainable Finance Disclosure Regulation and upgraded rating methodologies point towards tighter integration of environmental variables across asset classes. Scholars should test whether the spread premium we document extends to shorter-dated securities or to hybrid instruments, and whether similar patterns hold in loan pricing or in emerging derivatives linked to ESG indices.

CONCLUSION

Carbon pricing schemes, disclosure mandates, and investor preferences are moving targets, and their interplay may alter spread dynamics over time. In addition, while we cluster standard errors at the firm level and include a broad set of controls, unobserved heterogeneity—such as differential access to global capital markets—could still bias estimates. Future work could integrate more granular emissions data or exploit natural experiments around policy shocks to enhance causal inference. Even considering these limitations, one implication is unmistakable: the cost of capital is now tied to the carbon balance sheet. Firms that treat decarbonisation as a strategic imperative rather than a compliance burden will gain an advantage; those that do not will face a widening spread, diminishing investor demand, and tougher borrowing conditions. By documenting this relationship in India's bond market, our study contributes to the growing evidence that environmental risk is being priced rapidly and in certain case substantially into corporate finance. In practical terms, effective risk mitigation will require coordinated actions by investors, regulators, policy makers, and issuers. Investors need reliable data; regulators must mandate it; policy makers can provide incentives to facilitate the transition; and issuers must disclose and act on carbon exposure if they wish to keep borrowing costs in check. Such alignment would enhance market transparency and facilitate capital formation while explicitly incorporating climate-related credit risks.

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