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Does Carbon Carry a Cost?

Evidence on Emissions, Verification, and Cost of Debt in Scandinavia

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Abstract

This study examines whether carbon emissions and third-party verification of emissions data affect the cost of debt for publicly listed firms in Scandinavia (Sweden, Denmark, and Norway). Using a quantitative approach, we run fixed effects Ordinary Least Squares regressions on panel data covering 218 Scandinavian firms across several industries from 2021 to 2024. We find a significant positive relationship between carbon intensity and the cost of debt, suggesting that lenders penalize firms with higher emissions through higher borrowing costs. However, we find no consistent evidence that third-party emissions verification reduces the cost of debt or moderates the emissions-to-cost relationship. Our study contributes to the literature on ESG and debt markets by providing evidence from a Scandinavian context, where sustainability standards and stakeholder expectations are high, offering insight into how lenders price environmental performance.

Keywords: Cost of debt, carbon emissions, information asymmetry, emissions verification, Scandinavia

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1 Introduction

This section introduces the growing role of environmental factors in corporate finance, focusing on how carbon emissions influence firms' cost of debt. We present the purpose of the study, review prior research, and identify a gap in the Scandinavian context. Finally, we introduce the research question and briefly describe the scope and limitations of the study.

1.1. Background

Firms are facing growing pressure to manage not only their economic performance but also their environmental, social, and governance (ESG) impact. As a result, investors, financial institutions, and other stakeholders increasingly incorporate ESG considerations into their assessments of firms. This shift can be seen in the cost of capital, as lenders and investors adjust financing terms based on ESG performance (Friede et al., 2015). Among these ESG factors, carbon emissions have gained particular attention due to their measurability and regulatory relevance (Carbon et al., 2021).

In the European Union, recent regulatory initiatives have been introduced to strengthen ESG and emissions accountability. The Non-Financial Reporting Directive introduced the initial foundation for voluntary sustainability reporting, and its successor, the Corporate Sustainability Reporting Directive (CSRD), marks a shift toward mandatory and standardized environmental disclosure (EEA Joint Committee, 2019; European Union, 2022). Under the CSRD, large and listed companies in European Union member states, such as Sweden and Denmark, and in European Economic Area countries, like Norway, are required to disclose Scope 1 and Scope 2 greenhouse gas emissions. Scope 1 covers direct emissions from a firm's operations, while Scope 2 includes indirect emissions from purchased energy (European Union, 2022). This regulatory evolution reinforces the financial materiality of emissions data and places increased pressure on firms to demonstrate environmental accountability.

Following this, firms with high emissions may face higher borrowing costs, not necessarily due to ethical concerns, but because emissions can signal inefficiency, regulatory exposure, or vulnerability to future policy tightening (Christensen et al., 2021). Empirical evidence from both

European and emerging markets consistently shows a positive relationship between emissions and the cost of debt, suggesting that emission-intensive firms face higher borrowing costs (Caragnano et al., 2020; Kozak, 2021; Temiz, 2022). Country-level studies further reinforce this link, indicating that lenders penalize emissions more heavily in jurisdictions that implement concrete environmental programs (Lee & Choi, 2021). Collectively, these findings suggest that emissions are priced into credit risk assessments and that firms can improve borrowing conditions by managing and disclosing their environmental impact. However, the effectiveness of such disclosures depends heavily on their credibility—a factor complicated by challenges related to information asymmetry.

In the context of ESG, information asymmetry arises when lenders rely on firms' self-reported sustainability data, which may be strategically framed. This creates opportunities for greenwashing, where firms exaggerate or misrepresent their environmental performance. One mechanism proposed to enhance the reliability of these disclosures is third-party verification (Christensen et al., 2021). With the introduction of the CSRD, third-party verification of emissions data becomes mandatory for large and listed companies, starting with reports covering the 2024 financial year (European Union, 2022). Research has also increasingly emphasized the role of such verification. Palea and Drogo (2020) find that participation in the Carbon Disclosure Project, an environmental disclosure rating organization, serves as a form of verified disclosure that lowers borrowing costs among Eurozone firms. Further, Koutoupis et al. (2024) find that greenhouse gas assurance significantly reduces debt costs in developed markets, though the effect is less pronounced or absent in emerging economies. Similarly, Song and Rimmel (2025) caution that while mandatory reporting frameworks can lower borrowing costs by improving transparency, the absence of consistent and enforceable verification standards may limit their effectiveness. To conclude, while verification can enhance credibility and reduce borrowing costs, its effectiveness remains mixed and context-dependent.

1.2. Purpose and Research Question

While the link between emissions and the cost of debt has been well-documented across global and country-specific contexts, existing research has primarily focused on large economies or emerging markets. To the best of our knowledge, no study has yet examined this relationship within the Scandinavian region. We believe that Scandinavia represents a notable research gap, given its consistent leadership in sustainability practices. This geographical area is distinguished by strong institutional frameworks, active stakeholder engagement, and a long-standing integration of ESG values into corporate decision-making (Gjølberg, 2009). From 2015 to 2023, Nordic countries, and thereby Scandinavia, have frequently ranked among the global leaders in the UN Sustainable Development Goals (SDG) Index (Strand, 2024). This makes the region an interesting setting to test whether ESG commitments translate into tangible financial outcomes or whether they remain mostly symbolic. Based on this, we seek to fill these gaps by investigating how CO_2 emissions affect firms' cost of debt in Scandinavia, and what influence verification has on this relationship. Specifically, we seek to answer the following question:

What is the effect of CO_2 emissions on the cost of debt for firms in Scandinavia?

To examine this question, we use a quantitative approach based on firm-level panel data from 218 publicly listed Scandinavian companies between 2021 and 2024. Our empirical strategy involves fixed-effects Ordinary Least Squares (OLS) regressions to assess whether carbon emissions and third-party verification influence firms' cost of debt. We also conduct robustness checks to test the consistency of our findings across alternative specifications.

1.3 Delimitation

This study is limited to publicly listed companies in Scandinavia: Sweden, Norway, and Denmark. We exclude financial firms due to their distinct capital structure, which could distort comparability. However, this scope may introduce bias toward larger and more transparent firms, as smaller or private firms often lack data on emissions or verification. Still, given the study's focus on third-party verification and market-based borrowing costs, these firms represent the most relevant population for our research questions. Regarding emissions terminology, throughout this thesis, we use carbon and CO_2 interchangeably, and these refer to Scope 1 and Scope 2 emissions measured in CO_2 and CO_2 equivalents.

Our paper proceeds as follows: First, in Section 2, we present relevant literature and theoretical frameworks, including traditional determinants, ESG factors, and the theories that inform our hypotheses. In Section 3, we explain the research design, variables, and methodology, including the data sample, fixed effects approach, and robustness tests. Section 4 presents the empirical findings, including descriptive statistics, correlation analysis, and regression results for each hypothesis. Section 5 interprets these results in light of previous research and theory, highlighting practical and theoretical implications. Finally, Section 6 concludes the thesis by summarizing the key findings, acknowledging limitations, and suggesting directions for future research.

2 Literature and Theory

In this section, we present the academic literature and theoretical perspectives relevant to our study. We begin by reviewing traditional determinants of the cost of debt and then narrow the focus to recent research on the influence of ESG factors, particularly carbon emissions. Further, we highlight the role of disclosure and third-party verification in shaping lender perceptions of environmental risk. After reviewing the relevant literature, we introduce four theoretical frameworks: agency theory, information asymmetry, signaling theory, and stakeholder theory. These theories help explain the mechanisms underlying risk perception, thereby impacting firms' cost of debt. Finally, we present our three main hypotheses that will guide our study.

2.1 Literature Review

2.1.1 Cost of Debt and Traditional Determinants

The cost of debt is generally defined, as Brealey et al. (2011) explain, as the effective interest rate that firms pay on their borrowings, adjusted for the tax deductibility of interest payments. It represents the compensation that lenders require for providing capital to the firm and reflects their assessment of the firm’s creditworthiness and financial risk. The cost of debt directly impacts investment decisions, firm valuation, and the overall cost of capital. A high cost of debt can discourage firms from pursuing profitable investments, particularly when the returns primarily benefit existing debt holders. This underinvestment problem reduces strategic flexibility, as firms must weigh the tax advantages of debt against the increased risk of financial distress. As such, managing the cost of debt becomes important, not necessarily to maximize debt usage, but to ensure that financing remains affordable without compromising long-term financial stability (Brealey et al., 2011).

Traditionally, studies have identified several key determinants of the cost of debt, including firm size, profitability, leverage, industry characteristics, and broader macroeconomic conditions. These variables influence lenders' assessment of a firm's default risk and, consequently, the interest rate lenders require as compensation. Together, these variables shape the risk profile that creditors evaluate when setting loan terms (Altman, 1968; Fama & French, 1993).

Previous research has consistently shown that firm size is a significant determinant of a company's cost of debt. Denis and Mihov (2003) argue that larger firms are seen as more transparent, diversified, and less risky. These are characteristics that reduce lenders' required risk premium, thus lowering the firm's cost of debt. Conversely, smaller firms tend to have higher information asymmetries, greater default risk, restricted access to public debt markets, and reliance on costlier bank loans. This dynamic underscores a negative relationship between firm size and the cost of debt: as firm size increases, the cost of debt tends to decrease.

Profitability reflects a firm's ability to generate earnings and meet financial obligations. Studies show that more profitable firms are generally perceived as less risky by creditors, resulting in lower borrowing costs (Kozak, 2021). For example, Muspyta and Ruslim (2021) find that profitability, measured by return on equity (ROE), has a significant negative effect on the cost of debt in Indonesian firms. They suggest that more profitable firms benefit from increased financial credibility, leading to a decrease in the risk premium demanded by lenders. Moreover, profitable companies often rely more on internal financing, reducing their dependence on external debt (Santosuosso, 2014). This is consistent with Myers' (1984) Pecking Order Theory, which states that firms prefer internal funds for investment rather than taking on debt. Consequently, profitable firms tend to rely less on debt and benefit from lower borrowing costs over time.

Leverage is often presented as another determinant of a firm's cost of debt. It is typically measured as the ratio of a firm's debt to its equity or assets. It reflects the extent to which a firm relies on borrowed funds to finance its operations. Previous research suggests that firms with excessive leverage have an increased risk of default (Caragnano et al., 2020; Kumar & Firoz, 2018; Pizzutilo et al., 2020). In more severe cases, high leverage may also lead to insolvency, where the firm becomes unable to meet its obligations entirely. Both outcomes increase perceived credit risk, causing lenders to demand a higher risk premium and thereby raising the firm's cost of debt. However, some research offers another perspective. For example, Ross (1977) argues that higher leverage can be seen as an indicator of firm quality. Ross claims that managers of financially strong firms may take on more debt to signal confidence in future cash flows, thereby distinguishing themselves from weaker firms. As a result, lenders may perceive these highly leveraged firms as less risky, potentially resulting in more favorable borrowing terms. This view highlights that the relationship between leverage and the cost of debt may not always be straightforward and can depend on how leverage is interpreted by the market.

In addition to firm-specific characteristics, the industry or sector a firm operates in also plays a role in determining its cost of debt. Amiram et al. (2017) show that lenders consider industry-level risks, particularly how sensitive the industry is to economic shocks and its expected growth, when pricing loans. Similarly, Cahyono and Chawla (2019) find that sectoral behavior significantly shapes financing patterns, with industry-specific variables like competition intensity and market dynamism affecting leverage and, by implication, the cost of debt. These findings underline that the broader industry environment can directly impact a company's access to and cost of external financing (Amiram et al., 2017; Cahyono & Chawla, 2019).

At an even broader level, macroeconomic conditions also influence the cost of debt. According to the Fisher effect, higher expected inflation leads to higher nominal interest rates and, consequently, higher borrowing costs (Fisher, 1930). Inflation volatility further raises uncertainty for lenders, increasing credit spreads and raising the cost of debt (Kang & Pflueger, 2015). Furthermore, monetary policy impacts a firm's cost of debt by influencing overall borrowing conditions in the economy. By increasing both interest rates and perceived credit risk, a tightening in monetary policy raises the cost of debt (Bernanke & Gertler, 1995). During times of economic weakness, such as recessions, yield spreads between low- and high-grade bonds (default spreads) widen due to increased credit risk. In contrast, during strong economic periods, spreads narrow, leading to lower borrowing costs (Fama & French, 1989).

2.1.2 ESG, Emissions, and Cost of Debt

In addition to the traditional determinants of the cost of debt, a firm's environmental, social, and governance (ESG) performance has emerged as a potential determinant of borrowing costs by shaping lenders' perceptions of non-financial risk. For example, Dunne and McBrayer (2019) provide evidence from the U.S. context, showing that small firms benefit significantly from voluntary ESG disclosure in the form of reduced interest expenses. Furthermore, several studies have examined the relationship between ESG scores and the cost of debt, reporting a negative association, thus suggesting that firms with stronger ESG practices face lower borrowing costs (Apergis et al., 2022; Ariefianto et al., 2024; Arora & Sharma, 2022; Shi et al., 2024).

Within ESG factors, the environmental pillar has attracted particular attention, raising the question of whether firms with poorer environmental performance face higher debt costs due to perceived regulatory, operational, or reputational risks (Krueger et al., 2020). For example, Chava (2014) focuses on environmental externalities such as hazardous waste, toxic emissions, and climate change concerns, showing that firms with greater environmental exposure face higher costs of both equity and debt. The study demonstrates that various environmental risk indicators are associated with firms' borrowing conditions (Chava, 2014).

Among environmental risk factors, corporate greenhouse gas (GHG) emissions have emerged as a key area of focus (Bolton & Kacperczyk, 2021). Emissions are often viewed as a direct and measurable indicator of a firm's environmental footprint and its risk exposure. Because emissions data are relatively standardized and increasingly scrutinized by investors and regulators, they have become a central variable in studies investigating the link between environmental performance and financing outcomes (Chava, 2014).

Previous research has consistently found evidence supporting a positive relationship between emissions and the cost of debt. For example, several studies confirm a robust positive association between greenhouse gas emissions and the cost of debt in European markets, suggesting that lenders incorporate carbon risk into credit assessments (Caragnano, 2020; Kozak, 2021; Pizzutilo et al., 2020). Caragnano et al. (2020) show that this relationship holds across industries and that even low-emission firms are more heavily penalized for increases in intensity, which they conclude is likely because such changes are perceived as a weakening of the firm's environmental commitment. Similarly, Kozak (2021) confirms this effect across three different emission metrics: CO_2 per revenue, CO_2 per assets, and CO_2 per employee. Further, he identifies cross-country variation, with stronger penalties observed in countries like Norway, Poland, Portugal, and the UK. Collectively, these findings suggest that firms across Europe face tangible financial consequences for higher emissions (Caragnano, 2020; Pizzutilo et al., 2020; Kozak, 2021).

Furthermore, a growing body of research provides insight into emerging markets, where evidence also supports the positive association between emissions and the cost of debt (Kumar & Firoz, 2018; Temiz, 2022). Temiz (2022) analyzes 17 emerging economies, including China, India, and Brazil, and finds that improvements across three environmental pillars, including emissions reductions, are associated with significantly lower costs of debt. Kumar and Firoz (2018) examine Indian firms during the period 2011-2014. They find that firms with higher Scope 1 carbon emissions face significantly higher borrowing costs in environmentally sensitive sectors, like energy and utilities, while the effect is not statistically significant in less polluting industries. Together, these studies suggest that in emerging markets, low emissions are rewarded in terms of the cost of debt (Kumar & Firoz, 2018; Temiz, 2022).

2.1.3 The Role of Disclosure and Verification

Beyond emissions levels, recent research highlights the financial relevance of *how* firms disclose their environmental impact. In this context, transparent and voluntary carbon disclosure can lower borrowing costs by reducing information asymmetry and signaling accountability to lenders. The credibility of such disclosures often depends on the regulatory context. Lee and Choi (2021) find that South Korean firms in government-led carbon programs benefit from lower debt costs—a finding that is confirmed by Nasih et al. (2024), who observe the same effects for firms participating in a state-supervised disclosure scheme in Indonesia. Both studies argue that the credibility of state-supervised disclosure frameworks increases lenders' trust in the reported information.

This relationship between disclosure credibility and borrowing costs also holds in markets where participation is voluntary rather than state-mandated. In Australia, Jung et al. (2018) find that high-carbon firms face higher borrowing costs only if they fail to disclose emissions, with the penalty disappearing for firms that respond to the Carbon Disclosure Project. Lastly, Palea and Drogo (2020) also find that participation in the Carbon Disclosure Project is associated with lower debt costs due to enhanced transparency. Together, these findings suggest that emissions disclosure can mitigate lenders' perception of risk and lower the cost of debt by rewarding firms that actively manage and communicate their environmental impact (Jung et al., 2018; Lee & Choi, 2021; Nasih et al., 2024; Palea & Drogo, 2020).

Building on this, a smaller but growing body of research emphasizes that the key issue is not just whether firms disclose, but how credible and verifiable those disclosures are. Disclosure without trust may fail to reduce borrowing costs, especially when data appear unreliable or strategically framed, highlighting risks of information asymmetry and greenwashing. Third-party verification, where emissions data are independently assured, has been discussed as a potential signal of credibility. Palea and Drogo (2020) find that verification reduced debt costs for high-emitting Eurozone firms. Furthermore, Koutoupis et al. (2024) show that verification lowers borrowing costs in developed economies, particularly for low-risk firms, though the effect weakens for riskier firms and disappears in emerging markets where the institutional capacity for enforcing sustainability standards is more limited. Similarly, Song and Rimmel (2025) argue that while mandatory reporting improves transparency and reduces debt costs, inconsistent verification standards may limit its effectiveness. Together, these findings suggest verification can be seen as a credibility-enhancing mechanism, however, empirical evidence on its financial impact is mixed (Koutoupis et al., 2024; Palea & Drogo, 2020; Song & Rimmel, 2025).

2.2 Theoretical Perspective

2.2.1 Agency Theory and Information Asymmetry

Agency theory provides a foundational framework for understanding conflicts of interest within the firm, primarily between shareholders and managers, but also extends to other stakeholders such as creditors. (Jensen & Meckling, 1976) define it as a relationship where a principal delegates decision-making to an agent, potentially creating misaligned incentives that require monitoring or incentive systems to ensure long-term value creation. In our case, agency theory helps explain how misaligned incentives between managers and lenders can lead to higher borrowing costs, particularly for firms with high carbon emissions or disclosures that lack credibility. It can explain why lenders could view firms with low sustainability performance or limited disclosure as riskier, thus impacting borrowing conditions.

Information asymmetry occurs when one party in a transaction possesses more or better information than the other (Akerlof, 1970; Myers, 1984). While agency theory explains the misalignment of incentives between managers and lenders, information asymmetry focuses on unequal access to information. Information asymmetry occurs when one party in a transaction possesses more or better information than the other (Akerlof, 1970; Myers, 1984). Historically, ESG and emissions disclosure have, to a large extent, been voluntary and non-standardized. Thus, firms often hold more knowledge about their emissions and environmental risks than external stakeholders. This uncertainty can increase perceived credit risk and consequently raise borrowing costs. Furthermore, in the context of emission verification, information asymmetry may help explain why firms with similar emission levels, but differing verification statuses, could face different borrowing conditions.

2.2.2 Signaling Theory

Signaling theory, developed by Spence (1973), could help to explain why firms engage in third-party verification. It provides a framework for understanding how individuals in markets with information asymmetry convey unobservable qualities through observable signals. Spence argues that actions, such as verifying emissions, serve not necessarily to improve productivity, but also to credibly signal underlying abilities to decision-makers. Spence argues that credible signals often carry costs and that these costs are easier to bear for high-quality entities. Applied to our context, firms with strong sustainability practices are perhaps more likely to pursue third-party verification, as it is less risky and more affordable for them. For firms with weaker practices, verification may be prohibitively costly or expose shortcomings. Thus, third-party verification acts as a costly, credible signal that differentiates firms based on environmental performance (Spence, 1973).

2.2.3 Stakeholder Theory

Stakeholder theory can help explain why firms face pressure from a broad set of actors beyond shareholders. As sustainability becomes more central to business, a wide range of stakeholders, such as consumers, creditors, institutions, and the public, increasingly influence a firm's reputation and performance. Freeman (2001) argues that firms should not focus solely on value creation for their shareholders but for all stakeholders who affect or are affected by the firm. Donaldson and Preston (1995) extend this view by emphasizing that firms must recognize that stakeholder interests also carry ethical weight, not just strategic relevance. From this perspective, a firm's environmental practices are viewed as a societal responsibility, and not only a component of business performance.

This might be especially relevant in the Scandinavian context, where stakeholder expectations around sustainability are high. In addition to investors and creditors, actors such as customers, regulators, and employees play an important role in shaping firms' risk profiles in Scandinavia. For instance, Scandinavian consumers' strong environmental values (Hanss & Böhm, 2012) can influence market demand and brand strength. These stakeholder pressures can translate into reputational and operational risk, which lenders may factor into credit assessments. Thus, firms with strong environmental performance or credible sustainability disclosures may enjoy better borrowing conditions—driven not only due to financial metrics but also due to alignment with stakeholder expectations in a region where ESG norms are deeply embedded.

2.3 Hypotheses

Building on the theoretical perspectives and empirical findings discussed above, we formulate three main hypotheses that guide our analysis. First, prior research consistently finds that firms with higher carbon emissions face increased borrowing costs in both developed and emerging markets, reflecting how lenders price environmental risk. We expect the relationship to hold in a Scandinavian context as well, particularly given its advanced sustainability standards and strong expectations around corporate transparency. Based on this reasoning, we hypothesize that:

Hypothesis 1: *There is a significant positive relationship between CO2 emissions and the cost of debt for firms in Scandinavia.*

Second, while emissions disclosure is often seen as a step toward reducing information asymmetry, its effectiveness may hinge on the perceived credibility and trustworthiness of the information.

Self-reported sustainability data may be subject to manipulation or selective reporting, particularly in voluntary disclosure environments. As such, third-party verification serves as a mechanism to enhance disclosure credibility through independent assurance. To lenders, verified disclosures may signal greater transparency and a proactive approach to managing environmental risk, thus lowering the cost of debt. Although the literature provides mixed evidence on the impact of verification, we expect that Scandinavian firms engaging in third-party verification will face more favorable borrowing terms. We thus hypothesize that:

Hypothesis 2: *Scandinavian firms with third-party verified emissions data are associated with a lower cost of debt than firms without such verification.*

In addition to testing the direct effects of emissions and verification separately, we also examine whether third-party verification moderates the relationship between carbon intensity and the cost of debt. While firms with high emissions are generally penalized with higher borrowing costs, this effect may be less severe when emissions data are independently verified. Verification can reduce information asymmetry, enhance data credibility, and serve as a signal that the firm acknowledges and is managing its environmental risks. If this is the case, lenders may view verified emissions as less concerning than unverified disclosures, even when emissions levels are high. Based on this, our third hypothesis is as follows:

Hypothesis 3: *Third-party verification moderates the relationship between CO_2 emissions and the cost of debt in Scandinavia, such that the penalty for high emissions is smaller when emissions are verified.*

3 Method

In this section, we outline the empirical strategy used to test our three hypotheses: (H1) that carbon emissions are positively associated with the cost of debt, (H2) that third-party verification of emissions disclosures is negatively associated with the cost of debt, and (H3) that third-party verification moderates the relationship between CO_2 emissions and the cost of debt. The section proceeds as follows: First, we describe the research design and present the regression models.

Second, we describe the variables used in the analysis. Third, we explain the robustness tests to be conducted using an alternative measure of the cost of debt. Fourth, we detail the sample selection, including the data-cleaning procedures. Fifth and finally, we discuss methodological limitations that may affect the interpretation of our findings.

3.1 Research Design

To examine the relationship between CO_2 emissions and the cost of debt, we employ a quantitative approach using a firm-level panel dataset to estimate a series of fixed effects Ordinary Least Squares (OLS) regressions. This method is widely used for estimating linear relationships between variables, and it is appropriate for our study since it allows us to measure the impact of carbon intensity on the cost of debt while controlling for other firm-specific factors. To ensure valid, unbiased, and efficient OLS estimates, the Gauss-Markov assumptions are assumed to hold.

One key assumption is linearity in parameters, which is satisfied by construction, as the relationship between the dependent and independent variables is specified in a linear functional form. Furthermore, previous research has found a linear relationship between emissions and the cost of debt, as presented in the literature review (e.g., Caragnano et al., 2020; Kozak, 2021; Pizzutilo et al., 2020). Another assumption is homoscedasticity, that is, constant variance of the error terms, which we assess with a Breusch-Pagan test. The results indicate mild heteroskedasticity, and to address this, we apply Bartlett Kernel heteroskedasticity- and autocorrelation-consistent (HAC) standard errors. This approach also helps mitigate the impact of serial correlation. Finally, another key assumption is the absence of endogeneity, where it is assumed that the error term is uncorrelated with the independent variables. By controlling for key firm characteristics such as size, profitability, and leverage, the risk of omitted variable bias is minimized, thereby supporting the exogeneity assumption.

To further address endogeneity, we employ a combination of two approaches: a one-year lagged carbon intensity variable and fixed effects for sector and year. The lag ensures correct temporal ordering, reflecting how lenders incorporate environmental performance into their risk assessments first in the following period. Sector fixed effects help control for heterogeneity across industries, such as capital intensity, regulatory exposure, or industry-specific risk norms, that may simultaneously influence both emissions and borrowing costs. Year fixed effects, meanwhile, capture common shocks or macroeconomic conditions, such as interest rate movements, regulatory changes, or ESG-related trends, that may affect all firms in a given year. While these measures reduce key endogeneity risks, they cannot fully eliminate bias from time-varying, firm-specific unobservables. Still, given our aim to assess associations rather than causality, we consider this approach sufficiently robust.

To enhance the accuracy and reliability of our estimates, we take additional measures beyond testing the core model assumptions. Multicollinearity among independent variables is tested for by calculating Variance Inflation Factor (VIF) values for all variables, as well as constructing a Pearson's correlation matrix, and no severe multicollinearity is detected (see Section 4.2 for results). Moreover, to mitigate the influence of extreme values, all variables are winsorized at the 5th and 95th percentiles. This preserves the full sample of firms while reducing the impact of outliers on the regression estimates.

To examine the relationship between carbon emissions and the cost of debt, our analysis proceeds in three steps, each with its respective model. We begin with a baseline model that tests whether carbon intensity is associated with higher borrowing costs. This model controls for key firm-level financial characteristics and includes sector- and year-fixed effects. By estimating this initial model, we establish whether carbon intensity is priced into firms' borrowing costs. Our baseline regression model, model (1), is specified as follows:

$$COD_{i,t} = \beta_0 + \beta_1 CARBON\_INT_{i,t-1} + \beta_2 SIZE_{i,t} + \beta_3 ROA_{i,t} + \beta_4 LEVERAGE_{i,t} + \gamma_{Sector} + \gamma_{Year} + \varepsilon_{i,t} \quad (1)$$

Where γ_{Sector} and γ_{Year} are sector- and year-fixed effects, respectively (the remaining variable specifications are provided in the next section). In the second model, we extend the baseline specification to test Hypothesis 2: that firms whose carbon emissions have been independently verified by a third party face a lower cost of debt. We do so by adding a binary variable equal to one if a firm's emissions have been independently verified in a given year, and zero otherwise. This allows us to test whether, all else equal, firms that verify their emissions enjoy lower debt costs than those without verification. A negative and statistically significant coefficient on the verification variable would support the hypothesis that verification signals credibility, reduces perceived risk, and thereby improving borrowing conditions. Our verification regression model, model (2), looks as follows:

$$COD_{i,t} = \beta_0 + \beta_1\, CARBON\_INT_{i,t-1} + \beta_2\, VERIFICATION_{i,t-1} + \beta_3 SIZE_{i,t} + \beta_4\, ROA_{i,t} + \beta_5\, LEVERAGE_{i,t} + \gamma_{Sector} + \gamma_{Year} + \varepsilon_{i,t} \qquad (2)$$

The third model reflects our third hypothesis, whether emissions verification plays a moderating role in the relationship between carbon intensity and the cost of debt. In this specification, we include an interaction term between the verification variable and lagged CO_2 intensity. This model allows us to assess whether verified firms are penalized less for high emissions, compared to firms whose disclosures are not verified. A negative interaction coefficient would indicate that lenders are more forgiving of high carbon emissions when the disclosures are verified. Our interaction regression model, model (3) looks as follows:

$$COD_{i,t} = \beta_0 + \beta_1\, CARBON\_INT_{i,t-1} + \beta_2\, VERIFICATION_{i,t-1} + \beta_3\left(VERIFICATION_{i,t-1} \times CARBON\_INT_{i,t-1}\right) + \beta_4 SIZE_{i,t} + \beta_5\, ROA_{i,t} + \beta_6 LEVERAGE_{i,t} + \gamma_{Sector} + \gamma_{Year} + \varepsilon_{i,t} \qquad (3)$$

3.2 Variables

This section outlines the key variables used in our analysis and describes how they are constructed, summarized in Table 1 below. All financial variables are expressed in euros and measured in book values. Our dependent variable (COD) is a market-implied cost of debt, calculated using firm-specific credit curves at 1- and 10-year maturities. This approach is based on the Weighted Average Cost of Capital (WACC) framework and reflects the marginal borrowing rate a firm would face if issuing new debt. Compared to accounting-based measures such as interest expense over total debt, this metric offers an up-to-date and accurate proxy for lenders' perceptions of firm-specific credit risk.

Our main explanatory variable, denoted by CARBON_INT is a variable for carbon intensity. The variable includes Scope 1 and Scope 2 carbon dioxide and CO_2 equivalent emissions (methane, nitrous oxide, hydrofluorocarbons, perfluorinated compounds, sulfur hexafluoride, and nitrogen trifluoride) in tonnes. We exclude Scope 3 emissions due to limited data availability. Following Kozak (2021), we measure CO_2 intensity as emissions divided by total assets to allow comparability across firms of different sizes. While some studies (e.g., Palea and Drogo, 2020; Caragnano et al., 2020) use revenue as the denominator, we use assets to better reflect the capital base of the firm, which is more stable over time and less sensitive to short-term fluctuations. To improve coefficient interpretability, we scale the variable by 1,000. This transformation does not affect results but adjusts the coefficient magnitude to a more intuitive range. As mentioned in the previous section, it is lagged by one year ($t-1$) to reflect how past emissions influence current borrowing conditions. The variable is calculated as follows:

$$CARBON\_INT = \frac{Emissions}{(Total\_Assets \ / \ 1000)} \tag{4}$$

To test our second and third hypotheses, we introduce another explanatory variable, VERIFICATION, in the models (2) and (3). This variable is a binary variable indicating whether or not a firm's carbon emissions have been verified by a third party in period *t*. As with our main independent variable, we apply a one-year lag to this variable in order account for temporal order. In model (3), we construct an interaction term (CARBON_INT × VERIFICATION) to measure the moderating effect of verification in the emissions-cost of debt relationship.

To control for key financial factors and isolate the specific impact of CO_2 emissions on debt pricing, we include control variables consistent with prior studies, as discussed in the literature review section 2.1.1. Firm size (SIZE) is captured by the logarithm of total assets, as larger firms typically benefit from lower borrowing costs due to greater financial stability. Accordingly, the coefficient on SIZE is expected to be negative. To reduce multicollinearity and condition number, as well as to improve model interpretability and stability, the variable is mean-centered by subtracting its average value. Profitability is proxied by return on assets (ROA), with more profitable firms generally perceived as less risky, leading to lower borrowing costs. Accordingly, the coefficient on ROA is also expected to be negative. Lastly, (LEVERAGE), measured as the ratio of total debt to total equity is included. As discussed in the literature, its effect on the cost of debt is ambiguous. We therefore include it without a strong directional expectation, as its impact may depend on how lenders interpret a firm's level of leverage.

Table 1: Variable Descriptions Summary

Categories	***Variable Name***	***Descriptions***
Dependent Variables	[COD]	Marginal cost of issuing new debt based on credit curves (1Y & 10Y). Reflects lenders' perception of current credit risk.
	[REALIZED_COD]	(Interest Expense / Total Debt) × (1 – Tax Rate). Backward-looking measure of actual historical borrowing costs.
Explanatory Variables	[CARBON_INT]	CO_2 emissions / (Total Assets / 1000). Measures carbon emissions relative to firm size, scaled by 1,000 for coefficient interpretability. Lagged by one year to reflect how past emissions influence current borrowing conditions.
	[VERIFICATION]	1 = emissions are third-party verified, 0 = otherwise. Captures whether emissions disclosures are independently assured. Lagged by one year to reflect how past verification influences current borrowing conditions.
	[VERIFICATION × CARBON INTENSITY]	Interaction term that captures whether verification moderates the relationship between carbon intensity on the cost of debt.
Control Variables	[SIZE]	Logarithm(Total Assets – Mean(Total Assets)). Proxy for firm size; helps control for size-related effects on borrowing cost. Centralized to improve model interpretability and reduce multicollinearity.
	[ROA]	Net Income / Average Total Assets. Measures profitability; more profitable firms may face lower credit risk.
	[LEVERAGE]	Total debt / total equity. Measures the extent of debt financing relative to equity, which can influence the cost of debt depending on how risk and financial structure are perceived.

Notes: All financial values are calculated using book values and presented in euros.

3.3 Robustness Test

The forward-looking nature of our market-implied cost of debt introduces potential limitations when interpreting causal relationships based on past firm characteristics. Therefore, to test the robustness of our findings, we calculate an alternative cost of debt measure based on realized financing outcomes:

$$REALIZED\_COD = \left(\frac{Interest\_Expense}{Total\_Debt}\right) \times (1 - \text{Effective\_Tax\_Rate}) \tag{5}$$

Unlike our main variable, which captures market-perceived credit risk, this measure reflects historical borrowing costs tied to existing debt contracts. While the realized cost of debt may be influenced by older financing decisions and may not fully capture how markets currently price environmental risk, it serves as a useful comparison. We re-estimate our main regression models (1), (2), and (3) using this alternative measure to assess whether the relationship between emissions and borrowing costs holds beyond investor expectations.

3.4 Sample Selection

For our regression analysis, we use a sample of Scandinavian firms with financial, emissions, and verification data gathered from Eikon Refinitiv. The initial dataset comprised 1,342 public Scandinavian firms, spanning 15 years from 2009 to 2024. We then apply a series of data cleaning procedures to prepare the dataset for analysis (see Table 2). First, we excluded 146 financial firms (e.g., banks, insurance companies) due to differences in capital structure and financial reporting, resulting in 1202 firms. Upon closer inspection of the emissions data, we found considerable inconsistency in how many and which years firms had reported emissions. We removed 971 firms with fewer than four years of available data, as limited time coverage weakens the reliability of firm-level estimates and undermines the effectiveness of fixed effects in panel regression. Finally, we excluded seven firms with missing emissions or verification data for the years 2021–2024. After applying these criteria, we end up with a final sample of 218 companies and 872 firm-year observations. Before running our regressions, we remove some rows with missing values for variables used in each model, resulting in a different number of observations for each model.

Table 2: Data Cleaning Process

	Number of Firms	***Number of Firm-Year Observations***
Initial Sample	1342	5368
- Financial institutions	-146	-584
- Firms with less than four years of data	-971	-3884
- Firms with missing data 2021-2024	-7	-28
Final Sample	218	872

Notes: The number of observations varies across regression models depending on data availability for specific variables.

Our final sample consists of 132 Swedish firms, 47 Norwegian firms, and 39 Danish firms. Our sample includes companies from 75 different industries, but to mitigate correlation issues in our regressions when implementing fixed effects, we group the industries into nine more distinct sectors (see Appendix A, Table A1).

3.5 Data and Methodology Limitations

A key limitation of this study is the potential for self-selection bias, as firms that choose to disclose emissions data may systematically differ from those that do not. In particular, firms with stronger environmental commitments might be more likely to report and verify emissions, which may skew the sample toward greener and more transparent companies. Notably, our sample covers the years 2021 to 2024—a period when third-party verification was still largely voluntary. The CSRD verification requirement applies only from the 2024 financial year, meaning that most firms in our sample were not yet subject to mandatory verification.

Secondly, our analysis includes only Scope 1 and 2 emissions, excluding Scope 3. As Scope 3 can represent a significant share of total emissions, this limits our ability to capture firms' full carbon footprint. Third, our study does not control for credit ratings, despite this being a recognized indicator of borrowing costs. In our case, credit ratings are highly correlated with firm-level control variables already included in the model, which capture much of the same variation. Therefore, while we acknowledge their relevance, we do not include credit ratings in our analysis. Lastly, the study focuses on listed companies, which may not represent the broader population of Scandinavian firms. Caution is therefore needed in generalizing the findings.

4 Findings and Analysis

This section presents our study's empirical results and is structured in three main parts to provide a comprehensive understanding of the data and the relationships under investigation. First, we provide a descriptive overview of the dataset to summarize key sample characteristics and offer insight into the distribution and variability of the data. Second, we conduct a correlation analysis to assess potential multicollinearity and to examine whether the relationships between key variables are consistent with our theoretical expectations. Third, we turn to the regression analysis, where we formally test the study's main hypotheses.

4.1 Descriptive Statistics

Table 3 presents descriptive statistics for the main variables included in the analysis. The sample consists of 872 firm-year observations for most variables, with slightly fewer observations for the realized cost of debt and CO_2 intensity due to limited data.

The mean WACC-based cost of debt (COD) is 3.6%, while the realized cost of debt (REALIZED_COD) is slightly lower, at 2.8%. CO_2 intensity (CARBON_INT) shows a right-skewed distribution, with a mean of 0.044 and a maximum value of 0.936, indicating that while most firms report relatively low emissions intensity, a few firms have substantially higher values. SIZE, proxied by the logarithm of total assets, has been mean-centered to aid interpretation in the regression analysis and reduce multicollinearity. As expected, its mean is approximately zero. LEVERAGE shows considerable variation, with a mean of 1.173 and a maximum of 55.607, suggesting the presence of highly leveraged firms in the sample. Return on assets (ROA), a proxy for firm profitability, has a mean of 5.1% and ranges from -6.3% to 16.4%.

Table 3: Descriptive Statistics

Variable	*Count*	*Mean*	*Std Dev*	*Min*	*25%*	*Median*	*75%*	*Max*
COD	872	0.036	0.012	0.014	0.028	0.032	0.043	0.061
REALIZED_COD	660	0.028	0.020	0.000	0.015	0.024	0.036	0.145
CARBON_INT	654	0.044	0.115	0.000	0.002	0.008	0.023	0.936
SIZE	872	-0.000	1.471	-2.878	-1.040	0.019	1.080	2.524
ROA	872	0.051	0.056	-0.063	0.019	0.050	0.084	0.164
LEVERAGE	872	1.173	3.577	0.011	0.359	0.641	1.041	55.607

Notes: *COD* is the market-implied cost of debt based on credit curves; *REALIZED_COD* is calculated as (Interest Expense / Total Debt) × (1 – Tax Rate). *CARBON_INT* is CO_2 emissions relative to total assets (lagged one year) and scaled by 1000; *SIZE* is the mean-centered log of total assets; *ROA* is net income divided by total assets; *LEVERAGE* is the ratio of total debt to total equity. *VERIFICATION* is not included since it is a binary variable.

4.2 Correlation Analysis

To assess the risk of multicollinearity and gain preliminary insight into the relationships between our key variables, we conduct a Pearson correlation analysis (see Table 4) and a variance inflation factor (VIF) test (see Table 5). The results show that none of the variables exhibit high correlations with one another, indicating that multicollinearity is not a concern in our models. As shown in the correlation matrix, the highest correlation occurs between VERIFICATION and SIZE, with a correlation coefficient of 0.459. This is moderate, but still well below common multicollinearity thresholds. All other pairwise correlations are low, ranging between –0.132 (SIZE and LEVERAGE) and 0.065 (CARBON_INT and ROA). Notably, CARBON_INT is weakly positively correlated with VERIFICATION ($r = 0.102$), and weakly negatively correlated with LEVERAGE ($r = –0.047$), indicating minimal bivariate association.

Table 4: Pearson's Correlation Matrix

	Expl. Variable	*1*	*2*	*3*	*4*	*5*
1	**CARBON_INT**	1.000				
2	**SIZE**	-0.029	1.000			
3	**LEVERAGE**	-0.047	-0.132	1.000		
4	**ROA**	0.065	-0.030	0.030	1.000	
5	**VERIFICATION**	0.102	0.459	-0.104	0.035	1.000

Notes: *CARBON_INT* is CO_2 emissions relative to total assets (lagged one year) and scaled by 1000; *SIZE* is the mean-centered log of total assets; *ROA* is net income divided by total assets; *LEVERAGE* is the ratio of total debt to total equity; *VERIFICATION* is a dummy indicating whether a firm's emissions are verified by a third party.

We further assess multicollinearity using VIF values for all independent variables. The VIF values range from 1.009 (ROA) to 1.286 (VERIFICATION), confirming that multicollinearity is minimal and that the variables can be reliably included in the same regression model. The VIF for the constant term is high (274.360), as expected, but this does not affect model interpretability. Overall, the correlation and VIF tests indicate that our model specifications are not compromised by collinearity and that each explanatory variable contributes distinct information.

Table 5: Variance Inflation Factor (VIF) Test

Explanatory Variable	***VIF Test***
CONSTANT	274.360
CARBON_INT	1.016
SIZE	1.283
ROA	1.009
LEVERAGE	1.023
VERIFICATION	1.286

Notes: *CARBON_INT* is CO_2 emissions relative to total assets (lagged one year) and scaled by 1000; *SIZE* is the mean-centered log of total assets; *ROA* is net income divided by total assets; *LEVERAGE* is the ratio of total debt to total equity; *VERIFICATION* is a binary variable indicating whether a firm's emissions are verified by a third party.

4.3 Regression Results

4.3.1 Carbon Intensity and the Cost of Debt

Table 6 presents the results from the main regression model examining the relationship between lagged CO_2 intensity (CARBON_INT). The model includes financial control variables: SIZE (log of total assets), ROA (return on assets), LEVERAGE, and sector- and year-fixed effects using dummy variables. Standard errors are heteroskedasticity- and autocorrelation-robust (HAC), with one lag. The condition number is 68.7, indicating no severe multicollinearity issues. The model explains approximately 22.6 % of the variation in the cost of debt, as indicated by the adjusted R-squared. The F-statistic of 11.78 suggests that the model is statistically significant overall. Lagged CO_2 intensity is positively and significantly associated with the cost of debt ($\beta = 0.020$, $p = 0.000$), supporting Hypothesis 1 and indicating that firms with higher past emissions may face higher borrowing costs. Among the control variables, ROA is negatively and significantly associated with the cost of debt ($\beta = –0.075$, $p = 0.000$), consistent with expectations that more profitable firms may be seen as lower-risk borrowers. SIZE, proxied by the log of total assets and mean-centered, is also negatively associated with the cost of debt ($\beta = –0.002$, $p = 0.000$), suggesting larger firms benefit from lower borrowing costs. LEVERAGE shows a negative but statistically insignificant coefficient (β = –0.000, p = 0.778). The lack of statistical significance suggests that leverage does not play a significant role in explaining variation in the cost of debt in this sample.

Table 6: Regression Results for Model (1)

Expl. Variable	*Exp. Sign*	*Coef.*	*Std Err.*	*Z-score*	*P-value*	*CI 2.5%*	*CI 97.5%*
INTERCEPT		0.037***	0.002	23.173	0.000	0.033	0.040
CARBON_INT	+	0.020***	0.005	4.218	0.000	0.011	0.029
SIZE	-	-0.002***	0.000	-5.146	0.000	-0.003	-0.001
ROA	-	-0.075***	0.010	-7.508	0.000	-0.094	-0.055
LEVERAGE	?	-0.000	0.000	-0.282	0.778	-0.001	0.000
Dependent Variable	COD		Adjusted R-squared		0.226		
Observations	579		F-Statistic		11.780		
Fixed-effects	Sector, Year		Cond. Number		68.700		

Notes: Significance level: *** indicating 1%, ** indicating 5%, and * indicating 10%. Standard errors are heteroskedasticity- and autocorrelation-robust (HAC), estimated with one lag. "Exp. Sign" indicates the expected direction of the coefficient based on theory or prior studies. The "?" for LEVERAGE reflects theoretical ambiguity, as literature provides mixed findings on its effect.

As a robustness check, we re-estimate the main regression using the realized cost of debt (REALIZED_COD) as the dependent variable instead of the WACC-based measure. The results (see Appendix B, Table B1) show that the coefficient on CARBON_INT remains positive and statistically significant at the 5% level (β = 0.030, p = 0.036). Regarding the control variables, SIZE remains negatively and significantly associated with the cost of debt (β = -0.003, p = 0.000), consistent with the main findings. ROA also remains statistically significant, although the direction of its effect shifts from negative to positive (β = 0.059, p = 0.005), indicating a potential change in how profitability relates to borrowing costs across specifications. LEVERAGE continues to show no significant effect (p = 0.788). Overall, these findings suggest that the main results are generally robust to alternative ways of measuring the cost of debt.

4.3.2 The Role of Third-Party Verification

Table 7 presents the regression results for Hypothesis 2, which includes a variable for third-party verification of emissions disclosures. In this regression, CO_2 intensity becomes statistically insignificant (p = 0.612), indicating no clear association with the cost of debt in this specification. Similarly, the VERIFICATION variable has a non-significant effect (p = 0.881), suggesting that verified emissions disclosures do not independently influence borrowing costs. Among the control variables, both SIZE (β = -0.002, p = 0.000) and ROA (β = -0.081, p = 0.000) are negatively and significantly related to the cost of debt, consistent with our expectations. LEVERAGE also becomes statistically significant at the 1% level (p = 0.000), although the magnitude of the effect is economically very small (β = -0.000). The model explains a slightly greater share of the variation in the cost of debt, with an adjusted R-squared of 0.267. However, the addition of verification does not contribute meaningful explanatory power.

Table 7: Regression Results for Model (2)

Expl. Variable	***Exp. Sign***	***Coef.***	***Std Err.***	***Z-score***	***P-value***	***CI 2.5%***	***CI 97.5%***
INTERCEPT		0.036***	0.002	20.269	0.000	0.033	0.040
CARBON_INT	+	0.003	0.006	0.507	0.612	-0.009	0.016
VERIFICATION	-	0.000	0.001	0.149	0.881	-0.002	0.003
SIZE	-	-0.002***	0.000	-4.210	0.000	-0.003	-0.001
ROA	-	-0.081***	0.011	-7.312	0.000	-0.103	-0.059
LEVERAGE	?	-0.000***	0.000	-3.834	0.000	-0.001	-0.000
Dependent Variable	COD		Adjusted R-squared		0.267		
Observations	278		F-Statistic		7.124		
Fixed-effects	Sector, Year		Cond. Number		89.800		

Notes: Significance level: *** indicating 1%, ** indicating 5%, and * indicating 10%. Standard errors are heteroskedasticity- and autocorrelation-robust (HAC), estimated with one lag.

Once again, as a robustness check, we re-estimate the verification model on a reduced sample. The results (see Appendix B, Table B2) are generally consistent with the main findings. CARBON_INT remains positively associated with the cost of debt, but, contrary to our model with the WACC-based cost of debt, becomes statistically significant at the 10% level (β = 0.069, p = 0.057). Moreover, VERIFICATION is statistically insignificant in this model as well (p = 0.201). SIZE continues to have a significant negative association (β = –0.006, p = 0.001). Similar to the robustness test with Model (1), the coefficient on ROA becomes positive and remains significant (β = 0.085, p = 0.057). LEVERAGE is statistically insignificant at conventional levels (p = 0.932). The model explains a similar share of variation in the cost of debt (adjusted R-squared = 0.278), supporting the robustness of the main conclusions.

Table 8 presents the regression results for Hypothesis 3, which tests whether third-party verification moderates the relationship between CO_2 intensity and the cost of debt. The interaction term between CO_2 intensity and verification is negative but statistically insignificant (p = 0.560).

This suggests no moderating effect of verification on the emissions–the cost of debt relationship. Similarly, the main effects of CARBON_INT (β = 0.009, p = 0.479) and VERIFICATION (β = 0.001, p = 0.734) remain non-significant, indicating that neither variable independently explains variation in borrowing costs in this specification. Among the control variables, SIZE continues to show a significant negative association with the cost of debt (β = –0.002, p = 0.000), as does ROA, which has a strong negative effect (β = –0.080, p = 0.000), consistent with earlier models. LEVERAGE is also statistically significant at the 1% level (p = 0.000), though the coefficient remains economically negligible (β = –0.000). The adjusted R-squared of 0.265 indicates that the model explains 26.5% of the variation in the cost of debt, with sector and year fixed effects accounted for.

Table 8: Regression Results for Model (3)

Expl. Variable	*Exp. Sign*	*Coef.*	*Std Err.*	*Z-score*	*P-value*	*CI 2.5%*	*CI 97.5%*
INTERCEPT		0.036***	0.002	20.106	0.000	0.033	0.040
CARBON_INT	+	0.009	0.013	0.708	0.479	-0.016	0.034
VERIFICATION	-	0.001	0.001	0.340	0.734	-0.002	0.003
INTERACTION TERM	-	-0.009	0.015	-0.583	0.560	-0.037	0.020
SIZE	-	-0.002***	0.000	-4.240	0.000	-0.003	-0.001
ROA	-	-0.080***	0.011	-7.267	0.000	-0.102	-0.059
LEVERAGE	?	-0.000***	0.000	-3.784	0.000	-0.001	-0.000
Dependent Variable	COD		Adjusted R-squared		0.265		
Observations	278		F-Statistic		6.847		
Fixed-effects	Sector, Year		Cond. Number		136.000		

Notes: Significance level: *** indicating 1%, ** indicating 5%, and * indicating 10%. Standard errors are heteroskedasticity- and autocorrelation-robust (HAC), estimated with one lag.

As a robustness check for Hypothesis 3, we re-estimate the interaction model on a reduced sample once again. As shown in Table B3 (see Appendix B), the interaction term remains statistically insignificant (p = 0.295), suggesting some evidence that verification may moderate the relationship between emissions and the cost of debt. However, the main effects of CO_2 intensity and verification remain statistically insignificant. Regarding the control variables, SIZE remains negatively and significantly associated with the cost of debt, LEVERAGE becomes statistically insignificant, and ROA again changes sign, becoming positive while remaining statistically significant. The model explains 28% of the variation in the dependent variable (adjusted R-squared = 0.28), slightly higher than in the main specification.

5 Discussion

This section interprets the findings of our analysis, in light of the study's hypotheses, previous literature, and theoretical framework. The section begins with a summary of the study's key empirical findings. We then discuss the theoretical implications of Hypothesis 1, which examines the relationship between carbon intensity and the cost of debt. We then turn to Hypotheses 2 and 3, assessing the role of third-party verification both as an independent factor and as a potential moderator. Finally, we assess the robustness of our results using alternative specifications to evaluate the consistency and sensitivity of our findings.

5.1 Summary of Key Findings

The empirical results offer partial support for our hypotheses (see Table 9 for a summary of hypothesis outcomes). Our analysis finds a statistically significant, positive relationship between carbon intensity and the cost of debt, consistent with our Hypothesis 1. This suggests that higher emissions are associated with higher borrowing costs, even after controlling for firm size, profitability, and leverage. For Hypothesis 2, verification appears to have no robust standalone effect. The interaction term between verification and emissions is likewise statistically insignificant, providing no support for a moderating effect as proposed in Hypothesis 3. These results suggest that third-party verification does not consistently influence the cost of debt, neither directly nor as a moderator.

In addition to our main variables of interest, several control variables consistently show significant associations with the cost of debt. Firm size (SIZE) and profitability (ROA) are both negatively and significantly related to borrowing costs across all main model specifications. These findings are in line with prior research suggesting that larger and more profitable firms are perceived as lower-risk by lenders, leading to more favorable borrowing terms. Leverage (LEVERAGE), by contrast, shows no consistent or meaningful effect, suggesting that its influence on borrowing costs may be context-specific or absorbed by other firm-level characteristics. While these variables are not the central focus of the study, their consistent influence supports the validity of the model and highlights the multifaceted nature of credit risk assessment.

Table 9: Testing Outcomes for Study Hypotheses

Hypothesis	***Result***
H1: *There is a significant positive relationship between CO_2 emissions and cost of debt for firms in Scandinavia.*	Supported
H2: *Scandinavian firms with third-party verified emissions data are associated with a lower cost of debt than firms without such verification.*	Not Supported
H3: *Third-party verification moderates the relationship between CO_2 emissions and the cost of debt in Scandinavia, such that the penalty for high emissions is smaller when emissions are verified.*	Not Supported

Notes: Hypothesis support is based on the significance and direction of estimated coefficients in Models (1)–(3), as found in Section 4.

5.2 Carbon Intensity and the Cost of Debt

Following our empirical results, we find strong support for Hypothesis 1: firms with higher carbon intensity face a higher cost of debt. This suggests that lenders perceive carbon-intensive firms as riskier, likely due to their exposure to future regulatory, reputational, or environmental costs. In other words, our results indicate that carbon intensity is not just an environmental concern but also a material financial risk. These findings align with existing research across several contexts and reinforce the view that environmental performance, particularly in terms of emissions, plays a direct role in credit risk assessments. The findings have clear implications: firms that reduce their carbon footprint may benefit from improved borrowing conditions, while lenders are increasingly expected to incorporate environmental risk into their credit assessment.

Theoretically, the relationship aligns with agency theory and information asymmetry. From an agency perspective, high emissions may signal that managers are neglecting long-term risks—such as environmental liabilities or future regulatory costs—in favor of short-term gains such as profitability. This perceived misalignment raises concerns for lenders, who may view it as a sign of weak risk governance and therefore demand higher risk premiums. Information asymmetry theory helps explain how lenders respond when they lack reliable insight into a firm's environmental performance. Emissions reporting reduces information asymmetry by making carbon intensity a transparent and comparable indicator of environmental risk, thereby highlighting firms that may be more vulnerable to regulatory tightening and reputational pressures, as previously discussed. While this transparency helps lenders better assess firms, it also means that high-emitting firms are more clearly identified as risky, thereby justifying higher borrowing costs. In this way, reduced information asymmetry does not lead to lower costs in our cases, instead, it enables more accurate pricing of environmental risk.

Stakeholder theory offers a valuable framework for interpreting our findings, particularly the observed relationship between higher carbon intensity and increased borrowing costs, which may be influenced by the broader network of stakeholders that shape firms' operating environments. In the Scandinavian context, where environmental concerns are deeply embedded in public discourse and regulatory policy, firms are subject to pressure not only from shareholders and investors but also from consumers, regulators, employees, and the general public.

Our findings indicate that stakeholders may expect companies to align with sustainability norms and could penalize those who fail to do so through reduced demand, reputational harm, or increased scrutiny from regulators and the public. In turn, lenders, aware of these dynamics, may perceive carbon-intensive firms as facing elevated stakeholder-related risks and price this into the cost of debt. In this way, environmental performance becomes financially material not just because of internal firm risk, but because of the external expectations firms must meet to maintain legitimacy. For firms specifically, this implies that reducing emissions may be a financially prudent strategy, not just a reputational one. Higher carbon intensity increases the cost of debt, reinforcing a direct financial incentive to decarbonize.

5.3 The Role of Third-Party Verification

In contrast to Hypothesis 1, our findings do not provide support for either Hypothesis 2 or Hypothesis 3. Based on the results from Model (2), which includes the verification variable, it can be concluded that third-party verification of emission disclosure is not significantly associated with the cost of debt. Similarly, the interaction term of emissions and verification in Model (3) is statistically insignificant, which suggests that a third-party verification does not moderate the relationship between carbon intensity and the cost of debt. These results indicate that verified emission disclosures do not have a consistent impact on borrowing costs in our Scandinavian sample, neither as a standalone factor nor in combination with firms' emissions levels. Since the estimated coefficients are statistically insignificant, we cannot draw definitive conclusions: it may be that there is no real effect, or that an effect exists but is not detectable within the scope and limitations of our study. Consequently, the explanations that follow should be viewed as tentative and interpretative, rather than conclusive.

Compared to previous studies showing a significant association between verification and lower borrowing costs (e.g., Palea & Drogo, 2020; Koutoupis et al., 2024), our results diverge. These studies often examine verification linked to globally recognized platforms, such as the Carbon Disclosure Project, where credibility is more easily established. In contrast, our findings may reflect a regional context where ESG disclosure is already strong, leaving little room for third-party verification to add informational value. Alternatively, the credibility of verification may be difficult for lenders to assess, as our data does not specify who the verifier is or what standards are applied. In either case, the signaling value of verification may be diminished, helping to explain both the lack of a direct effect and the absence of a moderating role.

Relating our findings to theoretical frameworks—particularly signaling theory—one would expect the verification of emissions data to serve as a credible signal, distinguishing environmentally responsible firms from those with lower standards. However, our results suggest that this signal may not be perceived as meaningful. A possible explanation is the relatively advanced ESG reporting culture in Scandinavia, where third-party verification may not add sufficient incremental value to influence credit assessments.

From an information asymmetry perspective, credible disclosure is expected to reduce uncertainty and, consequently, perceived risk. Yet our findings show that perceived risk remains unaffected, suggesting that third-party verification may not significantly reduce information asymmetry in this context. One potential explanation is that the verification variable captures only the presence or absence of third-party verification, without reflecting the depth, credibility, or standardization of the verification process. In other words, it may not convey sufficient information to serve as a reliable signal. If lenders cannot distinguish between varying levels of verification quality, the binary nature of the variable may limit its influence on credit risk assessments.

5.4 Robustness and Sensitivity Analyses

To validate our main findings, we ran a robustness test to assess whether the relationship between carbon intensity and borrowing costs holds across different ways of measuring debt costs: forward-looking (market-based) versus backward-looking (realized). The robustness model for Model (1), assessing the relationship between carbon emissions and realized cost of debt, yields a positive coefficient for carbon intensity. This is in line with our model, but it becomes statistically insignificant.

The difference in statistical significance calls for caution in interpreting the effect's strength and immediacy. A possible explanation of this result could reflect differences between the two measures. Realized cost of debt might be “stickier,” not accounting for changes in environmental performance or ESG risk pricing immediately, while the WACC-based estimate is more forward-looking and sensitive to investor expectations. The stickiness of realized cost may be due to long-term contracts and renegotiation frictions, meaning elevated emissions can not be quickly reflected in reported interest expenses.

For Hypothesis 2, the verification variable remains statistically insignificant in the alternative specification, which supports our main finding that third-party verification does not appear to influence borrowing costs consistently. Similarly, the interaction term tested in Hypothesis 3 yields an unexpected result, but given its statistical instability across models, we urge caution in interpreting its meaning. Overall, the robustness tests reinforce the conclusion that third-party verification of emissions data does not have a clear or consistent impact on the cost of debt within our sample. The differences in statistical significance across model specifications highlight the sensitivity of results to how borrowing costs are measured and underscore the importance of not over-interpreting weak or inconclusive evidence.

Among the control variables, the most unexpected result is that profitability (ROA), which shows a negative association with the cost of debt in our main models, turns positive in the robustness tests using the realized cost of debt. A potential explanation is that this change reflects differences in how profitability is interpreted across forward-looking versus backward-looking measures of borrowing costs. It is possible that higher profitability leads to better credit spreads in market-based pricing, but also enables firms to take on more expensive debt in practice.

6 Conclusion

In this section, we summarize the study's key findings and reflect on their implications. We also outline limitations of the study and directions for future research.

6.1 Conclusion

Our study set out to assess the relationship between carbon emissions and cost of debt in Scandinavia—a setting characterized by a strong ESG focus with well-developed institutional frameworks and transparency norms. Our study was guided by the research question: *What is the effect of CO_2 emissions on the cost of debt for firms in Scandinavia?* Using panel data from 218 firms across several sectors and fixed effects Ordinary Least Squares regressions, we examined this question by testing three hypotheses related to the role of emissions, verification, and their interaction in terms of shaping the corporate cost of debt.

We find a statistically significant relationship between carbon emissions and the cost of debt, supporting our Hypothesis 1. In practice, this suggests that lenders in Scandinavia price firms' environmental impact, and more specifically emissions, into their credit assessments, penalizing carbon-intensive firms with a higher cost of debt. Theoretically, this aligns with agency theory, information asymmetry, and stakeholder theory, which together suggest that both emissions levels and a firm's environmental management practices reflect managerial priorities, perceived risk, and responsiveness to stakeholder expectations.

However, we find no support for our other two hypotheses related to whether emissions are verified by a third party. Our results indicate that third-party verification of emissions disclosures does not significantly reduce the cost of debt, nor does it moderate the emissions–cost of debt relationship. One possible explanation is that in a highly transparent context like Scandinavia, where ESG reporting is already expected, verification may not add enough informational value to influence lender assessments. Moreover, our verification variable may not capture meaningful differences in verification quality, which limits its signaling power.

Overall, our findings contribute to the literature on the intersection of ESG and capital markets by offering regional evidence that emissions carry economic consequences in markets with relatively strong transparency norms, lending support to the idea that sustainability is more than just a symbolic concern. If our results hold more broadly, this reinforces the strategic importance for firms of reducing carbon intensity to improve borrowing conditions. However, regarding verification, merely verifying emissions data may not be enough to lower borrowing costs unless that verification is seen as credible and valuable by lenders.

6.2 Limitations

Our study is not without limitations. First, the analysis is based on a relatively short period, largely due to the limited availability of carbon emissions data. Despite increased regulatory attention to non-financial disclosure and growing environmental awareness, the quantity, quality, and consistency of reported ESG data still vary significantly across firms. Second, the robustness tests, which involved calculating a realized cost of debt measure, led to a substantial reduction in sample size due to missing data. This smaller subsample limits the generalizability of the robustness results. Third, although the sample includes Scandinavian firms (i.e., Sweden, Denmark, and Norway), it is heavily skewed toward Sweden, with 132 of the 218 firms being Swedish. As a result, our findings may reflect Swedish market dynamics more strongly than those of the broader Scandinavian region.

Fourth, the analysis includes only Scope 1 and 2 emissions, excluding Scope 3 emissions, which often represent a large share of a company's total carbon footprint, encompassing upstream and downstream value chain emissions. The absence of Scope 3 limits the completeness of the environmental risk picture captured in this study. Lastly, the verification variable used to test Hypotheses 2 and 3 is derived from Eikon and does not provide information on who performed the verification or to what standard. This lack of detail limits the ability to assess the credibility or signaling strength of the verification and may partially explain the insignificant results.

6.3 Suggestions for Future Research

Future research could build on this study in several important ways. Firstly, future research could examine different forms of emissions verification, distinguishing between voluntary and mandatory assurance, as well as lighter forms of verification versus more in-depth audits. Such a breakdown would help clarify whether the credibility or standard of verification influences lenders' perceptions of environmental risk. Secondly, another research angle includes considering the application of non-linear models to explore whether the relationship between carbon intensity, verification, and borrowing costs varies across emission levels, firm sizes, or industries—potentially uncovering patterns that our linear models might miss.

Thirdly, with the Corporate Sustainability Reporting Directive (CSRD) now in effect, future research could continue to explore the evolving relationship between emissions disclosure, verification, and the cost of debt. As reporting and verification have become mandatory after our period of investigation, the informational value and credibility of emissions data are likely to increase, potentially altering how lenders assess environmental risk. This regulatory shift presents an opportunity for longitudinal research that compares firm behavior, disclosure practices, and borrowing costs before and after the implementation of CSRD. Such studies could offer valuable insight into whether mandatory frameworks enhance the financial relevance of emissions and verification in credit markets.

Finally, incorporating Scope 3 emissions would significantly enhance the understanding of firms' full environmental impact. Scope 3 covers indirect emissions across the value chain, such as those from suppliers, product use, and disposal. As ESG reporting standards continue to mature and data availability improves, future studies could prioritize including Scope 3 to provide a more complete picture of emissions-related financial risk.

Works Cited

Akerlof, G. A. (1970). The Market for "Lemons": Quality Uncertainty and the Market Mechanism. *The Quarterly Journal of Economics*, *84*(3), 488–500.

Altman, E. I. (1968). Financial Ratios, Discriminant Analysis and the Prediction of Corporate Bankruptcy. *The Journal of Finance*, *23*(4), 589–609.

Amiram, D., Kalay, A., & Sadka, G. (2017). Industry Characteristics, Risk Premiums, and Debt Pricing. *The Accounting Review*, *92*(1), 1–27.

Apergis, N., Poufinas, T., & Antonopoulos, A. (2022). *ESG scores and cost of debt*.

Ariefianto, D., Rahmansyah, F., Wijaya, V., & Audreane, V. (2024). The Role of Environment Social and Governance (ESG) Score To Cost of Debt: Evidence From ASEAN Countries. *International Journal of Finance & Economics*.

Arora, A., & Sharma, D. (2022). Do Environmental, Social and Governance (ESG) Performance Scores Reduce the Cost of Debt? Evidence from Indian firms. *Australasian Accounting, Business and Finance Journal*, *16*(5).

Bernanke, B. S., & Gertler, M. (1995). Inside the Black Box: The Credit Channel of Monetary Policy Transmission. *Journal of Economic Perspectiv*, *9*(4), 27–48.

Bolton, P., & Kacperczyk, M. (2021). Do investors care about carbon risk? *Journal of Financial Economics*, *142*(2).

Brealey, R. A., Myers, S. C., & Allen, F. (2011). *Corporate Finance* (10th ed.). McGraw-Hill/Irwin.

Cahyono, S. B., & Chawla, A. S. (2019). The determinants of firm financing structures across sectors: An evidence from indonesian listed companies. *Investment Management and Financial Innovations*, *16*(1), 100–118.

Caragnano, A., Mariani, M., Pizzutilo, F., & Zito, M. (2020). Is it worth reducing GHG emissions? Exploring the effect on the cost of debt financing. *Journal of Environmental Management*, *270*(2).

Carbon, S., Giuzio, M., Kapadia, S., Krämer, J. S., Nyholm, K., & Vozian, K. (2021). *The low-carbon transition, climate commitments and firm credit risk*.

Chava, S. (2014). Environmental Externalities and Cost of Capital. *Management Science*, *60*(9), 2223–2247.

Christensen, H. B., Hail, L., & Leuz, C. (2021). Mandatory CSR and sustainability reporting: Economic analysis and literature review. *Review of Accounting Studies*, *26*(1).

Denis, D. J., & Mihov, V. T. (2003). The choice among bank debt, non-bank private debt, and public debt: Evidence from new corporate borrowings. *Journal of Financial Economics*, *70*(1), 3–28.

Donaldson, T., & Preston, L. E. (1995). The Stakeholder Theory of the Corporation: Concepts, Evidence, and Implications. *The Academy of Management Review*, *20*(1), 65–91.

Dunne, T. C., & McBrayer, G. A. (2019). In the interest of small business' cost of debt: A matter of CSR disclosure. *Journal of Small Business Strategy*, *29*(2), 58–71.

EEA Joint Committee. (2019). *Decision of the EEA Joint Committee No 269/2019 of 25 October 2019 amending Protocol 31 to the EEA Agreement, on cooperation in specific fields outside the four freedoms*. Official Journal of the European Journal.

European Union. (2022). *Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting*.

Fama, E. F., & French, K. R. (1989). Business conditions and expected returns on stocks and bonds. *Journal of Financial Economics*, *25*(1), 23–49.

Fama, E. F., & French, K. R. (1993). Common risk factors in the returns on stocks and bonds. *Journal of Financial Economics*, *33*(1), 3–56.

Fisher, I. (1930). *The Theory of Interest, as determined by Impatience to Spend Income and Opportunity to Invest it*. MacMillan Company.

Freeman, E. R., & Mcvea, J. F. (2001). A Stakeholder Approach to Strategic Management. *Handbook of Strategic Management*, *1*(2).

Friede, G., Busch, T., & Bassen, A. (2015). ESG and financial performance: Aggregated evidence from more than 2000 empirical studies. *Journal of Sustainable Finance & Investment*, *5*(4).

Gjølberg, M. (2009). Measuring the immeasurable? Constructing an index of CSR practices and CSR performance in 20 countries. *Scandinavian Journal of Management*, *25*(1), 10–22.

Hanss, D., & Böhm, G. (2012). Sustainability seen from the perspective of consumers. *International Journal of Consumer Studies*, *36*, 678–687.

Jensen, M. J., & Meckling, W. H. (1976). Theory of the Firm: Managerial Behavior, Agency costs and Ownership structure. *Journal of Financial Economics*, *3*.

Jung, J., Herbohn, K., & Clarkson, P. (2018). Carbon Risk, Carbon Risk Awareness and the Cost of Debt Financing. *Journal of Business Ethics*, *150*(4), 1151–1171.

Kang, J., & Pflueger, C. E. (2015). Inflation Risk in Corporate Bonds. *The Journal of Finance*, *70*, 115–162.

Koutoupis, A. G., Davidopoulos, L. G., Hakimi, A., Azibi, J., & Mansali, H. (2024). Greenhouse gas assurance, board diversity and cost of debt: A quantile approach. *EuroMed Journal of Business*, *19*(4), 1141–1172.

Kozak, S. (2021). Will the Reduction of CO2 Emissions Lower the Cost of Debt Financing? The Case of EU Countries. *Energies*, *14*(24), 1–13.

Krueger, P., Sautner, Z., & Starks, L. T. (2020). The Importance of Climate Risks for Institutional Investors. *The Review of Financial Studies*, *33*(3).

Kumar, P., & Firoz, M. (2018). Impact of carbon emissions on cost of debt-evidence from India. *Managerial Finance*, *44*(12), 1401–1417.

Lee, S.-Y., & Choi, D.-K. (2021). Does Corporate Carbon Risk Management Mitigate the Cost of Debt Capital? Evidence from South Korean Climate Change Policies. *Emerging Markets Finance & Trade*, *57*(8).

Myers, S. C. (1984). The Capital Structure Puzzle. *The Journal of Finance*, *39*, 574–592.

Nasih, M., Puspitasari, A., Harymawan, I., Putra, F. K. G., & Djajadikerta, H. G. (2024). The Relationship of Carbon Emission Disclosure on The Cost of Debt. *SAGE Open*, *14*(4).

Palea, V., & Drogo, F. (2020). Carbon emissions and the cost of debt in the eurozone: The role of public policies, climate-related disclosure and corporate governance. *Business Strategy and the Environment*, *29*(7).

Pizzutilo, F., Zito, M., Caragnano, A., & Mariani, M. (2020). Dealing with carbon risk and the cost of debt: Evidence from the European market. *International Journal of Financial Studies*, *8*(4).

Ross, S. A. (1977). The Determination of Financial Structure: The Incentive-Signalling Approach. *The Bell Journal of Economics*, *9*(1), 23–40.

Ruslim, H., & Muspyta, R. (2021). The Effect of Profitability and Financial Leverage on Cost of Debt Moderated Earnings Management. *Jurnal Ekonomi*, *26*(1).

Santosuosso, P. (2014). Cost of Debt and Corporate Profitability. *International Business Research*, *7*(2).

Shi, Y., Zheng, S., Xiao, P., Zheng, H., & Wu, T. (2024). ESG performance and cost of debt. *China Journal of Accounting Research*, *17*(4).

Song, H., & Rimmel, G. (2025). Debtholders' reaction to sustainability reporting regulations: International evidence. *Business Strategy and the Environment*, *34*(1), 88–115.

Spence, M. (1973). Job Market Signaling. *The Quarterly Journal of Economics*, *87*(3), 355–374.

Strand, R. (2024). Global Sustainability Frontrunners: Lessons from the Nordics. *California Management Review*, *66*(3), 5–26.

Temiz, H. (2022). Environmental performance and cost of finance: Evidence from emerging markets. *Sustainability Accounting, Management and Policy Journal*, *13*(3).

Appendices

Appendix A: Sectors

Table A1: Industry Grouping

Sector	*Industries*
Industrial and Manufacturing	• Industrial Machinery & Equipment • Construction & Engineering • Construction Supplies & Fixtures • Heavy Machinery & Vehicles • Electrical Components & Equipment • Forest & Wood Products • Ground Freight & Logistics • Miscellaneous Specialty Retailers • Specialty Mining & Metals • Mining Support Services & Equipment • Diversified Industrial Goods Wholesale • Construction Materials
Healthcare and Pharmaceuticals	• Medical Equipment, Supplies & Distribution • Advanced Medical Equipment & Technology • Pharmaceuticals • Healthcare Facilities & Services
Energy and Utilities	• Oil Related Services and Equipmen • Oil & Gas Exploration and Production • Oil & Gas Transportation Services • Integrated Oil & Gas • Electric Utilities • Independent Power Producers • Renewable Energy Equipment & Services
Technology and Software	• Software • IT Services & Consulting • Online Services • Semiconductor Equipment & Testing • Semiconductors • Integrated Hardware & Software • Computer Hardware • Communications & Networking
Consumer Goods and Retail	• Apparel & Accessories • Apparel & Accessories Retailers • Auto Vehicles, Parts & Service Retailers • Auto, Truck & Motorcycle Parts • Auto & Truck Manufacturers • Department Stores • Discount Stores

	• Home Furnishings Retailers • Home Improvement Products & Services Retailers • Household Electronics • Phones & Handheld Devices • Personal Products • Textiles & Leather Goods
Transportation and Logistics	• Marine Freight & Logistics • Courier, Postal, Air Freight & Land-based Logistics • Airport Operators & Services
Food and Agriculture	• Food Processing • Food Retail & Distribution • Fishing & Farming • Brewers • Agricultural Chemicals
Telecommunications	• Wireless Telecommunications Services • Integrated Telecommunications Services • Broadcasting
Other	• Casinos & Gaming • Leisure & Recreation • Hotels, Motels & Cruise Lines • Specialty Chemicals • Commodity Chemicals • Paper Products • Paper Packaging • Non-Paper Containers & Packaging • Environmental Services & Equipment • Tobacco • Real Estate Rental, Development & Operations

Appendix B: Robustness Tests

Table B1: Robustness Test Model (1)

Expl. Variable	*Exp. Sign*	*Coef.*	*Std Err.*	*Z-score*	*P-value*	*CI 2.5%*	*CI 97.5%*
INTERCEPT		0.015***	0.003	4.589	0.000	0.008	0.021
CARBON_INT	+	0.030*	0.014	2.095	0.036	0.002	0.057
SIZE	-	-0.003***	0.001	-4.268	0.000	-0.005	-0.002
ROA	-	0.059***	0.021	2.816	0.005	0.018	0.101
LEVERAGE	?	-0.000	0.001	-0.269	0.788	-0.001	0.001
Dependent Variable	REALIZED_COD		Adjusted R-squared		0.279		
Observations	411		F-Statistic		12.400		
Fixed-effects	Sector, Year		Cond. Number		52.000		

Notes: Significance level: *** indicating 1%, ** indicating 5%, and * indicating 10%. Standard errors are heteroskedasticity- and autocorrelation-robust (HAC), estimated with one lag. "Exp. Sign" indicates the expected direction of the coefficient based on theory or prior studies. The "?" for Leverage reflects theoretical ambiguity, as literature provides mixed findings on its effect. Variable definitions: *COD* is the market-implied cost of debt based on credit curves; *REALIZED_COD* is calculated as (Interest Expense / Total Debt) × (1 – Tax Rate). *CARBON_INT* is CO_2 emissions relative to total assets (lagged one year) and scaled by 1000; *SIZE* is the mean-centered log of total assets; *ROA* is net income divided by total assets; *LEVERAGE* is the ratio of total debt to total equity.

Table B2: Robustness Test Model (2)

Expl. Variable	*Exp. Sign*	*Coef.*	*Std Err.*	*Z-score*	*P-value*	*CI 2.5%%*	*CI 97.5%*
INTERCEPT		0.016*	0.008	1.962	0.050	-0.000	0.032
CARBON_INT	+	0.069	0.036	1.902	0.057	-0.002	0.141
VERIFICATION	-	0.005	0.004	1.277	0.201	-0.003	0.013
SIZE	-	-0.006***	0.002	-3.212	0.001	-0.009	-0.002
ROA	-	0.085*	0.045	1.902	0.057	-0.003	0.172
LEVERAGE	?	-0.000	0.001	0.085	0.932	-0.002	0.002
Dependent Variable	REALIZED_COD		Adjusted R-squared		0.278		
Observations	169		F-Statistic		4.879		
Fixed-effects	Sector, Year		Cond. Number		54.900		

Notes: Significance level: *** indicating 1%, ** indicating 5%, and * indicating 10%. Standard errors are heteroskedasticity- and autocorrelation-robust (HAC), estimated with one lag. Variable Definition*: VERIFICATION* is a dummy indicating whether a firm's emissions are verified by a third party.

Table B3: Robustness Test Model (3)

Expl. Variable	*Exp. Sign*	*Coef.*	*Std Err.*	*Z-score*	*P-value*	*CI 2.5%*	*CI 97.5%*
INTERCEPT		0.017**	0.008	2.124	0.034	0.001	0.032
CARBON_INT	+	0.012	0.052	0.234	0.815	-0.090	0.114
VERIFICATION	-	0.004	0.004	0.852	0.394	-0.005	0.012
INTERACTION	-	0.063	0.060	1.047	0.295	-0.055	0.181
SIZE	-	-0.006***	0.002	-3.188	0.001	-0.009	-0.002
ROA	-	0.084*	0.044	1.906	0.057	-0.002	0.170
LEVERAGE	?	-0.000	0.001	-0.024	0.981	-0.002	0.002
Dependent Variable	REALIZED_COD		Adjusted R-squared		0.280		
Observations	169		F-Statistic		4.626		
Fixed-effects	Sector, Year		Cond. Number		90.100		

Notes: Significance level: *** indicating 1%, ** indicating 5%, and * indicating 10%. Standard errors are heteroskedasticity- and autocorrelation-robust (HAC), estimated with one lag. Variable definitions: *INTERACTION* is an interaction term defined as (*VERIFICATION* × *CARBON_INT*).

Appendix C: Use of Generative AI

For students at the Stockholm School of Economics, generative artificial intelligence (GenAI) is permitted to a limited extent, provided that it is used by the school guidelines and documented. In line with this, we offer a transparent account of how we have utilized generative AI tools during the thesis process. During the development of this thesis, we made limited use of generative AI tools, specifically ChatGPT provided by OpenAI. This tool was used to support the writing process in non-substantive ways. At the beginning of the project, we used AI to brainstorm ideas. Later, it was used occasionally to assist with coding and troubleshooting issues in Python. Throughout the writing phase, we occasionally used the tool to improve grammar, sentence structure, and overall readability. Importantly, generative AI was not used to produce original content, perform analysis, or influence the interpretation of our empirical results.