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The impact of carbon risk on the cost of debt in the listed firms in G7 economies: The role of the Paris agreement

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ABSTRACT

The Paris Agreement, signed in 2015, sets ambitious goals for diminishing greenhouse gas emissions and restricting the rise in global temperature to achieve a less carbon-intensive and climate-resilient global economy. The Paris Agreement marked a defining moment in the worldwide response to global warming and has significantly affected the financial sector. Given this background, this research explores the effects of carbon risk on the cost of debt (CoD) in 1428 listed firms across seven economies from 2011 to 2020. The paper also reflects the post-Paris Agreement's involvement and the ESG factors' moderating effect in the empirical models. The study finds a significant impact of carbon risk on CoD following the implementation of the Paris Agreement. Notably, companies with higher carbon risk face higher borrowing rates. However, the effect of ESG on moderating the relationship between carbon risk and CoD is found to be insignificant. Further analyses confirm this finding, as individual pillars of ESG (governance and social aspects) also show insignificant moderating effects.

1. Introduction

In the last two periods, the issue of global warming and its influence on the financial sector has become increasingly pressing. Companies, governments, and investors recognise the urgency to mitigate the risks presented by global warming and ensure that the financial sector supports the transition to less carbon-intensive and climate-resilient global market. There has been growing interest in carbon risk, climate change, ESG, and access to finance among scholars (Apergis et al., 2022; Jung et al., 2018; Matsumura et al., 2014; Palea and Drogo, 2020). This increased interest is mainly because of unusual and catastrophic weather patterns and rising greenhouse gas (GHG) levels, raising concerns about climate change (Ho et al., 2024). These concerns have led to the signing of several initiatives and agreements, including the Kyoto Protocol in 1997 and the Paris Agreement in 2015. Additionally, many governments have enacted legislation and policies to manage and lower industrial carbon emissions.

Climate policies are essential for mitigating carbon emissions, reaching net-zero carbon, and ensuring that financial flows align with a path to reducing carbon emissions while creating climate-resilient sustainable development. The Paris Agreement, which became legally binding in November 2016, signifies a global climate change framework extending the Kyoto Protocol's reach by involving developed and developing nations. The Paris Agreement's main goal is to curb the worldwide standard temperature increases to around 2 °C in comparison to the pre-industrialized levels and continue its efforts to restrict temperature rise to 1.5 °C (Chen et al., 2020).

These developments have placed carbon risk under the spotlight as investors increasingly consider it in investment decisions. Investors may reflect carbon risk in their financing decisions when there is a solid commitment to mitigating global warming (Jung et al., 2018). Although research into the financial consequences of carbon risk is still underway, present papers have shown that carbon emissions are inversely linked to corporate valuation (Clarkson et al., 2015) and corporate investments (Phan et al., 2022). Furthermore, other research has alluded that firms with great carbon risk are prone to experiencing an increase in their costs of capital and debt (Jung et al., 2018). Most of these studies are country-specific, focusing on countries such as Australia (Jung et al., 2018), the U.S.A (Clarkson et al., 2015), China (Ding et al., 2023; Wang et al., 2024), and selected EU countries like Germany, Italy, the Netherlands, and Poland (Eliwa et al., 2021; Pizzutilo et al., 2020).

Several researchers have explored how carbon risk affects CoD among major economies facilitating cross-country comparisons (Jung et al., 2018; Clarkson et al., 2015 Eliwa et al., 2021; Pizzutilo et al.,

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20205), except the Group of Seven (G7) countries. The Group of seven countries, namely, Canada, France, Germany, Italy, Japan, the UK, and the U.S., are among 196 countries participating in the Paris Agreement in 2015. The Group of seven economies prevails, accounting for about 50 % of the world's GDP, 36 % of global electricity generation capacity, 30 % of worldwide energy utilization, and 25 % of worldwide energy-related CO_2 emissions (World Bank, 2024). According to Li and Haneklaus (2022), despite the Group of Seven Nations taking measures towards a green and less-carbon-intensive society since the enactment of the Paris Agreement in 2015, the Group of Seven Economies have yet to achieve carbon emission reduction. These issues make a meaningful context that warrants further study.

On the other hand, investors and financial analysts increasingly consider improved ESG factors when allocating funds or making positive recommendations. The stronger a firm's track record in ESG aspects, the more willing financiers may be to provide financing at a reduced cost (Sharfman and Fernando, 2008). The ESG factors have emerged as a critical consideration in assessing carbon risk when determining CoD and credit ratings (Jung et al., 2018; Maaloul, 2018). For instance, Petersen and Vredenburg (2009) stated that most institutional shareholders now favour high ESG enterprises, suggesting that these firms can attract a broader spectrum of investors by achieving high ESG ratings. Eliwa et al. (2021) provided evidence that companies with more robust ESG performance need a reduced cost of debt.

Regarding the influence of climate agreements, prevailing studies have investigated the effect of the Kyoto Protocol on access to finance (Chen and Silva Gao, 2012; Nguyen et al., 2020). Nevertheless, there have been limited studies on the effect of the Paris Agreement focusing on the Group of Seven Countries, especially concerning carbon risk and the cost of debt. Present studies have primarily concentrated on the impact of climate reporting in the Eurozone. For example, Palea and Drogo (2020) concluded that increased disclosure of climate change-related issues may help mitigate carbon risk. Nguyen et al. (2023) examined the effect of company-level climate risk on default risk, finding a more substantial negative impact for firms with carbon pricing in specific locations. This effect was temporarily reinforced because of the Paris Agreement.

Given these backdrops, this research explores the effect of carbon risk on the CoD as related to the Paris Agreement on this relationship in the firms in the Group of Seven Countries. Additionally, the study explores the effect of ESG on this relationship. While previous research has examined the nexus between CoD and carbon risk (Jung et al., 2018; Maaloul, 2018), our paper is the first study to investigate this relationship within firms in the Group of seven countries. Also, with the extensive examination of the impact of ESG on the cost of capital, debt, and equity, there remains a notable gap in the literature concerning the moderating effect of ESG on the connection between carbon risk and the cost of debt. Our research bridges this gap by exploring how ESG performance affects the nexus between carbon risk concerning the cost of debt. The study covers the pre- and post-Paris Agreement era from 2011 to 2020.

We use a comprehensive dataset including 14,258 firm-year observations from 1428 unique publicly listed firms across G7 economics, from 2011 to 2020. Our dataset, sourced from Bloomberg and Refinitive, comprises variables such as carbon emissions, ESG scores, and financial information of firms. To test the impact of carbon risk on CoD, we employ pooled Ordinary Least Squares (OLS) regression model and control for financial metrics such as profitability, leverage, firm size, and default risk, while also including industry and country fixed effects. We also apply interaction terms to measure the impact of the Paris Agreement and ESG factors.

The findings suggest that, particularly after the Paris Agreement, carbon risk has a positive and significant effect on the CoD for firms in the Group of Seven countries. Our results prove lenders deem carbon risk factors in their borrowing decisions post-Paris Agreement. In addition, the results of the research indicate that ESG factors have a significant direct effect on the cost of debt, meaning that companies with better ESG Initiatives may experience lower borrowing costs. However, this impact does not extend to moderating the relationship between carbon risk and the cost of debt. In other words, while strong ESG initiatives can reduce overall borrowing costs, they do not change the way carbon risk affects this cost. Therefore, this paper adds to the increasing literature on the financial consequences of carbon risk and the role of ESG in mitigating such risk. Further detailed analyses are conducted for companies with various levels of ESG to augment our understanding of the link between carbon risk and CoD within various ESG contexts.

The robustness test was also performed using a two-stage Least Square (2SLS) approach. This approach addressed potential endogeneity, which can arise if both carbon risk and CoD are affected by a common factor, potentially biasing the results. The chosen Instrument Variable (IV) in our 2SLS model is the distance to capital, which serves as an appropriate instrument because it is correlated with carbon risk but not directly related to the firm' CoD. The findings remain robust and consistent with the primary results.

While earlier studies have laid the initial framework, our research contributes new insights to the current literature in various ways. First, this is the first research to investigate the link between carbon risk and the cost of debt within enterprises across G7 countries, particularly in the context of the Paris Agreement. Second, it investigates how ESG performance influences this link, filling a significant gap in the literature about ESG's moderating effect on the nexus between carbon risk and the cost of debt. Finally, this study provides empirical evidence of the significant positive impact of carbon risk on the cost of debt post-Paris Agreement, while also showing that strong ESG measures can reduce total borrowing costs, even though they do not alter the specific impact of carbon risk on the cost of debt. The findings will have practical implications for firms, governments, financial institutions, policymakers, and other market participants who must collaborate to address carbon risk issues.

The rest of the study is organised as follows: Chapter 2 will review the relevant literature and development hypotheses. Chapter 3 clarifies the data and the statistical models. Chapter 4 displays the results. Chapter 5 is the conclusion.

2. Literature review and hypotheses development

2.1. Carbon risk and cost of debt

One stream of literature emphasises the influence of carbon emissions on a company's market value (Griffin et al., 2017; Matsumura et al., 2014). According to Matsumura et al. (2014), there is an inverse relationship between CO2 emissions and the market value of firms in the United States. Specifically, each additional thousand tonnes of CO2 emissions results in a decrease of $212,000 in a firm's market value. Trinks et al. (2020) investigated the impact of carbon risk on the cost of equity, revealing a significant association with higher equity costs. They further demonstrated that this relationship persists even when considering primary (Scope One) and secondary emissions (Scope Two), indicating that financial providers consider both types of emissions. Few studies explored the impact of carbon risk on the cost of debt, with most of the earlier research focusing on firms located in the US (Chen and Silva Gao, 2012; Goss and Roberts, 2011; Griffin et al., 2017; Matsumura et al., 2014) and Australia (Clarkson et al., 2015; Jung et al., 2018; Li et al., 2014).

The Agency Theory helps to clarify the dynamics between carbon risk and the CoD (Armstrong et al., 2010). From the perspective of carbon risk, agency issues might occur once the carbon-related objectives of creditors and debtors diverge. Because of their vulnerability to carbon risk, lenders are liable to expect borrowers to take required actions, such as complying with environmental standards to decrease carbon risk (Thompson, 1998). In contrast, borrowers will likely prioritise financial performance, making different choices. For example,

Goss and Roberts (2011) explained that carbon-intensive projects are risky because they tend to offload carbon pollution onto the environment. This issue potentially results in carbon-related risks being passed back to the firm, leading to stricter borrowing conditions imposed by lenders.

When agency issues arise, such as increased default risk, creditors are anticipated to execute potential solutions such as incorporating carbon risk in their credit risk evaluation and protecting themselves by charging high interest rates. As a result, it is expected that creditors will set a high CoD for companies facing significant carbon risk, as established in earlier research (Jung et al., 2018; Li et al., 2014). Carbon risk can also diminish both firms' profit and capital (Barbose et al., 2008), thus increasing firms' default risk. Additionally, creditors may ponder how carbon risk affects corporate image (Li et al., 2014). Poor environmental practices by a company can damage its reputation and negatively impact its prospects, competitive advantage, and cash flows. These effects increase the risk of default, thereby raising the cost of debt.

Few researchers have explored the direct effect of carbon risk on CoD in countries such as Australia (Jung et al., 2018), the United States (Clarkson et al., 2015), and selected European countries including Italy, Germany, Poland, the Netherlands, among others (Pizzutilo et al., 2020). Henceforth, we state previous research on the relationship between *CSR*, environmental hazards and the CoD. For instance, Li et al. (2014) found that, among U.S. companies, those with greater social responsibility benefit from a reduced cost of debt (CoD) compared to those with less CSR involvement. Similarly, Chava (2014) observed that environmental risk factors are associated with an increase in the cost of debt, implying that corporations facing significant environmental challenges incur higher borrowing costs.

Carbon risk is inseparably linked to environmental hazards and is a key focus for governments, regulators, creditors, and other stakeholders (Zhou et al., 2018). For example, Weber (2012) found that Canadian banks incorporated ecological risk into their corporate lending decisions. Previous researchers have also examined how GHG affect the cost of debt. Overall, higher GHG emitters are deemed riskier and incur a higher CoD (Jung et al., 2018; Palea and Drogo, 2020; Zhou et al., 2018).

As carbon regulations and legislation have increased, firms might experience increased costs due to their carbon emissions. These charges can come in taxes, emission trading systems and costs related to GHG emissions by developing and adopting less-carbon-intensive technologies (Jung et al., 2018). Regulatory Theory suggests that an increase in carbon risk results in a higher cost of debt. Essentially, as carbon risk rises, regulatory demands from environmental protection bodies intensify. This leads to increased compliance costs, which in turn reduce a firm's financial capability to service debt, thus raising the cost of debt. (Zhou et al., 2018). Similarly, Wang et al. (2024) investigated the influence of carbon regulations on debt default risks in high-carbon enterprises, using China's entry into the Paris Agreement as an exogenous shock. According to the study, high-carbon firms' debt default risk decreases significantly once carbon regulations are implemented. This decrease is due to the promotion of green transformation, lower leverage, and greater legal compliance.

The influence of carbon emissions extends beyond compliance costs and borrowing rates. Ding et al. (2023) examined the effect of carbon emissions on the acquisition of new bank loans. Their findings showed that firms with higher carbon emissions are given fewer new loans. Although there is not a significant impact on the overall effect of carbon emissions on new loans, it leads to shorter loan term structures. This effect is more pronounced in state-owned firms, as well as in firms with better operational control quality and stronger environmental legislation enforcement.

According to Palea and Drogo (2020), firms with high emissions may face high-risk premiums based on their carbon emission levels because of changes made post-Paris Agreement. However, companies that were considered to emit less carbon into the atmosphere were also charged heavily based on the initiatives proposed by the Paris Agreement to ensure they maintain low carbon emissions. Relatedly, Ilhan et al. (2021) showed that following the Paris Agreement, the tail risk (i.e., low-probability extreme events) of high-carbon emitting firms increased significantly. According to Monasterolo and De Angelis (2020), their finding showed the scope of systematic risk for green stock indices in the United States, the European Union, and the international monetary market significantly decreased post-Paris Agreement, implying that introducing the Paris Agreement impacted investors' decisions on carbon-related investments.

In terms of carbon risk and cost of debt, Delis et al. (2018) conducted a study on the syndicated credit market, charged to fossil fuel enterprises with those charged to non-fossil fuel enterprises, using a sample of 72,742 loans from 58 countries. Their findings suggest that after adopting the Paris Agreement, financial institutions began to find the risk of stranded fossil fuel reserves by increasing the credit charges for fossil fuel firms and charging a high interest rate spread to those with more significant fossil reserves. In another study, Ehlers et al. (2022) examined how financial institutions price carbon risk across various industries. The authors found an impact on the syndicated loan market following adopting the Paris Agreement across various sectors. However, the effect was low, at around 3–4 basis points for the price of risk charged by the lenders. Capasso et al. (2020) suggested that post-Paris Agreement, firms' exposure to global warming reduced their default distance, indicating that exposure to carbon risk influences the creditworthiness of a firm's loans. Furthermore, Cevik and Jalles (2022) found that in the post-Paris Agreement, the bond yield spreads rose significantly, implying that bond investors react to regulatory changes. This evidence indicates that the Paris Agreement increased CoD for environmentally problematic firms facing more stringent regulatory oversight.

In conclusion, these studies have shown that the Paris Agreement influenced banks' lending decisions, leading them to price carbon risk. Therefore, we hypothesise the following:

H1. Carbon risk has a higher and more increasing impact on the cost of debt post-Paris Agreement.

2.2. *Moderating role of ESG on the relationship between carbon risk and the cost of debt*

The CSR, environmental sustainability, and governance practices collectively known as ESG are essential to corporate financial strategies and stakeholder relations. This review synthesises empirical evidence and theoretical perspectives on how these factors influence the relationship between carbon risk and the cost of debt.

The integration of CSR, environmental and governance practices has been argued to be essential for businesses to obtain the resources they need and the support of stakeholders. Hence, the Stakeholder Theory is used in several studies to help explain the link between the cost of debt, CSR, and environmental issues (Bauer and Hann, 2010; Goss and Roberts, 2011). These practices are posited to correlate with reduced capital costs by mitigating risks associated with environmental externalities. Bauer and Hann (2010) highlighted that environmental externality enforces specific risks on firms, including reputation, financial, and legal risks. The authors argued that firms with environmental misbehaviour could face costly penalties and strong adverse reactions from financial and non-financial stakeholders, impacting their default risk. The same could be argued about CSR, which is how CSR externalities can affect a firm's default risk (Attig et al., 2013) and CoD (Amiraslani et al., 2023).

Goss and Roberts (2011) investigated the relationship between CSR performance and bank loans using U.S. companies. The study revealed that companies with significant CSR issues paid seven to eighteen percentage points higher interest rates on their bank loans. These results suggested that CSR considerations can increase borrowing costs, as lenders are sensitive to such factors. While CSR initiatives can boost a company's reputation, significant shortcomings may lead to increased

borrowing costs because lenders perceive higher risk.

Sharfman and Fernando (2008) investigated if and in what way firms in the United States environmental risk management affected their cost of capital. The researchers found that strong and enhanced ecological risk management strategies led to a decrease in the cost of equity. This change often prompted a shift from equity to debt financing, resulting in increased tax benefits associated with higher levels of debt financing. In addition, Cahan et al. (2015) showed that firms with good ESG performance gain from positive publicity, leading to enhanced firm value and reduced cost of capital, especially for those receiving favourable media coverage. This finding underscores the significant effect of robust ESG performance in positively shaping investor perceptions and reducing financing costs.

From a governance perspective, Gao et al. (2021) examined how stakeholder engagement affects firms' cost of debt in the USA and found that the execution of stakeholder statutes resulted in lower costs of debt by alleviating conflicts of interest, restricting legal risk, and reducing takeover threats. This governance framework aligns corporate strategies with broader societal expectations, potentially reducing financial risks and the cost of debt.

The effectiveness of governance in moderating the ESG impacts on debt costs depends on institutional contexts and regulatory frameworks. For instance, Hoepner et al. (2016) that a one-point rise in a nation's environmental sustainability reduces CoD by 64 basis points on average. The findings imply that the environmental policies of a country are roughly twice as influential as social policies in shaping the cost of corporate loans, while there is no substantial evidence that a company's sustainability practices affect bank interest rates.

Using natural catastrophes as external shocks to views of climate change, Huang et al. (2022) demonstrated that corporate ESG ratings are higher in nations where perceptions about the negative repercussions of climate change are more significant. The authors claimed that firms in places with a greater awareness of climate change prefer to hedge against future climate hazards by spending more on CSR. Companies can proactively manage carbon-related risks and seize opportunities arising from the shift to a low-carbon economy by integrating ESG factors into their business plans. This may involve cutting emissions, creating sustainable goods and services, and responding to shifting legal requirements. This strategic alignment improves operational savings and increases market competitiveness, potentially lowering borrowing costs over the long term.

Investor attitudes towards ESG performance are instrumental in shaping corporate financing costs. Xu et al. (2020) highlighted that firms with both better ESG scores and performance in areas such as employee relations, diversity, community, and environment will likely profit from a higher level of trade credit. Amiraslani et al. (2023) found no relationship between bond spreads and the company's environmental and social performance from 2006 to 2019. However, they found that companies with high environmental and social performance profited from lesser bond spreads during the World financial crisis of 2008–2009 when trust and default risk were extensively impacted. Throughout the crisis, enterprises with high social capital were able to secure more debt at lower spreads and with longer maturities. This suggests that firms with strong ESG performance may experience lower costs of debt during market disruptions, such as financial crises, due to their resilience and ability to maintain investor trust. Also, Alves and Meneses (2024) showed that companies with robust ESG performance may experience reduced costs of debt, particularly in stable, relationship-driven financial systems.

The moderating of ESG on CoD and company performance is still being researched, with no clear consensus being reached. However, investors think about ESG while making investing decisions. Investor risk perception and capital market efficiency are other important considerations. Given these considerations, the prevailing argument is that the ESG effect on this relationship might improve a company's debt cost, notably by shaping the correlation between carbon risk and the cost of debt. We hypothesise that:

H2. ESG has a positive moderating impact on the relationship between carbon risk and the cost of debt.

In conclusion, while prior studies such as Griffin et al. (2017), Matsumura et al. (2014), and Palea and Drogo (2020) investigated how carbon emission impacted market value and equity costs, our study fills a significant gap by examining the post-Paris Agreement period within G7 countries, with a specific focus on the nexus between carbon risk and CoD. This approach is different from earlier research, such as Clarkson et al. (2015) and Jung et al. (2018), which focused on firms in the US and Australia. Furthermore, while previous studies like Bauer and Hann (2010) and Goss and Roberts (2011) argued that CSR and environmental risks can increase the costs of borrowing, our study contributes to the continuing discussion by investigating the complicated relationship between carbon risk, ESG factors, and cost of debt in a new context formed by the Paris Agreement. This provides novel insights into how carbon risk interlinks with ESG and the cost of debt, especially in the post-Paris Agreement era.

3. Data and empirical models

This chapter explains the data collection procedure and the sample selection. It describes the key variables and statistical models used to test our hypotheses.

3.1. Data

The data consists of 14,258 firm-year observations of 1428 unique publicly listed companies from G7 countries for 10 years, i.e., from 2011 to 2020. Data on firms' carbon emissions and ESG scores are obtained from Refinitiv. The financial data of companies are collected from Bloomberg. Firms from the financial and real estate sectors are excluded, given they have different regulatory requirements. Their liabilities are distinct, making them complex compared to other industries (Pittman and Fortin, 2004). The sample period covers both before the Paris Agreement (2011–2015) and after the Paris Agreement (2016–2020) periods. The decision to conclude data collection in 2020 was made owing to the compounded impact of the COVID-19 epidemic, which began to affect worldwide economic circumstances by the end of 2020. Furthermore, data for the years following 2020 were not completely accessible at the time of our study. This ensures that our data analysis is based on a comprehensive and consistent dataset for the entire sample period.

The sample distribution per industry, as shown in Table 1, is based on firms that reported carbon emissions data on Refinitiv, rather than random selection. This strategy was used to ensure that the research focuses on firms having available and valid carbon emission data from various industries, reflecting different levels of carbon risk and financial characteristics. The distribution covers six industrial categories: Industrials and Basic Materials (37 %), Consumer Cyclicals and Consumer

Table 1
Sector distribution.

Sector	Number of Observations (2011−2020)	%
Sector_Category 1	5290	37 %
Sector_Category 2	4289	30 %
Sector_Category 3	1250	9 %
Sector_Category 4	830	6 %
Sector_Category 5	1650	12 %
Sector_Category 6	948	7 %
Total	14,258	100 %

Note: Sector_Category 1: Basic Material and Industrial; Sector_Category 2: Consumer Cyclicals and Consumer Non-Cyclicals: Sector_Category 3: Energy: Sector_Category 4; Healthcare; Sector_Category 5: Technology; Sector_Category 6: Utilities.

Table 2
Country distribution.

Country	Number of Observations (2011–2020)	%
Canada	1440	10 %
France	870	6 %
Germany	1180	8 %
Italy	608	4 %
Japan	2880	20 %
UK	2170	16 %
USA	5110	36 %
Total	14,258	100 %

Non-Cyclicals (30 %), Technology (12 %), and Energy, Utilities, and Healthcare sectors, each accounting for less than 10 % of the sample.

Table 2 displays the distribution of our sample by country, and Table 3 displays the distribution by year.

The most represented countries are the United States and Japan, which together account for 56 % of the total firm-year sample. The United Kingdom and Canada follow, representing 16 % and 10 % of the sample, respectively. Germany, Italy, and France collectively make up 18 % of the overall sample.

3.2. Empirical models

We use a pooled OLS regression model to investigate the impact of carbon risk on CoD. In this study, CoD is the dependent variable, which refers to the expense incurred by a company when raising capital through bank loans or bond issuance (Palea and Drogo, 2020). We follow Maaloul (2018) using data on CoD obtained from Bloomberg.

The primary independent variable in this study is carbon risk, measured as total carbon emissions over revenues. This measure is consistent with prevailing studies (Ehlers et al., 2022; Jung et al., 2018). Carbon emissions are measured relative to revenue across different firm sizes and industries (Hoffmann and Busch, 2008). Total carbon emission includes emissions from the Scopes one and two categories, as defined by the Carbon Disclosure Project (*CDP*) obtained from Refinitiv.

Scope one emissions, referred to as direct emissions, are managed or owned by the firm, whereas Scope two emissions are indirect emissions stemming from the use of procured power, steam, or alternative sources of energy (CDP, 2024).

The second primary independent variable is the Paris Agreement (*PA2015*) dummy variable, where a firm-year observation is coded as 1 if it falls within the post-Paris Agreement period and 0 otherwise. The third primary variable is *CSR*, proxied as the *ESG* score obtained from Refinitiv. It is hypothesised that ESG will have a negative correlation with the cost of debt, as firms with poor ESG performance may face higher financing costs (Goss and Roberts, 2011).

We also control profitability, leverage, interest coverage, size, and default risk variables in line with the earlier literature (Goss and Roberts, 2011; Jung et al., 2018; Maaloul, 2018). Profitability is measured as Return on Asset (*ROA*), profitable businesses are expected to have a negative association with the cost of debt, due to their reduced risk of failure (Jung et al., 2018). Leverage is expressed as the ratio of total debt to total assets, it is predicted that high leverage will result in a higher CoD (Altman et al., 2017). Interest coverage is computed as the ratio of operating income to interest expenses, with an antagonistic relationship expected between the CoD and interest coverage (Zhou et al., 2018).

Firm size is calculated using the natural log of total assets as a proxy. We expect a negative association linking the CoD and a firm's size since larger companies are less likely to fail (Jung et al., 2018). The Altman *Z*-score is used to determine default risk and is predicted to have an inverse relationship with the cost of debt, with lower Z-scores (indicating higher default risk) leading to higher financing costs. (Goss and Roberts, 2011). Additionally, the effects of industry and country are controlled. We also winsorised the dependent, independent, and control variables to be consistent with previous studies.

The econometric model below is used to test the first hypothesis (H_1):

$$CoD_{i,t} = \beta_0 + \beta_1 CarbonRisk_{i,t} + \beta_2 PA2015_t + \beta_3 CarbonRisk_{i,t} \times PA2015_t + \beta_4 IND_i + \beta_5 REG_i + \sum_{j=1}^{k} \beta_j Controls_{i,t} + \varepsilon_{i,t} \quad (1)$$

We also test the second hypothesis (H_2), the following model is used:

$$CoD_{i,t} = \beta_0 + \beta_1 CarbonRisk_{i,t} + \beta_2 CarbonRisk_{i,t} \times PA2015_t + \beta_3 CarbonRisk_{i,t} \times ESG_{i,t} + \beta_4 ESG_{i,t} + \beta_5 IND_i + \beta_6 REG_i + \sum_{j=1}^{k} \beta_j Controls_{i,t} + \varepsilon_{i,t} \quad (2)$$

In Eq. (1) and Eq. (2), $CoD_{i,t}$ is the CoD for firm i at year t; $CarbonRisk_{i,t}$ is the carbon emission for firm i at year t that is measured as the total of scopes 1 and 2 GHG emissions for year t divided by the revenue of firm i in year t; $Controls_{i,t}$ is the set of control variables for firm i at year t; $PA2015_t$ is a post-Paris Agreement (i.e., post-2015) dummy variable that equals 1 for years after 2015 (i.e., 2016–2020) and 0 otherwise; IND_i is the industry sector for the firm i; and REG_i is the country for firm i and $Carbon\ Risk_{i,t} \times PA2015_t$ is an interaction term between carbon risk and the post-Paris Agreement dummy variable.

4. Findings and discussion

4.1. Preliminary findings

Table 4 displays the descriptive statistics for all variables included in the regression models. The average for CoD is 1.45, ranging from 0.02 to 3.57, constant with earlier studies (Jung et al., 2018; Maaloul, 2018; Zhou et al., 2018). The carbon emissions average is 4.011 t, while the mean carbon risk is 0.001. Regarding control variables, the mean *ROA* is 4.05 %, ranging from −19.15 % to 25.09 %. The average firm size is 22.07, with values ranging from 18.13 to 25.87, indicating that our sample included larger firms (Zhou et al., 2018). The mean leverage (*LEV*) is 108.52, ranging from 0.05 to 1741.6. The mean ESG Score (*ESG*) is 53.42, ranging from 0.47 to 94.65. The mean Altman *Z*-score is 3.83, indicating that, on average, firms in the sample are financially healthy and unlikely to face bankruptcy, with values ranging from −1.36 to 20.34.

In Table 5, we present the correlation array for the variables included in our regression model. As expected, there is a positive association between carbon risk and the CoD ($p < 0.01$). This supports H_1, which shows a positive correlation between carbon risk and the cost of debt, which aligns with previous research (Maaloul, 2018). Control variables in Table 5, show that leverage, interest coverage and ROA are all positively related with the CoD ($p < 0.01$), constant with preceding studies (Goss and Roberts, 2011). The correlation coefficient for size is negative and insignificant, which aligns with the preceding research (Goss and Roberts, 2011; Griffin et al., 2017). Both Altman Z-score and ESG are negatively related to the CoD ($p < 0.01$).

4.2. Carbon risk and cost of debt: The role of the Paris agreement effect

Table 6 displays the regression finding for Models 1 and 2. Model 1 presents the findings from the baseline regression, including the control variables. Carbon risk has a positive correlation with the CoD with all the control variables included. This evidence implies that higher carbon risk leads to a greater cost of debt, as suggested by previous studies (Li

Table 3
Distribution by year and country.

Country	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Canada	144	144	144	144	144	144	144	144	144	144	1440
France	87	87	87	87	87	87	87	87	87	87	870
Germany	118	118	118	118	118	118	118	118	118	118	1180
Italy	60	61	61	61	61	61	61	61	61	60	608
Japan	288	288	288	288	288	288	288	288	288	288	2880
UK	217	217	217	217	217	217	217	217	217	217	2170
USA	511	511	511	511	511	511	511	511	511	511	5110
Total	1425	1426	1426	1426	1426	1426	1426	1426	1426	1425	14,258

Table 4
Descriptive analysis.

Variables	NO	Mean	Standard Deviation	Minimum	Maximum
Cost of Debt	13,361	1.453	1.094	0.020	3.570
Carbon Risk	9612	0.001	0.001	0.000001	0.008
Size	13,122	22.07	1.631	18.130	25.87
Interest Coverage	13,512	52.06	184.3	−47.39	1467.8
Leverage	13,051	108.5	223.3	0.050	1741.6
ROA	12,060	4.050	6.315	−19.15	25.09
Altman Z	13,529	3.830	3.279	−1.360	20.34
ESG Score	11,726	53.42	19.15	0.470	94.65

et al., 2014; Maaloul, 2018). ESG score shows a significant negative result ($p < 0.01$), implying that a firm with better CSR performance has a lower cost of debt, as expected. Interest coverage is negative and significant ($p < 0.01$), this finding affirms the assertion that companies with a greater debt-servicing capacity are considered less risky and profit from the reduced cost of debt. Altman's *Z*-score is significant and negative ($p < 0.01$), suggesting that better credit quality of firms lowers their debt spread (Hull et al., 2004). Also, both *ROA* and size have significant and positive coefficients, indicating that profitability (Lins et al., 2017) and size (Capasso et al., 2020) increase CoD. The coefficients on industry dummies suggest energy and healthcare companies face a higher debt cost than utility companies. Moreover, from the coefficient on countries, the CoD for firms in all nations is significantly less than that in the United States and Canada. This is because of unconventional monetary policies in Japan, Europe, and the United Kingdom, which compresses long-term interest rates.

As expected, the coefficient on carbon risk is positive and significant ($p < 0.01$), indicating an increase in carbon risk by 1 unit raises the CoD by 0.02. The Adjusted R^2values are around 55 %, suggesting that the model provides a significant explanation for the variations in the cost of debt.

Model 2 in Table 6 includes the post-Paris Agreement dummy variable (*PA2015*) and its interplay with carbon risk to capture the impact of carbon risk on the CoD pre- and post-Paris Agreement. *Carbon-Risk×PA2015* shows a positive and significant correlation ($p < 0.01$), implying that lenders' awareness of carbon risk increased significantly after the 2015 Paris Agreement. This is consistent with our expectations in Hypothesis 1.

PA2015 has a negative and statistically significant coefficient ($p < 0.01$), signifying a significant decline in the CoD over the five years after 2015. This can be explained by imposed monetary policies to compress long-term interest rates in most countries, such as expanding the Quantitative Easing (*QE*) programme and cutting the policy rate in 2016 by the Bank of England, implementing a negative lending rate in 2014 by the European Central Bank, and launching extensive *QE* programme, and setting "yield curve control" policy by the Bank of Japan in 2014 and 2016, respectively.

4.3. Moderating effect of the ESG

Column 1 Table 7 shows the interplay between carbon risk and ESG Score (*Carbon Risk* × *ESG Score*) is insignificant, indicating no evidence of ESG score moderation in the relation between carbon risk and cost of debt. However, the coefficients for carbon risk and ESG score are significant, with ESG score having a negative coefficient and carbon risk having a positive coefficient. This evidence implies that companies with better ESG scores are likely to have lower debt costs, while firms with greater carbon risk tend to have high costs of debt. *PA2015* shows a significant and negative coefficient ($p < 0.01$), suggesting that during the post-Paris Agreement, firms had lower levels of CoD compared with the pre-Paris Agreement period. Firm size is significantly positive, indicating that bigger firms tend to have higher debt costs. Altman's *Z*-score is shown to be significantly negative ($p < 0.01$), suggesting that companies with a lower Altman Z-score tend to have higher cost of debt. Considering country dummies (*REG*), all three groups of countries have negative coefficients, with Japan having the biggest coefficient and the

Table 5
Correlation matrix.

Variable	Cost of Debt	Carbon Risk	Interest Coverage	Size	ROA	Leverage	Altman Z	ESG Score
Cost of Debt	1							
Carbon Risk	0.104***	1						
	(0.000)							
Interest Coverage	0.191***	−0.007	1					
	(0.000)	(0.520)						
Size	−0.005	0.042***	−0.105***	1				
	(0.619)	(0.000)	(0.000)					
ROA	0.025***	−0.066***	0.220***	−0.027***	1			
	(0.008)	(0.000)	(0.000)	(0.004)				
Leverage	0.144***	0.012	−0.108***	0.108***	−0.041***	1		
	(0.000)	(0.243)	(0.000)	(0.000)	(0.000)			
Altman Z	−0.062***	−0.082***	0.359***	−0.226***	0.563***	−0.159***	1	
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
ESG Score	−0.084***	−0.051	−0.100***	0.507***	0.013	0.018*	−0.082***	1
	(0.000)	(0.914)	(0.000)	(0.000)	(0.184)	(0.057)	(0.000)	

Notes: The probability values are in parentheses. *** $p < 0.01$, ** $p < 0.05$ & * $p < 0.10$.

Table 6
Baseline results.

Variable	Model 1	Model 2
Carbon Risk	0.023***	0.017*
	(0.008)	(0.009)
Post Dummy	N/A	−0.146***
		(0.009)
Carbon Risk × Post Dummy	N/A	0.035***
		(0.009)
ESG Score	−0.092***	−0.065***
	(0.010)	(0.010)
Size	0.043***	0.029**
	(0.013)	(0.013)
Interest Coverage	−0.015**	−0.014*
	(0.007)	(0.007)
Leverage	0.007	0.016*
	(0.009)	(0.009)
ROA	0.031**	0.014
	(0.013)	(0.013)
Altman Z	−0.105***	−0.094***
	(0.014)	(0.013)
Germany, France, Italy	−1.077***	−1.092***
	(0.034)	(0.031)
Japan	−1.813***	−1.774***
	(0.016)	(0.016)
United Kingdom	−0.554***	−0.562***
	(0.032)	(0.030)
Sector_Category 2	0.006	−0.003
	(0.021)	(0.021)
Sector_Category 3	0.110***	0.118***
	(0.037)	(0.037)
Sector_Category 4	0.067*	0.048
	(0.037)	(0.036)
Sector_Category 5	0.019	0.008
	(0.030)	(0.029)
Sector_Category 6	−0.078**	−0.060*
	(0.035)	(0.034)
Constant Term	0.851***	0.806***
	(0.033)	(0.033)
Observations	6428	6428
Adjusted R^2	0.547	0.564

Notes: The standard errors are in (). *** $p < 0.01$, ** $p < 0.05$ & * $p < 0.10$.

Table 7
ESG moderation effect.

Variable	ESG Moderation	ESG Low	ESG High
Carbon Risk	0.017**	0.023**	0.014
	(0.008)	(0.011)	(0.012)
Post-Paris Agreement Dummy	−0.145***	−0.145***	−0.158***
	(0.009)	(0.013)	(0.012)
Carbon Risk × Post Paris Agreement Dummy	0.035***	0.041***	0.029**
	(0.008)	(0.011)	(0.012)
ESG Score	−0.065***	N/A	N/A
	(0.010)		
Carbon Risk × ESG Score	−0.004	N/A	N/A
	(0.010)		
Size	0.029**	0.013	−0.032**
	(0.012)	(0.018)	(0.016)
Interest Coverage	−0.014	−0.006	−0.026
	(0.012)	(0.010)	(0.022)
Leverage	0.015*	0.020	0.019*
	(0.008)	(0.013)	(0.011)
ROA	0.014	0.028*	0.001
	(0.011)	(0.015)	(0.016)
Altman Z	−0.094***	−0.080***	−0.109***
	(0.013)	(0.018)	(0.020)
Germany, France, Italy	−1.092***	−1.255***	−1.039***
	(0.027)	(0.047)	(0.034)
Japan	−1.773***	−1.840***	−1.700***
	(0.023)	(0.032)	(0.034)
UK	−0.562***	−0.769***	−0.406***
	(0.026)	(0.037)	(0.037)
Sector_Category 2	−0.003	0.033	−0.037
	(0.021)	(0.031)	(0.029)
Sector_Category 3	0.117***	0.180***	0.069
	(0.032)	(0.042)	(0.051)
Sector_Category 4	0.048	0.057	0.030
	(0.036)	(0.059)	(0.046)
Sector_Category 5	0.007	−0.020	0.045
	(0.030)	(0.045)	(0.041)
Sector_Category 6	−0.060*	−0.010	−0.060
	(0.035)	(0.047)	(0.051)
Constant Term	0.622***	0.675***	0.609***
	(0.017)	(0.024)	(0.026)
Observations	6428	2955	3473
Adjusted R^2	0.564	0.611	0.526

Notes: The standard errors are in (). *** $p < 0.01$, ** $p < 0.05$ & * $p < 0.10$.

United Kingdom having the smallest coefficient compared to the base countries of the United States and Canada ($p < 0.01$). The results suggest that companies operating in different regions may have various levels of debt cost. Considering industry dummies, Energy and Utility showed significant results, with energy having a positive coefficient and Utility having a negative coefficient. The Adjusted R^2 is 56.5 %, suggesting that the model examined explains considerable variation in the cost of debt.

To further analyse the moderating impact of ESG on the association between carbon risk and the cost of debt, firms were split into two groups based on their ESG, i.e., Low ESG and High ESG. The findings are shown in Table 7.

From Column 2 of Table 7, carbon is significant and positive ($p < 0.05$), therefore reinforcing a positive correlation between carbon risk and cost of debt. *PA2015* coefficient is negative, indicating that low ESG-level companies experienced lower debt costs after the Paris Agreement. On the other hand, the positive coefficient of the interaction terms, namely, *Carbon Risk* × *Post Paris Agreement*, indicates that firms with high carbon risk experienced an increase in the CoD post-Paris Agreement. This positive relationship could be due to the increased scrutiny and higher perceived risk of investing in carbon-intensive industries. *ROA* has a positive coefficient, indicating that more profitable firms tend to have higher debt costs. The negative coefficient of Altman's Z-Score (−0.080) suggests that companies with a lower Z-score had a higher cost of debt, which is constant with the notion that companies with weaker financial health are riskier. Therefore, lenders require higher returns to compensate.

Additionally, the coefficients of countries indicated that companies in Germany, France, Italy, Japan, and the United Kingdom had a lesser CoD than corporations in Canada and the United States. This could be due to factors such as differences in regulatory environments, economic conditions, or cultural attitudes towards debt financing. The positive coefficient on the industry dummy of energy alludes that firms in the energy sector, which are considered as high emitting firms, have a greater cost of debt, which could reflect lenders' concerns about the financial risks associated with fossil fuel production and consumption, aligned with findings from previous papers (El Ghoul et al., 2011; Maaloul, 2018).

In Column 3 of Table 7, the carbon risk shows an insignificant coefficient, indicating no significant relationship between carbon risk and the cost of debt. Conversely, the *PA2015 coefficient is* negative and significant ($p < 0.01$). Additionally, the interplay CARBON *RISK X PA2015* exhibits be significant and positive coefficient ($p < 0.01$). This result implies that the period after the Paris Agreement is associated with lower debt costs for companies that emphasise ESG. Firm size shows a significant negative result, signifying that larger firms with substantial ESG gain from the lesser cost of debt. The result for Altman's *Z*-score continues to be significant and negative in the down-sample of firms with higher ESG scores. Results for the country and industry effects are consistent with those of firms with low ESG scores.

4.4. Endogeneity tests

Endogeneity is a common challenge in studies exploring causal relationships, where results might be influenced by a common factor affecting both carbon risk and CoD. To address potential endogeneity problems and check the reliability of our findings, we used a 2SLS approach as a robustness check. This approach uses an Instrumental Variable (IV) technique, which helps to reduce endogeneity by introducing an external instrument that is associated with the endogenous explanatory variable (i.e., carbon risk) but uncorrelated with the error term in the regression model.

The instrumental variable used for this analysis is the Distance Cap, which represents the distance in kilometres between the capital city of each country and global markets. The distance data is based on bilateral measurements provided by Conte et al. (2022). The rationale for using this geographic distance as an IV assumes that firms closer to the global markets may be subject to different economic activities. The average carbon risk score of firms situated within a certain distance from the capital city of each country serves as the instrumental variable for a particular company's carbon risk.

In the first stage of our analysis in Table 8, we predicted carbon risk and used this predicted value as the independent variable in our second-stage regression. Our results (not tabulated here) show in the first stage that the distance to the capital has a statistically significant influence on carbon risk. This evidence suggests that the carbon risk decreases as the distance from the global market increases. The relationship indicates that firms located further from regulatory scrutiny, where environmental regulations might be stricter and more enforced, will have lower carbon risks. These results suggest the research hypothesis is supported even after alleviating possible endogeneity concerns.

Table 8
Endogeneity test: instrumental variable regression-2SLS estimations.

	First Step	Second Step
Variable	Carbon Risk	Cost of Debt
Distance	−0.000***	N/A
	(0.00)	
Carbon Risk	N/A	0.314*
		(0.17)
Post_Dummy	N/A	−0.293***
		(0.02)
Post_Dummy#CarbonRisk	N/A	0.691***
		(0.09)
ESG Score	−0.000**	−0.004***
	(0.00)	(0.00)
Size	0.000	0.035***
	(0.00)	(0.01)
Interest Coverage	0.000	−0.000***
	(0.00)	(0.00)
Leverage	−0.000***	0.000***
	(0.00)	(0.00)
ROA	0.000**	−0.002***
	(0.00)	(0.00)
Altman_Z	−0.000**	0.008***
	(0.00)	(0.00)
Germany, France, Italy	−0.007***	−1.170***
	(0.00)	(0.03)
Japan	0.004**	−1.847***
	(0.00)	(0.03)
United Kingdom	−0.006***	−0.451***
	(0.00)	(0.04)
Sector_Category 2	−0.000**	−0.010
	(0.00)	(0.02)
Sector_Category 3	0.000	0.145***
	(0.00)	(0.04)
Sector_Category 4	−0.000***	0.062*
	(0.00)	(0.04)
Sector_Category 5	0.000	−0.054**
	(0.00)	(0.03)
Sector_Category 6	0.001***	−0.409***
	(0.00)	(0.08)
Constant Term	0.026***	1.702***
	(0.01)	(0.14)
Observations	6485	9206
Adjusted R^2	0.055	0.584

Notes: The standard errors are in (). *** $p < 0.01$, ** $p < 0.05$ & * $p < 0.10$.

Regarding the ESG Score, a high ESG score is related to a decreased carbon risk. This statistically significant association suggests that firms with stronger ESG practices may experience **reduced** carbon risk, potentially due to better management practices. Furthermore, a higher Altman Z-score, indicating better financial health, is associated with a lower carbon risk. The results suggest that financially healthier firms may have more resources and incentives to manage their carbon risks effectively.

Additionally, a higher *ROA* is linked with a rise in carbon risk. This evidence implies that more profitable firms take on more environmental risk. In the second state, the fitted carbon risk is positive and significant, signifying that higher carbon risks lead to higher borrowing costs, likely due to increased perceived risk by lenders. On the contrary, the coefficient on *PA2015* is negative and significant, which specifies that after the Paris Climate Agreement, CoD decreased. This evidence insinuates that the Paris Agreement has a positive impact on reducing borrowing costs, possibly due to improved environmental policies and increased investor confidence, which is in line with the result discussed in H_1.

The interaction term *Carbon Risk* × *PA2015* remains positive and significant, indicating the effect of carbon risk on the CoD becomes extra pronounced post- Paris Climate Agreement. Specifically, for firms with greater carbon risk, the CoD increased significantly post-agreement. A high ESG score is correlated with a decline in the cost of debt, implying that companies with better ESG implementation prefer low borrowing costs. The interest coverage ratio is significant, showing that a higher ratio is associated with a better adept to cover interest expenses, which is connected to a decline in the cost of debt. *ROA* has a negative and significant coefficient, signifying that higher profitability (*ROA*) is related to a reduction in the cost of debt, implying that profitable firms can secure debt at lower costs. These findings are consistent with those found in Table 6, ensuring that the findings are not impacted by endogeneity issues.

5. Conclusion

We explored the connection between carbon risk and CoD for firms in G7 countries during the period from 2011 to 2022, with a particular focus on how the Paris Agreement influences these dynamics. The choice of G7 countries for this study is particularly significant, as these countries are a major economic powerhouse, accounting for more than 60 % of global net wealth and 25 % of global energy-related carbon emissions. In addition, the study investigated if ESG had a moderating role in the association between carbon risk and the cost of debt, using the ESG score as a proxy. The findings reveal a significant positive correlation between carbon risk and the cost of debt, with this correlation becoming more pronounced post-Paris Agreement**.** Our findings corroborate H1, which proposes the effect carbon risk has on the cost of debt, as lenders weigh carbon risks more carefully when borrowers seek credit or loans.

Regarding ESG, while ESG on its own showed a significant and negative relation with the cost of debt, no significant results were found for the interaction between carbon risk and ESG, suggesting that ESG factors do not play a moderating role in the association between carbon risk and the cost of debt. Further analysis indicated that results were consistent for corporations with high and low ESG scores, indicating that the influence of ESG on CoD is direct instead of indirect.

Furthermore, this study enhances the academic literature in existence by evaluating the relationship between carbon risk and the cost of debt. The findings provide supporting proof of a positive relationship, implying that carbon risk increases borrowing costs. Furthermore, this research builds on previous studies by analysing a sample of listed firms from various sectors and across the Group of Seven countries and

investigating the effect of the Paris Agreement. While the results regarding the moderating effect of ESG factors are insignificant, the study's findings verify the direct impact of ESG factors on CoD rather than an indirect effect through the mitigation of carbon risk. The study proves that a strong climate policy commitment, such as the Paris Agreement, should encourage lenders to incorporate corporate carbon risks in their lending decisions.

This study has important policy implications for regulators, firms, and policymakers. Policymakers should capitalize on the progress made by strengthening climate policies to ensure they are consistent with the Paris Agreement. This could include having clearer targets for carbon reduction, enhancing the implementation of these targets, and increasing accountability for corporate carbon emissions. Regulators are recommended to require the integration of ESG factors into credit analysis and lending policies to encourage more responsible corporate management. By analysing the nexus between the carbon risk and the cost of debt in G7 economies, especially after the Paris Agreement, this study helps investors make more informed decisions and enables financial policymakers to emerge effective policies to reduce carbon risk. Therefore, firms can lower their cost of debt by employing sustainable operations and reducing their carbon risk. These conclusions align with the broader literature, such as the findings of Palea and Drogo (2020), but extend our understanding by focusing specifically on the post-Paris Agreement period. The study reveals that the impact of carbon risk, cost of debt and ESG factors differs across industries, implying that sector-specific actions may be crucial in mitigating the effects of carbon risk. These results are relevant for policymakers and financial institutions as they assess how well financial flows are consistent with climate targets under the Paris Agreement and other climate agreements.

The research is based on data from Refinitiv and Bloomberg, which may create biases due to data availability and consistency, particularly in reporting carbon emissions and ESG Score. Some firms may have insufficient or inconsistent reporting processes, potentially compromising the reliability of the data. However, Refinitiv ESG Scores and carbon risk have been used in previous empirical analysis and research (e.g., Danisman and Tarazi, 2024; Maaloul, 2018). Furthermore, the exclusion of data beyond 2020 due to the COVID-19 pandemic limits the research's potential to capture more recent trends. Future research should consider the impact of the COVID-19 pandemic on the interaction between carbon risk and firm performance including cost of equity and debt. In addition, the research is restricted to the G7 countries, further research can broaden the scope to include other countries contributing to carbon emissions, such as BRICS and other developing economies.

Furthermore, the study uses pooled OLS and 2SLS models to address endogeneity, but these methodologies may not fully capture unobserved variability or the dynamic nature of the interaction between carbon risk, ESG variables, and CoD. Future research should investigate alternative tools, such as dynamic panel data models or machine learning techniques, to capture more complex relationships and temporal patterns. Finally, while this study uses a quantitative approach, further studies could consider alternative methods, such as surveys or interviews with finance providers, including equity investors and lenders. Such qualitative techniques might offer more detailed insights into market players' opinions and decision-making processes regarding carbon risk and ESG issues.

CRediT authorship contribution statement

Ayotola Owolabi: Writing – original draft, Formal analysis, Data curation. **Mohammad Mahdi Mousavi:** Writing – original draft, Validation, Methodology, Writing – review & editing, Conceptualization. **Giray Gozgor:** Writing – original draft, Conceptualization, Writing – review & editing, Methodology. **Jing Li:** Writing – review & editing, Writing – original draft, Conceptualization, Methodology.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2024.107925.

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