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Original Research Article

Dynamics of carbon risk, cost of debt and leverage adjustments

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ABSTRACT

We evaluate the effects of carbon risk on the speed at which corporations adjust their leverage for the period 2006–2020. Primarily we address the question: Does national carbon risk impact firm-level speed of adjustment (SOA)? To address the main question, our study further classifies the companies in the sample based on borrowing costs and carbon risk. By doing so, we report on how borrowing costs may influence the company's conduct. Our research focuses on the energy sector, which is an important sector for emitting carbon. Our study uses physical climate risk changes as a proxy for carbon risk, and the second proxy for carbon risk is obtained by scaling the country's carbon emissions to the company level. We find that the carbon risk is positively related to the speed of adjustment; specifically, the firms with low cost of borrowing show a faster speed of adjustment toward the target than those whose cost of borrowing is higher. However, businesses with high (low) expenses and high carbon risk do not see a reason to change their leverage. In addition, we also examine the interaction effects of earnings yield, transaction contract cost, enforcement cost on carbon risk, and the speed of leverage adjustment. Our results confirm that the effects of transaction contract costs and enforcement costs are significant. The post-Paris Agreement period reveals a strong positive relationship between carbon risk and leverage SOA.

1. Introduction

Finance scholars are interested in finding out how quickly a company's capital structure converges to its desired structure. The empirical question is: whether and how carbon risk at a country-level affects the speed of adjustment (SOA) of the firms operating within the country? Capital structure decisions drive several vital decisions. This study examines how carbon risk and cost of debt affect the speed of debt adjustment. Ever since the adoption of the Kyoto Protocol in 2005, developed and developing countries have been required to limit greenhouse emissions. Further in 2015, the Paris Climate Conference formalised a new global climate pact applicable to all countries, aiming to keep global warming between 1.5 °C and 2 °C (IPCC). These initiatives were reaffirmed at the recent COP26 climate convention in Glasgow, UK. Making the switch to a low-carbon economy and adopting fuel-efficient technology

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is vital now. There is no perfect carbon reduction method in international agreements on CO2 emission control and climate change mitigation; thus, environmental concerns are increasing pressure on fuel-intensive economies, sectors, and companies.

The energy sector, which is heavily reliant on carbon emissions, is especially vulnerable to policy changes and climate change (Schaeffer et al., 2012). It is one of the few other sectors (transportation, utilities) with highest carbon footprints and is under the most pressure to adopt measures to mitigate carbon emissions (Cadez et al., 2016; Huisingh et al., 2015). The length and amplitude of daily and seasonal heating and cooling requirements have immediate consequences on energy supply and demand. Rising temperatures are predicted to increase cooling demand while decreasing heating demand in the future. Enterprises are affected by the risks and opportunities involved with the transition to a low-carbon economy. Because high carbon risk implies increased volatility in profitability, it is necessary to examine the implications of carbon risk on company behaviour and operations. It will be more expensive to resist climate change mitigation than it will to reduce carbon emissions (Rosenbloom et al., 2020). The frequency, duration, intensity, and geographic dispersion of extreme weather events have significantly increased despite only a 1 °C rise in global average temperatures (Field et al., 2012).

Carbon-intensive companies may face increased financing costs if banks restrict lending and institutional investors avoid such enterprises due to climate-related capital requirements and general tendencies toward sustainable investing in financial markets (Heo, 2024; Giacchetta & Giacometti, 2024). The opportunities and risks associated with adopting low-carbon technologies influence firms' investment decisions. It is, therefore, critical to assess the effects of carbon risk on corporate initiatives to low-carbon technology adoption, because rising carbon risk signals increased earnings variability (Amin et al., 2021).

Our study examines two questions: First, does carbon risk at the country-level affect the SOA of the firms operating within the country? And second, whether the cost of debt affects the relationship between the carbon risk and the speed of leverage adjustment? We study the carbon-intensive sector comprising 209 firms from 18 nations and five regions for the period 2006–2020. The empirical findings are interpreted considering the two capital structure hypotheses: the Trade-Off Theory and the Pecking Order Theory. Debt financing has both positive and negative consequences on a company's value, and the Trade-Off Theory describes how these effects are balanced. The pecking order hypothesis argues that firms prefer internal financing to debt financing and debt financing to issuing shares (Donaldson, 1961; Myers, 1984). Our study is among few studies looking at target leverage speed, carbon risk, and earnings yield. Recent studies documented a positive relationship between carbon risk and cost of capital (Jung et al., 2018; Kim et al., 2015; El Ghoul et al., 2024).

Further, using carbon intensity as a proxy for carbon risk, Kim et al. (2015) showed a lower association between high carbon GHG emissions volume and equity capital cost. Businesses adjust their capital structure quicker following COVID-19, and companies in countries where COVID-19 has a more significant impact change their target leverage faster. (Vo et al., 2021).

The relevance of the Stakeholder Theory is clear from the way the institutional investors are aiming to reduce their carbon footprint and are increasingly monitoring publicly traded firms' emissions of greenhouse gases. Furthermore, the Church of England Pension Fund and the Vatican, which recently invited Catholics to invest in ecologically friendly companies, display a consistent commitment to the Paris Agreement. Nearly 40 faith groups worldwide have pledged to divest from fossil fuel companies (Pullella, 2020), which aligns with the Paris Agreement's intentions. As per evidence from Australia, markets are more receptive to public calls/opinions than policy changes in rewarding better carbon performers (Qian et al., 2020). Furthermore, businesses that practice sustainability have lower financing or capital expenses and higher financial returns. According to a recent study (Bolton & Kacperczyk, 2021), investors are or can seek compensation for the risk of carbon emissions.

Financial markets and economic factors influence capital structure decisions. Capital structure research seeking to explain firm-specific leverage changes has focused on the topic of target leverage. The upgrading or acquiring new low-carbon technology is a component of the transition to a circular economy, which significantly contributes to climate change mitigation. Despite the substantial investments, the wealth prospects and value offerings are huge. Low-carbon technology can minimize CO2 emissions, increase efficiency, and optimize production capacity by redistributing resources. Finding the correct funding source and balancing debt and equity are critical to decreasing capital and transaction costs (Myers, 1984) and creating long-term value. As a result, we believe that the speed with which organisations adapt to new technologies is critical to building wealth. These capital structure decisions impact investors, shareholders, stakeholders, and the community.

We expand the literature in the following ways: First, our study uses carbon risk as a proxy for physical climate risk changes compared to Zhou and Wu (2022), who derive the climate risk exposure proxy from bigrams scaled by a total number of bigrams in earnings conference call transcripts. This proxy reflects the impressions and opinions of analysts, investors, and others. It emphasizes the effects of information on adjustment speed. We also use an alternative proxy for carbon risk by scaling the country's carbon emissions to the company level.

Secondly, our research focuses on the energy sector, which is an important sector for emitting carbon. Whereas Zhou and Wu (2022) employ worldwide data from across other industries. Thirdly, our study emphasizes and analyzes borrowing costs as a crucial factor to take into account when businesses adjust their leverage in order to adopt new technologies, in addition to the carbon risk which is not considered in the prior literature (e.g. Zhou & Wu, 2022). Fourth, our research recognises the differences in transitioning towards the low emission technologies within the companys' in the energy sector as it involves financing costs. We, therefore, categorize the firms based on the borrowing cost and carbon risk. We identify heterogeneity within the homogenous group of the energy sector.

Our research therefore demonstrates that carbon risk significantly impacts how soon businesses shift to their intended debt ratios. When the cost of debt and carbon risk is low, enterprises tend to make more rapid adjustments to their capital structure. Technology investments are critical for carbon emission reduction. As a result, the key concern is with funding accessibility and availability. Flexibility in reorganising financial structures for technology infrastructure is possible for firms with a strategic orientation, where loan costs and carbon risk are optimally balanced, accelerating the rate of adjustment.

Our analysis indicates that a company's carbon risk is positively related to the speed of leverage adjustment. Specifically, this link is positive and significant for firms with low costs and low carbon emissions. These findings indicate that, on average, it takes less than a year for a firm to adjust half of its leverage deviation, which is further reduced by low carbon risk. The country-level data support our hypothesis 1, that carbon risk is positively associated with SOA.

According to prior research, organisations that are proactive in mitigating carbon risk are those who strategize their actions by providing both funding and flexibility necessary to address environmental difficulties (Albertini, 2013; Hart & Dowell, 2011).

Our findings confirm the Stakeholder Theory that a corporation that prioritizes stakeholder needs will outperform competitors. The competitive edge may be achieved at the firm's expense. To fund assets and future growth, the organization could quickly access low-cost capital market debt. In the High cost of debt and low carbon risk (HCLCR) category, the Carbon Risk (CR) has a small but positive effect on the leverage SOA adjustments. As a result, while HCLCR firms have low carbon emissions, the high cost of debt forces them to adjust leverage more quickly to offset the disadvantages, whereas LCLCR firms already have low cost of debt, advanced technology to mitigate carbon risk, and greater flexibility in accessing the capital market. These corporations are not pushed to change their leverage faster.

We find that the earnings yield has a considerable effect on the leverage adjustments. This corroborates recent research indicating that businesses benefit financially from mitigating their carbon risk. While earnings yield has a negative and statistically significant effect on the link between carbon risk and SOA in the HCLCR category. This means that, despite their efforts to minimize carbon emissions, their earnings do not support SOA. The result is more robust for the HCLCR category in the post-Paris agreement period, implying that legislative restrictions on carbon emissions induce enterprises in the HCLCR category to reduce their leverage adjustment. Rather than strategic considerations, legislation is more likely to be the driving force behind the low-carbon technology uptake and Leverage SOA. Additionally, businesses with high borrowing costs have a higher capital intensity. In the past, it has been demonstrated that low finance costs and a low capital intensity boost efficiency (Chen & Silva Gao, 2012).

We also look at how the national institutional framework affects the link between carbon risk and leverage adjustment speed. There is a relationship between carbon risk and leverage speed of adjustment. The robustness of credit reporting systems and the score maintained in the database determine credit opportunities. Credit availability has little impact on the carbon risk-leverage SOA connection. For the HCLCR company category, contract enforcement predicts the link between carbon risk and leverage SOA. This combination of costs has a considerable impact on the leverage speed of adjustment throughout the study period but no impact after the Paris Agreement regime.

The rest of the paper is organized as follows. Section two proposes a literature review on the relationship between speed of adjustment and carbon risk, and section three details our data and methodology. In section four, we present our main results, and section five presents a discussion on implications and concludes.

2. Review of literature

2.1. Leverage adjustments, capital structure and carbon risk

2.1.1. Speed of leverage adjustment

According to the dynamic Trade-Off Theory, companies allow leverage to deviate from the target capital structure as long as the costs of adjustment (transactional and contractual costs) outweigh the rewards of reversion to the target (Fischer et al., 1989; Leland, 1994). The trade-off hypothesis predicts that firms will issue, repurchase, or retire debt and equity instruments when their target leverage differs from their actual leverage. Academics have used Modigliani and Miller's (1958) static Trade-Off Theory to evaluate the optimal capital structure. According to the Trade-Off Theory's dynamic form, firms often adjust their leverage ratios to achieve a target leverage ratio. The time necessary to accomplish this is known as the speed of adjustment (SOA). The adjustment rate is also determined by the relative costs of deviation and adjustment (Fitzgerald & Ryan, 2019).

Fama and French (2002) showed that enterprises slowly achieve their desired leverage (seven to eight percent) and other studies indicate that businesses have a somewhat higher SOA of roughly 25% (Lemmon et al., 2008) or 35% (Flannery & Rangan, 2006), suggesting that the SOA value is between zero and one. According to some research, the SOA can be heterogeneous for various reasons, including the speed at which businesses alter their leverage towards the objective. According to the researchers, the most critical factor in adjusting leverage is the transaction cost. Still, other factors such as corporate governance (e.g., Yung & Long, 2021; Sun et al., 2016) and, financing constraints (Korajczyk & Levy, 2003), macroeconomic conditions (e.g., Cook & Tang, 2010) also cause firms to deviate from their target leverage a The SOA's cross-country effects on, for example, business cycle (Drobetz et al., 2015), liquidity (Ho, Lv & Bai, 2021), social trust (Gan et al., 2021), corporate sustainability- (Gan et al., 2021; Woodward et al., 2001) have also been studied in one body of literature (Ho, Bai, et al., 2021).

2.2. Carbon risk

We focus on the effect of country-level climate change-related risk (hereafter known as carbon risk) on the corporate SOA. With the high emphasis by the United Nations Climate Change Council, COP 21, Paris (UNCCC 30th Nov–Dec 12th, 2015)[1] on the threat of climate change, many governments, as well as the academic research have paid attention to climate change and their respective field. Thus, the research on corporate finance issues has started looking at the environmental performance and complementary line of research based on environmental risk. Prior studies (Cooper & Uzun, 2015; Yeh et al., 2020) show that firms with higher corporate social responsibility reduce debt costs. In addition, Sharfman and Fernando (2008) argued that environmental risk management causes a reduction in the cost of capital.

Moreover, in the recent literature, the terms "environmental risk," "climatic risk," and "carbon risk" are frequently used as synonyms (Sharfman & Fernando, 2008). Extant research has provided few classifications of carbon risk. Wellington and Sauer (2005) classify carbon risk into two classifications: systematic and unsystematic risks following Portfolio Theory. They argue that the systematic component of the carbon risk links with macro issues. In contrast, unsystematic carbon risk is the company-specific risk as an element of investment risk (including industry-specific and company-specific risks). Further, Labatt and White (2011) classify carbon risk into three classifications; regulatory, physical, and business risk. Thus, in most recent literature, carbon risk (performances) has been used as a proxy for climate risk, for example, the effect of carbon performances on firm performances (Ruggiero & Lehkonen, 2017); cost of debt (Pizzutilo et al., 2020); and cost of equity (Kim et al., 2015). Chapple et al. (2013) argued that more carbon-intensive firms tend to reduce the market due to the market value penalty proposed under the carbon emissions trading scheme (ETS) within Australia on the market value in 2008. Pizzutilo et al. (2020) show that carbon intensity firms tend to have a higher cost of debt. They proposed that carbon risk significantly affects the lenders' overall risk assessment, leading to higher lending costs. On the other hand, studies have shown that carbon-intensive firms tend to have a higher cost of equity capital due to increased compliance (regulation) costs (Kim et al., 2015; Sharfman & Fernando, 2008). Additionally, Noh (2018) suggests that companies with a higher risk of climate change tend to have a higher cost of capital. The relationship is more pronounced with high climate change risk industries.

Climate change mitigation initiatives may have different consequences on different firms. Regulations that limit carbon emissions might lead to stranded assets or a considerable rise in carbon-intensive firms' operating costs. Furthermore, few losses and damages have been scientifically linked to human-caused climate change, such as the devastating 2003 European heatwave, floods, and drought (Williams, 2020). Prior studies provide insights into potential benefits for firms adopting strategies for transitioning towards low-carbon emissions. Jung et al. (2018) document a positive association between cost of debt and carbon risk for firms failing to respond to the Carbon Disclosure Project (CDP).

2.3. Research hypotheses

Carbon prices will be integrated into investment decisions if a government levies them unilaterally. Reasonable participants, on the other hand, will discount the expected carbon price even if the government does not adhere to its self-imposed pledge. Firms will then predict increased rates of return, resulting in a decrease in overall emissions (IEA, 2007). Thus, corporations need to consider how to internally enhance their commitment to low-carbon technology adaptation in order to create credibility with investors, regulators, and the public at large. From the alternative perspective, committing to low-carbon procedures and technology adaptation incurs expenses when essential criteria such as carbon mitigation costs are uncertain (Brunner et al., 2012). Owing to the fact that commitment entails making investments and utilising available funding options, such as the stock market or lending institutions, the firm's flexibility to seek future investment opportunities is reduced. As a result, adapting low-carbon operations requires a dynamic equilibrium of commitment and prudence.

As per the CDP (2012) report, MNEs and large-scale enterprises operating in the oil and gas and utility sectors are recognized as the two major contributors to carbon emissions. Thus, it is evident that carbon-intensive firms contribute significantly to the higher level of country-level carbon emissions. Consequently, high carbon-intensive firms are subject to tighter environmental regulation compliances (Phan et al., 2022) and are associated with higher costs to curb their carbon emission through their commitment (Boiral et al., 2011). The changes in the climate-related policies affect the changes in company cash flows and earnings (Krueger et al., 2020). Thus, the changes in climate risk at the country-level make changes to climate-related policies, and carbon-intensive firms are required to respond by adjusting their financial policies. For example, the Kyoto Protocol introduced in December 2007 in Australia has made a significant impact on a company's capital structure (Nguyen et al., 2020).

Thus, we argue that country-level climate-related risks, such as carbon risk, significantly and have a positive effect on a firm's leverage adjustment.

H1. All else being equal, country-level carbon risk has a significant positive effect on firm-level leverage adjustment.

Zhou, Zihan and Wu, Kai (2022) show that climate risk exposure positively affects the speed of adjustments. They suggest that climate risk exposure can reduce agency costs and increase information disclosures and enable them to reduce adjustment costs to have faster adjustment of their leverage. The Signalling Theory suggests that firms which issue short term debts are considered as high earnings, or high credit quality, companies irrespective of the high transaction cost in the short run (Flannery, 1986). Thus, firms with high credit quality shows that they adjust their capital structure faster than low credit quality firms (Samaniego-Medina & di Pietro, 2019), Nevertheless, Capasso et al. (2020) show that low carbon risk is associated with low default risk, indicating the easy access to external financing. Overall, their results indicate that the exposure to climate risks affects the creditworthiness of loans and bonds

[1] https://www.c2es.org/wp-content/uploads/2015/12/outcomes-of-the-u-n-climate-change-conference-in-paris.pdf.

issued by corporations.

Furthermore, borrowing costs vary amongst firms, for example, this can be due to the different financial conditions and disclosure practices. This leads us to assume that companies with low carbon risk and low borrowing costs adjust their leverage faster than firms with low carbon risk and high borrowing costs. Pizzutilo et al. (2020) found a positive relationship between carbon risk and cost of debt. Thus, we assume that due to high cost of borrowing, firms have less tendency to adjust its capital structure faster compared to firms with low borrowing cost irrespective of the low level of carbon risk. Further, firms with high commitment to climate change actions issue a higher proportion of debt with longer terms to maturity (Lemma et al., 2021).

The cost of borrowing differs among firms that are within and across sectors depending on corporate governance, risk at firm-level (Reddy & Scrimgeour, 2010; Rocca, 2007). Likewise, the shift towards low carbon technologies depends on institutional settings of a country and their dependence on these paths. For instance, the United Kingdom and Germany are at opposing extremes of the spectrum of liberalized market and competitive markets to coordination economies or inclusive “Energiewende”, and their financial institutions reflect this (Hall et al., 2016). Potential low-carbon investors in the United Kingdom confront ambiguity regarding national policy priorities, and there are financial constraints on low-carbon investment, such as sector inexperience and inconsistencies between fund management and renewable energy investment plans (Hall et al., 2015).

The growth of green finance helps to reduce carbon emissions. In particular, the growth of green financing can both lower local carbon emissions and lower emissions. Prior literature indicates that the development of the financial sector helps in the reduction of cost for green technological investments and reduction of carbon emissions (Chen & Chen., 2021) and adoption of technology improves the quality of environment (Stijn and Feijen, 2007).

While the study of Pang et al. (2022) indicates that the government has a crucial role to play in accelerating the development of an evaluation system and information disclosure standards that are compatible with green technology and carbon emissions, enhancing green finance support, and fostering sustainable development. The study of Hall et al. (2016) demonstrates the valuable role that can be played by locally focused institutions, where civic ownership is supported by a local banking sector. This study presents the implications for achieving a low-carbon energy transition in UK, Germany and other countries. The United Kingdom and Germany are at opposing extremes of the spectrum of liberalized market to coordination economies, and their financial institutions reflect this.

According to the prior research, the cost of borrowing, adoption of green technology, which leads to leverage adjustments among companies, depends on the country-level institutional setting, the role of financial institutions, the government as a catalyst between funding institutions and corporates, and so on, among other things.

Based on this, we propose that firm-level characteristics are not homogeneous and can differ even within the same industry. Some companies are proactive and adapt faster to the emerging current trends like transitioning to green technologies that minimize emissions and enhance output (Sharif et al., 2022) and be in the forefront in identifying the gaps in the market and while others follow the leaders in the sector. Likewise, the adaptation of technology that supports low carbon emission involves heavy investments. Firms with easier access to funds will adapt faster, while those with difficulty in obtaining funds will adapt slower. According to Stakeholder Theory, a corporation that prioritizes stakeholder needs will have an advantage over competitors who pay insufficient attention to stakeholder needs. The competitive advantage may manifest itself in the shape of financial capabilities acquired at the firm’s expense. By facilitating rapid access to low-cost capital market debt financing, the organization could fund its assets and future expansion. Reduced debt costs lower the firm’s cost of capital, allowing it to increase its value. Therefore, reducing carbon risk should boost firm value if investors view low-carbon firms to offer special incentives versus high-carbon ones. Thus, if investors consider low-carbon firms to offer superior incentives than high-carbon firms, it leads us to believe that firms that reduce carbon risk are more likely to increase firm value and have the potential and flexibility for leverage adjustments for the adaptation of low carbon technologies.

To summarize, we argue that firms operating in lower carbon risk countries will have either higher or lower costs of leverage adjustments depending on the cost of debt. We specifically focus on low cost of debt and low carbon risk (LCLCR) and high cost of debt and low carbon risk (HCLCR) categories. Accordingly, we propose that there will be a differential effect on the speed of adjustment.

Therefore, we consider four scenarios based on the firm-level cost of debt and country-level carbon risk. First, LCLCR category (strategy-driven efforts) defined as low cost of debt and low carbon risk; second, HCLCR category (cost-bearing efforts) defined as high cost of debt and low carbon risk (Boiral et al., 2012; Lemma et al., 2021); third, lose-lose category defined as high cost of debt and high carbon risk; and fourth, the lose-win category defined as low cost of debt and high carbon risk. In a HCLCR scenario, a costly carbon emission reduction strategy would affect corporate efficiency (Hahn & Stavins, 2011) and financial performance (Wang et al., 2014).

To summarize, we argue that firms operating in lower carbon risk countries will have either higher or lower costs of leverage adjustments depending on the cost of debt. We specifically focus on LCLCR and HCLCR categories. Accordingly, we propose that there will be a differential effect on the speed of adjustment.

H2a. The speed of adjustment is faster and significant for the firms under the LCLCR category.

H2b. The speed of adjustment is slower and significant for the firms under HCLCR category.

In addition to the country-level enforcement and policy considerations, the firm’s internal environment also should be supported to minimize the carbon risk. The countries with low carbon risk urge companies to go for large investments which require a high level of flexibility for leverage adjustment. Then, the firms with low cost of debt will make it faster than the firms with high cost of debt with similar level of carbon risk. The performance of the firm is measured through earnings yield, transaction costs, enforcing contracts, and credit opportunities paths are examined.

2.4. Data and methodology

We used annual data from the Worldscope via the Datastream database for our empirical research, which included firm-level, industry-level, and country-level data. The world bank database is used to collect macroeconomic data. The end-of-year exchange rate between the USD and the corresponding currency was used to convert all variables into USD. To filter our data, we used the methods mentioned below. We exclude firm-year observations with a zero book value for total assets, a zero market capitalisation, negative long-term and/or negative short-term debt, and so on. Firm-years with book leverage ratios or market leverage ratios greater than one are further discounted. To address the issue of short panel bias, we exclude firms that do not have data for two consecutive years. On the DataStream database, we found 579 firms in the energy sector. Out of which 437 firms were active and 142 were dead. After removing the dead firms, the sample size was reduced to 437. In addition, we identified and filtered 94 firms related to Waterborne trade and the US Commodity Futures Trading Commission. We combine these energy companies with the financial data available on the platform. We had 209 firms after cleaning the financial data for missing and incorrect values. Our final sample consists of 209 carbon-intensive enterprises from 18 nations spread over five regions: North America, Europe, Asia-Pacific, Middle East and South Africa/South America. The data set contains nearly 2394 data points for the years 2006–2020. To account for possible outliers, we winsorized both the dependent and independent variables at the 1st and 99th percentiles.

2.5. Model specification

This section describes how the target leverage is measured and how the carbon risk and earnings yield affect the leverage adjustment. There are two distinct partial adjustment models suggested in the literature for estimating the speed of adjustment (SOA). We followed the standard partial adjustment approach (two-step approach) to examine the speed of adjustments relating to each country under the first step. Following the literature (Heshmati, 2001; Hovakimian et al., 2001), the typical target leverage estimation model can be written as:

$$Lev^*_{ijt+1} = \pi X_{ijt} + u_{ijt} \tag{1}$$

We estimate Equation (1) by using the Fama and MacBeth's (1973) cross-sectional regressions to estimate target leverage (Byoun, 2008; Devos et al., 2017; Warr et al., 2012). We estimate both book and market target leverage. We specify the target leverage (Lev^*_{ijt+1}) as a function of the exogenous firm-specific, industry, and macroeconomic factors represented by X_{ijt} Both book and market value of leverage ratios are used in this study (Book leverage = Book value of total debt/book value of total assets; Market leverage = Book value of total debt/sum of the market value of equity and the book value of total debt) as separate models. As shown in Equation (1), the target leverage ratio varies across firms and time in our study. Following the literature (Fama & French, 2002; Flannery & Rangan, 2006; Hovakimian et al., 2001; Kayhan & Titman, 2007), we consider the most commonly used determinants of the target leverage (see Table 1 for the variable definition). Next, the fitted values from Equation (1), the target leverage (Lev^*ijt+1), apply to the second step in the following model.

$$Lev_{ijt+1} - Lev_{ijt} = \alpha + \delta_j (Lev^*_{ijt+1} - Lev_{ijt}) + u_{ijt+i} \tag{2}$$

The model in Equation (2) regresses the leverage change (i.e., $Lev_{ijt+i} - Lev_{ijt}$) on the leverage deviation (known as target distance "DIST"), i.e., $Lev^*_{ijt+1} - Lev_{ijt}$. In the Equation, Lev_{ijt} denotes the current year leverage for the ith firm in jth country, and Lev_{ijt+1} is the

Table 1
Description of the variables.

Variables	Acronym	Measurements
A. Firm-level variables		
Book leverage	BLEV	Book value of total debt divided by book value of total assets
Independent Variables		
Carbon Risk (Proxy one)	CR	Carbon risk is generated by applying principal composite analysis by considering the sub-indices of environment, economic, social and climate volatilities.
Carbon Risk (Firm-Level)	CR Firm	Carbon risk at firm-level is expressed as the deviations in the carbon intensity. This is derived by dividing carbon emissions at country-level divided by the total number of firms in the country multiplied share of by firms.
Earnings yield	EY	The earnings yield is expressed as earnings per share divided by the current market price per share.
Target Distance	DIST	Difference between target and observed leverage ratio
Control Variables		
Profitability	Prof	Earning before interests, taxes, depreciation and amortization divided by book value of assets
Industry median of leverage	INDMED	The median leverage ratio of an industry to which a firm belongs
Institutional Environment		
Transaction Costs	TC	Transaction costs expressed as a percentage of claims (attorney fees + court fees enforcing fees) (The World Bank, 2019).
Bank credit opportunities	BC	Score-Getting credit (The World Bank, 2019).
Regulatory Environment	EC	Regulatory environment for enforcing contracts includes resolving Insolvency & doing business score-regulations enforcement (The World Bank, 2019).
Country-level variable		
GDP growth rate	GGDP	Annual GDP growth rate

leverage of the ith firm in the next period. δ_j in Equation (2) represents the SOA, which measures how fast firms adjust their current leverage towards the target leverage, which is the aggregate SOA of firm leverage in a specific country.

2.6. Effect of carbon risk on leverage SOA

While the leverage adjustment speed δ_j in Eq. (2) is constant for all firms in a specific country, to test our hypotheses, we allow carbon risk to increase the firm's level of adjustment toward its target leverage ratio and firm performances to lower the adjustment speed. We also use; profitability ($Prof_{ijt}$) GDP growth rate ($GGDP_{jt}$) (Ho, Lu & Bai, 2021; Cook & Tang, 2010; Faulkender et al., 2012) and Industry median leverage (INDMED_{ijt}) as a set of control variables that could affect the leverage SOA. Thus, δ varies with carbon risk, earnings yield, and control variables:

$$\delta_{ijt} = \partial_0 + \beta_1 CR_{jt} + \beta_2 EY_{ijt} + \beta_3 Prof_{ijt} + \beta_4 INDMED_{ijt} + \beta_5 GGDP_{jt} \tag{3}$$

where CR_{jt} (carbon risk) is the proxy for climate change, and EY (Earings yield) is the proxy for firm performance. Since we hypothesize that carbon risk has a positive impact on the SOA, we expect the coefficient on the CR measure, β_1 to be positive.

Substituting Eq. (2) back to Eq. (3) yields the Equation for a partial adjustment model with heterogeneity in the leverage SOA:

$$Lev_{ijt+1} - Lev_{ijt} = \alpha_0 + \left(\partial_0 + \beta_1 CR_{jt} + \beta_2 EY_{ijt} + \beta_3 Prof_{ijt} + \beta_4 INDMED_{ijt} + \beta_5 GGDP_{jt}\right) \left(Lev^*_{ijt+1} - Lev_{ijt}\right) + u_{ijt+1} \tag{4}$$

Which can be further simplified to yield:

$$\Delta Lev_{ijt+1} = \alpha_0 + \left(\partial_0 + \beta_1 CR_{jt} + \beta_2 EY_{ijt} + \beta_3 Prof_{ijt} + \beta_4 INDMED_{ijt} + \beta_5 GGDP_{jt}\right) \left(Dist_{ijt}\right) + u_{ijt+1} \tag{5}$$

Using the estimate of target leverage from Eq. (1), we calculate each firm's distance from target ($Dist_{ijt}$) and substitute this estimated distance into Eq. (5).

Eq. (5) includes a pooled OLS regression of leverage changes on the product of $Dist_{ijt}$ and the main variable effecting leverage SOA (i.e., carbon risk and earnings yield) and control variables with bootstrapped standard errors to account for the generated regressors (Faulkender et al., 2012; Pagan, 1984).

2.7. Identification strategy

With observational data in hand, we decided to conduct panel data analysis. However, this method of analysis is subject to endogeneity concerns (Wooldridge, 2005; Costa & Habib, 2022). For example, some countries might create quantitative easing initiatives that can reduce the cost of capital for firms and ease of access to the capital faster than other countries. Similarly, the firm's capabilities, production inputs, and previous year's performance, among other things, may influence the speed of the leverage adjustment for the focal firm. At the same time, the competitive pressure and industry average leverage may influence a firm to speed up leverage adjustment. Any identification strategy needs to address these concerns of endogeneity and individual firm-level effects. Country-level. Therefore, we use systems dynamic panel models for dealing with endogeneity issues.

2.8. Measuring carbon risk

The terms, climate change risk, environmental risk, and carbon risk are often used interchangeably (Jung et al., 2018). We recognise the carbon risk in our analysis as a composite risk. As a result, we build a carbon risk variable using principal component analysis (PCA), a statistical technique that has the advantage of evaluating the entire movement inside a time series and condenses multidimensional datasets for study. The PCA calculates weights for various variables to maximize the sum of the squared coefficients of the correlation between the index (I) and the variables (X). Additionally, PCAs enable the comparison of various occurrences and the assessment of their relative relevance, status, or standing across time and geography using a single scale of measurement (Mishra, 2018). The regression utilises composite index as the proxy for carbon risk in the selected countries. A good composite index should comprise important information from all the indicators but will not be strongly biased towards one or more of these indicators (Cámara & Tuesta, 2014). Following Nagar and Basu (2004) and Cámara and Tuesta (2014), this study will apply a two-stage PCA Model to estimate the carbon risk. According to Mishra (2018), empirical evidence shows that PCA is biased towards the weights of highly correlated indicators. As a first step, we estimate two sub-indices that capture carbon emissions and climate change adversaries.

Climate change poses a threat to both people and governments, though responses vary greatly across the globe. While some implement politically and economically challenging climate change mitigation strategies, others refuse to acknowledge that it exists (Steves & Teytelboym, 2013). Previous research (Anderson et al., 2019) indicates that climate change will cause crop failures and hence most likely to result in lower crop yields and price variability. According to Kim and Mendelsohn (2023), a uniform 1 °C increase in temperature across the United States with no adjustment is expected to result in approximately 3.2 million additional failed acres or a 0.9% decline in acreage.

Climate change adversaries are driving price volatility. Crops whose yield is dependent on weather conditions, in particular, are more vulnerable to climate change. As a result, we use daily commodity price indices for sugar cane and meat as climate change proxies. We estimate the volatilities in their prices by using generalised autoregressive conditional heteroskedasticity (GARCH) model. Finally, we use a principal component analysis to combine energy efficiency indices (transport), environment indices, social indices (which includes unemployment, that is reflective of the economy's social health, i.e., low family income, which is sensitive to health-related issues and thus more vulnerable to climate change issues), energy consumed, carbon emissions at the country-level, and climate change volatility (commodity price volatilities -Agriculture and Diary sectors). The Kaiser-Meyer-Olkin (KMO) test is used to check the sampling adequacy and our result of nearly 0.80 confirms the sampling adequacy.

3. Empirical results

3.1. Summary statistics

Our final sample consists of 209 carbon-intensive enterprises from 18 nations spread over five regions: North America, Europe, Asia-Pacific, Middle East and South Africa/South America. The data set contains nearly 2394 data points for the years 2006–2020.

We report the overall sample basic statistics in Table 2. Table 2 reports the mean value of 0.189 of leverage. In terms of carbon risk, the mean value is −0.237. The carbon risk is a composite measure that includes five dimensions: carbon emissions, climate change volatilities, energy efficiency, social welfare, energy consumed, and environment. The firm performance measurement earnings yield is −3.721. The cost of debt reported as 36.5%. On average, the firms have a return on assets (profitability) ratio of −0.072, an industry leverage ratio of 0.142. GDP per capita of 41,457 USD.

Table 3 presents the correlation matrix of the dependent, independent and control variables used in the study. The results support no multicollinearity issue among the selected variables. Correlation results show that the leverage distance is positively associated with carbon risk and earnings yield. The correlation between leverage distance and cost of debt; profitability, industry leverage and GDP Per capital also show positive correlations.

4. Estimating of target leverage and SOA

4.1. Carbon risk and leverage adjustment

Table 4 Estimates the effects of carbon risk on the speed of adjustment. To test our first research hypothesis, whether or not country-level carbon risk has a positive association with the speed of leverage adjustment, we estimate the effects of carbon risk on the speed of adjustment. In this section, we examine the effect of CR on the SOA under two models and two panels. Model 1 presents the results obtained by using Generalised Least Square method, whereas the panel 2 presents the results of the System GMM. We estimate our models with the system Generalised Method of Moments (GMM) proposed by Blundell and Bond (1998) to obtain adequate estimates (Faulkender et al., 2012; Flannery and Hankins, 2013) and to control potential endogeneity issue. We used lag of all explanatory variables as instruments to solve the endogeneity and reverse causality issues as some of the explanatory variables and leverage ratios can be simultaneously determined. Under each model the carbon risk was measured by using two proxies. CRCL presents the carbon risk measured at country-level as defined in Table 1. CRFL uses country-level carbon emissions scalded to the firm-level based on the firm's sector/industry using the carbon intensity strategy measure.

The results in Table 4, show a positive effect of CR on the leverage adjustment under two models and for all four panels, suggesting firms with low carbon risk have a positive effect on reducing the adjustment speed. Model with CRFL is significant at 1% under Model 1 and it is significant at 10% level under Model 2. The model with CRCL is significant at 1% level only under Model 2. It is evident from the results that an increase in one standard deviation of CR, will increase the SOA by 5% (2.392*0.0221) under Model 1 with the CRFL Model compared to the baseline SOA[2] of 73 percent (1–0.268). Under the Model 2 panel with CRFL, the adjustment speed accelerated by 28% (2.392*.1193). The findings indicate that, on average, it takes less than two years (1.3 years = 100%/73%) for a firm to adjust half of its leverage deviation, but the decrease is further accelerated due to high carbon risk. The duration decreases as a result of the high carbon risk firms' need to raise capital in order to adapt to low-carbon emission technology at the expense of shareholders through leverage adjustments. Model 2 results are consistent with the results of panel Model 1 with CRFL panel showing a positive effect of carbon risk on the firm's leverage adjustment. With regards to the magnitude of the speed of adjustment of the panel with CRFL under Model 2, it is almost 100% (2.392*0.4553). Our hypothesis 1, that carbon risk is positively associated with SOA, is validated by the country-level results more specifically with Model 2.

4.2. Sample selection bias – empirical results

Our study uses the propensity score matching estimate for validating if the results are confounded by the sample selection bias. As the data is purposely obtained from the energy industry, this study may be influenced by sample selection bias. Prior research (McAvinchey, 2003) reveals bias created when a group of data is purposely excluded from consideration according to a particular characteristic, which is the primary cause of sample selection bias. (McAvinchey, 2003).

In Table 5, we use propensity score matching estimation to verify the effects of policy considerations from Paris Agreement in the year 2015. This table reports the results over two panels 1 and 2. The Panel 1 presents the effects of carbon risk (country-level) on the leverage adjustments in the years following the Paris agreement. The Panel 2 presents the effects of carbon risk (firm-level) on the

[2] The authors have estimated the baseline SOA of the whole sample, and it is reported as 73%.

Table 2
Descriptive statistics.

Full Sample	Observations	Mean	Std. Dev	Min	Max
Leverage	2394	0.189	0.218	0.000	0.998
Leverage Distance	2391	0.000	0.214	−0.909	0.699
Carbon Risk	2383	−0.237	2.392	−12.397	3.125
Earnings Yield	2328	−3.721	88.64	−531.68	522.72
Cost of Debt (Kd)	2326	0.365	2.768	0.000	89.398
Profitability	2394	−0.072	0.340	−2.390	0.354
Industry-Leverage	2394	0.142	0.151	0.000	1.075
GDP Per Capita	2394	41,457	17,046	1358	68,150

Note: Table 2 presents the number of observations, mean, standard deviation, minimum and maximum values of the full sample over the period of 2006–2020.

Table 3
Correlation matrix.

	Full Sample	1	2	3	4	5	6	7	8
1	Leverage	1							
2	Leverage Distance	−0.723*	1						
3	Carbon Risk	−0.070*	0.050*	1					
4	Earnings Yield	−0.062*	0.038	−0.122*	1				
5	Cost of Debt (Kd)	−0.089	0.050*	0.047*	−0.016	1			
6	Profitability	−0.065*	0.01	−0.259*	0.295*	−0.029	1		
7	Industry-Leverage	0.124*	0.031	−0.299*	0.029	−0.044*	0.131*		
8	GDP Per Capita	0.032	0.014	0.615*	−0.170*	0.017	−0.208*	−0.022	1

Note: Table 3 presents the correlation coefficient among the selected variables and * represent the level of significance at 1% level. The variable definitions are given in Table 1.

Table 4
Effects of carbon risk on the SOA.

Variables	Model 1		Model 2	
	CRCL	CRFL	CRCL Sys-GMM	CRFL Sys-GMM
CR * Dist	0.0008	0.0221***	0.1193***	0.4553*
	0.0087	0.0065	0.0189	0.2406
Profitability* Dist	0.1306***	0.1328***	0.1444***	−0.1411*
	0.0371	0.0366	−0.0471	−0.0816
GDP-PCI * Dist	2.13E-07	1.74E-07	−1.68e-05***	−5.51e-06***
	4.92E-07	4.51E-07	−1.53E-06	−1.38E-06
Industry Level * Dist	0.00362	0.0303	0.8764**	−5.5554***
	0.0968	0.0897	0.3421	−0.2761
Post-Paris Agreement	0.0658***	0.0613***	0.0251*	0.004
	0.0194	0.0207	0.0134	0.0089
Lag1 Δ leverage			0.5862***	0.7634***
			0.0501	0.0705
Lag2 Δ leverage			−0.0093	−0.2233***
			−0.021	−0.0137
Constant	−0.0323	−0.0397	0.0139	0.0003
	−0.0476	−0.0496	0.0088	0.0092
Country Fixed Effects				
Time Effects				
Observations	2382	2158	1972	694
Number of Comp	192	190	174	100
Diagnostics Test				
AR (1) test (*p*-value)			0.0001***	0.0003***
AR (2) test (p-value)			0.4804	0.2094
Sargan test of over-identification (*p*-value)			0.2063	0.2343

Note: Table 4 Estimates the effects of carbon risk on the speed of adjustment using the model: $\Delta L_{ijt+1} = (\beta_{ijt}CR_{ijt} + \alpha_{ijt}X_{ijt})*(Dist_{ijt}) + \delta_{ijt}$. The dependent variable is changes in book leverage. CRCL presents the Carbon risk at country-level, and CRFL shows carbon risk is scaled to the firm-level. The results obtained from the Generalised Least Square estimation is presented under first ismodel. The results of the system GMM is presented in Model 2. The coefficients are presented on the top row, and standard errors are presented below for each variable. ***, **, * indicate significance at the 1% and 5%, 10% respectively. The variable definitions are given in Table 1.

Table 5
Propensity Score matching models and speed of adjustment.

Dependent variable: Δ Book value of leverage	Propensity Score Matching		
Treatment Effect Estimations	Coef.	Std. Err.	z-test
Panel 1: Carbon Risk (CR)-First Proxy			
ATE-DV-Paris Agreement (1vs 0)	0.019	0.008	2.46***
ATET- DV-Paris Agreement (1vs 0)	0.020	0.011	1.85*
ATE-Nearest Neighbour, DV-Paris (1vs 0)	0.028	0.009	2.79***
ATE-Propensity Score Matching, DV-Paris (1vs 0)	0.019	0.009	2.14**
Panel 2: Carbon Risk (CR)-Second Proxy			
ATE-DV-Paris Agreement (1vs 0)	0.026	0.012	3.00***
ATET- DV-Paris Agreement (1vs 0)	0.021	0.012	1.72*
ATE-Nearest Neighbour, DV-Paris (1vs 0)	0.031	0.010	3.08***
ATE-Propensity Score Matching, DV-Paris (1vs 0)	0.020	0.011	1,84*

Note: Effects of Propensity score matching before and after the period following Paris agreement in are presented in Table 5 above. Further, the asterisk ***, **, * indicate significance at the 1% and 5%, 10% respectively.

leverage adjustments in the years following the Paris agreement. The first and second columns show the standard errors and coefficient obtained from the propensity score matching using the years following the Paris agreement (2016–2020) as treatment group. The period from 2016 to 2020 is considered as a period of transition towards low carbon emissions.

The propensity score matching across the four estimations provides an indication of the significant effects of climate change policy initiatives on the speed of leverage adjustment. The results validate the empirical findings reported in Table 4. Therefore, we conclude that the data is not influenced by sample selection bias.

Table 6 shows the results of the impact of carbon risk on the leverage adjustment of the two categories of firms, LCLCR and HCLCR. The results of two-generalised least squares regression are presented under Model 1 and the Model 2 presents the results of system GMM. The dependent variables show the changes in book leverage. We provide the results by firm in four panels under LCLCR and HCLCR categories. We define HCLCR firms as cost-bearing efforts and LCLCR as strategy-driven efforts. Moreover, the LCLCR category is the firms that are associated with lower levels of cost of debt and carbon risk, and conversely, the companies with a higher level of cost of debt and a low level of carbon risk are referred to as an HCLCR group.

The carbon risk interaction with distance under the LCLCR category under Model 1 and Model 2 has a significant impact on the leverage adjustment. The impact of CR is 22% (2.047*0.106)[3] under Model 1, compared to 73% in the initial SOA calculations. It is evident from the results that an increase in one standard deviation of CR, will increase the SOA by 22% under Model 1. The results show that lowering the carbon risk and borrowing funds at a low cost of debt takes less than a year on average for a company to adjust half of the leverage deviation. In the HCLCR category, the CR has no significant impact on the SOA under both models. As per the Model 2, under the LCLCR category, the effect of CR on the SOA is 24%, indicating that the speed of adjustment is faster and significant when compared to the original results shown in Table 4. Thus, the hypothesis 2 (H2a), the speed of adjustment is faster and significant is accepted. However, the hypothesis 2 (H2b), the speed of adjustment is slower and significant for the firms under HCLCR category is not supported by our findings.

We also use the post-Paris agreement, profitability, GDP, and Industry leverage as control variables in these results. Post-Paris agreement shows a positive and significant impact on the SOA under the Model 1 of LCLCR category and negative under the Model 2. HCLCR category also shows a significant but negative effect on SOA under both model 1 and 2. GDP is positively affected by the SOA for both categories under both models. The effect of Industry leverage shows a negative effect on the SOA by both categories under both models.

5. Examining the effects of SOA through various other channels/pathways using earnings yield, transaction costs, credit opportunities and enforcement costs

5.1. Interaction effects of earnings yield on the relationship between the carbon risk and leverage adjustment

Table 7 presents the results of the interaction effects of earnings yield on the relationship between the carbon risk and leverage adjustment. Results are arranged under Models 1 and 2 for the full sample period and post-Paris agreement period under the categories of LCLCR and HCLCR. Our arguments on hypothesis 2 are that companies can obtain financial rewards by reducing their carbon risk.

While the interaction effects of earnings yield on the relationship between the carbon risk and SOA is negative and statistically insignificant for HCLCR category under Model 1. This means that companies with higher borrowing rates may be forced to increase their capital intensity in order to comply with climate change adaptation laws. Similarly, that of the LCLCR is negative and insignificant under the Model 1. This means that earnings do not support SOA even though they are working towards reducing carbon emissions. Legislation rather than strategic reasons are more likely to be the driving force behind this trend. The result is more robust in the post-Paris agreement period for the HCLCR category, implying that legislative constraints on carbon emissions cause businesses in

[3] The standard deviation of the carbon risk of the LCLCR category is 2.0472.

Table 6
Effects of Carbon Risk on the SOA: Whether the SOA is motivated by varying degrees of carbon risk?

	Model 1		Model 2	
Variables	LCLCR	HCLCR	LCLCR	HCLCR
			Sys-GMM	Sys-GMM
CR * Dist	0.106**	0.349	0.121**	0.418
	0.0521	0.268	0.051	0.255
Profitability* Dist	−0.122	1.147	0.277	2.852***
	−0.249	1.143	0.289	0.895
GDP-PCI * Dist	3.10E-06	3.92E-06	1.67e-6	3.76e-5***
	3.20E-06	9.04E-06	4.29e-6	6.37e-6
Industry Level * Dist	−0.884	−1.197	−1.733*	−5.688***
	−1.002	−1.733	−1.019	−1.216
Post-Paris Agreement	0.203**	−0.305**	−0.155***	−0.075
	0.0852	−0.145	−0.045	−0.055
Lag1 Δ leverage			0.025	0.009
			0.055	0.027
Lag2 Δ leverage			−0.044	0.097***
			−0.041	0.018
Constant	0.621***	0.409**	0.277	2.852***
	0.0934	0.176		
Country Fixed Effects	Yes	Yes	Yes	Yes
Time Effects	Yes	Yes	Yes	Yes
Observations	957	228	774	694
Number of Comp	108	55	103	100
Diagnostics Test				
AR (1) test (*p*-value)			0.0001***	0.0003***
AR (2) test (p-value)			0.5825	0.2017
Sargan test of over-identification (*p*-value)			0.2223	0.2235

Note: Table 6. Estimates the effects of carbon risk on the speed of adjustment using the model: $\Delta L_{ijt+1} = (\beta_{ijt}CR_{ijt} + \alpha_{ijt}X_{ijt})*(Dist_{ijt}) + \delta_{ijt}$. The results of two generalised least square regression Models 1 and 2 by using original carbon risk measurement and carbon risk is scaled by the country-level carbon emissions to the firm-level based on the sector/industry, respectively. The dependent variables show the changes in book leverage. We provide the results by firm in six panels. Results are presented in four panels under LCLCR and HCLCR categories. The results obtained from the System dynamic panel-data estimation are presented in Panels 3 and 4. The co-efficient are presented on the top row, and standard errors are presented below for each variable. ***, **, * indicate significance at the 1% and 5%, 10% respectively. The variable definitions are given in Table 1.

Table 7
Interaction effects of Earnings yield on the relationship between the carbon risk and SOA.

	Model-1: Full Period		Model-2: Post PA	
Variables	Panel-1	Panel-2	Panel-1	Panel-2
	LCLCR	HCLCR	LCLCR	HCLCR
CR * Dist	0.073	−0.460	−0.094	33.16
	0.068	−0.725	−0.137	22.48
EY * Dist	−0.001	−0.045	0.052**	−0.155***
	−0.001	−0.028	0.025	−0.059
CR *EY* Dist	$-4.0E^{-4}$	−0.029*	0.035**	−0.088***
	$-4.0E^{-4}$	−0.018	0.017	−0.034
Control Variables				
Profitability* Dist	Yes	Yes	Yes	Yes
GDP-PCI * Dist	Yes	Yes	Yes	Yes
Industry Leverage * Dist	Yes	Yes	Yes	Yes
Constant	0.559**	0.345	0.771	12.49**
	0.233	0.213	0.742	5.22
Country Fixed effects	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes
Observations	943	199	327	70
Number of Groups	105	54	84	31

Note: Table 7. Estimates the interacting effects of earnings yield, carbon risk and distance on the speed of adjustment for full sample and by varying degrees of carbon risk: $\Delta L_{ijt+1} = (\beta_{ijt}CR_{ijt} + \lambda_{ijt}EY_{ijt} + \gamma_{ijt}(CR_{ijt} * EY_{ijt})\ \alpha_{ijt}X_{ijt})*(Dist_{ijt}) + \delta_{ijt}$. The co-efficient are presented on the top row and standard errors are presented below for each variable. The FGLS and the System dynamic panel-data estimation are used to estimate the results. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. The variable definitions are given in Table 1.

the HCLCR category to reduce their leverage adjustment. While earnings yield has a positive and significant interaction effect on LCLCR category under the Model 2, indicating that, these firms may easily adjust their leverage after the Paris agreement's regulations take effect. Prior literature shows that firms that are proactive in alleviating carbon risk concerns are those that strategize their actions by enabling the funds and flexibility needed to deal with environmental challenges (Albertini, 2013; Hart & Dowell, 2011). Thus, in addition, we find that the leverage modifications are significantly influenced by the earnings yield after the enforcement of the Paris agreement.

5.2. *CR and leverage adjustment: the effect of transaction costs*

Companies can only survive if they can deliver goods and services at competitive prices. Effective contract structures must explain efficient capital arrangements. Furthermore, a shared interest in the time-series discrepancies between revenue and expense orients an organization's contract structure towards long-term survival. Due to the huge investments, payoff-contract costs connected with low-carbon technology adoption are critical (Fama, 1990). Theoretically, debt and equity are the securities used to fund asset acquisitions. In a broader sense, finance decisions include claims made to lenders. Contracts inflict uncertainty on all agents for example, lending institutions, investors, bond holders and equity holders (Fama & Jensen, 1983), since relative prices can no longer be predicted accurately, an optimum allocation of resources may fail to manifest. Consequently, it affects credit availability and financial stability (Baum et al., 2021). Limited residual claims also raise transaction costs (Watts & Zimmerman, 1983). Further, undifferentiated equity claims are a crucial factor for modern conglomerates due to residual risk (Watts & Zimmerman, 1983) and the high contract costs occur when claims are allocated to undefined activities and cash flows from one activity substantially affect net cash flows in another.

So, more loans and bonds can be issued with low default risk and low fixed-payoff costs. To reduce default risks and contract costs, more equity must be allocated to assets with high firm-specific components. Equity is required in capital structures to reduce default risks and contract costs. A capital structure with more fixed-payoff stock contracts than fixed-payoff bonds is less risky. Environmental transaction costs (TC) reduce the speed of adjustment to target debt (Tascónet al., 2021). We examine whether transaction contract costs affect the relationship between carbon risk-speed or speed of leverage adjustment.

Myers (1984) suggests that transaction cost causes firms to lag behind their optimal leverage, while Gilson (1997) claims that financially distressed firms are significantly affected by the transaction cost when they restructure their debt capital. We define transaction cost as the cost associated with the enforcement of any contract which entails the enforcement, cost of writing, and potential inflexibility, for example, attorney fees, court fees, and enforcement fees. Thus, we test the effect of carbon risk on the leverage adjustment by controlling for transaction costs. Thus, carbon intensive firms tend to adjust the current leverage to the target faster.

Table 8 presents the results for the full sample period (Model 1), and we extend the analysis to consider the effect of the Paris agreement (Model 2) on carbon risk enforced in 2015. Results are presented under three panels for each model; full sample, LCLCR and HCLCR. The coefficients of CR in Model 1 is positive and statistically significant at the 5% level under the LCLCR category after controlling for transaction cost, implying that transaction cost affects the relationship between CR and leverage SOA for LCLCR throughout the sample period but does not have any effect in the period following the Paris agreement. Suggesting that the LCLCR firms have been following the regulations even before the regulations were made mandatory. More importantly, the coefficients on the

Table 8
Interaction Effects of Transaction Costs, carbon risk and Distance on the SOA.

	Model-1: Full Period			Model-2: Post Paris Agreement		
Variables	Full	LCLCR	HCLCR	Full	LCLCR	HCLCR
CR * Dist	0.069*	0.079**	−1.662**	−0.044	0.029	−42.27*
	0.037	0.040	−0.774	−0.104	0.120	−22.850
TC * Dist	−0.001	−0.004	0.075**	0.006	−0.001	1.441*
	−0.002	−0.003	0.032	−0.009	−0.010	−0.757
CR*TC*Dist	−0.003*	−0.004**	0.063***	0.002	−0.002	1.016*
	−0.001	−0.001	0.023	0.005	−0.007	0.536
Control Variables						
Profitability* Dist	Yes	Yes	Yes	Yes	Yes	Yes
GDP-PCI * Dist	Yes	Yes	Yes	Yes	Yes	Yes
Industry Lev * Dist	Yes	Yes	Yes	Yes	Yes	Yes
Constant	−0.093	−0.094	0.064	−0.931*	−0.818	10.54**
	−0.163	−0.073	0.202	−0.504	−1.995	4.460
Country Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2382	957	228	619	218	43
Number of Groups	188	107	55	167	84	24

Note: Table 8. Estimates the interacting effects of earnings yield, carbon risk and distance on the speed of adjustment for full sample and by varying degrees of carbon risk: $\Delta L_{ijt+1} = (\beta_{ijt}CR_{ijt} + \lambda_{ijt}TC_{ijt} + \gamma_{ijt}(CR_{ijt} * TC_{ijt}) + \alpha_{ijt}X_{ijt})*(Dist_{ijt}) + \delta_{ijt}$. Three panels show the findings of Models 1 and 2. First panel presents the results for the entire sample, second panel for the LCLCR scenario, and a third panel provides the findings of HCLCR scenario. The co-efficient are presented on the top row and standard errors are presented below for each variable. A cross sectional time-series FGLS-regression approach is used to estimate the results. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. The variable definitions are given in Table 1.

interaction terms carbon risk, transaction costs and distance are negative and statistically significant at the 5% level, among the LCLCR category under the Model 1, indicating that the transaction cost is impediments to achieve the target leverage and the SOA makes slower. However, the link between CR and leverage SOA is substantial and negative in the HCLCR category under each model, showing that firms in the HCLCR category take longer to modify their leverage SOA than their LCLCR counterparts. Firms in the HCLCR category already suffer large debt costs and have a significantly limited ability to adjust their leverage SOA. Moreover, the interaction between CR, TC and Distance under the HCLCR category is positive and highly significant under the Model 1 at 1% level and significant at 10% level under the Model 2, implying that HCLCR are trying to adjust the leverage SOA due to high transaction cost and most likely that equity claims are allotted to activities that are clearly defined (Watts & Zimmerman, 1983).

5.3. *CR and leverage adjustment: the effect of credit opportunities*

We propose that low carbon emission firms tend to have more information on credit opportunities than high-carbon intensive firms. Thus, the firms with a high chance of credit availabilities increase the adjustment speed quicker. We measure the credit opportunity by using the strength of credit reporting systems and the score available in the database which is the basis of the information about the credit availability (World Bank, 2019).

Table 9 reports the results for the full period (Model 1) and post-Paris agreement (Model 2) for the full sample, LCLCR and HCLCR panels. All coefficients of CR under Model 1 are negative but not significant after controlling for credit opportunities under Model 1. However, the effect of CR is significant only in the HCLCR category under Model 2, implying that the availability of credit is vital for the HCLCR firms to adjust the leverage faster even after the enactment of the legislation. Overall, the interaction between CR, CO and Distance suggests that information availability is important for the companies under HCLCR categories, but which do not add value to the LCLCR firms to adjust their leverage SOA.

5.4. *CR and leverage adjustment: the effect of enforcing contracts*

Table 10 presents the results for the full period (Model 1), and we extend the analysis to consider the effect of the Paris agreement (Model 2). Three panels were tested under each model; full sample, LCLCR and HCLCR. The coefficients of CR in Model 1 and Model 2 are negative and not significant for both the models and all categories, after controlling for enforcing contracts. However, the co-efficients on the interaction terms CR, EC and Distance are positive and statistically significant at the 5% level, among the HCLCR category under Model 2, indicating that the contract enforcement is supporting the HCLCR firms to achieve the target leverage and making the adjustment faster SOA. However, the LCLCR firms are driven by the technology, and they are adopting the latest technology, thus having no impact from the enforcement of the new regulations.

We examine the aggregate influence of bank credit, contract enforcement, and transaction costs on the relationship between CR and adjustment in this section. Recent research indicates that while effective carbon risk management reduces credit default risk (Duong, Kalev, Kalimipalli, & Trivedi, 2022), increased carbon risk increases the cost of capital (Park & Noh, 2018); both the cost of equity and debt (Pizzutilo, 2020). To the degree that a firm's CR increases, the cost of equity and debt also increases; consequently, the availability of bank credit, transaction costs, and contract enforcement should be expected to be positively influenced as a substitute for the carbon

Table 9
Interaction Effects of the credit opportunities, carbon risk and distance on the SOA.

	Model-1: Full Period			Model-2: Post Paris Agreement		
Variables	Full	LCLCR	HCLCR	Full	LCLCR	HCLCR
CR * Dist	−0.016	−0.023	−0.318	0.023	0.045	2.930***
	−0.012	−0.03	−0.451	0.025	0.088	1.089
CO * Dist	0.014	0.069	0.879	−0.038	−0.119	−2.446
	0.032	0.071	0.679	−0.068	−0.234	−1.762
CR*CO*Dist	0.019	0.028	0.765	−0.045	−0.058	−1.775
	0.015	0.036	0.523	−0.029	−0.097	−1.324
Control Variables						
Profitability* Dist	Yes	Yes	Yes	Yes	Yes	Yes
GDP-PCI * Dist	Yes	Yes	Yes	Yes	Yes	Yes
Industry Lev* Dist	Yes	Yes	Yes	Yes	Yes	Yes
Constant	−0.029	−0.014	0.016	−0.108	0.263	6.326***
	−0.048	−0.033	0.104	−0.134	0.278	0.986
Country Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2382	957	228	619	218	43
Number of Groups	188	107	55	167	84	24

Note: Table 9. Estimates the interacting effects of credit opportunities, carbon risk and distance on the speed of adjustment for full sample and by varying degrees of carbon risk: $\Delta L_{ijt+1} = (\beta_{ijt}CR_{ijt} + \lambda_{ijt}CO_{ijt} + \gamma_{ijt}(CR_{ijt} * CO_{ijt}) + \alpha_{ijt}X_{ijt})*(Dist_{ijt}) + \delta_{ijt}$. The co-efficient are presented on the top row and standard errors are presented below for each variable. We use FGLS estimation for analysing the data. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 10
Interaction Effects of the Enforcing contracts, carbon risk and distance on the SOA.

	Model-1: Full Period			Model-2: Post Paris Agreement		
Variables	Full	LCLCR	HCLCR	Full	LCLCR	HCLCR
CR * Dist	−0.008	−0.005	−0.048	−0.006	−0.020	−1.155
	−0.0101	−0.020	−0.343	−0.019	−0.034	−1.158
EC * Dist	$5.0E10^{-4}$	$-3.0E10^{-4}$	0.015	$1.0E10^{-4}$	0.003	0.051*
	$4.0E10^{-4}$	−0.0010	0.009	$8.0E10^{-4}$	0.003	0.027
CR*EC*Dist	$1.0E10^{-4}$	0.0002	0.008	$1.0E10^{-4}$	0.001	0.038**
	$2.0E10^{-4}$	0.0003	0.006	$4.0E10^{-4}$	0.001	0.019
Control Variables	$-4.0E^{-4}$					
Profitability* Dist	Yes	Yes	Yes	Yes	Yes	Yes
GDP-PCI * Dist	Yes	Yes	Yes	Yes	Yes	Yes
Industry Lev* Dist	Yes	Yes	Yes	Yes	Yes	Yes
Constant	−0.033	−0.006	0.017	−0.118	0.255	7.016***
	−0.047	−0.031	0.100	−0.135	0.312	1.003
Country Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2382	957	228	619	218	43
Number of Groups	188	107	55	167	84	24

Note: Table 10. Estimates the interacting effects of enforcing contracts, carbon risk and distance on the speed of adjustment for full sample and by varying degrees of carbon risk: $\Delta L_{ijt+1} = (\beta_{ijt}CR_{ijt} + \lambda_{ijt}EC_{ijt} + \gamma_{ijt}(CR_{ijt} * EC_{ijt}) + \alpha_{ijt}X_{ijt})*(Dist_{ijt}) + \delta_{ijt}$. Three panels show the findings of Models 1 and 2. First panel presents the results for the entire sample, second panel for the LCLCR scenario, and a third panel provides the findings of HCLCR scenario. The co-efficient are presented on the top row and standard errors are presented below for each variable. A cross sectional time-series FGLS-regression approach is used to estimate the results. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. The variable definitions are in Table 1.

Table 11
Interaction Effects of Enforcing contracts, transaction costs, carbon risk and distance on the SOA.

	Model-1: Full Period			Model-2: Post Paris Agreement		
Variables	Full	LCLCR	HCLCR	Full	LCLCR	HCLCR
CR * Dist	0.003	0.026	0.121	−0.010	−0.098	−30.070
	0.012	0.023	0.586	−0.024	−0.081	−42.760
TC * Dist	−0.002	−0.007***	−0.009	0.001	−0.008	0.983
	−0.002	−0.003	−0.027	0.005	−0.009	1.455
CR*TC*Dist	−0.003**	−0.004***	0.005	0.001	−0.002	0.667
	−0.001	−0.002	0.021	0.004	−0.005	1.018
EC*Dist	1.0e-04	−0.002	−0.032	−0.001	0.027	0.613
	6.0e-04	−0.002	−0.024	−0.002	0.021	0.656
TC*EC*Dist	6.6e-05**	1.0e-04**	0.002**	1.0e-04	−6.0e-04	−0.013
	1.0e-04	1.0e-04	7.0e-04	1.0e-04	−6.0e-04	−0.015
CR*EC*Dist	1.0e-04	−2.0e-04	−0.019	2.0e-04	0.019	0.420
	2.0e-04	−4.0e-04	−0.016	5.0e-04	0.014	0.449
CR*TC*EC*Dist	**5.1e-05****	**5.94e-05****	**8.0e-04***	**1.0e-05**	**−5.0e-04**	**−0.008**
	1.0e-07	**1.0e-07**	**5.0e-04**	**1.0e-04**	**−4.0e-04**	**−0.011**
Control Variables						
Profitability* Dist	Yes	Yes	Yes	Yes	Yes	Yes
GDP-PCI * Dist	Yes	Yes	Yes	Yes	Yes	Yes
Industry Lev* Dist	Yes	Yes	Yes	Yes	Yes	Yes
Constant	−0.0430	−0.0209	−0.0491	−0.2900	−0.6680	5.602*
	−0.0480	−0.0325	−0.1320	−0.2020	−1.4130	3.3910
Country Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2382	957	228	619	218	43
Number of Groups	188	107	55	167	84	24

Note: Table 11. Estimates the interacting effects of enforcing contracts, transaction costs, carbon risk and distance on the speed of adjustment for full sample and by varying degrees of carbon risk: $\Delta L_{ijt+1} = (\beta_{ijt}CR_{ijt} + \lambda_{ijt}TC_{ijt} + \nu_{ijt}EC_{ijt} + \gamma_{ijt}(CR_{ijt} * TC_{ijt}) + \theta_{ijt}(CR_{ijt} * EC_{ijt}) + \chi_{ijt}(TC_{ijt} * EC_{ijt}) + \varphi_{ijt}(CR_{ijt} * EC_{ijt} * TC_{ijt}) + \alpha_{ijt}X_{ijt})*(Dist_{ijt}) + \delta_{ijt}$. Three panels show the findings of Models 1 and 2. First panel presents the results for the entire sample, second panel for the LCLCR scenario, and a third panel provides the findings of HCLCR scenario. The co-efficient are presented on the top row and standard errors are presented below for each variable. A cross sectional time-series FGLS-regression approach is used to estimate the results. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. The variable definitions are given in Table 1.

penalty cost faced by firms. The results are presented in Table 11 for the entire time (Model 1), and we extend the study to include the influence of the Paris Agreement (Model 2). Each model was tested on three panels: complete sample, LCLCR, and HCLCR. For all panels, the coefficient of the interaction CR, TC, EC and Dist is positive and significant under Model 1. More significantly, the results of the HCLCR enterprises indicate that if they are resistant to change, they will avoid the high cost of the new investments, which will speed the adaptation of new technologies uptake.

6. Discussion and implications

Our analysis indicates that a company's carbon risk is positively related to the speed with which it adjusts its debt. The country-level data support our hypothesis 1, that carbon risk is positively associated with SOA. Our results favour the second hypothesis. For the companies under the LCLCR category, this link is positive and significant, that is with companies that have low costs and low carbon emissions. The findings indicate that on average, it takes less than two years for a firm to adjust half of its leverage deviation, but the reduction is further accelerated due to high carbon risk. These results support the Stakeholder Theory perspective, that a firm prioritising stakeholder requirement will gain an edge over competitors that do not. The competitive advantage may take the form of financial capabilities acquired at the expense of the firm. The organization might fund its assets and future expansion by allowing speedy access to low-cost capital market debt borrowing. In the HCLCR category, the CR has a negligible effect on the leverage SOA adjustments, but the relationship is favourable. The result indicates that, while firms in the HCLCR category have low carbon emissions, the high cost of debt necessitates firms to adjust leverage more quickly to offset the disadvantages of the high cost of debt, whereas firms in the LCLCR category already have the advantage of low cost of debt and advanced technology to mitigate carbon risk, as well as greater flexibility in accessing the capital market due to their superior carbon emission performance. As a result, these firms are not compelled to modify their leverage more quickly.

Further we test the interaction effects of target leverage deviations, carbon risk and earnings yield on the speed of adjustments. We find that earnings yield has insignificant impact on leverage adjustments with both categories for the full sample period and both the LCLCR and HCLCR are significant after the post Paris agreement. According to prior studies, companies that are proactive in mitigating carbon risk are those who plan their actions strategically by giving both financing and the flexibility necessary to handle environmental challenges (Albertini, 2013; Hart & Dowell, 2011). This is consistent with recent research indicating that firms benefit financially from carbon risk mitigation. While earnings yield has a positive and significant interaction effect on LCLCR categories, this indicates that these firms can change their leverage quickly even after the Paris Agreement's rules take full effect. While earnings yield in the HCLCR category has a negative and statistically significant influence on the relationship between carbon risk and SOA.

Low carbon technology adaptation is driven by legislation rather than strategic reasons; therefore, despite efforts by high cost and low carbon firms to reduce carbon emissions, their earnings do not allow quick leverage adjustment. Due to their higher capital intensity, these firms also experience performance challenges. It has been established in the past that low finance costs and a low capital intensity increase efficiency (Chen & Silva Gao, 2012). The results are more robust in the post-Paris agreement period for the HCLCR category, meaning that legislative constraints on carbon emissions lead HCLCR firms to minimize their leverage adjustment.

Our findings show that carbon risk has no noticeable effect on the rate of adjustment for the HCHCR (High cost of debt and high carbon risk) and LCHCR (Low cost of debt and high carbon risk) categories. These findings are not included in the manuscript, but they are available upon request. These businesses also support the dynamic Trade-Off Theory's claim that the benefits of accelerating the rate of adjustment outweigh the costs. The slower rate of leverage adjustment indicates that the incentive or benefit of reaching the target is trivial.

7. Conclusions

Overall, this study emphasizes the importance of carbon risk in influencing corporate capital structure dynamics through leverage adjustments. By including carbon risk into investment decisions, the impact on financing costs and business value is demonstrated. Concerns about climate change adversaries are motivating businesses to reallocate financial resources to low carbon solutions for carbon emission management. The absence of a perfect carbon-reduction mechanism has put pressure on fuel-intensive economies, sectors, and enterprises engaging in international negotiations on CO2 emission reduction and climate change mitigation in recent years. Carbon emissions are a significant factor in investors' investment decisions. Additionally, religious, financial market, and national regulatory concerns on climate change are increasing pressure on firms, funds, and financial institutions to invest in less-carbon-intensive or low-carbon enterprises. Thus, from a stakeholder and corporate perspective, investments in low-fuel technologies are critical for a sustainable future, and the relevance of carbon risk in relation to the speed with which leverage is adjusted is underlined.

We find that the carbon risk is positively related to the speed of adjustment, specifically, the firms with low cost of borrowing show a faster speed of adjustment toward the target than those whose cost of borrowing is higher. This confirms the Trade-Off Theory's theoretical predictions that value-relevant firms will adapt more quickly than their counterpart firms (Elsas & Florysiak, 2011). Firms with low cost of capital have significant long-term investment prospects and effective risk management, which means companies seek to lower their insurable risks to lenders, which raises their projected creditworthiness (Huberman, 1997), and allows them to have more financial flexibility.

Additionally, we examine the effect of the national institutional context on the connection between carbon risk and leverage adjustment speed. We explore the effects of credit possibilities, transaction costs, and enforcing contracts on the link between carbon risk and leverage speed of adjustment. We determine credit opportunities based on the robustness of credit reporting systems and the score stored in the database, which serves as the foundation for information regarding credit availability. Credit availability has no effect on the link between carbon risk and leverage SOA. Additionally, we discover that contract enforcement is a significant predictor of the link between carbon risk and leverage SOA for the HCLCR company category. However, the combined effect of the transaction contract cost, the cost of enforcing contracts, carbon risk, and distance has a significant effect on the leverage speed of adjustment throughout the study period but has no effect during the period following the Paris agreement regime.

Our findings suggest that capital structure targeting is not equally important to all firms. Indeed, in line with the prior literature (Zhou et al., 2016) we confirm that evidence of the Trade-Off Theory can be found in substantively selected sub-samples of firms, namely those classified as LCLCR and HCLCR.

Authors' contribution

Prof. Douglas conceptualized the idea, motivation, identifying the gaps in the literature, provided data and necessary data sources for country level-data, drafting the manuscript, discussions on implications and contributions and overall project.

Dr. Geeta Duppati, conceptualized the ideas, reviewed the literature, performed the formal data analysis, participated in design of study, interpretation, application of software and participated in drafting conclusion and implications of study. Dr. Ruwani, shared her experience on leverage adjustments and contributed towards review of literature and data analysis part, and participated in data curation. Dr. Shivendu, contributed to developing the design of the study and research methods, made revisions to manuscript, Dr. Aviral contributed towards the data research methods and suitability of the models used for the study. All authors read and approved the final manuscript.

We look forward in anticipation.

Declaration of competing interest

The authors declare that they have no competing interests.

Data availability

Data will be made available on request.

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