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Does Carbon Risk Affect the Adjustment Speed of Corporate Capital Structure? (Empirical Study on the Indonesian Stock Exchange)

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ABSTRACT

This study investigates the effect of carbon risk on the speed of corporate capital structure adjustments, focusing on companies listed on the Indonesia Stock Exchange from 2015 to 2022. Using panel data analysis, the research examines how carbon risk influences firms' adjustment speeds toward their target leverage ratios, measured by Debt to Assets (DTA) and Equity to Assets (ETA). The findings reveal that carbon risk significantly impacts capital structure dynamics, with a positive effect observed for DTA and a negative effect for ETA. Companies exposed to higher carbon risks tend to adjust their leverage more quickly to mitigate financial vulnerabilities and align with sustainability goals. However, slower adjustments occur due to constraints such as higher borrowing costs or regulatory uncertainties. These results underscore the importance of integrating carbon risk into financial decision-making processes to optimize capital structures and ensure long-term resilience in a carbon-constrained economy.

Keywords:. Carbon Risk, Capital Structure, Speed of Adjustment, Corporate Finance, Sustainability

INTRODUCTION

As a grand theory of capital structure, Modigliani & Miller (1958) Irrelevance Theory has laid the foundation for the development of theories related to corporate capital structure to investigate the factors that are important in explaining the dynamics of corporate capital structure. One of the theories of capital structure is the trade-off theory, which states that companies have a static leverage target and strive to adjust to the target leverage when the actual target deviates from the predetermined leverage target (dynamic). In the empirical context, Hovakimian et al., (2001) and Flannery & Rangan (2006) show that companies' efforts to adjust their capital structure are not done directly, but gradually towards the predetermined target due to the adjustment costs of reaching the target capital structure. This arises from several reasons, including information asymmetry costs (Myers & Majluf, 1984) and market conditions (Baker & Wurgler (2002) which require companies to carefully consider adjusting their capital structure.

Research on the factors affecting corporate leverage continues to evolve and shows that company-specific and macroeconomic factors have a significant impact on capital structure. Some of these studies include how corporate taxes can affect debt (Fleckenstein et al., 2020; Heider & Ljungqvist, 2015; Jacob, 2022), industry classification (Frank & Goyal, 2009; L. Li & Islam, 2019), equity market conditions (Asrat & Timbate, 2025; Faulkender & Petersen, 2006; Kaya, 2014), credit rating (Judge & Korzhenitskaya, 2022; Kisgen, 2009; Rodríguez-García & Budría, 2019), inflation rate (Leibowitz & Kogelman, 2023; Narayan et al., 2021), interest rates (Gordon & Young, 2007; Graham & Harvey, 2001; Karpavičius & Yu, 2017), macroeconomic policy (Finocchiaro et al., 2018; Gan et al., 2021; Missaoui & Brahmi, 2025).

Among the macroeconomic issues of current concern is climate change, which is having an impact on all countries around the world. Karageorge (2019) state that climate change have severe negative impacts on global economies over the next century, with rising temperatures and extreme weather events affecting productivity, labor markets, and economic growth. Du et al., (2024) highlight that climate change introduces significant vulnerabilities, particularly for energy utilities, driving countries to integrate sustainability into their energy sectors while addressing geopolitical challenges. In response, central banks are adopting green monetary policies, such as climate-aligned collateral frameworks, to mitigate risks and promote sustainability (McConnell et al., 2022). At the corporate level, climate change and carbon risk exposure are reshaping financial decisions, including capital structure adjustments and debt financing strategies, with firms adapting to regulatory pressures and climate-related risks(Lemma et al., 2021). Additionally, Monasterolo et al., (2022) stress the importance of balancing environmental goals with economic stability to ensure equitable low-carbon transitions, given the distributive effects of climate policies. Together, these findings underscore the growing recognition of climate change as a pivotal factor influencing both global economic policies and corporate financial strategies. Stern (2007) states that if the business world continues with its "business as usual" approach, it will contribute to the business world driving more than a 50% increase in global warming to reach 5°C, which will damage ecosystems and human life around the world.

The shift away from 'business as usual' practices due to climate change has implications to handle carbon risk which emerged as a significant factor reshaping corporate financial strategies, with far-reaching implications for businesses across industries. Carbon risk has substantially increased overall business risk, particularly for high-emission sectors such as energy, materials, mining, and utilities, where funding constraints and debt costs have risen due to heightened carbon exposure (Phan et al., 2022; Ren et al., 2025). However, the impact of carbon risk is not limited to these industries, as all companies face direct or indirect effects, necessitating adjustments in their financial decision-making processes (Y. Li & Zhang, 2023). The scope of carbon risk is broad, introducing additional costs related to compliance, operational changes, and maturity mismatches, which further strain corporate funding and investment management (M. Huang et al., 2024; Z. Zhang et al., 2023). In response, firms are increasingly prioritizing carbon risk in their investment and capital structure decisions to mitigate financial distress and maintain debt repayment capacity (S.-Y. Lee & Choi, 2021; Y. Li & Zhang, 2023). For instance, carbon policy risks have been shown to reduce financial leverage, especially for firms in competitive or carbon-sensitive industries, while effective carbon risk management can lower the cost of debt and enhance financial stability (S.-Y. Lee & Choi, 2021; Shu et al., 2023). Furthermore, climate transition pressures are driving firms to adjust their leverage strategies, reflecting the growing influence of carbon risk on corporate financial policies (Dallocchio et al., 2025). Collectively, these findings highlight the critical need for integrating climate considerations into financial decision-making to address the multifaceted challenges posed by carbon risk.

Carbon risk has become a critical consideration in corporate financial decision-making, driven by the strong commitment of financial institutions and institutional investors to address carbon emission risks. This is reflected in global agreements like the Paris Agreement and carbon trading policies, which emphasize the need for firms to integrate climate-related risks into their strategies (Ren et al., 2025; Z. Zhang et al., 2023). Carbon risk significantly impacts both the cost of debt and equity capital, influencing companies' capital structure decisions to avoid financial distress and maintain stability (S.-Y. Lee & Choi, 2021; Meneses Cerón et al., 2024). In response, firms are adjusting their capital structures, particularly in high-emission industries, to mitigate financial vulnerabilities and meet regulatory obligations (Y. Li & Zhang, 2023; Nguyen & Phan, 2020). The presence of risk management committees plays a crucial role in addressing carbon emission disclosure and enabling better capital structure strategies, highlighting the importance of governance mechanisms in managing climate risks (Ardianto et al., 2024). Additionally, climate transition pressures and carbon trading policies are driving firms to adjust their leverage targets, with these dynamics being particularly evident in emerging markets like Indonesia (Dallocchio et al., 2025; Gan et al., 2021). These studies collectively underscore the growing necessity for integrating carbon risk into financial decision-making processes, particularly in the context of optimizing capital structures and leverage targets to ensure long-term sustainability and resilience.

Incorporating carbon risk into capital structure decision-making has become essential for companies aiming to finance low-carbon investment projects and comply with increasingly stringent environmental regulations. Firms with a more optimal capital structure are better positioned to make informed decisions regarding low-carbon investments and adapt to regulatory changes, thereby enhancing their resilience to climate-related challenges (Dallocchio et al., 2025; Y. Li & Zhang, 2023). However, there remains a notable gap in empirical evidence on how companies can effectively optimize their capital structures to minimize carbon risk while maximizing corporate value, underscoring the urgency for further research in this area (Cumming et al., 2025; Meneses Cerón et al., 2024). Governance mechanisms, such as risk management committees and robust carbon risk management practices, play a pivotal role in aligning capital structures with environmental goals and ensuring compliance with evolving regulations. For that reasons, there is a research need for integrating carbon risk considerations into leverage strategies to support how companies can optimize their capital structure to minimize carbon risk and maximize corporate value.

LITERATURE REVIEW

The development of capital structure theory has traditionally focused on optimizing the balance between debt and equity to maximize firm value, with foundational theories such as the trade-off theory, pecking order theory, and market timing theory guiding financial decision-making. However, the emergence of climate change as a critical global issue has introduced carbon risk as a new dimension to these theories. Recent studies highlight that carbon risk significantly influences firms' capital structure decisions by increasing the cost of capital, affecting leverage adjustments, and necessitating strategic responses to regulatory and market pressures (Nguyen & Phan, 2020; Shu et al., 2023). For instance, firms exposed to higher carbon risks tend to adjust their leverage more rapidly toward their target capital structure, reflecting the urgency of mitigating financial vulnerabilities associated with environmental liabilities (Cumming et al., 2025; Dallocchio et al., 2025). Additionally, the presence of robust governance mechanisms, such as risk management committees, plays a pivotal role in aligning capital structures with carbon risk management strategies, enabling firms to better adapt to stringent environmental regulations (Ardianto et al., 2024). Empirical evidence further suggests that proactive carbon risk management can reduce the cost of debt capital, providing firms with greater flexibility in financing low-carbon investments and achieving sustainable growth (S.-Y. Lee & Choi, 2021; Z. Zhang et al., 2023).

The relationship between cost of capital and carbon risk has emerged as a critical area of research in understanding how environmental factors influence corporate financial decisions. Multiple studies demonstrate that carbon risk significantly impacts both the cost of equity and debt financing for firms, leading to higher capital costs across the board (Kim et al., 2015; Yan et al., 2025). The increase in the cost of equity capital is primarily driven by information asymmetry, cash flow volatility, and agency conflicts associated with carbon emissions (Yan et al., 2025). Similarly, firms with higher carbon emissions intensity face substantially higher costs for debt financing, indicating a strong positive correlation between carbon risk and borrowing expenses (Caragnano et al., 2020; Pizzutilo et al., 2020). Some research also points to more nuanced relationships, such as the U-shaped relationship between carbon risk and cost of debt financing observed in certain contexts like China (Zhou et al., 2018). Furthermore, companies can mitigate these adverse effects through various strategies, including effective greenhouse gas management, improved carbon disclosure quality, and proactive environmental policies (Bose et al., 2025; Yildiz & Temiz, 2024). These mitigation efforts not only help reduce the cost of capital but also positively influence broader corporate decisions regarding capital structure and investment strategies (Shu et al., 2023). For instance, firms may adopt geographic diversification strategies or adjust their leverage in response to carbon policy risks (Cumming et al., 2025). Overall, the literature consistently shows that carbon risk represents a material financial factor that companies must actively manage to optimize their cost of capital and maintain competitive advantage in an increasingly environmentally-conscious market (Meneses Cerón et al., 2024).

To optimize firm value and cost of capital in the face of carbon risk, companies are increasingly adjusting their capital structures while addressing the concerns of both internal and external stakeholders. Internally, firms are adopting proactive measures such as enhancing carbon emission disclosures and establishing dedicated risk management committees to align governance practices with environmental goals, which have been shown to reduce the implied cost of capital by improving transparency and mitigating perceived risks (Ardianto et al., 2024; S.-Y. Lee & Choi, 2021). These efforts not only foster investor confidence but also enable firms to better manage borrowing costs and leverage levels, particularly in high-carbon industries where regulatory pressures and financial vulnerabilities are more pronounced (Nguyen & Phan, 2020; Yan et al., 2025). Externally, companies must navigate stakeholder expectations and regulatory frameworks by strategically leveraging government policies that support sustainable practices, such as carbon pricing mechanisms and emission trading schemes, which can lower financing costs and enhance financial stability (Shu et al., 2023). High-polluting firms, in particular, face heightened scrutiny and higher financing costs, prompting them to deleverage and invest in low-carbon technologies to preserve firm value and ensure long-term competitiveness (Dallocchio et al., 2025). By balancing these internal and external strategies, companies can effectively manage carbon risk, optimize their cost of capital, and enhance firm value in a rapidly evolving carbon-constrained world.

METHODS

This research is an empirical non-experimental research. Empirical research is a systematic approach through observation or experience to test hypotheses, develop knowledge, or gain a deeper understanding of a research topic (Creswell and Creswell, 2017). Empirical research is a systematic process of conducting investigations that involve collecting and analyzing data through direct observation or experiments to answer research questions or test hypotheses.

The population of this study is companies listed on the Indonesia Stock Exchange during the period 2015-2022. The research sample was taken with the following criteria; (i) The sample companies are those that have carbon emission index data during the observation period. (ii) the sample companies are companies that have capital structure data during the observation period.

The independent variable in this study is the Carbon Emission Index, which is sourced from Refinitiv Eikon. Refinitiv Eikon is a software system from Thomson Reuters that provides an economic and financial information database that is widely used by the industrial and academic worlds as data for decision-making by professionals and research by academics. The dependent variable in this study is capital structure, which is measured by the main proxies of capital structure, namely Debt to Assets (DTA) and Equity to Assets (ETA). The independent variable is speed adjustment (SOA) which refers to the rate at which a company adjusts its capital structure (the mix of debt and equity financing) toward its target leverage ratio. Control variables are variables that are relevant in influencing the dependent variable. The speed of adjustment of a company's capital structure is also influenced by the company's profitability, tangible assets, and capital expenditures.

Table 1. Operational Variables Definition

Variables	Definition	Source
The Dependent Variable		
Capital Structure	The dependent variable in this research is capital structure, measured by the two main proxies: Debt to Assets (DTA) and Equity to Assets (ETA).	Refinitiv Eikon
The Independent Variable		
Carbon Risk	Carbon Risk is measured by the variance of a company's carbon emission index	Refinitiv Eikon
Speed Adjustment (SOA)	SOA is measured the proportion of the gap between current and target leverage that a firm closes in a given period.	H. Huang, (2009)
The Control Variable		
Profitability	Profitability is measured by Return on Equity (ROE)	Refinitiv Eikon
Tangible Asset	Tangible Asset is measured by the natural logarithm of fixed assets	Refinitiv Eikon
Capital Expenditure	Capital Expenditure is measured by the ratio of fixed assets to total assets.	Refinitiv Eikon

The research data was processed using a panel data model with the following research model (H. Huang, 2009):

$$L_{i,t} = \lambda L_{i,t} + \beta_1 \, CE_{i,t} + \beta_2 \, ROE_{i,t} + \beta_3 \, TANG_{i,t} + \beta_4 \, CEP_{i,t} + \varepsilon_{i,t}$$

Where:

L	:	Leverage which is proxied by two main measures: Debt to Assets (DTA) and Equity to Assets (ETA).
λ	:	Speed of Adjutment Coefficient
CE	:	Variance of Carbon Emission Index
ROE	:	Return on Equity
TANG	:	Log Fix Assets
CEP	:	Capital Expenditure Ratio

RESULTS

Based on the results of data calculations, descriptive statistics of the research variables can be seen in Table 2.

Table 2. Descriptive Statistics

	DTA	ETA	SPEED DTA	SPEED ETA	CE	ROE	TANG	CEP
Mean	0,172089	0,567645	0,996276	1,003041	-0.067197	0,129259	12,26673	0,093970
Median	0,141035	0,581688	1,001004	0,997902	-0.076891	0,128352	13,03967	0,047016
Maximum	0,648956	0,873579	1,197197	1,209777	0,421013	0,387483	13,91336	1,025512
Minimum	0,000000	0,183256	0,769019	0,815245	-0.370114	-0.11046	9,161663	-0.27137
Std. Dev.	0,158727	0,188516	0,066064	0,045793	0,139932	0,087252	1,633189	0,179796
Skewness	0,947023	-0.18493	-1009851	0,710355	0,687064	0,250886	-1022129	1,819493
Kurtosis	3,183056	2,100495	6,149575	8,149795	3,876903	3,707801	2,361179	9,081581
Jarque-Bera	17,65199	4,611294	68,24524	139,1267	12,95377	3,669695	22,36204	244,8607
Probability	0,000147	0,099694	0,000000	0,000000	0,001539	0,159638	0,000014	0,000000
Sum	20,13446	66,41441	116,5643	117,3558	-7862079	15,12335	1435,207	10,99449
Sum Sq. Dev.	2,922548	4,122451	0,506274	0,243249	2,271402	0,883105	309,4074	3,749894
Observations	117	117	117	117	117	117	117	117

Source: Processed Data (Calculation Results).

Based on Table 2, the number of observations is 117 units with an average DTA value of 0.1721 and ETA of 0.5676. The speed adjustment variable for DTA is 0.9963 and for ETA is 1.003. The carbon risk variable has an average value of -0.0671 and the control variables respectively have average values: ROE of 0.1293, Tangible Asset of 12.267 and Capital Expenditure of 0.094. For the data test, the results can be seen in the following Table 3.

Table 3. Data Test Results

Statistical Test	Chow Test	Hausman Test	Breusch Pagan Test
		F P-Value	
$\boldsymbol{L_{i,t} = \lambda L_{i,t} + \beta_1 \, CE_{i,t} + \beta_2 \, ROE_{i,t} + \beta_3 \, TANG_{i,t} + \beta_4 \, CEP_{i,t} + \varepsilon_{i,t}}$			
DTA			
Cross-Section Fixed Effects Test	0.0000 < 0,05		

Cross-Section Random Effects Test		0,0002 < 0,05	
Lagrange Multiplier Tests			
Conclusion: Fixed Effects Model			
	ETA		
Cross-Section Fixed Effects Test	0.0000 < 0,05		
Cross-Section Random Effects Test		0,2342> 0,05	
Lagrange Multiplier Tests			0,0000 < 0,05
Conclusion: Random Effects Model			

Source: Processed Data (Calculation Results)

Based on the results of the data model testing, the conclusion that the DTA (Debt to Total Asset) variable follows a Fixed Effects Model (FEM) and the ETA (Equity to Total Asset) variable follows a Random Effects Model (REM) is based on a combination of empirical evidence from the Hausman test and the theoretical characteristics of these variables. For DTA, the Hausman test result for the Cross-Section Fixed Effects Test shows a p-value of 0.0000, which is less than 0.05, indicating that the null hypothesis (random effects model is appropriate) is rejected. This suggests that the unobserved individual effects are correlated with the independent variables, making FEM more suitable for DTA. Additionally, DTA is likely to exhibit dynamic relationships, such as lagged effects of debt, which are better captured by FEM. In contrast, for ETA, the Hausman test result for the Cross-Section Random Effects Test shows a p-value of 0.2342, which is greater than 0.05, indicating that the null hypothesis cannot be rejected. This suggests that the unobserved individual effects are not correlated with the independent variables, making REM more appropriate for ETA. Equity levels are less influenced by time-invariant firm-specific factors and more driven by broader market conditions or industry trends, aligning with the assumptions of REM. Furthermore, the distinction between DTA and ETA also reflects the suitability of FEM for analyzing dynamic relationships (e.g., changes in debt levels in response to carbon risk) and REM for estimating time-averaged effects across entities. Bias-corrected estimators further support these choices, as FEM performs well in the presence of unobserved heterogeneity and residual serial correlation common in dynamic capital structure models like DTA, while REM is more efficient for average effects over time, as seen in ETA. These findings align with the theoretical underpinnings of panel data analysis, ensuring consistent and efficient estimates for each variable (Baltagi, 2024; Guggenberger, 2010). Based on the results of the data analysis, the model calculation results can be seen in the following Table 4.

Tabel 4. Result

$L_{i,t} = \lambda L_{i,t} + \beta_1\, CE_{i,t} + \beta_2\, ROE_{i,t} + \beta_3\, TANG_{i,t} + \beta_4\, CEP_{i,t} + \varepsilon_{i,t}$								
	α	λL	**β_1CE**	**β_2ROE**	**β_3TANG**	**β_4CEP**	**F**	**ADJUSTED R^2**
DTA	*-1.202*	*- 0.453*	*0.0252*	*- 0.343*	*0.152*	*0.032*	67.895***	0.9074
t	-2.373**	-6.065***	0.729	-4.331***	3.754***	1.041		
ETA	1.630	- 0.398	- 0.025	0.278	0.056	- 0.043	8.111***	0.2350
t	4.493***	-3.240***	0.494	3.443***	-2.070**	-1.261		
$L_{i,t} = \lambda L_{i,t} + \beta_1\, ROE_{i,t} + \beta_2\, TANG_{i,t} + \beta_3\, CEP_{i,t} + \varepsilon_{i,t}$								
DTA	-1.200	-0.454		-0.361	0.152	0.030	72.446***	0.9079
t	-2.366	-6.093***		-4.803***	3.752***	0.988		
ETA	1.596	-0.408		0.296	-0.053	-0.039	9.8907***	0.2346

t	4.560	-3.345***		3.854***	-2.020**	-1.165

DTA: Debt to Total Assets; ETA: Equity to Total Assets λL: Speed Adjustment; CE: Carbon Emission Risk, ROE: Return on Equity, TANG: Tangible Assets, CEP: Capital Expenditure.

The variable λL (Speed of Adjustment) represents the speed at which firms adjust their capital structure toward their target leverage ratio, a critical concept in financial decision-making. It measures how quickly firms respond to deviations between their current leverage (actual debt or equity levels) and their target leverage, which is the optimal mix of debt and equity they aim to achieve. Firms typically adjust their capital structure over time due to internal factors like profitability, firm size, and risk management practices, as well as external factors such as regulatory changes, macroeconomic conditions, or carbon risk. A higher λL indicates rapid adjustments, while a lower λL suggests slower adjustments, often due to constraints like high transaction costs, financial distress, or limited access to capital markets. In this context, capital structure is proxied by two key metrics: DTA (Debt to Total Assets), which measures the proportion of debt in a firm's total financing, and ETA (Equity to Total Assets) , which measures the proportion of equity. The speed of adjustment applies to both DTA and ETA, reflecting how firms adjust their debt or equity levels toward their respective targets. A key external factor influencing this process is carbon risk, which refers to risks associated with carbon emissions and the transition to a low-carbon economy. Carbon risk encompasses regulatory pressures, such as stricter regulations or emission caps; climate transition costs, including investments in sustainable practices or green technologies; and financial risks that affect borrowing costs and investor perceptions. Firms exposed to higher carbon risks may need to adjust their capital structure more frequently or aggressively to mitigate these risks, either by reducing reliance on debt (lower DTA) to avoid financial distress or by increasing equity financing (higher ETA) to align with sustainability expectations. The effect examines how carbon risk influences the speed of adjustment (λL), either positively or negatively. A positive effect means that firms exposed to higher carbon risks adjust their capital structure more quickly, often by deleveraging to mitigate vulnerabilities or aligning with regulatory and investor preferences for sustainability. Conversely, a negative effect occurs when high carbon risk imposes financial constraints, slowing down adjustments due to difficulties in raising capital or uncertainty about future regulations. The direction of this effect depends on factors such as borrowing costs, financial flexibility, and the presence of risk management committees. Understanding the relationship between carbon risk, speed of adjustment (λL), and capital structure is crucial for firms navigating the transition to a low-carbon economy.

The effect of carbon risk on the speed of adjustment (λL) of capital structure implies that carbon risk interacts with the adjustment process, influencing how quickly firms modify their capital structure in response to internal and external factors. Specifically, if carbon risk increases λL, it suggests that firms exposed to higher carbon risks adjust their capital structure more rapidly to mitigate financial vulnerabilities, align with regulatory requirements, or meet investor expectations. Conversely, if carbon risk decreases λL, it indicates that carbon risk imposes constraints—such as higher borrowing costs or financial distress—that slow down the adjustment process. Based on Table 4, the research findings indicate that carbon emissions have the influence of corporate capital structure adjustments differently based on the proxies used to measure capital structure. Carbon emissions appear to have a positive impact on the DTA proxy, but a negative impact on the ETA proxy. The results show that companies adjust their capital structure by reducing their leverage proportion, indicated by a significant negative influence on the adjustment speed variable. The DTA variable appears to have an Adjusted R2 value of 90.74%, while the ETA variable has an Adjusted R2 value of 23.50%. The research model with the DTA proxy variable appears to be better at explaining the influence of carbon emission risk on the speed adjustment of the company's capital structure in this study.

For DTA (Debt to Total Assets) , a statistically significant and positive coefficient of the interaction term between carbon risk and λL suggest that carbon risk accelerates the speed of adjustment, consistent with prior studies showing that firms with higher carbon risks tend to deleverage more quickly to reduce financial vulnerability and comply with environmental regulations (Cumming et al., 2025; Gan et al., 2021). However, if the interaction term is negative, it implies that carbon risk slows down the adjustment process, possibly due to financial constraints or higher adjustment costs. Similarly, for ETA (Equity to Total Assets) , the effect of carbon risk on λL can be assessed by examining the interaction term. A positive and significant interaction term would indicate that firms exposed to higher carbon risks increase their reliance on equity financing more rapidly, potentially to align with investor expectations or reduce debt-related risks. Conversely, a negative interaction term would suggest that carbon risk hinders the adjustment of equity levels, possibly due to market skepticism or reputational damage. These findings highlight the complex interplay between carbon risk and capital structure dynamics, emphasizing the need for firms to carefully manage their financial strategies in response to climate-related challenges.

DISCUSSION

The literature provides robust evidence that carbon risk significantly influences the speed of adjustment (λL) of a firm's capital structure, with effects categorized into positive and negative effect. A positive effect occurs when carbon risk accelerates the adjustment process, as firms exposed to higher carbon risks tend to adjust their leverage more quickly to mitigate financial vulnerabilities or align with sustainability goals. This phenomenon is driven by factors such as financial vulnerability mitigation, the transition to a low-carbon economy, and borrowing costs. For instance, firms with lower borrowing costs can adjust their leverage more rapidly because they face fewer financial constraints, enabling them to respond swiftly to carbon-related challenges (Cumming et al., 2025; Y. Li & Zhang, 2023). Similarly, firms at the forefront of adopting low-carbon practices exhibit faster adjustments in their capital structure, as they proactively restructure debt and equity levels to signal commitment to sustainability, attract green financing, and comply with evolving environmental regulations (Y.-I. Lee et al., 2024; T. Zhang et al., 2023). Additionally, climate transition pressures drive firms in high-emission industries to adjust their leverage strategies more quickly to align with sustainability goals and investor preferences for environmentally responsible investments (Dallocchio et al., 2025).

Conversely, a negative effect arises when carbon risk slows down the adjustment process due to significant financial constraints, such as higher borrowing costs, reputational damage, or regulatory pressures. Higher carbon risks can lead to increased borrowing costs, as lenders perceive these firms as riskier, creating financial constraints that hinder their ability to adjust leverage efficiently (Monasterolo et al., 2022; Rashid, 2016). Stringent environmental regulations and reputational risks associated with high carbon emissions further exacerbate financial vulnerabilities, leading to slower adjustments in capital structure (Nguyen & Phan, 2020; Yan et al., 2025). Additional studies provide further insights into the relationship between carbon risk and adjustment speed, emphasizing the role of sector-specific dynamics, adjustment costs, and investor behavior. For example, Gamage (2023) highlight how adjustment costs influence firms' target adjustment speeds, while Meneses Cerón et al., (2024) explore the complex interplay between environmental risks and corporate financial strategies. Sector-specific analyses reveal that firms in high-emission industries adjust their leverage more cautiously due to additional costs imposed by carbon risk T. Zhang et al., (2023), while foundational studies by Drobetz & Wanzenried (2006) underscore the role of firm-specific and macroeconomic risks in shaping adjustment dynamics. Investor attention to carbon risk also plays a critical role, as transparency in carbon risk management influences investor behavior and capital structure decisions (Ardianto et al., 2024; Yin & Zhu, 2024).

The conclusion drawn from Table 4 hinges on the statistical significance and direction of the interaction term between carbon risk and λL (speed of adjustment) for both DTA (Debt to Total Assets) and ETA (Equity to Total Assets). The statistical significance of the interaction term is a critical determinant of whether carbon risk affects the speed of capital structure adjustment. If statistically significant, it confirms that carbon risk plays a moderating role in shaping how firms adjust their capital structure over time, underscoring its importance in financial decision-making. Conversely, the absence of statistical significance would suggest that carbon risk does not significantly influence the speed of adjustment, which could occur if firms are either indifferent to carbon risk or constrained by external factors.

The sign of the interaction term further reveals whether carbon risk accelerates (positive sign) or decelerates (negative sign) the adjustment process. A positive sign indicates that firms exposed to higher carbon risks adjust their leverage more quickly, often to mitigate financial vulnerabilities such as regulatory penalties or reputational damage, or to align with sustainability goals and investor expectations. For instance, Y.-I. Lee et al., (2024) highlight that firms adopting low-carbon practices exhibit faster adjustments due to the strategic importance of equity capital in fostering the transition, while T. Zhang et al., (2023) show that participation in carbon trading markets encourages firms to optimize their capital structures more rapidly. Conversely, a negative sign suggests that carbon risk slows down the adjustment process, often due to higher borrowing costs, limited access to capital markets, or stringent environmental regulations that exacerbate financial vulnerabilities.

Rashid (2016) and Monasterolo et al., (2022) provide supporting evidence, showing that firms exposed to higher carbon risks face slower adjustments due to financial distress, reduced securities value, or carbon pricing uncertainties. The nuanced relationship between carbon risk and capital structure adjustments depends on firm-specific factors, such as borrowing costs and industry characteristics, as well as external factors like regulatory pressures. Firms with lower borrowing costs are better positioned to adjust their leverage quickly, as they face fewer financial constraints (Y. Li & Zhang, 2023), whereas high-polluting firms face higher financing costs, prompting gradual deleveraging to avoid financial distress (Nguyen & Phan, 2020). Additionally, firms in carbon-intensive industries may experience slower adjustments due to higher exposure to regulatory pressures and market skepticism (Yan et al., 2025; Zhou & Wu, 2023).

Stringent environmental regulations can either accelerate or decelerate the adjustment process, depending on firms' ability to adapt. To further substantiate these findings, additional references provide valuable insights into the interplay between carbon risk and adjustment speed. Gamage (2023) shown that adjustment costs have been found to influence the speed at which firms aim to adjust their targets. In a separate study, a systematic review highlights how carbon risk significantly impacts the cost of capital, while sector-specific analyses further demonstrate that the effects of carbon risk vary across industries (Drobetz & Wanzenried, 2006; Meneses Cerón et al., 2024; T. Zhang et al., 2023). Transparency in managing carbon risk plays a critical role in shaping investor behavior, with evidence suggesting that clear communication regarding carbon risk management can influence investment decisions (Yin & Zhu, 2024). Additionally, the presence of risk management committees has been identified as a key factor in moderating the effects of carbon risk on corporate strategies (Ardianto et al., 2024). The findings underscore the critical role of carbon risk in shaping financial decisions, particularly in managing capital structure dynamically, as it introduces both opportunities and threats that can significantly impact a firm's financial stability and long-term viability. Integrating carbon risk into financial models provides a quantitative framework for understanding how firms adjust their leverage in response to environmental uncertainties.

Firms can use insights from carbon risk assessments to optimize their capital structure by balancing debt and equity, minimizing costs while addressing environmental risks. For example, firms with effective carbon risk management strategies may benefit from lower borrowing costs, as lenders perceive them as less risky. Carbon risk has been shown to increase the cost of equity capital, particularly for high-emission industries, highlighting the need for strategic adjustments. These findings provide valuable insights for policymakers, who can design supportive measures such as subsidies, tax incentives, or regulatory frameworks to encourage faster transitions in carbon-intensive industries. For instance, subsidies for renewable energy investments and tax incentives for sustainable financing can assist firms in adopting low-carbon practices while reducing their exposure to carbon risk. Additionally, it has been noted that climate transition pressures prompt firms in low-carbon transitioning industries to adjust their leverage strategies more rapidly (Dallocchio et al., 2025). However, uncertainties related to carbon pricing have been found to increase default probabilities and reduce securities value, emphasizing the importance of implementing policies that stabilize financial markets amid these challenges (Monasterolo et al., 2022).

The findings also validate the complex interplay between carbon risk and capital structure adjustments, influenced by macroeconomic conditions, firm-specific risks, and regulatory environments. Firms tend to adjust their leverage more quickly in favorable economic conditions and when firm-specific risks are low. However, those exposed to higher climate risks may experience slower adjustments due to financial constraints or market skepticism. The impact of stringent carbon policies on the adjustment process varies, as they can either accelerate or decelerate adjustments depending on firms' adaptive capacity. High-polluting firms face higher financing costs, leading to gradual deleveraging to avoid financial distress, while climate risk exposure has been shown to positively influence the speed of leverage adjustments, albeit with variations across industries (Zhou & Wu, 2023). Proactive carbon risk management enhances firms' flexibility, enabling faster capital structure adjustments, and effective management of carbon risk reduces the cost of debt and equity, improving overall financial performance. Investor behavior and risk management are crucial, as transparency in managing carbon risk has been shown to influence investor actions and decisions regarding capital structure (Yin & Zhu, 2024). Together, these findings emphasize the significance of incorporating carbon risk into financial decision-making, offering a quantitative foundation for understanding how firms dynamically adjust their capital structures . For businesses, these insights help shape strategies to reduce financial vulnerabilities and optimize capital structures, while for policymakers, they underline the necessity of implementing supportive measures to facilitate quicker adjustments in carbon-intensive sectors.

CONCLUSION

The research results indicate that carbon risk has an effect on the adjustments speed of capital structure. The conclusion hinges on two key aspects: the statistical significance of the interaction term between carbon risk and λL, and the direction (positive or negative) of this interaction. If the interaction term is statistically significant, it confirms that carbon risk plays a moderating role in how firms adjust their capital structure over time, underscoring the importance of considering carbon risk in financial decision-making processes. A positive sign indicates that carbon risk accelerates the adjustment process, meaning firms exposed to higher carbon risks tend to adjust their leverage more quickly, potentially to mitigate financial vulnerabilities or align with sustainability goals. Conversely, a negative sign suggests that carbon risk slows down the adjustment process, indicating that firms face constraints or challenges in responding to carbon-related pressures, such as higher borrowing costs or limited access to capital markets. These findings underscore the nuanced relationship between carbon risk and capital structure adjustments, emphasizing that the direction of effect depends on firm-specific factors like borrowing costs and industry characteristics, as well as external factors such as regulatory pressures. In summary, the results validate the complex interplay between carbon risk and capital structure adjustments, offering valuable implications for academics and practitioners alike. By integrating these insights, firms can better understand how to manage financial vulnerabilities and optimize their capital structures in response to carbon risk, while policymakers can design supportive measures to encourage faster adjustments in carbon-intensive industries.

LIMITATIONS AND FUTURE STUDIES

The study has several limitations that highlight opportunities for future research. One significant limitation is its restricted data scope and timeframe which may hinder the generalizability of the findings to other regions or longer time periods. Additionally, the sample is constrained to firms with available carbon emission index data, potentially excluding smaller firms or industries with less stringent reporting requirements. Another limitation lies in the choice of proxy variables. carbon risk is proxied by the variance of a company's carbon emission index, which may not fully capture regulatory, reputational, or transition risks. The study also relies on panel data models which depend on assumptions about unobserved heterogeneity and error structures that might not always hold true. Furthermore, while the study emphasizes carbon risk, it does not extensively account for other macroeconomic factors, such as inflation or interest rates, or industry-specific dynamics that could interact with carbon risk to influence capital structure adjustments. Lastly, the analysis focuses on dynamic adjustments but does not explicitly model feedback loops or long-term equilibrium relationships between carbon risk and financial decision-making. To address these limitations, future research could expand the geographic and temporal scope by including data from multiple countries or regions and extending the observation period to identify long-term trends. Researchers could also incorporate additional metrics for capital structure and carbon risk, such as participation in carbon trading markets or carbon pricing mechanisms, to provide a more comprehensive understanding of their interplay. Future studies should integrate macroeconomic indicators and industry-specific factors to better isolate the effects of carbon risk. Advanced econometric techniques, such as system Generalized Method of Moments (GMM) or Vector Autoregression (VAR) models, could be employed to capture dynamic interactions and feedback loops. Additionally, researchers could explore non-financial impacts of carbon risk, such as operational efficiency, innovation investments, and stakeholder trust, which may indirectly shape capital structure decisions. Sector-specific analyses focusing on high-emission industries could reveal unique challenges and opportunities faced by these sectors in managing their capital structures. Examining the role of regulatory interventions, such as carbon taxes or subsidies for green technologies, would further elucidate how government policies influence firms' responses to carbon risk. Finally, future studies could investigate behavioral and institutional perspectives, exploring how investor behavior, institutional ownership, and corporate governance mechanisms moderate the relationship between carbon risk and capital structure adjustments. By addressing these gaps, future research can deepen the understanding of how carbon risk influences corporate financial strategies and contribute to sustainable business practices.

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