

The moderating role of carbon emissions on capital structure dynamics in listed firms from Africa, Americas, Asia, Europe, and Oceania*

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Abstract

Using a dynamic model of capital structure decisions, we investigate the moderating role of carbon emissions in the corporate financing decisions of listed firms. In fact, carbon emissions constitute a highly relevant topic in corporate finance and have attracted growing attention from researchers. From a methodological perspective, we estimate dynamic partial adjustment models by continent, with firm, industry, and country fixed effects, and conduct robustness checks using alternative proxies for capital structure (debt, indebtedness, and net-debt). We investigate the financial decisions of listed firms in Africa, Asia, the Americas, Europe, and Oceania over the period 2015–2024. In addition, for robustness, we also conduct a subsample analysis focusing on firms listed in G20 countries. Our results confirm the hypothesis that the moderation of carbon emissions reduces the corporate speed of adjustment. Thus, our results contribute to theory by presenting that, although carbon emissions do not exhibit a statistically significant relationship with the dynamics of corporate decisions (except for European firms), the moderating effect does matter for the speed of this dynamic adjustment. Methodologically, our model makes an empirical contribution by integrating sustainable finance considerations into a dynamic partial adjustment framework for corporate financing decisions. In practice, our results documented that carbon emissions play a relevant role in the dynamics of corporate financing decisions, mainly by moderating the speed of adjustment. In addition, we conduct Wald tests to assess differences in the speed of adjustment coefficients between the baseline and moderated models. The results indicate that these coefficients differ statistically, providing further evidence consistent with the moderating role of carbon emissions.

Keywords: Carbon emissions. Capital Structure. Speed of adjustment. Sustainable finance. Trade-off theory.

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1 Introduction

Corporate capital structure decisions (the mix of debt and equity) remain central in corporate finance because they reflect firms' responses to financing costs within a dynamic adjustment process toward target leverage (Esghaier, 2024; Hoerlle & Kayo, 2025; Cumming et al., 2025). These decisions concern the sources of capital used to finance corporate investments, and it is well known that an optimal capital structure minimizes firms' cost of capital and maximizes shareholder value (Shu et al., 2023; Goldstein & Yang, 2024). This optimal mix represents a target, implying that deviations from it generate incentives for gradual adjustment rather than instantaneous correction.

Thus, corporate capital structure decisions are dynamic in relation to a target, and to achieve this, managers' ability to close the gap between observed and target leverage crucially depends on financing conditions, which are summarized by the cost of capital. In this sense, these financing conditions are shaped by a range of risk factors that affect both the cost and availability of external funds (Billio, Murgia, & Vismara, 2024; Flannery & Öztekin, 2024; Heo, 2024; Leandro de Lima, Silva & Armada, 2025; Stulz, 2025).

One of the most critical risks addressed in the current literature is climate-related risk (Starks, 2023; Cumming, Farag & Johan, 2024; Edmans, 2024; Jiang et al., 2025). In this context, investigations into corporate carbon emissions have gained considerable attention due to the potential impact of carbon emissions on climate change (Bugshan et al., 2024; Amin et al., 2025; Luo, Zhang & Zheng, 2025). This has triggered reactions in the capital market, with increasing demand for informative reports on carbon emissions (Wang et al., 2024; Cho, Hsiao & Liao, 2025). In addition, researchers have documented that financiers tend to require a lower cost of capital from firms with lower carbon emissions (Shu et al., 2023; Arian & Sands, 2024; Cumming et al., 2025; Yan, Guo & Wen, 2025).

Previous studies that investigated carbon emissions and capital structure decisions focus on carbon emissions on idiosyncratic risk and capital costs (Arian & Sands, 2024), or carbon risk (Shu et al., 2023; Cumming et al., 2025; Yan et al., 2025), and climate risk on capital structure decisions (Jiang et al., 2025). However, while the value relevance of capital structure dynamics is well established, existing evidence provides limited insight into how carbon emissions

shape the dynamic process through which firms adjust leverage toward target levels. Based on this gap our objective was investigating a methodological approach to evaluate the effect of carbon emissions on corporate capital structure decisions in listed firms from Africa, Americas, Asian, European and Oceanian.

Thus, our results provide three main contributions. First, we offer a novel theoretical contribution by showing that carbon emissions operate through the dynamics of the capital structure adjustment process, rather than exerting only a direct level effect on leverage. While previous studies focus mainly on static relationships between carbon risk and financing levels, we demonstrate that carbon emissions systematically condition the speed at which firms converge toward target leverage, consistent with the dynamic trade-off theory and the notion of implicit adjustment costs. As far as we know, this mechanism has not been explicitly modeled in prior work.

Second, from an empirical perspective, we provide the most comprehensive global evidence to date on how carbon emissions influence the dynamics of capital structure adjustment. By examining listed firms across Africa, the Americas, Asia, Europe, and Oceania, including a dedicated analysis for G20 economies, we uncover substantial regional heterogeneity driven by institutional and regulatory differences. This cross-regional comparison is rare in the literature and reveals patterns that single-country research are unable to detect. We also reinforce the empirical robustness of our findings by employing three alternative leverage measures (debt ratio, indebtedness, and net debt).

These proxies capture distinct economic dimensions of capital structure and allow us to confirm that the moderating effect of carbon emissions is not driven by a specific leverage definition. This multi-proxy approach strengthens the empirical credibility of the results. To support these contributions, we explicitly address identification concerns through lagged emissions, multi-level fixed effects, and a two-step adjustment framework. Moreover, we quantify the economic magnitude of the moderating effect by translating estimated speeds of adjustment into implied convergence horizons. These calculations show that realistic changes in carbon emissions (e.g., one-standard deviation) produce economically meaningful differences in adjustment time, strengthening the practical relevance of our findings.

Third, from a practical perspective, our findings suggest that carbon emissions constitute economically relevant constraints in corporate financing decisions by increasing implicit adjustment costs, with important implications for managers, investors, and policymakers operating in environments with differing levels of institutional engagement in climate policies. Taken together, these contributions advance the capital structure and sustainable finance literature by revealing that environmental externalities shape not only the level of corporate leverage but also the dynamic process through which firms adjust toward their financial targets.

2 Research Framework and Hypothesis

Since the early discussions on firms' financing decisions, it has been well established in the literature that capital structure matters for firm value (Durand, 1952). Lintner's (1956) model was fundamental in explaining the partial adjustment (by estimating the optimal target) of firms' financial decisions. In fact, the firms' cost of capital has implications for corporate cash flow, the main determinant of market value (Modigliani & Miller, 1963). Despite the difficulty in understanding the benefits of debt on the corporate cost of capital, for a long time, divergent proposals emerged regarding the trade-off theory of capital structure (Modigliani & Miller, 1958; Miller, 1977; Myers, 1984; Baker & Wurgler, 2003).

However, investigating firms' financing structure decisions has led to the development of a robust framework in the field (Harris & Raviv, 1991; Fama & French, 2012; Titman, 2017; Frank & Shen, 2019; DeAngelo, Gonçalves, & Stulz, 2022; Benmelech, Kumar, & Rajan, 2024; Esghaier, 2024; Hoerlle & Kayo, 2025; Leandro-de-Lima, Silva & Armada, 2025). Particularly, with the robustness of the results obtained using dynamic capital structure adjustment models to explain firms' financing decisions (Frank & Shen, 2019; Esghaier, 2024; Cumming et al., 2025; Leandro-de-Lima, Silva & Armada, 2025). In fact, the theoretical framework developed on firms' financing decisions provides solid foundations for understanding the phenomena related to sustainable finance.

One of the central topics that has concerned researchers is understanding the rapid evolution of the carbon emissions landscape, with firms worldwide face the challenges it imposes (Shu et al., 2023; Arian & Sands, 2024; Wang et al.,

2024; Cho, Hsiao & Liao, 2025; Cumming et al., 2025; Yan, Guo & Wen, 2025). This is due to the fact that regulators have introduced demands related to carbon emissions (Arian & Sands, 2024; Cumming et al., 2024; Jiang et al., 2025; Luo, Zhang, & Zheng, 2025), which affect firms' market value and, consequently, investor interest (Bugshan et al., 2024; Wang et al., 2024; Cumming et al., 2025; Yan, Guo & Wen, 2025).

The carbon emissions are relevant to investors because it affects the corporate cost of capital (Shu et al., 2023; Arian & Sands, 2024; Cumming et al., 2025; Yan, Guo & Wen, 2025). In fact, the reduction of carbon emissions plays a central role in the global agenda for confronting the challenges of climate change (Shu et al., 2023; Arian & Sands, 2024; Wang et al., 2024; Cho, Hsiao & Liao, 2025; Cumming et al., 2025). There is a remarkable degree of attention from stakeholders and regulators toward corporate carbon risk (Bugshan et al., 2024; Jiang et al., 2025; Yan, Guo & Wen, 2025). Namely, the Sustainable Development Goals (SDGs), introduced in 2015 by the United Nations, as a global call to protect the Earth (Cumming et al., 2025).

Thus, adapting to the risks associated with tightening carbon regulations has become a critical emission for firms' survival (Shu, Tan, & Wei, 2023). Firms with higher carbon emissions are exposed to elevated idiosyncratic risk, and higher capital costs in both debt and equity markets (Arian & Sands, 2024). To summarize, we argue that firms with higher carbon emissions will face higher costs of capital structure adjustments and slower capital structure adjustments. We specifically focus on carbon emissions and, accordingly, propose that these emissions affect the speed of adjustment.

H1. Carbon emissions negatively moderate the speed of adjustment for African, American, Asian, European, and Oceanian listed firms.

3 Methodology

The research methodology was developed in three stages. In the first stage, we define the proxies for corporate capital structure based on data obtained from the Refinitiv Eikon database. In the second stage, we estimate firms' target capital structures. In the third stage, we estimate the speed of adjustment toward the target leverage. Carbon emissions are measured using

Refinitiv Eikon's estimated total carbon emissions metric. All empirical analyses were conducted using Stata (version 19 MP).

In the first stage, we use the proxies in Table 1 to measure the capital structure.

Table 1

Capital structure proxies

Variable	Equations	Source
Debt	$\frac{Total\ Debt_{it}}{Total\ Assets_{it}}$	Frank and Shen (2019), DeAngelo, Gonçalves, and Stulz (2022), and Mishra et al. (2024)
Indebtedness	$\frac{Total\ Liabilities_{it}}{Total\ Assets_{it}}$	Welch (2011), and DeAngelo, Gonçalves, and Stulz (2022)
Net-debt	$\frac{Total\ Debt_{it} - Cash\ holdings_{it}}{Total\ Assets_{it}}$	DeAngelo, Gonçalves, and Stulz (2022)

We used three different proxies for capital structure. First, the total debt ratio, as it represents the portion used for financing purposes, in accordance with our theoretical framework (e.g., tax benefits) (Mishra et al., 2024). Second, we used total liabilities, that is, the portion of obligations for transaction purposes, as an alternative measure of capital structure to ensure the robustness of our findings, as well as to address divergences in the use of each one (Welch, 2011). Third, we used net-debt ratios (defined as debt minus cash holdings, divided by total assets) to incorporate the dynamics of cash documented by DeAngelo, Gonçalves, and Stulz (2022).

In the second stage, from the adjustment speed model of Frank and Shen (2019), we estimated the target capital structure in accordance with Equation 1. We chose this model because Frank and Shen (2019) documented results that are superior when compared to those of other classical models in the literature for explaining the speed of adjustment.

*Capital structure*_{it}

$$= \beta_0 + \beta_1 Market - to - book_{it-1} + \beta_2 \ln(Total\ Assets_{it-1}) \quad (1) \\ + Firm\ Effect_i + Sector\ Effect_s + Country\ Effect_c + \varepsilon_{it}$$

Thus, β_0 refers to the constant, *Market – to – book* refers to the Market-to-Book, $\ln(Total\ Assets)$ refers to the natural logarithm of total assets, the

subscript i refers to the firm, the subscript t refers to time, subscript s refers to sector, subscript c refers to country and ε refers to the residual term. In Equation 1, the estimated model incorporates lagged independent variables as instruments, in order to address endogeneity and increase the precision of the estimates.

We used Equation 1 as our methodological strategy to estimate the value of the target capital structure, in accordance with Equation 2.

$$\begin{aligned} \text{Target capital structure}_{it}^* \\ = \hat{\beta}_0 + \hat{\beta}_1 \text{Market-to-book}_{it-1} + \hat{\beta}_2 \text{Total Assets}_{it-1} \end{aligned} \quad (2)$$

As is usually the case, $\varepsilon_{it} \neq 0$ so $\text{Capital structure}_{it} \neq \text{Target capital structure}_{it}^*$. Then, in accordance with Equation 3, we calculated the capital structure gap as the difference between the estimated target (Equation 1) and the capital structure in the previous period.

$$\begin{aligned} \text{Capital Structure Gap}_{it} \\ = \text{Target capital structure}_{it}^* - \text{Capital structure}_{it-1} \end{aligned} \quad (3)$$

In the third stage, from the capital structure gap calculated in Equation 3 (based on Frank and Shen, 2019), we estimated the speed of adjustment, in accordance with Equations 4 and 5. As in Equation 1, the estimated models in Equations 4 and 5, incorporates lagged independent variables as instruments, in order to address endogeneity and increase the precision of the estimates.

$$\begin{aligned} \text{Capital structure}_{it} - \text{Capital structure}_{it-1} \\ = \alpha_0 + \lambda_1 \text{Capital Structure Gap}_{it} + \beta_2 \text{Carbon Emissions}_{it-1} \\ + \text{Firm Effect}_i + \text{Sector Effect}_s + \text{Country Effect}_c + \varepsilon_{it} \end{aligned} \quad (4)$$

$$\begin{aligned} \text{Capital structure}_{it} - \text{Capital structure}_{it-1} \\ = \alpha_0 + \lambda_1 \text{Capital Structure Gap}_{it} + \beta_2 \text{Carbon Emissions}_{it-1} \\ + \beta_3 (\text{Capital Structure Gap}_{it} \cdot \text{Carbon Emissions}_{it-1}) \\ + \text{Firm Effect}_i + \text{Sector Effect}_s + \text{Country Effect}_c + \varepsilon_{it} \end{aligned} \quad (5)$$

Thus, α_0 refers to the constant, the subscript i refers to the firm, the subscript t refers to time, subscript s refers to sector, subscript c refers to country, and ε refers to the residual term. From the partial adjustment approach, the coefficient λ_1 in Equation 4 is interpreted as the speed of adjustment. It represents the proportion of the gap between the current capital structure and its target that is closed in each period. Thus, the smaller the λ_1 , the higher the gap remaining to be adjusted in future periods, and the higher the λ_1 , the smaller the gap remaining to be adjusted in future periods.

3.1 Robustness tests

We conduct a set of robustness checks and extensions to our baseline analysis. Specifically, we employ three alternative proxies to measure corporate capital structure dynamics in order to assess the robustness of our findings to different leverage definitions and mitigate potential measurement bias. Following the literature, we acknowledge that these proxies capture distinct economic dimensions of financing decisions and rely on different theoretical and methodological perspectives (Welch, 2011; DeAngelo, Gonçalves, & Stulz, 2022; Mishra et al., 2024). Accordingly, each capital structure proxy is analyzed in a separate model specification and interpreted independently, rather than being combined within a single regression framework.

We employ a two-step partial adjustment framework, estimated using ordinary least squares with fixed effects, following Frank and Shen (2019), who show that OLS provides reliable and stable estimates of capital structure adjustment dynamics. This approach allows us to decompose the adjustment process into two stages: in the first stage, we estimate time-varying target leverage as a function of firm characteristics and fixed effects; in the second stage, we estimate the speed at which firms adjust toward this target.

The adjustment gap is constructed mechanically as the difference between the estimated target leverage and lagged observed leverage, rather than being separately estimated. Although the gap is a deterministic transformation, it depends on an estimated object, implying that the two-step procedure involves a generated regressor whose sampling uncertainty originates from the first-stage target estimation. To mitigate endogeneity concerns, we combine this framework

with lagged explanatory variables and a rich fixed-effects structure, which reduces simultaneity bias and supports more reliable inference.

In second stage, we also employ the Breusch–Pagan, Hausman, and Chow F tests (Wooldridge, 2025) to guide the selection of the appropriate panel data specification (see Table 3). All estimated models include firm, industry, and country fixed effects, which absorb time-invariant heterogeneity related to firms' technology, efficiency, sectoral characteristics, and institutional environments. This fixed-effects structure allows us to control for unobserved firm-level heterogeneity and to exploit within-firm variation over time, thereby strengthening the internal validity of the estimates. Moreover, carbon emissions enter the model lagged by one period, which mitigates concerns of contemporaneous reverse causality between financing decisions and emission levels.

We also report robust standard errors following Wooldridge (2025) to account for potential heteroskedasticity and ensure valid statistical inference. Thus, in order to ensure that multicollinearity was not present among the estimated coefficients, we applied the Variance Inflation Factor (VIF), and all models presented values well below 10 (see results in Table 3), a commonly accepted threshold (Hair Jr., 2017; Wooldridge, 2025). In addition, considering the unbalanced distribution of observations and the inherent heterogeneity across regions, all analyses were conducted separately by region rather than relying on a pooled full-sample approach.

We applied the Wald test to assess whether the estimated speed-of-adjustment coefficients from the moderated specification differ significantly from those obtained in the non-moderated model (see Table 3). Consistent with Wooldridge (2025), this procedure constitutes a formal test of coefficient differences, allowing us to evaluate whether the speed-of-adjustment parameters differ between the moderated and baseline models.

4 Sample and data description

The selection of the sample period from 2015 to 2024 was guided by the availability of the estimated total CO₂ and CO₂ equivalents emission in tones, considering firms with at least one year of observation. We collected data from

listed firms across Africa, the Americas, Asia, Europe, and Oceania. Table 1 presents the population and sample per region.

Table 2

Population and sample per region

Region	Observations Population	Close to Bankruptcy	Observations “Missing”	Observations Sample
Africa	1,936	28	871	1,037
Americas	38,016	3,143	15,747	19,126
Asia	48,301	620	29,413	18,268
Europe	22,506	529	10,237	11,740
Oceania	4,290	99	1,499	2,692
Total	115,049	4,419	57,767	52,863

To capture authentic capital structure adjustment trajectories and distinguish transient fluctuations from long-term systematic trends, firms with fewer than three consecutive years of observations were excluded. We also excluded firms with negative equity, since, although this does not necessarily imply an inability to operate in the short term, these firms are strictly focused in solve financial issues. In Appendix, Tabe A.2 Sample Description, we present sample in detail.

In Appendix, Table A.3 Descriptive Statistics, we present the descriptive statistics of evaluated variables for each region. Table A.3 indicates that debt levels are broadly similar across the regions analyzed, with average values ranging from 22 per cent in Oceanian firms to 27 per cent for firms from the Americas. Similar patterns were also observed in the indebtedness level, with average values ranging from 55 per cent in European firms to 44 per cent in Oceanian firms, and in the average net-debt values, which ranged from 5 per cent in Asian firms to 15 per cent in African firms. These patterns are consistent with target-based explanations, in which firms dynamically converge toward time-varying leverage and liquidity targets shaped by common underlying determinants (DeAngelo, Gonçalves, and Stulz 2022).

In Table A.3, a larger difference across regions was observed for the carbon emission variable. Asian firms exhibit higher average carbon emissions (1.086 per cent greater) than Oceanian firms. Asian firms also present the highest average emissions overall, with levels approximately 34 per cent higher than those in Africa, 233 per cent higher than those in the Americas, and around 237

per cent higher than those in Europe. In addition, Table A.4 presents the correlation matrix between the analyzed variables. The results did not indicate any potential issues of high correlation among the variables analyzed.

5 Empirical results

Table 3 presents the empirical results. To clarify the interpretation of the moderating effect, we model the speed of adjustment as a function of carbon emissions. Specifically, the adjustment equation is given by $\Delta Capital Structure_{it} = \alpha_0 + \lambda_1 Gap_{it} + \lambda_2 (Gap_{it} \times CarbonEmissions_{it}) + X'_{it}\gamma + \mu_i + \varepsilon_{it}$. This specification implies that the marginal speed of adjustment equals $\lambda_1 + \lambda_2 \cdot CarbonEmissions_{it}$. Hence, carbon emissions do not affect the adjustment gap itself, but rather condition the intensity with which firms close this gap. A negative estimate of λ_1 indicates that higher carbon emissions reduce the speed at which firms adjust leverage toward their target levels.

Our results suggest that carbon emissions are directly related to capital structure adjustment, in terms of debt, only in European firms. The same negative and statistically significant effect was documented in the adjustment of capital structure through net debt among American firms. No statistically significant effects were found between carbon emissions and capital structure adjustment measured by indebtedness.

The results from Table 3, Panel A, with debt as the dependent variable, provide evidence of a negative relationship between carbon emissions and the speed of adjustment exclusively among European firms. In all other cases, we do not find statistically significant evidence of a direct relationship between the speed of adjustment of capital structure and carbon emissions. As expected in our research hypothesis, except for firms listed in Oceania, we find a negative moderating effect of carbon emissions on the speed of adjustment of capital structure in all other cases. The absence of significant effects for Oceanian firms may reflect the relatively smaller sample size in this region, which limits statistical power, as well as potential heterogeneity in sectoral composition and disclosure practices.

Table 3

Empirical results

Panel A – Dependent variable in terms of debt – Equations 4 and 5

Var	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
SA	0.377*** (12.22)	0.630*** (5.35)	0.481*** (35.99)	0.658*** (13.79)	0.422*** (11.83)	0.683*** (12.59)	0.453*** (25.23)	0.663*** (10.90)	0.434*** (13.88)	0.483*** (4.18)	0.451*** (38.61)	0.651*** (21.40)	0.463*** (33.49)	0.642*** (17.92)
CE	0.005 (1.07)	0.005 (1.00)	0.001 (0.81)	0.001 (0.58)	-0.000 (-0.29)	-0.001 (-1.10)	-0.002** (-2.21)	-0.003** (-2.58)	-0.001 (-0.23)	-0.001 (-0.27)	-0.000 (-0.51)	-0.001 (-1.02)	0.000 (0.13)	-0.000 (-0.26)
MOD	—	-0.022** (-2.18)	—	-0.017*** (-4.29)	—	-0.021*** (-4.91)	—	-0.019*** (-3.81)	—	-0.005 (-0.46)	—	-0.018*** (-6.51)	—	-0.017*** (-4.87)
Cons	-0.051 (-1.00)	-0.049 (-0.91)	-0.007 (-0.65)	-0.006 (-0.60)	0.003 (0.32)	0.010 (0.96)	0.029** (2.36)	0.035*** (2.91)	0.010 (0.36)	0.011 (0.41)	0.005 (0.73)	0.008 (1.14)	0.001 (0.06)	0.003 (0.34)
EF.N	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
EF.S	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
EF.C	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R² Ad	0.0688	0.0725	0.1193	0.1232	0.0966	0.1040	0.0857	0.0913	0.0980	0.0979	0.1003	0.1055	0.1133	0.1175
Obs.	1038	1038	19155	19155	18270	18270	11737	11737	2703	2703	52903	52903	39908	39908
F	79.4***	57.9***	648.4***	480.0***	73.5***	73.0***	322.1***	217.4***	96.6***	64.5***	750.2***	554.3***	569.2***	422.9***
Chow	1.82***	1.83***	2.22***	2.25***	2.15***	2.20***	1.81***	1.83***	1.85***	1.84***	2.03***	2.06***	2.14***	2.16***
BP	0.00	0.00	6.65***	7.21***	10.08***	10.16***	0.00	0.00	0.00	0.00	7.50***	7.80***	6.27***	6.04***
Haus	155.2***	158.4***	3569.6***	3616.9***	3272.6***	3373.1***	2037.1***	2076.2***	394.8***	391.0***	9478.6***	9636.2***	7390.9***	7478.3***
VIF	1.04	-	1.04	-	1.03	-	1.05	-	1.01	-	1.00	-	1.01	-
Wald	8.21***		22.87***		3.42**		9.55***		4.34**		20.17***		19.62***	

Note: Dependent variable: capital structure adjustment in terms of debt. t-statistics in parentheses. Var refers to variables. (1) and (2), (3) and (4), (5) and (6), (7) and (8), (9) and (10), (11) and (12), and (13) and (14) refer to Africa, Americas, Asia, Europe, Oceania, Full Sample, and G20 Group, respectively. SA refers to the Speed of Adjustment. CE refers to the Carbon Emission. MOD refers to the moderation (SA*CB). Cons refers to the constant. EF.N, EF.S, and EF.C, refer to firm, sector, and country fixed effects. R² Ad refers to the R² Adjusted. Obs. refers to the total of Observations. Chow refers to the Chow F test. BP refers to the Breusch-Pagan test. Haus refers to the Hausman test. Wald refers to the Wald test for equality of coefficients across models using SUEST. VIF refers to the Variance Inflation Factor. * p<0.10, ** p<0.05, *** p<0.01.

Panel B – Dependent variable in terms of indebtedness – Equations 4 and 5

Var	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
SA	0.369*** (10.66)	0.430*** (3.37)	0.484*** (32.84)	0.748*** (15.66)	0.390*** (25.31)	0.697*** (13.12)	0.454*** (24.61)	0.669*** (11.17)	0.448*** (13.61)	0.594*** (6.39)	0.450*** (48.64)	0.702*** (22.88)	0.455*** (43.33)	0.684*** (19.45)
CE	0.000 (0.11)	0.001 (0.17)	0.001 (0.58)	0.002 (1.52)	-0.001 (-1.21)	-0.002* (-1.80)	-0.001 (-0.66)	0.000 (-0.01)	0.004 (1.23)	0.005 (1.39)	0.000 (0.24)	0.001 (1.21)	0.001 (0.88)	0.002* (1.78)
MOD	—	-0.005 (-0.51)	—	-0.028*** (-6.75)	—	-0.026*** (-6.34)	—	-0.021*** (-4.19)	—	-0.017* (-1.88)	—	-0.025*** (-9.87)	—	-0.023*** (-7.96)
Cons	0.001 (-0.02)	-0.005 (-0.09)	-0.004 (-0.31)	-0.021* (-1.67)	0.013 (-1.19)	0.017 (-1.55)	0.009 (-0.70)	0.000 (-0.01)	-0.036 (-1.12)	-0.044 (-1.32)	0.000 (-0.03)	-0.010 (-1.34)	-0.006 (-0.67)	-0.018* (-1.91)
EF.N	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
EF.S	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
EF.C	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R² Ad	0.0673	0.0666	0.1070	0.1172	0.0430	0.0572	0.0689	0.0764	0.0979	0.1014	0.0805	0.0910	0.0876	0.0962
Obs.	1038	1038	19155	19155	18270	18270	11737	11737	2703	2703	52903	52903	39908	39908
F	95.6***	63.7***	2100.3***	1469.3***	1526.9***	1095.5***	1106.3***	765.8***	272.9***	185.6***	5195.7***	3647.0***	4017.1***	2793.8***
Chow	2.07***	2.03	2.18***	2.21***	1.98***	2.07***	1.89***	1.93***	1.87***	1.86***	2.03***	2.06***	2.08***	2.10***
BP	0.25	0.04	0.17	0.55	0.63	0.88	5.32**	6.70***	0.00	0.00	10.10***	8.82***	8.06***	6.46***
Haus	159.1***	158.5***	3166.4***	3211.9***	2767.1***	2944.5***	1910.0***	1967.0***	407.1***	404.0***	8888.6***	8674.8***	6627.0***	6667.0***
VIF	1.00	-	1.13	-	1.05	-	1.01	-	1.02	-	1.04	-	1.06	-
Wald	5.19**		78.02***			10.67***		6.17**		32.29***		18.72***		18.94***

Note: Dependent variable: capital structure adjustment in terms of indebtedness. t-statistics in parentheses. Var refers to variables. (1) and (2), (3) and (4), (5) and (6), (7) and (8), (9) and (10), (11) and (12), and (13) and (14) refer to Africa, Americas, Asia, Europe, Oceania, Full Sample, and G20 Group, respectively. SA refers to the Speed of Adjustment. CE refers to the Carbon Emission. MOD refers to the moderation (SA*CB). Cons refers to the constant. EF.N, EF.S, and EF.C, refer to firm, sector, and country fixed effects. R² Ad refers to the R² Adjusted. Obs. refers to the total of Observations. Chow refers to the Chow F test. BP refers to the Breusch-Pagan test. Haus refers to the Hausman test. Wald refers to the Wald test for equality of coefficients across models using SUEST. VIF refers to the Variance Inflation Factor. * p<0.10, ** p<0.05, *** p<0.01.

Panel C – Dependent variable in terms of net-debt – Equations 4 and 5

Var	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
SA	0.421*** (13.50)	0.785*** (4.36)	0.524*** (38.65)	0.668*** (17.40)	0.466*** (21.96)	0.757*** (14.06)	0.536*** (28.82)	0.821*** (16.16)	0.481*** (13.10)	0.439*** (5.64)	0.502*** (50.96)	0.686*** (23.14)	0.508*** (45.70)	0.653*** (19.31)
CE	0.003 (0.41)	0.002 (0.28)	0.003 (1.65)	0.002 (1.51)	0.000 (0.02)	-0.001 (-0.62)	-0.003 (-1.58)	-0.003 (-1.53)	0.001 (0.08)	0.001 (0.07)	0.000 (0.38)	0.000 (0.27)	0.001 (1.10)	0.001 (0.96)
MOD	—	-0.032** (-2.16)	—	-0.015*** (-4.34)	—	-0.025*** (-5.56)	—	-0.028*** (-6.78)	—	0.005 (0.66)	—	-0.018*** (-7.09)	—	-0.015*** (-4.88)
Cons	-0.027 (-0.37)	-0.017 (-0.22)	-0.024 (-1.41)	-0.027 (-1.58)	0.001 (0.06)	0.007 (0.45)	0.033* (1.72)	0.034* (1.76)	-0.001 (0.01)	0.001 (0.02)	-0.002 (-0.13)	-0.003 (-0.23)	-0.012 (-0.88)	-0.014 (-0.94)
EF.N	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
EF.S	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
EF.C	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R ² Ad	0.0888	0.0980	0.1505	0.1537	0.1267	0.1380	0.1355	0.1486	0.1294	0.1295	0.1348	0.1348	0.1458	0.1492
Obs.	1038	1038	19155	19155	18270	18270	11737	11737	2703	2703	52903	52903	39908	39908
F	106.7***	74.7***	2558.4***	1729.3***	2267.6***	1586.1***	1504.4***	1559.9***	319.6***	213.4***	6686.1***	4571.2***	5251.7***	3554.1***
Chow	1.99***	2.06***	2.36***	2.39***	2.30***	2.38***	2.11***	2.19***	2.04***	2.04***	2.23***	2.27***	2.32***	2.34***
BP	0.00	0.00	32.99***	32.29***	0.00	0.03	25.78***	31.33***	0.00	0.00	58.12***	68.36***	42.30***	49.13***
Haus	175.1***	183.6***	3855.6***	3903.7***	3664.4***	3819.7***	2378.5***	2492.8***	460.2***	461.4***	10605.9***	10842.2***	8186.6***	8291.4***
VIF	1.01	-	1.15	-	1.06	-	1.01	-	1.00	-	1.03	-	1.05	-
Wald	3.54**		7.92***		5.87**		4.79**		3.25**		9.24***		7.70***	

Note: Dependent variable: capital structure adjustment in terms of net-debt. t-statistics in parentheses. Var refers to variables. (1) and (2), (3) and (4), (5) and (6), (7) and (8), (9) and (10), (11) and (12), and (13) and (14) refer to Africa, Americas, Asia, Europe, Oceania, Full Sample, and G20 Group, respectively. SA refers to the Speed of Adjustment. CE refers to the Carbon Emission. MOD refers to the moderation (SA*CB). Cons refers to the constant. EF.N, EF.S, and EF.C, refer to firm, sector, and country fixed effects. R² Ad refers to the R² Adjusted. Obs. refers to the total of Observations. Chow refers to the Chow F test. BP refers to the Breusch-Pagan test. Haus refers to the Hausman test. Wald refers to the Wald test for equality of coefficients across models using SUEST. VIF refers to the Variance Inflation Factor. * p<0.10, ** p<0.05, *** p<0.01

The results are also persistent in Panel C, with net debt used as the independent variable. Also, in Panel B, with indebtedness as the dependent variable, only African firms does not present statistical significance, while in all other cases the results are consistent with the effects documented in Panels A and C. In Panels A, B, and C, all models were estimated using fixed effects for firms, sectors, and countries, as supported by the Chow, Breusch–Pagan, and Hausman test results.

Thus, our results documented that the dynamics of the capital structure adjustment speed are higher and, therefore, remain closer to the target for firms with lower carbon emissions. Our results are robust according to the Wald test, as the null hypothesis of equality between the capital structure adjustment-speed coefficients in the models with and without moderation is rejected. In addition, the results indicate the absence of relevant multicollinearity among the explanatory variables, as indicated by the variance inflation factors (VIF).

6 Discussion and implications

Our results provide evidence that managers partially adjust firms' capital structures toward a target level, in accordance with the dynamic trade-off theory, with adjustment costs playing a central role in preventing instantaneous convergence (Frank & Shen, 2019; Esghaier, 2024; Cumming et al., 2025; Leandro-de-Lima, Silva & Armada, 2025). In fact, our results extend the literature on capital structure adjustment constraints by identifying carbon emissions as a moderating factor that negatively conditions the speed of adjustment toward target capital structures.

From a practical standpoint, our findings indicate that, while carbon emissions do not exhibit a statistically significant direct relationship with capital structure adjustment (except for Europeans firms), they play a central moderating role by negatively affecting the speed of adjustment. In the European context, the stronger institutional engagement with carbon emission policies helps explain the negative relationship observed between carbon emissions and capital structure adjustment (Starks, 2023; Cumming et al., 2024; Billio et al., 2024). Under this institutional setting, the accumulation of regulatory, reputational, and financing pressures associated with higher carbon emissions materially restricts managers'

ability to adjust capital structures, resulting in a reduced intensity of adjustment toward target leverage (Arian & Sands, 2024; Bugshan et al., 2024; Cumming et al., 2025).

To assess economic magnitude, we follow Frank and Shen (2019) and translate the estimated speed of adjustment into an implied adjustment horizon. Specifically, the expected number of periods required to close the adjustment gap is given by $1/(1 - \lambda)$. In the moderated specification, the effective speed of adjustment is $\lambda = \lambda_0 + \lambda_1 \cdot CE$, which allows us to evaluate how economically plausible changes in carbon emissions (e.g., one-standard deviation increase) affect the time needed to converge toward target leverage.

From an economic perspective, our findings are meaningful. When focusing on the speed of adjustment, African firms exhibit a lower adjustment speed coefficient relative to firms in other regions. While firms in most regions converge toward their target capital structures in approximately two periods, African firms require, on average, about three periods to complete this adjustment. These regional differences likely reflect baseline heterogeneity in institutional environments and financial market development (Starks, 2023). However, once the moderating effect of carbon emissions is introduced, African firms with lower carbon emissions also require less than two periods to close the adjustment gap. In addition, these results are robust to Wald tests comparing the estimated speeds of adjustment. Taken together, the evidence is consistent with the sustainable finance literature, which emphasizes the role of environmental factors in shaping firms' dynamic financing decisions (Starks, 2023; Billio et al., 2024).

Therefore, our findings show that carbon emissions matter for listed firms by conditioning the speed at which managers adjust capital structures toward target levels. This finding is in accordance with recent evidence showing that climate-related risks and carbon exposure affect corporate financing dynamics by increasing adjustment constraints (Shu et al., 2023; Arian & Sands, 2024; Cumming et al., 2025). While prior studies primarily focus on the direct effects of carbon risk on financing decisions (Shu et al., 2023; Arian & Sands, 2024; Jiang et al. 2025; Yan et al., 2025), our results indicate that carbon emissions mainly operate through a dynamic moderating channel, shaping the speed rather than the level of capital structure adjustment.

By documenting that carbon emissions shape financing decisions through adjustment dynamics, our results bridge the capital structure literature and the sustainable finance framework, in which environmental risks are increasingly internalized through financial mechanisms rather than normative considerations (Starks, 2023; Billio et al., 2024; Farag & Johan, 2024; Cumming et al., 2025). Taken together, our results present strong robustness and external validity, as they remain consistent across three alternative proxies of corporate capital structure using a global sample of listed firms.

7 Conclusions

Using a partial adjustment framework, we investigate the moderating role of carbon emissions in the dynamics of capital structure adjustment across a global sample of listed firms from Africa, the Americas, Asia, Europe, and Oceania over the 2015–2024 period. From a theoretical perspective, our findings extend the literature by documenting that carbon emissions play a moderating role in the corporate capital structure adjustment process, shaping the speed at which firms converge toward target capital structure. This contribution underscores that environmental externalities constitute economically relevant constraints in firms' financing decisions, emphasizing how sustainable finance decisions influence dynamic capital structure adjustment mechanisms.

From a methodological perspective, within the partial adjustment framework, adjustment costs are treated as latent and not directly observable and are therefore inferred from the estimated speed of adjustment. By incorporating carbon emissions as a moderating variable, our approach provides an empirical channel to capture heterogeneity in implicit adjustment costs. In this setting, higher carbon emissions are associated with higher implicit adjustment costs, which slow down the capital structure adjustment process.

From a practical standpoint, our findings are particularly relevant because, except for Europeans listed firms, we do not observe a statistically significant direct relationship between carbon emissions and capital structure adjustment. This absence of a direct effect underscores that carbon emissions primarily operate through a moderating channel, negatively shaping the speed at which managers adjust capital structures toward target levels. A notable exception is

observed for European firms, where a significant negative direct relationship emerges, likely reflecting the stronger institutional engagement with carbon emission policies.

A limitation of our empirical setting is that the availability of carbon emission data depends on firms' disclosure practices and on Refinitiv's estimation procedures. As a result, the coverage is not universal, and firms included in the usable sample may differ systematically from those for which carbon data are missing. This creates the possibility of sample selection bias. However, several features of our empirical design mitigate this concern. First, differences in disclosure practices are partly driven by institutional and regulatory requirements at the country and industry level (factors that are absorbed by our firm, industry, and country fixed effects). Second, the adjustment model relies on within-firm variation over time, reducing the influence of cross-sectional compositional differences. Third, lagged emissions and robustness across three capital structure proxies help ensure that the moderating effects we document are not driven by disclosure-driven sample composition.

Future research could investigate alternative carbon emission databases, thereby enabling a deeper assessment of how different measurement frameworks and disclosure practices shape the estimated dynamics of corporate financing adjustments. In fact, future research could benefit from more granular and harmonized emission data as disclosure standards continue to evolve. In addition, future research could explore the moderating role of carbon emissions across a broader set of corporate decisions, including dividend policy, cash holdings, investment choices, and liquidity management.

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Appendix

Table A.1

Methodological construct

Variable	Definition
Indebtedness	Item TotalLiabilities / Item TotalAssetsReported
Debt	Item TotalDebtOutstanding / Item TotalAssetsReported
Net-Debt	Item TotalDebtOutstanding - Item CashAndSTInvestments / Item TotalAssetsReported
Carbon emissions	The estimated total CO2 and CO2 equivalents emission in tonnes by Refinitiv
Market-to-book	(Item PriceClose * Item TtlCmn SharesOut) / Item TotEq
Total Assets	Item TotalAssetsReported

Table A.2

Sample description

Variable	Definition
Africa	Egypt, Kenya, Morocco, Nigeria, South Africa, Uganda, and Zimbabwe
Americas	Argentina, Bahamas, Bermuda, Brazil, Canada, Cayman Islands, Chile, Colombia, Mexico, Panama, Peru, Puerto Rico, United States, and Uruguay
Asia	Azerbaijan, Bahrain, Cambodia, China, Hong Kong, India, Indonesia, Israel, Japan, Jordan, Kazakhstan, Korea (South), Kuwait, Macau, Malaysia, Mongolia, Oman, Pakistan, Philippines, Qatar, Saudi Arabia, Singapore, Sri Lanka, Taiwan, Thailand, Turkey, United Arab Emirates, and Vietnam
Europe	Austria, Belgium, Cyprus, Czech Republic, Denmark, Faroe Islands, Finland, France, Germany, Gibraltar, Greece, Guernsey, Hungary, Iceland, Ireland, Isle of Man, Italy, Jersey, Lithuania, Luxembourg, Malta, Monaco, Netherlands, Norway, Poland, Portugal, Romania, Russia, Slovenia, Spain, Sweden, Switzerland, Ukraine, and United Kingdom
Oceania	Australia, and New Zealand
G20 Group	Argentina, Australia, Brazil, Canada, Mexico, United States of America, France, Germany, Italy, United Kingdom, China, India, Indonesia, Japan, Korea; Republic (S. Korea), Saudi Arabia, Turkey, and South Africa

Table A.3

Descriptive statistics

Variable	Observations	Africa			
		Average	Std. Dev.	Minimum	Maximum
Debt	1,038	0.2576	0.1612	0.0000	0.9780
Indebtedness	1,038	0.5358	0.1663	0.0186	0.9840
Net Debt	1,038	0.1533	0.2097	-0.6705	0.8237
Carbon Emissions	1,038	11.6931	2.2878	2.5248	18.0180
Market-to-book	1,038	2.1972	2.6633	0.0000	44.0274
Total Assets	1,038	21.0522	1.2732	14.6109	25.0174

Table A.3 continued on next page

Table A.3
Descriptive statistics (*Continued*)

Americas					
Variable	Observations	Average	Std. Dev.	Minimum	Maximum
Debt	19,155	0.2648	0.1944	0.0000	0.9650
Indebtedness	19,155	0.5293	0.2109	0.0028	0.9997
Net Debt	19,155	0.0936	0.3487	-0.9978	0.9473
Carbon Emissions	19,155	10.7803	2.9563	-2.2538	19.1810
Market-to-book	19,155	10.1698	408.342	0.0000	38747.8
Total Assets	19,155	21.6810	1.8135	14.4307	27.7742
Asia					
Variable	Observations	Average	Std. Dev.	Minimum	Maximum
Debt	18,270	0.2306	0.1702	0.0000	0.8929
Indebtedness	18,270	0.4677	0.1949	0.0031	0.9978
Net Debt	18,270	0.0523	0.2744	-0.9471	0.8679
Carbon Emissions	18,270	11.9828	2.6619	-1.5141	19.7919
Market-to-book	18,270	3.2117	13.4654	0.0000	1206.30
Total Assets	18,270	22.1869	1.5384	15.2325	27.2209
Europe					
Variable	Observations	Average	Std. Dev.	Minimum	Maximum
Debt	11,737	0.2573	0.1626	0.0000	0.9444
Indebtedness	11,737	0.5533	0.1870	0.0000	0.9984
Net Debt	11,737	0.1265	0.2411	-0.9980	0.8633
Carbon Emissions	11,737	10.7675	3.0761	-1.1712	19.8645
Market-to-book	11,737	3.4783	10.3011	0.0000	593.048
Total Assets	11,737	21.7746	1.8626	14.3184	27.2199
Oceania					
Variable	Observations	Average	Std. Dev.	Minimum	Maximum
Debt	2,703	0.2215	0.1668	0.0000	0.9713
Indebtedness	2,703	0.4358	0.2004	0.0028	0.9972
Net Debt	2,703	0.0720	0.3138	-0.9851	0.9132
Carbon Emissions	2,703	9.5100	3.1501	-4.4351	17.5981
Market-to-book	2,703	4.2545	18.6983	0.0227	606.622
Total Assets	2,703	20.4660	1.9080	13.9827	25.5020

Table A.4
Correlation Matrix

Africa							Americas						
	1	2	3	4	5	6		1	2	3	4	5	6
1	1.00						1	1.00					
2	0.56*	1.00					2	0.73*	1.00				
3	0.91*	0.46*	1.00				3	0.82*	0.66*	1.00			
4	-0.05*	0.01	-0.04	1.00			4	0.31*	0.37*	0.52*	1.00		
5	0.10*	0.25*	0.02	-0.03	1.00		5	-0.01*	-0.01*	-0.04*	-0.02*	1.00	
6	0.13*	0.04	0.15*	0.49*	-0.09*	1.00	6	0.42*	0.42*	0.53*	0.73*	-0.02*	1.00
Asia							Europe						
	1	2	3	4	5	6		1	2	3	4	5	6
1	1.00						1	1.00					
2	0.75*	1.00					2	0.61*	1.00				
3	0.88*	0.69*	1.00				3	0.85*	0.52*	1.00			
4	0.32*	0.27*	0.34*	1.00			4	0.19*	0.26*	0.28*	1.00		

Table A.4 continued on next page

Table A.4Correlation Matrix (*continued*)

5	-0.02*	0.05*	-0.05*	-0.09*	1.00		5	-0.01	0.09*	-0.07*	-0.10*	1.000	
6	0.32*	0.38*	0.33*	0.62*	-0.11*	1.00	6	0.26*	0.30*	0.33*	0.74*	-0.10*	1.00
Oceania							Full Sample						
	1	2	3	4	5	6		1	2	3	4	5	6
1	1.00						1	1.00					
2	0.69*	1.00					2	0.69*	1.00				
3	0.82*	0.61*	1.00				3	0.82*	0.61*	1.00			
4	0.26*	0.33*	0.41*	1.00			4	0.26*	0.34*	0.41*	1.00		
5	0.04*	0.13*	-0.06*	-0.09*	1.00		5	0.04*	0.13*	-0.06*	-0.09*	1.00	
6	0.38*	0.35*	0.55*	0.74*	-0.12*	1.00	6	0.38*	0.35*	0.55*	0.74*	-0.12*	1.00

Note: (1) is the debt, (2) is the indebtedness, (3) is the net-debt, (4) is the ln(carbon emission), (5) is the market-to-book, and (6) is the ln(total assets).