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Internal Governance, Voluntary Climate Commitments and Regulatory Quality as Drivers of Corporate Climate Risk Management: Evidence from a 43-Country Panel of Carbon-Intensive Firms

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Abstract

Carbon-intensive firms face mounting pressure to develop substantive corporate climate risk management (CCRM), yet its firm-level and country-level antecedents remain unevenly understood. Drawing on stakeholder and institutional theory, we examine three drivers of CCRM: sustainability governance, voluntary climate-membership commitments, and regulatory quality. Our data cover 1,295 firm-year observations across 43 countries over 2018–2022. We estimate ordered logistic regressions with lagged regressors, with ordered probit, two-step system GMM, and sub-sample robustness checks. In the main specification, sustainability governance and regulatory quality are both positive antecedents ($\beta = 2.441$ and $\beta = 1.676$, $p < 0.001$); climate membership exerts a sector-conditional effect concentrated in energy and basic materials. Sub-sample analyses reveal that internal governance dominates among non-state-owned firms, while among state-owned firms (a sub-sample heavily concentrated in Chinese SOEs) regulatory quality dominates instead. We frame the latter as suggestive context-conditional substitution rather than a universal feature of state ownership. CCRM is highly persistent (system-GMM lagged coefficient = 0.693, $p < 0.001$), suggesting that climate risk management is best understood as a path-dependent organizational capability built incrementally over time. Firms strengthening CCRM should invest in integrated governance architecture; regulators should treat regulatory-quality reform as complementary to direct climate mandates.

Keywords: corporate climate risk management; sustainability governance; climate membership; regulatory quality; ESG; net-zero transition; ordered logit; system GMM; institutional theory; stakeholder theory

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1. Introduction

Climate change has emerged as one of the defining challenges of the twenty-first century, reshaping markets, communities, and corporate strategy [1]. The World Economic Forum [2] ranks climate-related risks among the most material long-horizon threats to global economic activity, and recent industry surveys indicate that a clear majority of large firms now classify climate change as a material financial risk [3]. A growing stream of cross-country evidence shows that national-level innovation capacity and regulatory quality reduce climate vulnerability [4,5]. The present study turns from the country to the firm and asks which firm-level and country-level mechanisms most reliably translate into substantive corporate climate risk management. The corporate sector occupies a dual position in the climate landscape: it is at once a major contributor to greenhouse-gas emissions [6] and a primary site at which climate impacts crystallize into operational damage and financial losses [7].

The Task Force on Climate-related Financial Disclosures [8] divides corporate climate exposure into two categories. Physical risks include acute events such as floods and chronic shifts such as sea-level rise. Transition risks arise from the move to a low-carbon economy and include policy, technology, market, and reputational pressures. Both categories translate into financial risk that, if unmanaged, can materially impair operations and long-term viability [9,10]. In response, regulators, investors, and standard setters have intensified pressure on firms to disclose, govern, and substantively manage these risks. The implementation of TCFD-aligned disclosures, the IFRS Sustainability Disclosure Standards (S1 and S2), the European Corporate Sustainability Reporting Directive (CSRD), and the proliferation of voluntary initiatives such as the Science Based Targets initiative (SBTi) and Climate Action 100+ collectively constitute a fast-evolving institutional environment for corporate climate risk management (CCRM).

Despite this policy salience, the empirical literature on the firm-level and country-level antecedents of CCRM remains underdeveloped. Existing studies have tended to (i) measure CCRM using single-item or restricted indicators, (ii) examine antecedents in isolation rather than jointly, and (iii) rely on estimators that do not adequately address the endogeneity, simultaneity, and dynamic feedback that plausibly characterize the relationship between governance, voluntary commitments, and risk management [11,12]. As a result, three important questions remain only partially answered. First, which internal governance mechanisms most reliably translate into CCRM? Second, do voluntary climate alliances such as RE100, SBTi, and the UN Global Compact actually shift firm behavior, or do they primarily signal pre-existing commitments? Third, does the broader regulatory environment substitute for, or complement, firm-level governance in driving CCRM?

This study addresses these questions using an unbalanced panel of 1,295 firm-year observations on carbon-intensive firms drawn from 43 countries over 2018–2022. We make four contributions. First, we examine sustainability governance, climate membership, and regulatory quality jointly within a single integrated framework anchored in stakeholder theory [13] and institutional theory [14,15]. This extends prior cross-country work on the institutional drivers of climate vulnerability and adaptive capacity [4,5] to the firm-level domain. Second, we provide new evidence on how voluntary climate-membership commitments shape CCRM, distinguishing this construct from related concepts such as climate disclosure and CSR strategy. Third, we adopt a methodologically rigorous identification strategy that combines ordered logistic regression with one-period-lagged independent variables as the main model, and adds ordered probit, two-step system Generalised Method of Moments (GMM), and sub-sample analyses as robustness checks. This battery addresses concerns about endogeneity, dynamic feedback, and unobserved heterogeneity. Fourth, we document substantial persistence in CCRM (lagged-DV coefficient = 0.693, $p < 0.001$ in the system-GMM specification), which we read as evidence that climate risk management is a path-dependent organizational capability built incrementally over time, with implications for both research design and managerial practice.

The cross-country panel design we adopt is well suited to identifying institutional patterns that are most informative for emerging-market regulators and policymakers, complementing the OECD-centric focus that has characterized much of the prior literature on CCRM antecedents.

The remainder of the paper is organized as follows. Section 2 develops the theoretical framework and hypotheses. Section 3 describes the data, variables, and empirical strategy. Section 4 reports descriptive, main, and robustness results. Section 5 discusses the findings in relation to theory and prior evidence. Section 6 concludes with implications, limitations, and directions for future research.

2. Theoretical Background and Hypotheses

2.1. Corporate Climate Risk Management

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Corporate climate risk management (CCRM) refers to the structured set of organizational processes by which a firm identifies, assesses, monitors, and mitigates climate-related physical and transition risks, and integrates the resulting risk information into strategic decision-making [16,17]. The TCFD framework, which has been widely adopted as the de facto international standard, articulates four pillars of effective CCRM: governance, strategy, risk management process, and metrics and targets [8]. Effective CCRM is therefore both a process (how risks are identified and tracked) and a strategic posture (how risk information shapes capital allocation, product portfolios, and supply-chain choices).

Prior empirical work on CCRM antecedents is sparse and methodologically heterogeneous. Kouloukoui et al. [6,18] report that profitability, firm size, regulatory exposure, and creditor pressure shape CCRM among the world's largest emitters. Sakhel [17] finds that European firms exhibit substantial heterogeneity in CCRM preparedness, with regulatory and market risk perceptions as primary drivers. Mbanyele and Muchenje [19] and Chalabi-Jabado and Ziane [20] provide cross-country evidence linking climate exposure to financial performance and lending growth. Wijethilake and Lama [21] argue that internalising sustainability into organisational core values is a stronger predictor of sustainability risk management than reactive compliance. Adamolekun [22] shows that climate risk can translate into bankruptcy risk, motivating proactive CCRM as a strategic response. At the country level, Abdelzaher et al. [4] show that innovation capacity, regulatory quality, and openness to trade reduce a country's vulnerability to climate change. Abdelzaher, Abdel Zaher, and Chambers [5] separate governance "push" (government effectiveness) from governance "pull" (voice and accountability) and show that both, conditional on innovation capacity, build national adaptive capacity to climate change. The present study extends this country-level evidence to the firm level, asking whether the analogous internal-external distinction operates at the corporate scale.

Notwithstanding these contributions, the literature continues to suffer from three shortcomings: a tendency to measure CCRM using single binary indicators that fail to capture the layered nature of the construct; the examination of antecedents in isolation, which obscures their relative importance and potential interactions; and the use of identification strategies that rarely address the bidirectional relationship between governance choices and risk management. Firms that recognize climate risk may simultaneously establish governance structures and climate-management processes, generating simultaneity bias that confounds inference about which drivers truly cause CCRM. Our study addresses each of these gaps.

2.2. Theoretical Framework

2.2.1. Stakeholder Theory

Stakeholder theory [13] holds that firms are accountable to a broad constellation of constituencies, including investors, customers, employees, regulators, communities, and the natural environment. The claims of these constituencies must be balanced for long-run organizational legitimacy and survival. Applied to climate risk, stakeholder theory predicts that firms exposed to growing pressure from climate-conscious stakeholders will develop internal governance architecture that operationalises climate accountability [23,24]. Sustainability governance, through committees, executive compensation, and reporting, is the institutional embodiment of this accountability inside the firm. We therefore use stakeholder theory to develop our hypothesis on sustainability governance.

2.2.2. Institutional Theory

Institutional theory [14,15] explains how firms adopt structures and practices in response to coercive, mimetic, and normative pressures from their institutional environment. Coercive pressures derive from regulatory mandates and powerful resource-providers. Mimetic pressures arise when firms imitate the practices of successful peers under uncertainty. Normative pressures stem from professional networks, industry associations, and shared standards. The push/pull governance framework articulated by Abdelzaher, Abdel Zaher, and Chambers [5] usefully maps these institutional channels onto two complementary mechanisms: governance "push" is the coercive pressure exerted by effective regulation, and governance "pull" is the normative pressure exerted by voice and accountability mechanisms that draw firms toward higher standards. Applied to CCRM at the firm level, this framework predicts that the regulatory quality of a firm's home country (a coercive force) and its participation in voluntary climate alliances (a normative-mimetic pull) will both influence the depth and quality of climate risk management. We use institutional theory, informed by this push/pull mapping, to develop our hypotheses on regulatory quality and climate membership.

2.3. Hypothesis Development

2.3.1. Sustainability Governance and CCRM

Sustainability governance encompasses the formal mechanisms through which a firm encodes environmental and social objectives into its decision-making architecture. Following prior research [25–27], we identify three principal components: a board-level sustainability committee, sustainability-linked executive compensation, and sustainability reporting. Each operates through a distinct theoretical mechanism. A sustainability committee creates a dedicated organizational locus for environmental oversight, ensuring that climate matters reach the highest levels of corporate governance [28,29]. Sustainability-linked executive compensation aligns managerial incentives with environmental outcomes [30,31]. Sustainability reporting enhances transparency and creates accountability that motivates substantive climate action [32]. Aggregated, these mechanisms constitute a governance architecture that we expect to be the most consequential firm-level driver of CCRM.

H1. *Stronger sustainability governance is positively associated with corporate climate risk management.*

2.3.2. Climate Membership and CCRM

Voluntary climate alliances such as RE100, Climate Action 100+, the Science Based Targets initiative (SBTi), and the UN Global Compact are a fast-growing institutional category through which firms make collective commitments to climate-related goals. From an institutional-theoretic perspective, membership in such alliances exerts both normative and mimetic pressures on participating firms. This is what Abdelzaher et al. [5] characterize as the governance "pull" channel: members internalize shared norms about appropriate climate behavior and become subject to peer accountability [15]. Membership also generates mimetic pressure as members observe practices among peers and are pressed to imitate. Barbero et al. [33] report that climate-club membership improves environmental performance among regional firms. Orsato et al. [34] document the institutional drivers of carbon-club participation among Brazilian banks. Adamolekun et al. [35] find that climate membership is positively associated with climate risk exposure, although they do not test whether this translates into stronger CCRM. Our study addresses this gap.

H2. *Membership in a climate-related organization or initiative is positively associated with corporate climate risk management.*

2.3.3. Regulatory Quality and CCRM

Beyond firm-level antecedents, the macro-institutional environment shapes the costs and benefits of climate risk management. Regulatory quality, as measured by the World Bank's Worldwide Governance Indicators, captures perceptions of a government's ability to formulate and implement sound policies that promote private-sector development [36]. High regulatory quality typically co-occurs with predictable, well-enforced environmental rules, which exerts coercive pressure on firms to manage climate risks systematically. This is what Abdelzaher et al. [5] identify

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as the governance "push" channel [37–39]. Country-level evidence supports this argument directly. Abdelzaher, Martynov, and Abdel Zaher [4] show that higher regulatory quality reduces a country's vulnerability to climate change. Handoyo and Fitriyah [40] provide cross-national evidence that regulatory quality is positively associated with environmental sustainability outcomes. We extend this country-level evidence to the firm level by hypothesizing a parallel positive relationship between regulatory quality and corporate climate risk management.

H3. *Regulatory quality is positively associated with corporate climate risk management.*

Figure 1 summarises the conceptual model. Stakeholder theory motivates H1, in which sustainability governance is the firm-level architecture through which stakeholder pressure is converted into substantive climate risk management. Institutional theory's normative-mimetic ("pull") channel motivates H2, in which voluntary climate-membership commitments draw firms toward higher CCRM through peer accountability and imitation. Institutional theory's coercive ("push") channel motivates H3, in which the regulatory quality of the firm's home country exerts coercive pressure to manage climate risks systematically. The model also reflects the strong path-dependence in CCRM that we document empirically (system-GMM autoregressive coefficient = 0.693), shown as the self-loop on the dependent variable.

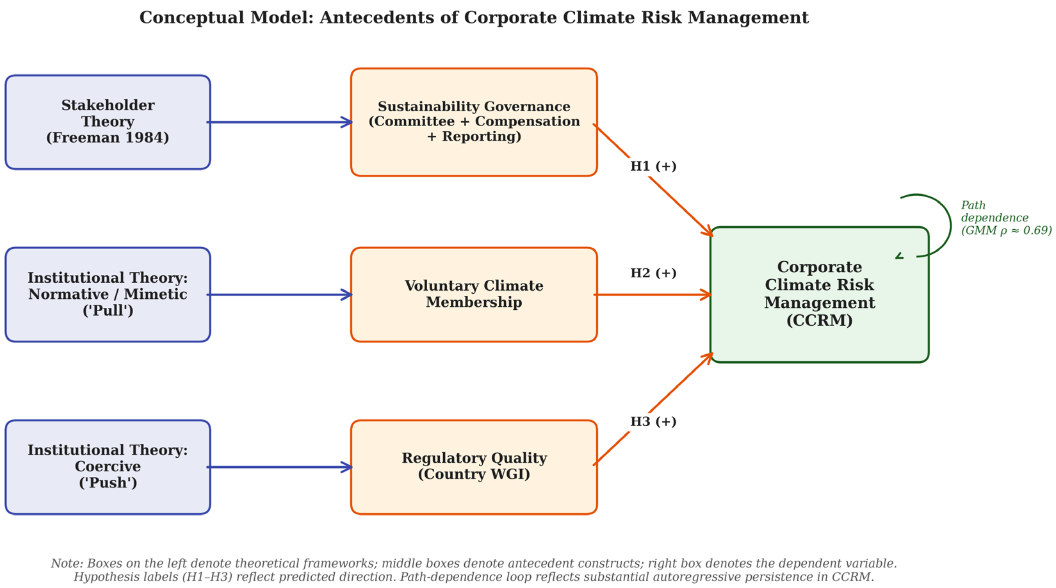

Figure 1. Conceptual model: theoretical drivers of corporate climate risk management. The left column denotes theoretical frameworks; the middle column denotes the antecedent constructs we test; and the right column denotes the dependent variable, CCRM. Stakeholder theory motivates H1 (sustainability governance → CCRM); the normative-mimetic ("pull") channel of institutional theory motivates H2 (climate membership → CCRM); and the coercive ("push") channel of institutional theory motivates H3 (regulatory quality → CCRM). The self-loop on CCRM denotes the path-dependence pattern documented empirically (system-GMM autoregressive coefficient = 0.693).

Note on CSR strategy. Corporate social responsibility (CSR) strategy is closely related to but conceptually distinct from sustainability governance: CSR strategy reflects a firm's stated commitment to balancing economic, environmental, and social objectives, whereas sustainability governance is the organizational architecture through which such commitments are operationalized. We treat CSR strategy as conceptually downstream of sustainability governance for two reasons. First, the architectural mechanisms that constitute SG (a board-level sustainability committee, sustainability-linked compensation, sustainability reporting) are organizational preconditions for

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translating a CSR commitment into substantive action; without these mechanisms, CSR strategy is a stated intention without an enforcement structure. Second, prior empirical work suggests that CSR strategy operates at least partly through governance mechanisms rather than as an independent channel [41–43]. Because our identification strategy emphasizes the temporal precedence of governance over CCRM, and because including a downstream variable on the same side of the equation as its upstream antecedent risks attenuating the SG coefficient through over-controlling, we include CSR strategy as a control variable rather than as a hypothesized antecedent. This decision is supported empirically by our results, in which CSR strategy is consistently non-significant once governance is controlled, with the exception of a within-country effect under country fixed effects (§4.7) that we discuss as a finding worth flagging for future work.

3. Materials and Methods

3.1. Sample and Data

The sample comprises carbon-intensive firms (those classified within the energy, industrials, and basic materials sectors) drawn from 43 countries over the period 2018–2022. The sectoral focus is motivated by the disproportionate climate exposure of these industries: they account for the bulk of corporate greenhouse-gas emissions and consequently face the most intense pressure to develop CCRM capabilities. The sample period begins in 2018 to align with the consolidation of TCFD-aligned disclosures and ends in 2022, the most recent year for which complete data on all variables were available at the time of analysis.

Firm-level data on the dependent variable, sustainability-governance components, climate membership, CSR strategy, and firm-level controls were sourced from LSEG Workspace (formerly Refinitiv Eikon), which has been widely used in recent corporate sustainability research. Country-level controls (regulatory quality, log GDP, and climate vulnerability) were sourced from the World Bank's Worldwide Governance Indicators (WGI), the World Bank's World Development Indicators (WDI), and the ND-GAIN Country Index, respectively. After requiring non-missing values on all variables of interest, the analytical sample for descriptive analysis comprises 1,295 firm-year observations across 259 firms. Lagging the explanatory variables and applying listwise deletion across all covariates yields 707 firm-year observations across 243 firms for the main ordered logit estimation.

3.2. Variable Measurement

Table 1 summarises the measurement and source of each variable. The dependent variable, CCRM, is constructed as the equally weighted average of two binary LSEG indicators. The first, drawn from the LSEG Workspace ESG environmental pillar, captures whether the firm has a documented process to manage climate-related risks (LSEG field: "Climate Change Risk Mitigation – Policy"; values 0/1). The second captures whether the firm has integrated climate risk management into its broader business strategy (LSEG field: "Strategy to Reduce Environmental Impact – Climate Change"; values 0/1). The composite therefore takes one of three values: 0 (firm reports neither a documented process nor strategic integration; "None"), 0.5 (firm reports one but not both; "Partial"), and 1 (firm reports both; "Full"). LSEG codes these indicators based on a structured review of corporate disclosures, sustainability reports, and policy documents, with annual updates.

The three-category ordinal scale has two trade-offs we want to acknowledge. On the one hand, it provides limited gradation — a richer continuous measure (such as the LSEG ESG environmental pillar score) would carry more information per observation. On the other hand, the binary underlying indicators are objective and reproducible from public disclosures, whereas continuous ESG scores embed proprietary scoring weights that vary substantially across providers and have been shown to correlate poorly across them [48]. We therefore favour the construct-valid but coarser ordinal measure and explicitly model its discreteness using ordered logit. Because the construct is ordinal rather than continuous, our preferred estimator is ordered logistic regression, with linear models reported only as supplementary robustness.

Table 1. Variable measurement and sources.

Variable	Operational definition	Source
	Dependent variable	
CCRM (ClimateRiskMgt)	Equally weighted average of two binary indicators: (1) firm has a process to manage climate-related risks; (2) firm integrates climate risk management into business strategy. Range: 0–1; values: {0, 0.5, 1}.	LSEG Workspace
	Independent variables	
Sustainability Governance (SG)	Equally weighted index of three binary mechanisms: sustainability committee, sustainability-linked compensation, and sustainability reporting. Range: 0–1.	LSEG Workspace
Climate Membership (CM)	Binary: 1 if firm is a member of any climate-focused organization or initiative; 0 otherwise.	LSEG Workspace
Regulatory Quality (RQ)	WGI regulatory-quality estimate; range −2.5 to +2.5; higher is stronger.	World Bank WGI
	Control variables	
CSR Strategy (csrstr)	LSEG CSR strategy score (0–100).	LSEG Workspace
ROA	Net income divided by total assets.	LSEG Workspace
Log Firm Size	Natural log of total assets.	LSEG Workspace
Log GDP	Natural log of country GDP (current USD).	World Bank WDI
Climate Vulnerability	ND-GAIN vulnerability score (0–1); higher is more vulnerable.	ND-GAIN

3.3. Empirical Strategy

Identifying the determinants of CCRM raises three methodological challenges. First, the dependent variable is ordinal with three values (0, 0.5, 1), making linear estimation suboptimal. Second, the relationship between governance choices and CCRM is plausibly bidirectional, as firms recognizing climate risk may concurrently invest in governance mechanisms, which generates simultaneity bias. Third, panel diagnostics (reported in Section 4) indicate heteroskedasticity and within-firm autocorrelation that bias OLS standard errors. To address these issues, we adopt a triangulated estimation strategy.

Main model: Ordered logistic regression with one-period-lagged independent variables.

We estimate an ordered logit model with the lag of each independent and control variable to mitigate reverse causality and impose temporal precedence of governance over CCRM:

$$Pr(CCRM_{it} = j) = \Lambda(\tau_j - [\beta_1 SG_{it-1} + \beta_2 CM_{it-1} + \beta_3 RQ_{it-1} + \gamma' X_{it-1}]) - \Lambda(\tau_{j-1} - [\cdot]),\ j \in \{0, 1, 2\}$$

where $\Lambda(\cdot)$ is the logistic CDF, τ_j are the cut-points, and X_{it-1} is the vector of controls (CSR strategy, ROA, log firm size, log GDP, climate vulnerability). Standard errors are clustered at the firm (company) level. Industry (TRBC sector) and year fixed effects are included.

Robustness 1: Ordered probit.

We re-estimate the main model using ordered probit to ensure findings are not driven by the logistic functional-form assumption.

Robustness 2: Two-step system Generalized Method of Moments (GMM).

To address potential endogeneity from unobserved firm heterogeneity and dynamic feedback, we estimate a two-step system GMM model [44,45], instrumenting endogenous regressors with their second and third lags in levels and first differences (collapsed to limit instrument count). We treat CCRM as continuous in this specification because the dynamic-panel framework presumes a linear conditional expectation. The system-GMM estimation also yields a coefficient on the lagged dependent variable, providing direct evidence on the persistence of CCRM. We report Hansen J statistics for instrument validity and Arellano–Bond AR(1)/AR(2) tests for first- and second-order autocorrelation.

Robustness 3: Sub-sample analyses by sector and state ownership.

We re-estimate the main model separately for the energy, industrials, and basic-materials sub-samples, and separately for state-owned and non-state-owned firms, to assess whether the determinants of CCRM operate uniformly across institutional contexts.

Robustness 4: Horse-race specification with lagged dependent variable.

To assess whether the contemporaneous effects of governance and regulatory quality survive once the autoregressive structure of CCRM is accounted for in the ordered-logit framework, we re-estimate the main specification including the one-period-lagged ordinal CCRM as a categorical regressor. This complements the system-GMM specification by separating contemporaneous drivers from path-dependent persistence within the same ordinal-DV framework as the main model.

Robustness 5: Country fixed effects and supplementary checks.

We further re-estimate the main specification with country fixed effects (which absorb time-invariant country-level institutional variation, including regulatory quality and log GDP), and conduct drop-one country-level control sensitivity analyses to address the multicollinearity among country-level variables.

4. Results

4.1. Descriptive Statistics

Table 2 reports descriptive statistics for the analytical sample. The mean CCRM score is 0.438 (SD = 0.429). Of the 906 non-missing CCRM observations, 41.2 % score zero, 22.5 % score 0.5, and 34.0 % score 1.0, confirming substantial cross-sectional variation in CCRM adoption. Sustainability governance averages 0.705 (SD = 0.265), indicating that governance mechanisms are widely (though not uniformly) adopted in the carbon-intensive sample. Only 11.6 % of firm-years involve climate-membership participation, underscoring the still-nascent diffusion of voluntary climate alliances. CSR strategy averages 67.1 out of 100. Regulatory quality varies from −0.418 to 2.014 (mean = 0.796), reflecting meaningful institutional heterogeneity across the 43 sample countries.

Table 2. Descriptive statistics.

Variable	Obs	Mean	SD	Min	Max
CCRM	906	0.438	0.429	0.000	1.000
Sustainability Governance	1,295	0.705	0.265	0.000	1.000

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Climate Membership	1,720	0.116	0.321	0.000	1.000
Regulatory Quality	1,295	0.796	0.812	−0.418	2.014
CSR Strategy	1,295	67.112	26.602	0.000	99.980
Climate Vulnerability	1,295	0.332	0.041	0.250	0.460
ROA	1,295	0.052	0.070	−0.288	0.541
Log GDP	1,295	4.426	0.397	3.280	5.037
Log Firm Size	1,295	10.131	0.572	8.447	11.643

Note: Sample restricted to firms with non-missing values on the indicated variable; observation counts vary because of variable-specific missingness. Source: Authors' compilation.

4.2. Diagnostic Tests

Pre-estimation panel diagnostics on the linear specification of CCRM indicate that a modified Wald test rejects homoskedasticity (χ^2 = 432,376; p < 0.001), and a Wooldridge test rejects no first-order autocorrelation (F = 280.43; p < 0.001). Pesaran's CD test fails to reject cross-sectional independence (statistic = −0.566; p = 0.571). The Hausman test rejects the random-effects specification in favor of fixed effects (χ^2 = 48.92; p < 0.001). Together, these results confirm that linear-OLS standard errors would be misleading and motivate (i) the choice of ordered logit (which addresses the discrete nature of the dependent variable directly) for the main model and (ii) the use of system GMM as a dynamic-panel robustness check that accommodates unobserved heterogeneity.

Variance Inflation Factors (untabulated for brevity, but reported in Supplementary Materials) show that the highest VIF is for log GDP (7.99), followed by regulatory quality (5.55) and climate vulnerability (3.53), all below the conservative threshold of 10 [46]. Because three country-level variables are highly correlated, we conduct drop-one sensitivity analyses (also reported in Supplementary Materials) confirming that the substantive results are robust to omitting any one of the country-level controls.

4.3. Main Results: Ordered Logit with Lagged Independent Variables

Table 3 presents the main results from the ordered logit model with one-period-lagged regressors. Sustainability governance is positively and strongly associated with CCRM (β = 2.441, p < 0.001), supporting H1 with a substantial effect size. Climate membership exhibits a marginal positive effect (β = 0.928, p = 0.075), providing partial support for H2. Regulatory quality is positively and significantly associated with CCRM (β = 1.676, p < 0.001), supporting H3. CSR strategy is not significant (β = 0.007, p = 0.323), consistent with our decision to treat it as a control rather than a hypothesized antecedent. The Pseudo R^2 of 0.308 indicates good model fit for an ordered-logit specification, and the Wald $\chi^2(13)$ of 186.61 (p < 0.001) confirms overall model significance. The ordered probit specification (column 2) yields qualitatively identical results, confirming that findings are not driven by the logistic functional form.

Table 3. Main results — ordered logit and ordered probit (lagged regressors).

Variable (lagged)	(1) Ordered Logit	(2) Ordered Probit
Sustainability Governance (SG)	2.441*** (0.634)	1.531*** (0.354)
Climate Membership	0.928† (0.521)	0.501† (0.275)
CSR Strategy	0.007 (0.007)	0.003 (0.004)

Regulatory Quality	1.676*** (0.384)	0.949*** (0.218)
ROA	4.808* (2.105)	2.697* (1.198)
Log Firm Size	0.531† (0.280)	0.284† (0.157)
Log GDP	−0.054 (0.970)	−0.034 (0.550)
Climate Vulnerability	1.304 (6.365)	0.570 (3.584)
Industry FE (TRBC Sector)	Yes	Yes
Year FE	Yes	Yes
Cut-point τ_1	9.269 (6.229)	5.053 (3.471)
Cut-point τ_2	11.119 (6.265)	6.116 (3.488)
Observations	707	707
Clusters (firms)	243	243
Pseudo R^2	0.308	0.307
Wald χ^2 (df = 13)	186.61***	221.43***

*Notes: Robust standard errors clustered at the firm level in parentheses. †p < 0.10; *p < 0.05; **p < 0.01; ***p < 0.001. Source: Authors' estimation.*

4.4. Robustness: Two-Step System GMM

Table 4 reports two-step system GMM estimates that address endogeneity from unobserved firm heterogeneity and dynamic feedback. The lagged dependent variable enters with a coefficient of 0.693 ($p < 0.001$), indicating substantial persistence in CCRM: roughly 69 % of the previous year's CCRM score carries into the following year. Once persistence is accounted for, the contemporaneous coefficients on sustainability governance, climate membership, and regulatory quality are no longer statistically significant at conventional thresholds. We read this as evidence that CCRM is a slowly accumulating organizational capability. The lagged ordered-logit specifications identify the influence of governance and regulation on CCRM transitions across periods, while the GMM specification additionally absorbs the strong autoregressive component of CCRM into the lagged-DV term. Diagnostic tests support the GMM specification: the AR(1) test rejects ($p < 0.001$), the AR(2) test does not reject ($p = 0.456$), and the Hansen J-test ($\chi^2(10) = 15.13$, $p = 0.127$) does not reject the over-identifying restrictions. The difference-in-Hansen test for the additional level moment conditions of the system estimator yields $p = 0.086$, which is borderline at the 10% level; we read this as suggestive but not strong evidence against the additional level moments, and we therefore report system-GMM rather than difference-GMM as our preferred dynamic specification while noting that the lagged-IV ordered logit (Table 3) remains our primary estimator. The number of instruments (23) is well below the rule-of-thumb ceiling of one instrument per panel (259 firms).

Table 4. Two-step system GMM estimation.

Variable	Coefficient	Std. error
CCRM (t−1)	0.693***	0.089
Sustainability Governance	−0.034	0.148
Climate Membership	−0.031	0.058

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CSR Strategy	0.003†	0.002
Regulatory Quality	0.104	0.080
ROA	0.028	0.129
Log Firm Size	−0.018	0.032
Log GDP	−0.058	0.162
Climate Vulnerability	−0.335	0.426
Year FE	Yes	
Constant	0.496	0.594
Observations	1,036	
Number of firms (groups)	259	
Number of instruments	23	
F-statistic	823.26 (p < 0.001)	
AR(1) test (p-value)	0.000	
AR(2) test (p-value)	0.456	
Hansen J test (p-value)	0.127	
Diff-in-Hansen test (p-value)	0.086	

*Notes: Two-step system GMM with Windmeijer-corrected robust standard errors. Endogenous variables (lagged CCRM, SG, climate membership, CSR strategy, regulatory quality) instrumented with second and third lags in levels and first differences (collapsed). Strictly exogenous variables (ROA, log firm size, log GDP, climate vulnerability) and year dummies enter the level equation directly. †p < 0.10; *p < 0.05; **p < 0.01; ***p < 0.001. Source: Authors' estimation.*

4.5. Sub-Sample Analyses

4.5.1. Sectoral Heterogeneity

Table 5 disaggregates the main ordered-logit specification by industry sector. Sustainability governance is the dominant driver in the industrials sub-sample (β = 3.429, p < 0.001) and remains positive but non-significant in energy and basic materials. Climate membership exhibits the opposite pattern: it is significant in energy (β = 1.749, p = 0.017) and basic materials (β = 2.043, p = 0.063), but not in industrials. Regulatory quality is most influential in basic materials (β = 2.926, p < 0.001) and significant in industrials (β = 1.417, p = 0.015), but not in energy. These patterns suggest that the substitutability of internal governance and external institutional pressure depends on sectoral context. In industrials, where firms are larger, more diversified, and operate under heterogeneous regulatory regimes, internal governance is the primary lever. In energy and basic materials, sectors under sustained climate scrutiny, voluntary alliances and regulatory environments play more visible roles.

Table 5. Sub-sample ordered logit by sector (lagged regressors).

Variable (lagged)	Industrials	Energy	Basic Materials
Sustainability Governance	3.429*** (0.954)	1.846 (1.775)	1.715 (1.187)
Climate Membership	0.121 (0.544)	1.749* (0.734)	2.043† (1.097)

CSR Strategy	0.005 (0.009)	0.019 (0.021)	0.001 (0.014)
Regulatory Quality	1.417* (0.585)	1.496 (1.028)	2.926*** (0.714)
ROA	6.100* (2.977)	6.156 (5.593)	2.341 (2.929)
Log Firm Size	0.182 (0.391)	−0.142 (0.547)	1.765** (0.599)
Log GDP	−0.050 (1.721)	0.440 (3.199)	−1.732 (1.547)
Climate Vulnerability	−7.469 (11.089)	0.103 (20.990)	9.358 (9.208)
Year FE	Yes	Yes	Yes
Observations	354	116	237
Clusters (firms)	122	41	80
Pseudo R^2	0.336	0.298	0.326
Wald χ^2 (df = 11)	108.78***	55.41***	101.23***

*Notes: Robust standard errors clustered at the firm level in parentheses. †p < 0.10; *p < 0.05; **p < 0.01; ***p < 0.001. Source: Authors' estimation.*

4.5.2. State Ownership

Table 6 contrasts state-owned enterprises (SOEs) with non-state-owned firms. The pattern is striking. Among non-SOEs, sustainability governance ($\beta = 2.234$, $p = 0.001$) and regulatory quality ($\beta = 1.035$, $p = 0.041$) both exert significant positive effects, with internal governance carrying a larger coefficient than external institutional quality. Among SOEs, the picture inverts: regulatory quality dominates with a much larger effect ($\beta = 4.591$, $p = 0.002$), while internal governance is non-significant. The Pseudo R^2 is also markedly higher for the SOE sub-sample (0.431 vs 0.246), reflecting the tighter coupling between regulatory environment and CCRM in firms with direct state ties. We note an important caveat. The SOE analytical sub-sample is composed disproportionately of Chinese firms: 145 of the 185 SOE firm-year observations (78.4%) are from China (Mainland), with the next-largest contributors being India (4.9%), Indonesia (4.3%), and Saudi Arabia (3.8%). When we attempt to re-estimate the SOE specification excluding Chinese SOEs, the model fails to converge on the residual sub-sample of 40 observations across 13 firms because of complete separation, indicating that the data do not permit a clean test of whether the SOE pattern generalises beyond China. We therefore read the SOE results in this section as suggestive evidence about Chinese SOEs specifically, rather than as evidence about state-owned firms in general. We discuss the substantive interpretation, and the corresponding caveat for the institutional-substitution argument, in Section 5.3.

Table 6. Sub-sample ordered logit by state ownership (lagged regressors).

Variable (lagged)	**State-Owned Enterprises**	**Non-State-Owned**
Sustainability Governance	2.772 (2.821)	2.234*** (0.698)
Climate Membership	0.801 (0.913)	0.812 (0.529)
CSR Strategy	0.030 (0.033)	0.010 (0.007)
Regulatory Quality	4.591** (1.455)	1.035* (0.506)
ROA	−0.555 (5.379)	4.859* (2.163)

Log Firm Size	0.649 (0.805)	0.886** (0.317)
Log GDP	4.885† (2.713)	−0.492 (1.128)
Climate Vulnerability	20.994 (18.860)	−3.021 (7.351)
Industry FE (TRBC)	Yes	Yes
Year FE	Yes	Yes
Observations	185	511
Clusters (firms)	58	181
Pseudo R^2	0.431	0.246
Wald χ^2 (df = 13)	216.35***	130.00***

*Notes: Robust standard errors clustered at the firm level in parentheses. †p < 0.10; *p < 0.05; **p < 0.01; ***p < 0.001. Source: Authors' estimation.*

4.6. Horse-Race Specification with Lagged Dependent Variable

Table 7 reports the horse-race specification, which adds the one-period-lagged ordinal CCRM as a categorical regressor to the main ordered-logit model. The lagged dependent variable enters with very large coefficients (β = 3.85 for L_CCRM = Partial; β = 25.61 for L_CCRM = Full), confirming the persistence pattern documented in the system-GMM specification within the ordinal-DV framework. After this strong autoregressive component is absorbed, regulatory quality remains positively and significantly associated with CCRM (β = 2.190, $p < 0.001$) and indeed grows in magnitude relative to the main specification. Sustainability governance retains a positive sign and substantial magnitude (β = 1.620, similar to the main estimate of 2.441) but the standard error widens (1.115) and the coefficient does not reach conventional significance (p = 0.146). Climate membership and CSR strategy similarly lose statistical significance in this specification.

Three interpretive caveats apply. First, the model reports that 190 of 576 observations (33%) are completely determined, indicating substantial quasi-separation: firms with full CCRM in the previous period almost always remain at full CCRM, mechanically inflating standard errors for all covariates. Second, the SG point estimate remains economically meaningful with an odds ratio of approximately five for a one-unit increase in the governance composite, similar in magnitude to the main specification. Third, and most important for interpretation, the horse-race specification is structurally biased against finding effects of slowly-changing covariates such as sustainability governance: SG has substantially more between-firm than within-firm variation in the panel, so once 69% of CCRM variance is absorbed by the lagged dependent variable, little within-firm variation remains for SG to explain. Regulatory quality, by contrast, exhibits genuine year-on-year movement in our 43-country sample (driven by changes in WGI scores) and therefore retains explanatory power. We therefore read the horse-race results not as overturning H1 but as separating two complementary questions: the lagged-IV main specification (Table 3) is the appropriate test for whether SG, membership, and RQ are associated with the level of CCRM, while the horse race identifies which of these covariates additionally drives year-on-year transitions. Regulatory quality drives both. Sustainability governance is robustly associated with the level of CCRM but, on these data, we cannot cleanly identify a contemporaneous transition effect separable from the persistent capability stock itself.

Table 7. Horse-race ordered logit (lagged regressors plus lagged ordinal CCRM).

Variable	Coefficient	Std. error

L_CCRM = Partial (vs None)	3.849***	0.653
L_CCRM = Full (vs None)	25.614***	0.949
L_Sustainability Governance	1.620	1.115
L_Climate Membership	0.905	0.798
L_CSR Strategy	−0.003	0.011
L_Regulatory Quality	2.190***	0.446
L_ROA	2.575	2.209
L_Log Firm Size	0.977**	0.343
L_Log GDP	−1.980†	1.077
L_Climate Vulnerability	−7.969	7.115
Industry FE (TRBC Sector)	Yes	
Year FE	Yes	
Observations	576	
Clusters (firms)	220	
Pseudo R^2	0.765	
Wald χ^2 (df = 15)	2638.77***	

*Notes: Robust standard errors clustered at the firm level in parentheses. The ordinal lagged DV enters as i.L_CCRM with three categories (None, Partial, Full); coefficients reported relative to None. The model reports 190 observations as completely determined due to quasi-separation in firms with persistent Full CCRM, which mechanically widens standard errors. †p < 0.10; *p < 0.05; **p < 0.01; ***p < 0.001. Source: Authors' estimation.*

4.7. Country Fixed Effects Robustness

The country-level variables in our analytical sample are highly correlated. The highest pairwise correlation is 0.89 between log GDP and regulatory quality, and three pairwise correlations among the country-level controls exceed |0.73| (see Appendix B). Given this, we re-estimate the main specification with country fixed effects in place of the country-level controls. Country fixed effects absorb all time-invariant cross-country variation, leaving only within-country variation across the five sample years. Because regulatory quality and log GDP exhibit minimal within-country variation over a 5-year window, this specification serves as a stringent test of the firm-level antecedents (SG, CSR strategy, membership, ROA, firm size). In this specification, sustainability governance becomes statistically insignificant (β = 0.59, p = 0.488), reinforcing the interpretation that the governance-CCRM association documented in the main specification operates partly through cross-country institutional differences. CSR strategy emerges as significant within countries (β = 0.033, p < 0.001), suggesting that within-country variation in CSR signaling carries information about CCRM that is not captured by governance architecture alone. The full table is reported in Appendix C.

5. Discussion

This study set out to identify the firm-level and country-level antecedents of corporate climate risk management among carbon-intensive firms across 43 countries. Across an ordered-logit main model with lagged regressors (Table 3), an ordered-probit specification, and a battery of sub-sample analyses (Tables 5 and 6), three findings emerge consistently. First, sustainability governance is a robust positive antecedent of CCRM. Second, regulatory quality is a robust positive antecedent of CCRM. Third, voluntary climate-membership commitments exert a marginal effect that is conditional on sectoral context, supporting H2 in energy and basic materials but not in industrials. The system-GMM specification (Table 4) reveals an additional finding that we treat as a contribution in its own right: CCRM is a highly persistent organizational trait, with the previous year's score explaining roughly 69 % of the current year's variation.

5.1. Sustainability Governance as the Primary Internal Driver

The result that sustainability governance is the strongest single predictor of CCRM in the main ordered-logit specification ($\beta = 2.441$, $p < 0.001$) provides clear support for H1 and corroborates a stakeholder-theoretic interpretation: governance mechanisms are the institutional vehicles through which stakeholder pressure is converted into substantive corporate action [23]. The composite governance index aggregates three operative mechanisms (sustainability committee, sustainability-linked compensation, and sustainability reporting) that prior literature has treated as distinct levers [25–27]. Our results suggest that the joint adoption of these mechanisms produces a coherent governance architecture that materially raises the probability of higher CCRM categories.

The horse-race specification (§4.6, Table 7) qualifies this finding. The SG coefficient retains a positive sign and substantial magnitude ($\beta = 1.62$, similar to the main estimate of 2.44) but does not reach conventional significance ($p = 0.146$) once lagged CCRM is included as a regressor. We read this not as evidence against H1 but as evidence that sustainability governance and CCRM co-evolve as part of an integrated, persistent firm-level capability bundle rather than operating as a one-way causal channel from governance to risk management at year-on-year frequencies. Two pieces of evidence support this interpretation: the SG point estimate remains economically meaningful (an odds ratio of approximately five for a unit increase in the composite), and 33% of the analytical sample exhibits perfect persistence at high CCRM categories, mechanically widening standard errors. The lagged-IV specification therefore provides the most reliable estimate of the SG-CCRM relationship; the horse race confirms substantial path dependence while leaving the governance pathway intact in expected sign and magnitude.

The sub-sample analysis sharpens this finding. Governance is most strongly associated with CCRM in the industrials sub-sample ($\beta = 3.429$, $p < 0.001$), where firms tend to be larger, more diversified, and exposed to a heterogeneous mix of regulatory regimes, conditions under which a coherent internal governance architecture provides clear value as a coordinating mechanism. In energy and basic materials, the governance coefficient remains positive but is statistically indistinguishable from zero in the smaller sub-samples; this reflects both reduced statistical power and the partial substitution of external institutional pressures for internal governance in those sectors.

5.2. Climate Membership as a Sector-Conditional Channel

Climate membership exerts a marginal positive effect on CCRM in the full sample ($\beta = 0.928$, $p = 0.075$) and a clearer effect in the energy and basic-materials sub-samples ($\beta = 1.749$ and $\beta = 2.043$ respectively). The marginal full-sample significance should be read with caution: only 11.6 % of firm-years involve climate-membership participation, and rare-event regressors in finite samples are known to bias toward zero, potentially understating the true effect. The institutional-theoretic interpretation is twofold. First, membership generates normative pressure (Abdelzaher et al.'s [5] governance "pull" channel) by which firms internalize shared norms about appropriate climate behavior and become subject to peer accountability [15]. Second, membership generates mimetic pressure as members observe practices among peers and are pressed to imitate. The fact that membership effects are concentrated in the two sectors with the most intense climate scrutiny (energy and basic materials) suggests that the institutional pressure of voluntary alliances is conditioned on the credibility of the broader sectoral signal. Adamolekun et al. [35] report that members of emission-trading schemes face higher climate-risk exposure. Our study complements this by showing that membership is associated with stronger CCRM in sectors where such exposure is most material, supporting a strategic-response interpretation rather than a purely symbolic one.

5.3. Regulatory Quality and Institutional Substitution

Regulatory quality is a robust positive antecedent of CCRM in the main specification ($\beta = 1.676$, $p < 0.001$), supporting H3 and consistent with institutional theory's coercive-pressure mechanism. Regulatory quality is also the only firm-level antecedent whose effect survives the horse-race specification with the lagged dependent variable (§4.6, Table 7: $\beta = 2.190$, $p < 0.001$), where it grows in magnitude rather than diminishing. This is the strongest causal claim the data support: regulatory quality predicts year-on-year transitions in CCRM independently of the autoregressive structure that absorbs much of the cross-sectional variation in governance and membership. Our finding parallels at the firm level the country-level result of Abdelzaher, Martynov, and Abdel Zaher [4] that regulatory quality reduces national vulnerability to climate change. In both settings, regulatory quality functions as a coercive institutional force that channels external pressure into climate-protective action.

The state-ownership analysis (Table 6) yields a finding that is suggestive but bounded by sample composition. Regulatory quality is positively associated with CCRM in both ownership types but operates with much greater apparent intensity among state-owned firms ($\beta = 4.591$) than among non-state-owned firms ($\beta = 1.035$), while internal governance is significantly associated with CCRM only among non-state-owned firms ($\beta = 2.234$, $p = 0.001$). The qualitative direction of the SOE result is robust to the choice of standard-error estimator ($\beta = 4.591$, $p < 0.001$ with non-clustered robust SE), and the SOE-specific non-significance of internal governance similarly holds across SE specifications, indicating that neither finding is an artefact of cluster-robust inference. The SOE analytical sub-sample is, however, composed disproportionately of Chinese firms (78.4%; see §4.5), and when we attempt to re-estimate the SOE specification excluding Chinese firms, the residual sub-sample of 40 observations across 13 firms exhibits complete separation and the model fails to converge. We therefore cannot empirically distinguish a generalisable SOE pattern from a Chinese-SOE pattern within these data.

This composition matters for the theoretical interpretation. Chinese SOEs operate under a distinctive institutional configuration: they face top-down environmental quotas tied to provincial and national five-year plans, party-state oversight that runs in parallel with conventional corporate governance, and direct accountability of senior management to government supervisory bodies. In this context, what looks like a "regulatory quality" effect at the WGI level may also reflect the unusually direct transmission of state environmental priorities through the Chinese SOE governance structure. Reading our SOE result through the push/pull governance framework of Abdelzaher et al. [5], Chinese SOEs appear to be governed primarily through a coercive "push" channel where regulatory direction translates rapidly into corporate climate behavior, while non-state-owned firms across our 43-country sample rely additionally on the internal-governance counterpart of "pull" (voluntarily adopted accountability architecture). The Chinese-SOE pattern is consistent with, and offers suggestive support for, the broader institutional-substitution argument developed in comparative institutional analysis [49–51], in which strong country-level institutions and strong firm-level governance can act as functional substitutes for protecting the interests of dispersed stakeholders. Whether this substitution pattern generalises to state-owned firms in non-Chinese institutional contexts is a question our data cannot answer; addressing it would require purposive sampling of SOEs from a wider set of national contexts. We therefore frame the SOE finding as suggestive of a context-conditional substitution mechanism rather than as direct evidence of institutional substitution as a universal feature of state ownership.

5.4. CCRM as a Path-Dependent Capability

Two specifications converge on a striking finding. The system-GMM lagged DV coefficient of 0.693 ($p < 0.001$) and the horse-race ordered-logit coefficients on lagged ordinal CCRM (3.85 for transitioning into Partial; 25.61 for being in Full) both indicate that CCRM is one of the most persistent organizational characteristics yet documented in this literature. Once persistence is absorbed in the GMM specification, the contemporaneous coefficients on sustainability governance, climate membership, and CSR strategy lose statistical significance; only regulatory quality's effect survives the horse race. This pattern has important implications for both theory and practice. Theoretically, it supports a capability-based view of CCRM: rather than being a discrete choice that firms make in response to current pressures, CCRM appears to be a cumulative organizational capability that builds slowly through prior investments in governance, learning, and external commitments. This is consistent with Wijethilake and Lama's [21] finding that internalizing sustainability into core values is a stronger predictor of risk management than reactive compliance.

The lagged-IV ordered-logit specifications (Tables 3, 5 and 6), the system-GMM specification (Table 4), and the horse-race specification (Table 7) answer subtly different questions and are best read as a triangulated set rather than as competing tests. The lagged ordered logit identifies the influence of governance, membership, and regulatory environment on the level of CCRM, holding past CCRM implicit through industry, year, and country-clustered standard errors. The system GMM and the horse race, by including the lagged DV explicitly, isolate the residual contemporaneous effect after the autoregressive component is absorbed. The fact that regulatory quality alone retains significance once persistence is controlled distinguishes its role: regulatory quality drives transitions in CCRM, whereas governance is most strongly associated with the persistent firm-level capability stock itself. Practically, this implies that firms cannot adopt strong CCRM off the shelf. Building substantive climate-risk management requires sustained investment over multiple periods, with each year's score depending heavily on the prior year's foundation. This is consonant with a path-dependent view of organizational change [47].

5.5. CSR Strategy as a Correlate, Not a Driver

CSR strategy is consistently non-significant across all specifications: main ordered logit, ordered probit, system GMM, and every sub-sample. This is informative. It suggests that CSR communications, in the absence of governance architecture, do not translate into substantive climate-risk management. Once internal governance and external institutional quality are held constant, CSR strategy adds no further predictive power. The implication is consequential for both research and practice. CSR scores by themselves are unreliable proxies for climate-risk capabilities, and firms aiming to strengthen CCRM should invest in governance mechanisms rather than CSR rhetoric.

6. Conclusions

6.1. Summary

Using an unbalanced panel of 1,295 firm-year observations on carbon-intensive firms across 43 countries over 2018–2022, this paper investigates the antecedents of corporate climate risk management. Across an ordered-logit main model with lagged regressors and five robustness specifications (ordered probit, two-step system GMM, sector and ownership sub-samples, horse race with lagged DV, and country fixed effects), three findings emerge. First, sustainability governance and regulatory quality are both positive and significant antecedents of CCRM in the main lagged-IV specification ($\beta = 2.441$ and $\beta = 1.676$, $p < 0.001$), with similar substantive magnitudes. Second, in the more demanding horse-race specification that adds the lagged dependent variable, regulatory quality retains its sign, magnitude, and significance ($\beta = 2.190$, $p < 0.001$), while sustainability governance retains its sign and economic magnitude ($\beta = 1.620$) but loses statistical significance as a pattern we read as reflecting the structural bias of horse-race specifications against slowly-changing covariates with primarily between-firm variation, rather than as evidence that SG does not matter. The lagged-IV main specification is the appropriate test for level effects; the horse race usefully isolates which covariates additionally drive year-on-year transitions. Third, climate membership exerts a marginal positive effect concentrated in energy and basic materials. Across the GMM and horse-race

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specifications, CCRM is highly persistent (system-GMM lagged coefficient = 0.693; horse-race lagged-DV coefficients of 3.849 and 25.614 for partial and full categories), implying that climate risk management is a path-dependent capability built incrementally rather than a quick response to current pressures. The relative weight of internal governance versus external institutional quality varies across firm types: governance is significantly associated with CCRM only among non-state-owned firms, while regulatory quality is positively associated in both ownership types and operates with much greater apparent intensity among state-owned firms. We caveat the SOE-specific finding by noting that 78% of our SOE observations are from China, and the small non-Chinese SOE sub-sample does not permit a clean test of whether this pattern generalises beyond Chinese state-corporate governance; we therefore frame the SOE result as suggestive evidence of context-conditional institutional substitution rather than as a universal feature of state ownership.

6.2. Theoretical Contributions

The study advances stakeholder theory by demonstrating that governance architecture is the primary mechanism through which stakeholder pressure translates into substantive climate risk management among privately held firms. It advances institutional theory by providing direct evidence of substitution between coercive (regulatory quality) and internal (governance) accountability mechanisms, with the relative strength of these channels conditional on ownership type. The persistence finding contributes to the dynamic-capabilities literature by showing that CCRM exhibits the slow-building, path-dependent characteristics associated with strategic capabilities rather than the responsive characteristics of compliance-oriented practices.

6.3. Practical Implications

6.3.1. For Corporate Managers and Boards.

The findings imply that effective CCRM requires sustained investment in integrated governance architecture rather than reliance on standalone CSR commitments. Boards should establish a dedicated sustainability committee, attach a meaningful share of executive compensation to environmental performance, and adopt a rigorous external sustainability reporting framework. Joining a credible climate-focused alliance can amplify these efforts through normative reinforcement, particularly in sectors under intense climate scrutiny such as energy and basic materials. Given the persistence finding, managers should recognize that CCRM cannot be improved overnight: sustained, multi-year investment in governance is the reliable path to higher CCRM.

6.3.2. For Investors and Analysts.

The differential significance of governance and CSR strategy implies that ESG screening based on CSR scores alone is likely to misclassify firms. Analysts evaluating corporate climate exposure should integrate governance-architecture measures and climate-membership status into screening frameworks, while remaining alert to the possibility of symbolic membership in firms with weak underlying governance.

6.3.3. For Regulators and Policymakers.

The robustly positive effect of regulatory quality on CCRM, and its especially large apparent magnitude among state-owned firms in our data (driven principally by Chinese SOEs), suggests that broad-based regulatory-quality reform (beyond climate-specific mandates) generates positive spillovers into corporate climate behavior. Policymakers should view investments in regulatory quality as complementary to direct climate mandates. The Chinese-SOE pattern in particular suggests that, where ownership and oversight structures align state authority directly with corporate decision-making, regulatory-quality improvements may translate into corporate climate behavior more rapidly than in arms-length privately held firms. This implication is particularly salient for emerging-

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market regulators in countries such as Egypt, Malaysia, and others in our sample, where carbon-intensive sectors are economically significant, regulatory quality varies considerably, and state ownership remains a meaningful feature of the corporate sector. The findings suggest that incremental investments in regulatory quality, even where adoption of bespoke climate disclosure frameworks lags, can yield meaningful improvements in corporate climate risk management.

6.4. Limitations

Several limitations qualify our conclusions. First, the dependent variable, although improved by ordinal modelling, ultimately rests on two underlying binary indicators in commercial ESG data; richer measures incorporating textual disclosures and qualitative scoring would strengthen future research. Second, the sample is restricted to firms with sufficient disclosure footprint to be captured by LSEG, biasing inference toward larger, listed, more transparent firms. Third, the analytical sample used for the main ordered-logit estimation ($n = 707$) differs from the descriptive sample ($n = 1{,}295$) on three covariates. It is tilted toward firms in lower-regulatory-quality countries (mean RQ = 0.67 vs 0.94, $p < 0.001$), more climate-vulnerable countries ($p = 0.001$), and includes a higher share of state-owned enterprises (26.6% vs 14.9%, $p < 0.001$). The analytical sample does not differ from dropped observations on firm size, profitability, sectoral composition, or membership rate. To verify that this selection does not drive the headline regulatory-quality finding, we re-estimate the main specification with a Heckman two-step correction (including the inverse Mills ratio from a first-stage selection probit) and with inverse probability weighting (IPW) using fitted propensity scores trimmed at the 1st and 99th percentiles. The lagged regulatory-quality coefficient retains its sign and statistical significance under both corrections, and its magnitude grows relative to the uncorrected baseline ($\beta = 1.676$ in the main specification; $\beta = 1.708$, $p < 0.001$ under Heckman; $\beta = 2.876$, $p < 0.001$ under IPW). The inverse Mills ratio enters significantly ($\beta = -10.64$, $p = 0.022$), indicating that selection on unobservables is detectable, but it operates in a direction that makes the uncorrected estimates conservative rather than inflated: once selection is corrected for, both regulatory quality and sustainability governance appear more strongly associated with CCRM. The sustainability-governance coefficient strengthens under the Heckman correction ($\beta = 2.730$, $p < 0.001$) and softens under IPW ($\beta = 1.586$, $p = 0.065$), consistent with the interpretation that SG is a more powerful driver of CCRM in lower-RQ institutional contexts (over-represented in the analytical sample) than in higher-RQ contexts (over-represented under IPW reweighting). Full results are reported in Table S1 of the Supplementary Materials. Appendix A reports the full sample-comparison test results. Fourth, the 2018–2022 sample period spans the consolidation of TCFD adoption but pre-dates the full implementation of IFRS S2 and CSRD, meaning that more recent regulatory shifts are not yet captured. Fifth, climate membership is operationalized as a binary indicator that does not distinguish between alliance types or membership intensity. Sixth, the system-GMM estimation, while methodologically rigorous, treats CCRM as continuous and may understate the contemporaneous effects of slowly-changing covariates that are largely absorbed by the lagged dependent variable. Seventh, the state-ownership sub-sample analysis is constrained by the geographic concentration of SOEs in our data: 78% of SOE firm-year observations come from China, and the residual non-Chinese SOE sub-sample is too small ($n = 40$ across 13 firms) to support reliable estimation. The SOE-specific findings reported in Table 6 are therefore best interpreted as suggestive evidence about Chinese SOEs operating under a distinctive party-state governance configuration, rather than as evidence of a generalisable SOE pattern. Disentangling whether the apparent regulatory-quality effect among Chinese SOEs reflects general institutional substitution between firm-level governance and country-level institutions, or reflects features specific to Chinese state-corporate governance (top-down environmental quotas, party committees on boards, direct accountability to government supervisory bodies), would require purposive sampling of SOEs from a wider set of national contexts.

6.5. Future Research

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Several extensions follow. First, future studies should construct disclosure-quality CCRM indices using textual analysis of annual reports and TCFD disclosures, going beyond the binary indicators used here. Second, quasi-experimental designs exploiting exogenous regulatory shocks (for example, the entry into force of IFRS S1/S2 or sectoral carbon-pricing schemes) would strengthen causal identification. Third, the differential effects of climate membership across alliance types (RE100, Climate Action 100+, SBTi, UN Global Compact) merit dedicated investigation. Fourth, formal moderation analyses examining the interaction of governance, membership, and ownership type would test the institutional-substitution hypothesis directly. Fifth, extending the analysis to the post-2022 period will reveal whether the strengthening of climate-disclosure regimes amplifies or moderates the drivers identified here.

Appendix A. Sample Comparison: Analytical Sample vs Dropped Observations

Table A1 compares the analytical sample (n = 707, all variables non-missing) to dropped observations on key covariates. The analytical sample does not differ significantly on firm size, profitability, sectoral composition, or membership rate, but differs on three country-level dimensions: it is tilted toward lower-regulatory-quality, lower-GDP, more climate-vulnerable, and more state-owned-enterprise contexts. This pattern reflects the more complete data coverage of LSEG for firms in higher-disclosure environments and is acknowledged as a limitation in Section 6.4.

Table A1. Mean comparison test (analytical sample vs dropped observations).

Variable	Analytical (n=707)	Dropped (n=613)	Difference	p-value
Log Firm Size	10.151	10.108	−0.043	0.169
ROA	0.053	0.052	0.000	0.915
Regulatory Quality	0.673	0.937	0.263	<0.001
Log GDP	4.384	4.474	0.090	<0.001
Climate Vulnerability	0.336	0.328	−0.008	0.001
State Ownership (share)	0.266	0.149	−0.117	<0.001
Membership Rate (share)	0.124	0.110	−0.014	0.371
Sector composition (χ^2)	—	—	—	0.148

Notes: Differences from two-sample t-tests (variables 1–7) and Pearson chi-squared test (sector composition). Source: Authors' estimation.

Appendix B. Correlation Matrix of Lagged Independent Variables

Table A2 reports pairwise Pearson correlations among the lagged independent and control variables in the analytical sample (n = 707). The three country-level variables (RQ, log GDP, vulnerability) are highly correlated, motivating the country-fixed-effects specification reported in Appendix C and the drop-one sensitivity analyses described in Section 4.2.

Table A2. Pairwise correlations of lagged regressors (n = 707).

	L_SG	L_Mem	L_CSR	L_RQ	L_ROA	L_Size	L_GDP	L_Vuln
L_SG	1.00							

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L_Membership	0.24	1.00						
L_CSR Strategy	0.61	0.21	1.00					
L_RQ	0.34	0.17	0.03	1.00				
L_ROA	−0.07	−0.04	0.02	−0.04	1.00			
L_Log Firm Size	0.22	0.26	0.34	−0.06	−0.18	1.00		
L_Log GDP	0.25	0.13	−0.01	0.89	−0.07	0.04	1.00	
L_Vulnerability	−0.30	−0.16	−0.05	−0.74	0.07	−0.09	−0.83	1.00

Notes: Pairwise Pearson correlations on the analytical sample. Highest correlations are among the country-level controls: RQ × Log GDP = 0.89; Log GDP × Vulnerability = −0.83; RQ × Vulnerability = −0.74. Source: Authors' estimation.

Appendix C. Country Fixed Effects Robustness

Table A3 re-estimates the main ordered-logit specification with country fixed effects in place of the country-level controls (regulatory quality and log GDP, which are absorbed by country FE in a 5-year panel). Twelve country dummies are omitted due to collinearity (single-firm or single-year-per-firm countries within the analytical sample). Sustainability governance loses statistical significance in this specification ($\beta = 0.59$, $p = 0.488$), reinforcing the interpretation that the SG-CCRM association documented in the main specification operates partly through cross-country institutional variation. CSR strategy emerges as positive and significant within countries ($\beta = 0.033$, $p < 0.001$), suggesting that within-country variation in CSR signaling carries information about CCRM that is complementary to governance architecture. Climate vulnerability becomes significantly negative within countries, consistent with adaptation-capacity arguments at the firm level. The pseudo-R^2 rises substantially (0.487), reflecting the additional explanatory power of country fixed effects.

Table A3. Ordered logit with country fixed effects (selected coefficients).

Variable (lagged)	Coefficient	Std. error
Sustainability Governance	0.590	0.851
Climate Membership	0.025	0.462
CSR Strategy	0.033***	0.008
ROA	4.635*	2.076
Log Firm Size	1.178***	0.363
Climate Vulnerability	7.628	24.273
Industry FE (TRBC)	Yes	
Year FE	Yes	
Country FE (43 countries; 12 omitted)	Yes	
Observations	707	
Clusters (firms)	243	

Pseudo R^2	0.487

*Notes: Robust standard errors clustered at the firm level in parentheses. Country fixed effects absorb regulatory quality and log GDP, which exhibit minimal within-country variation across the 5-year sample period. Twelve country dummies were omitted for collinearity due to single-firm representation in the analytical sample. †p < 0.10; *p < 0.05; **p < 0.01; ***p < 0.001. Source: Authors' estimation.*

Appendix D. Country Composition of the Sample

The full panel (1,720 firm-year observations) covers 43 countries. Table A4 lists each country represented in the sample. The analytical sample of 707 firm-years draws from the same set, with composition shifted toward middle-income and emerging-market jurisdictions (see Appendix A).

Table A4. Countries represented in the sample.

Region	Countries
Asia-Pacific	Australia, China (Mainland), Hong Kong, India, Indonesia, Japan, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand
Europe	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Jersey, Netherlands, Norway, Spain, Sweden, Switzerland, Turkey, United Kingdom
Americas	Bermuda, Brazil, British Virgin Islands, Canada, Cayman Islands, Chile, Curacao, Mexico, United States
Middle East & Africa	Kuwait, Qatar, Saudi Arabia, South Africa

Notes: Country classification by country of incorporation (LSEG). Total: 43 countries. Source: Authors' compilation.

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