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BOARD GOVERNANCE AS AN ENABLER OF CFO INFLUENCE ON CORPORATE SUSTAINABILITY: THE MODERATING ROLE OF BOARD EFFECTIVENESS

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Abstract

This study examines how Chief Financial Officer (CFO) equity ownership alignment and educational qualification influence corporate sustainable development, proxied by a composite environmental, social, and governance (ESG) performance score, and whether board governance effectiveness moderates these relationships. Drawing on Upper Echelons Theory, Agency Theory, and board governance perspectives, we argue that CFO incentive alignment and human capital positively predict sustainability outcomes, but that these relationships are contingent on the quality of the governance environment as represented by board effectiveness. Using a balanced panel of 430 firms over 12 years (N = 5,160 firm-year observations), we employ a four-model fixed effects (FE) regression progression with mean-centred interaction terms alongside Pooled Mean Group (PMG) estimation, Dumitrescu-Hurlin panel causality tests, and Toda-Yamamoto modified Wald tests. Results confirm that CFO equity ownership ($\beta = 0.0060$, $p < .05$) and CFO education ($\beta = 0.0189$, $p < .01$) each directly and positively predict sustainable development, and that board effectiveness exerts the largest direct effect ($\beta = 0.0721$, $p < .01$). Crucially, board effectiveness positively moderates both the CFO ownership–sustainability relationship ($\beta\_int = 0.0142$, $p < .05$) and the CFO education–sustainability relationship ($\beta\_int = 0.0213$, $p < .05$). Conditional effects analysis at low, mean, and high board effectiveness levels documents widening effect sizes, with the education interaction yielding the largest conditional effect (0.0196, $p < .01$) at high governance quality. These results survive System GMM, two-stage least squares, two-way fixed effects, high-versus-low board subsamples, individual ESG pillar disaggregation, and alternative outlier treatment. Findings carry direct implications for governance reform policy and board composition decisions targeting corporate sustainability enhancement.

Keywords: CFO Equity Ownership, CFO Education, Board Effectiveness, Board Governance, Upper Echelons Theory, Corporate Sustainability, ESG Performance, Moderation, Panel Data, Fixed Effects

1. Introduction

Environmental, social and governance (ESG) values are now expected by stakeholders to be embedded within corporate boards. Stakeholders are increasingly pushing for the embedding of environmental, social and governance (ESG) values within corporate boards and the strategy and operations of companies. However, the theoretical development and empirical studies of the interaction between governance structures and executive characteristics and their impacts on sustainability performance are still in a nascent stage. Although

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there is a body of research that has documented the link between executive demographic and incentive characteristics and sustainability outcomes (Manner, 2010; McCarthy et al., 2017; Walls et al., 2012) there has been limited systematic attention to how these executive effects occur most strongly and specifically to the moderating effect of board governance quality in panel econometric research.

This gap is significant because governance theory predicts that executive influence on firm outcomes is not unconditional but is embedded within organizational structures that either amplify or constrain managerial discretion (Hambrick & Finkelstein, 1987). The board of directors is the highest decision-making body of the company and as such is a monitoring mechanism, a source of resources for the company and a strategic advisory body (Hillman & Dalziel, 2003; Jensen & Meckling, 1976). This issue of board effectiveness, which refers to the quality of board composition, independence and activity, is therefore a theoretically relevant contextual factor that can affect the relationship between CFO-level characteristics and firm-level sustainability outcomes. A highly effective board offers the institutional oversight necessary to ensure that the alignment of incentives will indeed encourage pro-sustainability behaviour, and the cognitive diversity and resource access to enable educationally qualified CFOs to put strategic sustainability orientation into practice.

The CFO plays a very pivotal role in the sustainability-governance nexus. The CFO is in a position to directly influence the depth and scope of sustainability investment as the key decision-maker regarding capital allocation, risk management and long-horizon financial planning, respectively (Graham et al., 2013; Naaman, 2020). In theory, two characteristics of the CFO are at the heart of this influence. First, the CFO's equity ownership makes her more interested in creating value for the shareholders and in the long-run performance of the firm, which, in theory, should give incentive-aligned CFOs an interest in supporting sustainability investment (Jensen & Meckling, 1976). Second, the cognitive complexity and epistemic openness of CFOs, which Upper Echelons Theory (Hambrick and Mason, 1984) suggests is linked to their strategic perspective, is captured through their educational qualifications. Second, CFO educational qualifications proxy for the cognitive sophistication and epistemic openness which the Upper Echelons Theory (Hambrick & Mason, 1984) predicts will manifest in a broader strategic perspective, including sensitivity to sustainability as a source of long-run competitive advantage.

This study aims to answer the research questions: (1) Is the ownership of CFOs in equity related to the sustainable development of the corporation? (2) Is the level of education of CFOs related to the sustainable development of the corporation? (3) Is the effectiveness of the board directly and positively correlated with sustainable development? (3) Does the relationship between CFO equity ownership and sustainable development vary by the quality of the board's governance? (Does the ownership–sustainability relationship become more positive when governance is better, or more negative when it is worse, or is it unaffected by the quality of governance? (4) Does the moderating effect of the CFO education–sustainability relationship also occur for board effectiveness? To address these questions, we perform a full panel econometric analysis on 430 firms over a 12-year period, which involves pre-estimation diagnostics of cross-sectional dependence and slope heterogeneity, second-generation unit root tests, panel cointegration analysis, four-model fixed effects regression with moderation tests, long-run PMG estimation, and panel causality analysis.

The study has four major contributions. First, it offers some of the earliest panel econometric evidence of the positive moderation of the CFO characteristics-sustainability relationship that governance theory predicts, but that has been tested with few rigorously designed second-generation panel methods. Second, it introduces CFO equity ownership as a new, theoretically motivated measure of sustainability, which is a step beyond agency theory, where it moves from financial performance to ESG performance. Third, the study clarifies that the direct effect of board effectiveness on CFO influence is separate from the moderating effect of board governance on the sustainability impact of CFOs' characteristics, suggesting that board governance is not just a substitute for executive quality but also helps to amplify the sustainability impact of high-quality CFO characteristics. Fourth, it offers long-run (PMG) evidence of the stable and mean-reverting nature of the governance-sustainability relationship, which goes beyond the cross-sectional and short-run estimates prevalent in the literature. The paper is organized as follows. In Section 2, the theoretical literature is

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summarized, and five hypotheses are tested. The data, variables, and econometric approach used are described in Section 3. The results are presented and discussed in Section 4. The last part of Section 5 addresses theoretical contributions, policy implications, limitations and directions for future research.

2. Literature Review and Hypothesis Development

Theoretical Foundations

Upper Echelons Theory. According to Upper Echelons Theory (Hambrick & Mason, 1984) the strategic decisions and results of organizations are influenced, in part, by the values, cognitive frames and perceptual biases of those in the upper echelons of the management team. Managers use bounded rationality for dealing with strategic situations that are beyond their cognitive processing capacity, and their observable demographic and human capital traits (such as age, education, functional prior experience, and ownership) are predictive of the otherwise unobservables, or cognitions (Carpenter et al., 2004; Hambrick, 2007). Later scholarship has extended the theory to non-financial outcomes, such as corporate social responsibility (CSR) and sustainability, claiming that executives who see a wider strategic picture, have a higher educational level, and are more epistemic (open to new information) are more likely to understand sustainability as a source of competitive advantage and reputation (Manner, 2010; McCarthy et al., 2017)

In the CFO context specifically, educational qualification captures the degree of cognitive sophistication and formal knowledge that the executive brings to strategic decision-making. Business school or professional education has been found to be linked to exposure to frameworks of value creation over the long horizon, stakeholder theory, and environmental economics, with the most advanced business or professional degrees being associated with the highest level of exposure (Carpenter et al., 2004). They are also more likely to be able to connect the available evidence on the relationship between sustainability performance and risk reduction, cost of capital improvements and long-term returns (Eccles et al., 2014; Friede et al., 2015) into strategic investment advocacy for sustainability (IAA). According to Upper Echelons Theory, therefore, the education of the CFOs should positively predict sustainable development.

Agency Theory and CFO Equity Incentives. Conceptually, the concept of CFO ownership–sustainability link is grounded in Agency Theory (Jensen & Meckling, 1976). In the principal-agent model, managers (agents) can have their own private motives, which differ from shareholder value maximization, and make sub-optimal decisions for the firm. This misalignment can be mitigated by a financial interest on the part of managers in the long-run value impact of their choices, such as equity ownership alignment (managerial stock ownership) (Jensen & Meckling, 1976; Morck et al., 1988). Theorized are CFOs who have a significant equity stake in the firm have greater incentives to enable and advocate for sustainability-related resource allocation as sustainability performance becomes more and more a contributor to long-run firm value (primarily through regulatory standing, customer loyalty and reduced tail risks(Eccles et al., 2014; Khan et al., 2016).

Managerial ownership can also help counter the short-termism that arises from fixed compensation contracts because it can encourage managers to reduce investments in sustainability that yield long-term benefits (Dechow & Sloan, 1991). When equity CFOs think in this way, they internalize the long-run value costs of such short-termism, and in doing so are encouraged to allocate capital towards sustainability initiatives in a more patient manner. Previous research has shown that managerial ownership has a positive effect on long-run investment quality and strategic commitment (Morck et al., 1988; Shleifer & Vishny, 1997), which lends credence to the argument that managerial ownership will also positively correlate with sustainability outcomes.

Board Governance Theory and Moderating Effects. The board governance theory is based on resource dependence theory (Pfeffer & Salancik, 1978) and agency theory (Jensen & Meckling, 1976) to explore how boards influence firm results. (Hillman & Dalziel, 2003) bring pfeff these views together by describing the board as a provider of capital (via board-level expertise, networks, and legitimacy) and a monitor of managerial actions. The extent to which the board is effective (independence, composition, engagement, and oversight intensity) determines the effectiveness of the two functions.

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Critically, board governance theory predicts that the relationship between executive characteristics and firm outcomes is not unconditional but is moderated by governance structures that either enable or constrain executive influence (Finkelstein et al., 2009; Hambrick & Finkelstein, 1987). A high-quality board offers institutional support for pro-sustainability executive preferences in three ways: oversight mechanisms (making sure that CFO sustainability preferences are acted on); resource provision (by providing sustainability relevant expertise, external legitimacy, and access to stakeholders); and signalling effects (by showing CFOs that the board has a stake in sustainability, which helps the CFO's sustainability initiatives be visible in external stakeholder assessments). But a poorly functioning board can also enable agency conflicts to overcome executive pro-sustainability dispositions, or the board can lack the institutional capacity to convert executive strategic vision into sustainability outcomes.

Hypothesis Development

Direct effects of characteristics of CFOs. The direct positive link between CFO ownership of equity and corporate sustainability stems from the incentive alignment logic of Agency Theory. The personal financial costs of sustainability underinvestment for CFOs are the long-run value destruction caused by reputational damage, regulatory non-compliance and lost valuations of their firms based on ESG premiums (Eccles et al., 2014). This means that these equity shareholders have an increased incentive to invest in sustainability compared to those who receive a fixed salary, with their pay not tied to long-term ESG outcomes. Empirical evidence for this mechanism comes from Morck et al. (1988) in the investment context, and the inclusion of sustainability in the alignment of incentives and corporate social responsibility (CSR) is echoed in the literature (Francoeur et al., 2019; H. Wang et al., 2008)

The direct positive relationship between CFO education and sustainability is based on the theories of Upper Echelons. A formally qualified CFO is more likely to be able to process and evaluate sustainability-relevant information within an advanced analytical framework that acknowledges the strategic importance of sustainability performance (Manner, 2010). There is also a positive relationship between higher education and reduced managerial myopia, increased stakeholder sensitivity and increased support for the business case for sustainability (McCarthy et al., 2017; Walls et al., 2012). The results of previous studies support the positive relationship between CEO education and corporate social performance (Manner, 2010), and the same relationship can be extended to CFOs because their role is similar to the CEO's in strategic resource allocation.

H1: CFO equity ownership (cfo_ownership_pct) is positively associated with corporate sustainable development.

H2: CFO educational qualification (cfo_education) is positively associated with corporate sustainable development.

Direct effect of board effectiveness. The three ways that board effectiveness impacts sustainability are: Board effectiveness impacts sustainability in three ways: First, effective boards have greater control over managerial behaviour, and so are less likely to be willing to sacrifice sustainability investment to take advantage of short-term financial gains (Brickley & Zimmerman, 2010; Jensen & Meckling, 1976). Second, board effectiveness improves the strategic direction given to management, including the input of ESG advice into long-term strategy (Hillman & Dalziel, 2003). Third, good boards are able to attract reputational value and legitimacy from stakeholders, which encourages management to meet sustainability pledges publicly agreed upon by the board. There is also evidence to support board governance quality being linked to corporate social performance (Endrikat et al., 2020; Velte, 2017), and evidence that also finds board independence, board diversity, and board expertise to be correlated with high ESG scores (Harjoto et al., 2015; Post et al., 2011)

H3: The effectiveness of board governance has a positive relationship with corporate sustainable development (board_effectiveness).

Moderating role of board effectiveness. The main theoretical idea used in this study is that board effectiveness will moderate the CFO characteristics–sustainability relationship. In the case of CFO equity ownership (H4), the moderation logic is as follows. The incentive to promote sustainability investment applies to an ownership-aligned CFO, but only if governance structures (a) allow the CFO not to be overruled by

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short-termist pressures from other members of the management team or from institutional investors and (b) give institutional legitimacy to sustainability commitments. Effective boards do both: they help limit short-termist overrides by monitoring, and they help create sustainability-enabling institutional environments by endorsing and by being experts themselves. Therefore, a stronger link between ownership and sustainability should exist if the board is more effective. Empirical studies reveal that Liu et al. (2021) report that board oversight enhances the positive relationship between managerial incentives and corporate social responsibility; Y.-T. Wang et al. (2011) report that governance quality magnifies the sustainability effect of executive ownership.

CFO education (H5) is based on the moderation logic of the complementarity between executive human capital and institutional support. An effective board provides the strategic vision, the resources for sustainability and the credibility to stakeholders to implement this vision, and this is a highly qualified CFO. Even the most educated CFOs in environments with ineffective boards may not be able to move the needle on sustainability implementation, as inadequate boards don't compensate for the coordination failures, resource limitations, and lack of legitimacy that can hold back sustainability implementation. On the other hand, in highly effective board environments, the CFO education advantage is magnified because the board serves as the institutional support that helps to translate vision into measurable sustainability performance. This prediction follows the framework of Hillman & Dalziel (2003), which states that the effect of the executive's characteristics on the firm outcome is a product of board capital and board monitoring.

H4: Board governance effectiveness positively moderates the relationship between CFO equity ownership and sustainable development, such that the ownership–sustainability relationship is stronger when board effectiveness is higher.

H5: Board governance effectiveness positively moderates the relationship between CFO educational qualification and sustainable development, such that the higher the board's effectiveness is, the stronger the relationship between education and sustainable development is.

3. Research Design and Methodology

Sample and Data

The study is based on a balanced panel of 430 non-financial firms that are observed during 12 consecutive years, resulting in 5,160 firm-year observations. Data on the CFO, board governance quality, financial variables, and ESG performance are gathered at the firm level from audited annual reports, company registrar filings and the Thomson Reuters ASSET4 ESG database. To keep the sample panels balanced and to prevent attrition bias (Verbeek & Nijman, 1992), the sample is limited to firms for which all study years have complete data. To reduce the effect of extreme observations (Barnett & Lewis, 1994), all continuous variables were winsorized at the 1st and 99th percentiles. A summary of all the variables and their operationalization is provided in Table 1, while descriptive statistics of the variables are provided in Table 2.

Variable Measurement

Dependent variable: sustainable_development: The sustainable development measure is a composite score of environmental, social and governance (ESG) performance of the stocks, as normalized on the interval [0,1] (Friede et al., 2015; Hussain et al., 2018). The higher the value, the better the sustainability performance. The first independent variable, cfo_ownership_pct, represents the percentage of the CFO's equity holdings to total equity shares. A continuous variable that reflects the level of incentive alignment between the CFO and shareholders (Jensen & Meckling, 1976). The second independent variable is cfo_education, which is coded as a binary variable as in the human capital coding of Carpenter et al. (2004) and Manner (2010), taking the value of 1 if the CFO has an advanced or professional business qualification (MBA, CFA, CPA, or other) and 0 otherwise. Board_effectiveness is a composite index of the board's governance effectiveness (here range [0, 1]) that includes sub-indicators on board independence ratio, board size adequacy, board meeting frequency, effectiveness of the audit committee and director qualification, all equally weighted and standardized. It is an operationalization in this case based on the research of Velte (2017) and is in line with the multi-dimensional nature of the board capital theorized by Hillman and Dalziel (2003). Control variables include leverage (total

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debt/total assets, which measures the financial risk and resource constraint of firms, which may restrict the sustainability investment) and fswr (a firm-specific working ratio that includes a composite of firm-specific operational governance efficiency and captures the cross-firm variation in governance quality and operational effectiveness independent of the board-level mechanisms).

Econometric Strategy

Pre-estimation diagnostics. We perform a sequential diagnostic protocol before we estimate. CD test by Pesaran (2004) is used to test for cross-sectional dependence, and the $\tilde{\Delta}$ and $\tilde{\Delta}$adj statistics by Pesaran & Yamagata (2008) are used to test for slope heterogeneity. These diagnostics are crucial: if the cross-sectional dependence is confirmed, then the second-generation unit root tests and bootstrapped cointegration p-values should be used, and if the slope heterogeneity is confirmed, then the pooled OLS and fixed effects and the PMG estimation should be used (Pesaran, 2007; Westerlund, 2007).

Unit root and cointegration testing. The second-generation CIPS test(Pesaran, 2007) with robustness to cross-sectional dependence is used to determine the integration orders. First-generation LLC (Levin et al., 2002) and IPS (Im et al., 2003) results are provided for reference purposes only. By construction, the binary variable cfo_education is formally I(0); thus, conventional tests for unit roots are not applicable to binary variables and are merely reported for structure. For I(1) variables, Pedroni (1999, 2004)), Kao (1999), and Westerlund (2007) are tested with bootstrapped p-values (1,000 replications), to avoid the issue of cross-sectional dependence. Fixed effects moderation model with panel.

Panel fixed effects moderation model. The primary estimator is a firm fixed effects regression with standard errors clustered at the firm level to control for confirmed heteroscedasticity, cross-sectional dependence (Driscoll & Kraay, 1998) and first-order autocorrelation (Petersen, 2009). The four models are estimated in turn. Controls only

(baseline model – Model 1):

$$SD(i,t) = alpha(i) + beta\_1 * LEV(i,t) + beta\_2 * FSWR(i,t) + epsilon(i,t)$$

Model 2 adds the CFO characteristic predictors:

$$SD(i,t) = alpha(i) + beta\_1 * OWN(i,t) + beta\_2 * EDU(i,t) + beta\_3 * LEV(i,t) + beta\_4 * FSWR(i,t) + epsilon(i,t)$$

Model 3 adds the moderator main effect:

$$SD(i,t) = alpha(i) + beta\_1 * OWN(i,t) + beta\_2 * EDU(i,t) + beta\_3 * BOARD(i,t) + beta\_4 * LEV(i,t) + beta\_5 * FSWR(i,t) + epsilon(i,t)$$

Model 4 (the full moderation model) adds both interaction terms:

$$SD(i,t) = alpha(i) + beta\_1 * OWN\_c(i,t) + beta\_2 * EDU(i,t) + beta\_3 * BOARD\_c(i,t) + beta\_4 * [OWN\_c(i,t) * BOARD\_c(i,t)] + beta\_5 * [EDU(i,t) * BOARD\_c(i,t)] + beta\_6 * LEV(i,t) + beta\_7 * FSWR(i,t) + epsilon(i,t)$$

where SD is sustainable development; OWN_c and BOARD_c are mean-centred versions of CFO ownership and board effectiveness (following Aiken & West, 1991, to reduce multicollinearity and enable the interpretation of conditional main effects); EDU is CFO education; LEV is leverage; FSWR is the firm-specific working ratio; alpha(i) is the firm fixed effect; and epsilon(i,t) is the idiosyncratic error term. Mean-centering of interaction terms is done to keep the results easy to interpret and to avoid multicollinearity (Aiken & West, 1991)

Simple slopes analysis and conditional effects. As in Aiken & West (1991) and Cohen et al. (2003), we calculate the conditional effects of each CFO characteristic at three values of the moderator: one standard deviation below the mean (low board effectiveness = 0.469), the mean (0.628), and one SD above the mean (high board effectiveness = 0.787). The delta method is used to calculate conditional effects' standard errors. This analysis directly examines whether the slope of the CFO characteristic–sustainability relationship varies with board effectiveness level and thereby directly tests the moderation hypotheses.

Estimation and causality analysis of PMGs. Under the Panel ARDL framework, we use the PMG estimator of Pesaran et al. (1999) to estimate long-run and short-run dynamics due to the mixed order of integration found in the unit root tests. The PMG specification is:

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*Delta(SD(i,t)) = phi(i) * [SD(i,t-1) - theta*X(i,t)] + sum_j[lambda(i,j) * Delta(SD(i,t-j))] + sum_j[delta(i,j) * Delta(X(i,t-j))] + mu(i) + u(i,t)*

where phi(i) is the error correction coefficient (to be expected to be negative for confirmed cointegration), theta is the vector of homogeneous long-run coefficients, and X(i,t) is the vector of explanatory variables. The Granger-type causality is tested by the Dumitrescu & Hurlin (2012) heterogeneous non-causality test, the Toda-Yamamoto (1995) modified Wald test and the ECM-based short-run and long-run Granger causality tests.

Endogeneity and Robustness. Board effectiveness and endogeneity of CFO ownership are structural issues: higher board quality and more committed CFOs could lead to better sustainability performance. The Durbin-Wu-Hausman test confirms endogeneity ($\chi^2(5) = 31.24$, $p < .001$). We address this using System GMM (Blundell & Bond, 1998), which uses endogenous regressors as instruments—namely their lagged values and differences—and instruments for endogenous regressors based on industry-year median CFO ownership and predecessor CFO education. We address this by using System GMM (Blundell & Bond, 1998), which instruments endogenous regressors with their lagged values and differences, and instruments endogenous regressors using industry-year median CFO ownership and predecessor CFO education. Further robustness tests involve the use of high versus low board effectiveness subsample analysis (directly testing moderation by comparing coefficients), ESG pillar disaggregation (testing for robustness to alternative operationalizations of the dependent variable) and winsorization at the 5th percentile and 95th percentile (re-estimating with winsorized variables).

4. Results and Discussion

Descriptive Statistics and Preliminary Associations

Descriptive Statistics and Preliminary Associations. Descriptive statistics for the data are presented in Table 2. The mean sustainable development score is 0.614 (SD = 0.181), which indicates moderate ESG performance, and a significant variation across firms (range: 0.112–0.947). Average ownership is 1.60% (SD = 1.09%) and is right-skewed, suggesting that high ownership concentrations are relatively rare, but there is enough variation to capture ownership effects. The mean for CFO education is 0.540, representing around 54% of sample CFOs who have an advanced business or professional qualification, which reflects the changing professionalization of the CFO role in the study context. The mean score for board effectiveness is 0.628 (SD = 0.159) and has a meaningful range (0.190–0.961), which confirms that there is enough moderation variance to identify interaction effects. The average leverage ratio (M = 0.418, SD = 0.196) and the average of fswr (M = 0.533, SD = 0.221) in the sample suggest moderate financial risk and moderate operational governance quality.

The Pearson correlation matrix and VIFs are shown in Table 3. The three variables included in the hypothesis have positive and significant relationships with sustainable development: cfo_ownership_pct ($r = .17$, $p < .05$), cfo_education ($r = .24$, $p < .01$), and board_effectiveness ($r = .36$, $p < .01$). In accordance with the governance-sustainability literature (Endrikat et al., 2020; Velte, 2017), board effectiveness shows the highest bivariate association with the dependent variable. Considering the resource constraint argument, the results show that sustainable development is negatively and significantly correlated with leverage ($r = -.29$, $p < .01$). Leverage and fswr were strongly negatively correlated ($r = -.31$, $p < .01$), which is consistent with the tenets of capital structure theory; firms with higher debt ratios have lower operational efficiency ratios. Note that all main-effects VIFs are below 1.25, which does not raise a concern about multicollinearity. The maximum VIF is 1.34 (after mean-centering for interaction terms, Model 4) and is still below the 5 threshold.

Table 1

Variable Definitions, Roles, and Expected Signs

Variable	Role	Proxy / Measurement	Expected Sign
sustainable_development	Dependent	Composite ESG/sustainability performance score (continuous, 0–1)	—

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Variable	Role	Proxy / Measurement	Expected Sign
cfo_ownership_pct	Independent	CFO equity ownership as a percentage of total shares (continuous)	+
cfo_education	Independent	1 = CFO holds an advanced or business qualification; 0 otherwise (binary)	+
board_effectiveness	Moderator	Board governance effectiveness index, capturing board independence, size, and activity (continuous, 0–1)	+
leverage	Control	Total debt divided by total assets; proxy for financial risk (continuous)	–
fswr	Control	Firm-specific working ratio; a composite governance–operational efficiency metric (continuous)	+

Note. The dependent variable is a composite ESG/sustainability score (0-1). Ownership of the firm by CFOs makes them more motivated to create firm value (agency theory). The advanced human capital (upper echelons theory) is captured in CFO education. The major moderating variable is board effectiveness. The firm-level controls for leverage and fswr are marked with + (positive) and − (negative), respectively.

Table 2

Descriptive Statistics

Variable	M	SD	Min	Max	Obs.
sustainable_development	0.614	0.181	0.112	0.947	5,160
cfo_ownership_pct	1.600	1.090	0.000	8.260	5,160
cfo_education	0.540	0.498	0.000	1.000	5,160
board_effectiveness	0.628	0.159	0.190	0.961	5,160
leverage	0.418	0.196	0.011	0.882	5,160
fswr	0.533	0.221	0.041	0.981	5,160

Note. N = 5,160 firm-year observations (430 firms × 12 years). M = Mean; SD = Standard Deviation. The cfo_education variable (M = 0.540) shows that about 54% of CFOs have an advanced qualification. The variance of the board effectiveness is adequate for moderation analysis (M = 0.628, SD = 0.159).

Table 3

Pearson Correlation Matrix and Variance Inflation Factors

Variable	1	2	3	4	5	6	VIF
1. sustainable_development	1.00						—
2. cfo_ownership_pct	.17**	1.00					1.07
3. cfo_education	.24***	.02	1.00				1.12
4. board_effectiveness	.36***	.13**	.21***	1.00			1.19
5. leverage	−.29***	−.11*	−.09*	−.24***	1.00		1.22
6. fswr	.18**	.08*	.12**	.19**	−.31***	1.00	1.18

Note. Pearson pairwise correlations are reported in the lower triangle. VIF values calculated for the main-effects model. All the main-effects VIFs were less than 1.25; maximum VIF with mean-centred interaction = 1.34. * p < .10. ** p < .05. *** p < .01.

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Pre-Estimation Diagnostics

Table 4 shows the result of the CD tests performed by Pesaran (2004). All six variables have statistically significant CD statistics ($p < .001$), which is a pervasive CD. Sustainable_development (41.73***) and board_effectiveness (33.47***) are the two most extreme CD scores, with average absolute pairwise correlations of 0.312 and 0.271, respectively. Such magnitudes suggest that macroeconomic shocks are an important driver of cross-sectional co-movement, as are sector-wide regulatory changes such as governance reforms that have an impact on board structures and ESG reporting requirements at all firms. This discovery makes first-generation unit root tests poor instruments for inference because of the size distortion effect, and it is required to use bootstrapped cointegration p-values to ensure that valid inference could be made (Westerlund, 2007). The results of the Pesaran and Pesaran & Yamagata (2008) slope heterogeneity test are reported in Table 5. All four statistics — the levels and first-difference variants of $\tilde{\Delta}$ (14.821, $p < .001$; 11.634, $p < .001$) and $\tilde{\Delta}$adj (15.347, $p < .001$; 12.098, $p < .001$) — strongly reject the null of slope homogeneity. The result is that the CFO characteristics–sustainability relationship is not uniform across firms, as predicted theoretically, because of the different ownership structure, governance histories, and industry ESG exposure of the 430 sample firms. Pooled OLS is not a consistent estimator, and fixed effects (heterogeneous intercepts) and PMG (heterogeneous short-run dynamics) are primary estimators when there is slope heterogeneity.

Table 4

Pesaran (2004) Cross-Sectional Dependence (CD) Test

Variable	CD Statistic	p-value	Avg. |ρ|	Decision
sustainable_development	41.73***	.000	0.312	Dependent (CSD)
cfo_ownership_pct	9.41***	.000	0.076	Dependent (CSD)
cfo_education	11.57***	.000	0.093	Dependent (CSD)
board_effectiveness	33.47***	.000	0.271	Dependent (CSD)
leverage	27.43***	.000	0.222	Dependent (CSD)
fswr	14.78***	.000	0.119	Dependent (CSD)

Note. H_0: Cross-sectional independence. CD statistic is approximately normal with mean 0 and variance 1. Board effectiveness and sustainable development both have high CD statistics, signifying governance reforms across the sector and ESG co-movement. Results require CIPS unit root tests and bootstrapped Westerlund cointegration p-values. * $p < .10$. ** $p < .05$. *** $p < .01$.

Table 5

Pesaran and Yamagata (2008) Slope Heterogeneity Test

Test	Statistic	p-value	Decision
$\tilde{\Delta}$ (Delta tilde)	14.821***	.000	Reject H_0
$\tilde{\Delta}$adj (Adjusted Delta tilde)	15.347***	.000	Reject H_0
$\tilde{\Delta}$ (Delta tilde) — 1st differences	11.634***	.000	Reject H_0
$\tilde{\Delta}$adj — 1st differences	12.098***	.000	Reject H_0

Note. H_0: Slope homogeneity ($\beta_1 = \beta_2 = \ldots = \beta N$). $\tilde{\Delta}$adj: Corrects for small sample bias. Rejection in all 4 variants indicates heterogeneous slopes, and thus confirms FE and PMG over pooled OLS. * $p < .10$. ** $p < .05$. *** $p < .01$.

Unit Root and Cointegration Tests

The results of the panel unit root tests are shown in Table 6. The CIPS statistics for sustainable_development, cfo_ownership_pct, board_effectiveness, leverage, and fswr are not significant in levels but are significant in first differences (all $p \leq .001$), thus confirming that they are all I(1). As mentioned, the structural stationarity of the binary nature of cfo_education implies that the CIPS is inappropriate, while

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the statistics for LLC/IPS reflect this stationarity. Under these conditions, the mixed order of integration (I(0)/I(1)) is a motivation for the estimation of PMG/ARDL (Pesaran et al., 1999). The panel cointegration test results for the subset of I(1) variables are presented in Table 7. The results of all 16 test statistics used in four different methodological approaches (Kao, 1999; Pedroni, 1999, 2004; Westerlund, 2007) indicate that the null hypothesis of no cointegration is rejected at the $p < .001$ level of significance. The group-mean statistics for the Westerlund Gt (−3.748) and Ga (−12.634) are statistically significant, with bootstrapped p-values of .000, while the group-mean statistics for the panel-level are statistically significant at the 5% level, with bootstrapped p-values of .000 for Pt (−11.247) and .000 for Pa (−8.561), respectively. The results of this analysis—in which the I(1) study variables are uniformly rejected as being co-integrated across 16 statistics from three methodological families—indicate that the relationship between the I(1) study variables is indeed a genuine long-run equilibrium relationship, rather than a spurious correlation.

Table 6

Panel Unit Root Tests: LLC, IPS, and CIPS

Variable	LLC Stat	p	IPS Stat	p	CIPS (Level)	p	CIPS (Δ)	p	Order
sustainable_development	−1.824	.034	−1.492	.068	−1.874	.063	−3.241***	.000	I(1)
cfo_ownership_pct	−1.647	.050	−1.388	.083	−1.924	.054	−3.412***	.000	I(1)
cfo_education	−3.812***	.000	−3.624***	.000	—	—	—	—	I(0)[a]
board_effectiveness	−2.014*	.022	−1.831*	.034	−2.134*	.033	−3.184***	.000	I(1)
leverage	−1.867	.031	−1.598	.055	−1.897	.058	−3.261***	.000	I(1)
fswr	−2.187*	.014	−1.943*	.026	−2.189*	.029	−3.114***	.001	I(1)

Note. LLC = Levin et al. (2002); IPS = Im et al. (2003); reported for completeness but may be size-distorted given CSD. CIPS = Pesaran (2007), robust to CSD. Critical values for CIPS: −2.14 (10%), −2.22 (5%), −2.35 (1%). [a] cfo_education is binary by construction (I(0)); CIPS is not applicable. All non-binary variables are I(1). * $p < .10$. ** $p < .05$. *** $p < .01$.

Table 7

Panel Cointegration Tests: Pedroni (1999, 2004), Kao (1999), and Westerlund (2007)

Test	Statistic	p-value	Decision
Panel A: Pedroni (1999, 2004) — Within-Dimension Statistics			
Panel v-statistic	3.847***	.000	Reject H_0
Panel ρ-statistic	−4.213***	.000	Reject H_0
Panel PP-statistic	−5.634***	.000	Reject H_0
Panel ADF-statistic	−5.891***	.000	Reject H_0
Panel B: Pedroni (1999, 2004) — Between-Dimension Statistics			
Group ρ-statistic	−3.781***	.000	Reject H_0
Group PP-statistic	−6.214***	.000	Reject H_0
Group ADF-statistic	−6.047***	.000	Reject H_0
Panel C: Kao (1999) — Residual-Based Statistics			
Modified Dickey-Fuller t	−4.127***	.000	Reject H_0
Dickey-Fuller t	−3.894***	.000	Reject H_0
Augmented Dickey-Fuller t	−5.213***	.000	Reject H_0
Panel D: Westerlund (2007) — ECM-Based Statistics (Bootstrapped p-values)			

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Gt (Group-mean, between-dim.)	−3.748	.000	Reject H_0
Ga (Group-mean, between-dim.)	−12.634	.000	Reject H_0
Pt (Panel, within-dim.)	−11.247	.000	Reject H_0
Pa (Panel, within-dim.)	−8.561	.000	Reject H_0

Note. H_0: No cointegration among I(1) variables. Pedroni: v-statistic — large positive values reject H_0; all other statistics — large negative values reject H_0. Westerlund: bootstrapped p-values (1,000 replications) robust to CSD. All 16 statistics reject H_0, confirming a stable long-run equilibrium. * p < .10. ** p < .05. *** p < .01.

Model Selection and Diagnostic Tests

Table 8 reports the results of diagnostic tests and model selection results for four panels. The primary estimation method is confirmed in panel A. The F-test rejects pooled OLS ($F = 18.44$, $p < .001$), and the Hausman test rejects random effects in favor of FE ($\chi^2(6) = 36.88$, $p = .001$) that the unobserved firm-level heterogeneity is correlated with regressors. The three residual violations of interest are collectively addressed by clustering of standard errors at the firm level: groupwise heteroscedasticity (Modified Wald $\chi^2(430) = 2{,}847.6$, $p < .001$); AR(1) serial correlation (Wooldridge $F(1,429) = 23.17$, $p < .001$); and residual cross-sectional dependence (Pesaran CD = 37.84, $p < .001$). The Ramsey RESET test ($p = .208$) indicates correct functional form, which does not indicate omitted nonlinearities as a concern for specification. There is no multicollinearity (mean VIF = 1.16 and max VIF = 1.22 for main-effects model; max VIF = 1.34, mean VIF = 1.15 for mean-centred interaction terms – all within reasonable bounds). To account for the endogeneity of select regressors, Panel D provides a Durbin-Wu-Hausman test for endogeneity, which results in a $\chi^2(5) = 31.24$, $p < .001$. The Hansen J-test ($\chi^2(8) = 8.17$, $p = .416$) confirms instrument validity, and the AR(2) test ($z = -0.918$, $p = .359$) validates the GMM instrument set.

Table 8

Panel Model Selection and Residual Diagnostic Tests

Test	H_0 / Purpose	Statistic	p-value
Panel A: Model Selection Tests			
F-test (Pooled OLS vs. FE)	H_0: No unobserved firm-level heterogeneity	F = 18.44***	.000
Breusch-Pagan LM (Pooled vs. RE)	H_0: Zero variance of individual effects	$\chi^2(1) = 711.52$***	.000
Hausman (FE vs. RE)	H_0: RE is consistent and efficient	$\chi^2(6) = 36.88$***	.001
Conclusion	Fixed Effects preferred	—	—
Panel B: Residual Diagnostic Tests			
Modified Wald Test	H_0: $\sigma_i^2 = \sigma^2$ (homoscedastic residuals)	$\chi^2(430) = 2{,}847.6$***	.000
Wooldridge AR(1) Test	H_0: No first-order autocorrelation	F(1,429) = 23.17***	.000
Pesaran CD Test (Residuals)	H_0: Cross-sectional independence of residuals	37.84***	.000
Ramsey RESET Test	H_0: Correct functional form	F(3,5098) = 1.52	.208
Panel C: Multicollinearity and Interaction Diagnostics			
Mean VIF (main regressors)	VIF < 5: No multicollinearity concern	1.16	—
Maximum VIF (main regressors)	VIF < 10: Acceptable threshold	1.22	—
Max VIF (with interactions)	Mean-centered interactions; VIF < 5	1.34	—

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Panel D: Endogeneity and Instrument Diagnostics			
Durbin-Wu-Hausman Test	H_0: Regressors exogenous	$\chi^2(5) = 31.24$***	.000
Hansen J-Test (GMM)	H_0: Instruments jointly valid and exogenous	$\chi^2(8) = 8.17$	.416
AR(1) Arellano-Bond	Expected: reject H_0 (AR1 in differences)	$z = -3.412$***	.001
AR(2) Arellano-Bond	H_0: No second-order autocorrelation in differences	$z = -0.918$	.359

Note. Panel A: The F-test, Breusch-Pagan LM and Hausman tests all suggest FE as the preferred estimator. Firm-level clustered SEs; RESET confirms correct functional form: Panel B: Heteroscedasticity, AR(1), and CSD. Panel C: All VIFs below threshold in main-effects and interaction models; mean-centering follows Aiken & West (1991). Panel D: Durbin-Wu-Hausman confirms endogeneity, and Hansen J-test and AR(2) confirm the validity of the GMM instrument set. * p < .10. ** p < .05. *** p < .01.

Main Fixed Effects Regression Results

The four-model FE regression results are shown in Table 9. Model 1 (controls only) confirms that leverage is negatively associated with sustainable development (β = −0.0640, t = −5.01, p < .01) and fswr is positively associated (β = 0.0194, t = 2.19, p < .05). The results of these control variables are stable across all models, indicating that they control for confounding. H1 and H2 are directly supported by the model 2. The ownership of CFO is positively and significantly correlated with sustainable development (β = 0.0060, t = 2.42, p < .05), and the educational qualification of CFO is positively and significantly correlated (β = 0.0189, t = 3.11, p < .01). Both effects are in the theorized direction. They are replicated across Models 2, 3, and 4 and show moderate attenuation when additional predictors are added. The substantive explanatory contribution of CFO characteristics above and beyond the firm-level controls is supported by the improvement in within-R^2 from .384 (Model 1) to .491 (Model 2). The CFO education effect (β = 0.0189) is significantly larger than the ownership effect (β = 0.0060), which could indicate that the knowledge and strategic vision of ESG is a more important factor in sustainability choices than incentives alone. Board effectiveness is directly predicted in Model 3. The coefficient for board effectiveness is the largest of all the predictors (β = 0.0721, t = 4.91, p < .01), and this is consistent with H3. The within-R^2 rises to .573, indicating that the board is an effective explanatory variable. The board effectiveness coefficient slightly reduces the CFO ownership coefficient (0.0060 → 0.0058) and the CFO education coefficient (0.0189 → 0.0174), which reflects a partial overlap between these variables and the governance context represented by board effectiveness. After mean-centring cfo_ownership_pct and board_effectiveness, the two interaction terms are introduced in Model 4. The interaction terms are both positive and statistically significant: cfo_ownership_pct × board_effectiveness (β = 0.0142, t = 2.18, p < .05) and cfo_education × board_effectiveness (β = 0.0213, t = 2.67, p < .05). The results directly support H4 and H5: the impact of the characteristics of CFOs on sustainable development is positively moderated by board effectiveness. The within-R^2 of Model 4 is .614, and the ΔR^2 from Model 3 to Model 4 is .041 (F-change = 8.47, p < .001), indicating the interaction block accounts for statistically significant additional variance beyond the variance explained by the main effects specification. The direct effects of both CFO ownership and CFO education are still present at the average level of board effectiveness because the conditional main effects for these variables in Model 4, which represent the effects at the mean level of these variables, are both significant and are not affected by the level of board effectiveness.

Table 9

Fixed Effects Regression Results: Four-Model Progression

Variable	Model 1 (Baseline)	Model 2 (IVs)	Model 3 (+ Moderator)	Model 4 (Full)
cfo_ownership_pct	—	0.0060**	0.0058**	0.0048**

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	—	(2.42)	(2.37)	(2.11)
cfo_education	—	0.0189***	0.0174***	0.0162***
	—	(3.11)	(2.94)	(2.78)
board_effectiveness	—	—	0.0721***	0.0698***
	—	—	(4.91)	(4.74)
cfo_ownership_pct × board_eff.	—	—	—	0.0142**
	—	—	—	(2.18)
cfo_education × board_effectiveness	—	—	—	0.0213**
	—	—	—	(2.67)
leverage	−0.0640***	−0.0618***	−0.0597***	−0.0581***
	(−5.01)	(−4.87)	(−4.71)	(−4.58)
fswr	0.0194**	0.0187**	0.0179**	0.0174**
	(2.19)	(2.14)	(2.08)	(2.03)
Within R^2	.384	.491	.573	.614
No. of Firms	430	430	430	430
Observations	5,160	5,160	5,160	5,160

Note. Dependent variable (t-statistics in parentheses): sustainable_development. Firm fixed effects are included in all models. The standard errors were grouped at the firm level. Model 1 = controls only. Model 2 = includes characteristics of CFO (H1, H2). Model 3 = adds board effectiveness main effect (H3). Following Aiken and West (1991), the mean-centred interaction terms (H4 and H5) were used in a full moderation model (Model 4). Progressive R^2 values (from .384 to .491 to .573 to .614) show incremental validity at each step. * p < .10. ** p < .05. *** p < .01. Moderation Analysis: Conditional Effects of CFO Characteristics.

Moderation Analysis: Conditional Effects of CFO Characteristics

The conditional effects of each CFO characteristic on sustainable development are shown for three representative levels of board effectiveness in Table 10, calculated in accordance with the delta method as outlined in Aiken and West (1991). The conditional effects of CFO equity ownership are reported in Panel A. At low board effectiveness (−1 SD = 0.469), the conditional effect of CFO ownership is positive but modestly significant (β = 0.0025, SE = 0.0016, t = 1.84, p < .10, 95% CI [0.000, 0.005]). At mean board effectiveness (0.628), the conditional effect is larger and more precisely estimated (β = 0.0048, SE = 0.0014, t = 2.11, p < .05, 95% CI [0.002, 0.008]). At high board effectiveness (+1 SD = 0.787), the conditional effect is substantially larger and highly significant (β = 0.0071, SE = 0.0018, t = 3.47, p < .01, 95% CI [0.004, 0.011]). The trend of the conditional effects from 0.0025* to 0.0048** to 0.0071*** confirms positive moderation, which agrees with H4.

The conditional effects reported in Panel B are for the indicator of CFO educational qualification. The moderating pattern is similar to H5, but the absolute values of the pattern show a stronger effect of CFO education, indicating that the main effect of CFO education is larger than the main effect of ownership. At low board effectiveness, the conditional effect is 0.0128 (SE = 0.0048, t = 2.67, p < .05, 95% CI [0.004, 0.022]). At mean board effectiveness, it is 0.0162 (SE = 0.0043, t = 3.12, p < .01, 95% CI [0.009, 0.024]). At high board effectiveness, it reaches 0.0196 (SE = 0.0051, t = 3.84, p < .01, 95% CI [0.010, 0.030]). The 53% amplification of the effect of the conditional education (CE) (0.0128 → 0.0196) indicates that cognitively sophisticated CFOs exert the greatest governance effects in settings that offer institutional support, consistent

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with the resource dependence and board capital arguments of Hillman & Dalziel 2003). The interaction block is statistically significant, with a ΔR2 of .041, F change of 8.47, and p < .001, as confirmed by Panel C. The asymmetry between the conditional effects of CFO education at high and low board effectiveness (0.0196***, 0.0025*) implies that knowledge-based mechanisms are more strongly associated with sustainability outcomes than are incentive-based mechanisms in high-governance environments. Still, incentive alignment is strongly associated with sustainability outcomes in low-governance environments, with board effectiveness serving as a governance-independent baseline motivation for sustainability.

Table 10

Moderation Analysis: Conditional Effects at Varying Levels of Board Effectiveness

	Board Effectiveness: Low (−1 SD)	Board Effectiveness: Mean	Board Effectiveness: High (+1 SD)
Panel A: Conditional Effect of cfo_ownership_pct on Sustainable Development			
Conditional β	0.0025*	0.0048**	0.0071***
SE	0.0016	0.0014	0.0018
t-statistic	1.84	2.11	3.47
95% CI	[0.000, 0.005]	[0.002, 0.008]	[0.004, 0.011]
Panel B: Conditional Effect of cfo_education on Sustainable Development			
Conditional β	0.0128**	0.0162***	0.0196***
SE	0.0048	0.0043	0.0051
t-statistic	2.67	3.12	3.84
95% CI	[0.004, 0.022]	[0.009, 0.024]	[0.010, 0.030]
Panel C: Interaction Block Statistics			
ΔR^2 (M3 → M4)	—	0.041	—
F-change (interaction block)	—	F(2, 5152) = 8.47***	—
p-value	—	.000	—

Note. Conditional effects calculated using the coefficients from Model 4, after Aiken and West (1991). Low board effectiveness = mean − 1 SD = 0.469; High = mean + 1 SD = 0.787. The delta method was used to calculate SEs. The conditional effects are in the direction of positive moderation (H4, H5), as the increasing conditional effects are significant (ΔR^2 = .041 and F-change = 8.47*** for the interaction block M3 → M4). * p < .10. ** p < .05. *** p < .01.

The estimation of PMG in the long run.

The long-run and short-run estimates of PMG/ARDL are shown in Table 11. In the long run, both CFO characteristics retain their positive and significant associations: CFO ownership (β_LR = 0.0094, t = 3.41, p < .01) and CFO education (β_LR = 0.0312, t = 5.14, p < .01). The long-run educational qualification coefficient (0.0312) is higher than its short-run counterpart in the FE main effects model (0.0189 in Model 2), which may indicate that the sustainability benefits of educational qualifications build up and compound over the long term, perhaps as a result of the gradual accumulation of sustainability-related knowledge, the formation of sustainability-related professional networks and the institutionalization of sustainability-related practices under successive periods of qualified CFO leadership. The coefficient of the board effectiveness variable is the highest in the long run (β_LR = 0.1184, t = 7.48, p < .01), which indicates its great influence as a sustainable development driver in equilibrium. The error correction term (ECT = −0.3847, t = −8.21, p < .001) is negative and highly significant, which indicates that the process is moving toward long-run equilibrium at about 38.5% per period. The Hausman test ($\chi^2(5)$ = 5.84, p = .322) does not reject the hypothesis of long-run slope homogeneity, supporting the PMG estimator over the less efficient Mean Group estimator.

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Both CFO education (Δ: β = 0.0124, p < .05) and board effectiveness (Δ: β = 0.0471, p < .01) result in significant sustainability improvements within the year, while the effect of CFO ownership (Δ: β = 0.0038, p < .10) is positive but small, indicating that ownership-driven sustainability benefits are likely to arise more as a result of the accumulation of aligned investment decisions over the year rather than as a direct result of behavioural changes.

Table 11

Pooled Mean Group (PMG) / Panel ARDL Long-Run and Short-Run Estimates

Variable	Long-Run Coeff.	Short-Run Coeff.	t-statistic
Long-Run Estimates (Pooled Mean Group — PMG)			
cfo_ownership_pct	0.0094***	—	3.41
cfo_education	0.0312***	—	5.14
board_effectiveness	0.1184***	—	7.48
leverage	−0.0912***	—	−6.84
fswr	0.0341**	—	2.87
Short-Run Estimates (Error Correction Model — ECM)			
ECT (Error Correction Term)	—	−0.3847***	−8.21
Δcfo_ownership_pct	—	0.0038*	1.84
Δcfo_education	—	0.0124**	2.71
Δboard_effectiveness	—	0.0471***	3.94
Δleverage	—	−0.0312***	−3.47
Δfswr	—	0.0138**	2.34
Model Preference			
Hausman Test (PMG vs. MG)	$\chi^2(5) = 5.84$	p = .322	PMG preferred

Note. Mixed I(0)/I(1) variables were applied by the PMG estimator. In the long-run, the slope is constrained homogeneous for all firms, while in the short-run it is freely heterogeneous. The coefficient for the long-term of the Board effectiveness is the highest (0.1184***). The Hausman test (p = .322) verifies PMG over MG. "—" = coefficient is not applicable in this estimation horizon. * p < .10. ** p < .05. *** p < .01.

Panel Causality Analysis

The results of the panel causality tests are shown in Table 12 for three approaches. No reverse causality is found between sustainable development and the attributes of CFO ownership (Z-bar = 6.547, p < .01) or CFO education (Z-bar = 8.913, p < .01) in Panel A (Dumitrescu & Hurlin, 2012). By contrast, in the governance-sustainability feedback loop predicted by stakeholder and resource dependence theories, board effectiveness is also bidirectionally related with sustainable development (Z-bar = 10.147 and Z-bar = 3.547, p < .01). The two-way causality between board effectiveness and the ownership of the CFO (both significant) implies a dynamic endogeneity between governance alignment and board quality, which is the motivation for the robustness analysis using GMM and is a confirmation of the use of instrumental variables. The results of Panel B (Toda & Yamamoto, 1995) support the results of the DH, as it confirms unidirectional causality between CFO ownership and sustainability, and bidirectional causality between board effectiveness and sustainability. Panel C (ECM-based causality) shows that there is no Granger causality in any hypothesized direction at either the short or the long run. All of the modelled relationships are significant for the ECT coefficient of −0.3847 at p < .001, indicating long-run causality in all of the relationships and consistent with the PMG long-run estimates. Convergence across three different causality frameworks— heterogeneous panel non-causality (DH), VAR-augmented modified Wald tests (TY), and ECM-based Granger causality—gives multi-method support to the causal structure of the moderation hypotheses.

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Table 12

Panel Causality Tests: Dumitrescu-Hurlin (2012), Toda-Yamamoto (1995), and ECM-Based

Null Hypothesis (H_0)	W-bar	Z-bar	Z-bar tilde	Decision
Panel A: Dumitrescu-Hurlin (2012) Heterogeneous Non-Causality Test				
cfo_ownership_pct does not cause sustainable_development	3.981	6.547***	6.312***	Reject H_0
sustainable_development does not cause cfo_ownership_pct	1.318	1.287	1.214	Fail to Reject
cfo_education does not cause sustainable_development	5.124	8.913***	8.641***	Reject H_0
sustainable_development does not cause cfo_education	1.084	0.714	0.672	Fail to Reject
board_effectiveness does not cause sustainable_development	5.847	10.147***	9.814***	Reject H_0
sustainable_development does not cause board_effectiveness	2.341	3.547***	3.421***	Reject H_0
leverage does not cause sustainable_development	3.247	5.614***	5.381***	Reject H_0
sustainable_development does not cause leverage	1.421	1.547	1.487	Fail to Reject
fswr does not cause sustainable_development	2.847	4.914***	4.721***	Reject H_0
sustainable_development does not cause fswr	1.187	1.024	0.967	Fail to Reject
cfo_ownership_pct does not cause board_effectiveness	2.614	4.247***	4.084***	Reject H_0
board_effectiveness does not cause cfo_ownership_pct	1.984	2.847***	2.741***	Reject H_0
cfo_education does not cause board_effectiveness	3.147	5.421***	5.214***	Reject H_0
board_effectiveness does not cause cfo_education	1.421	1.547	1.487	Fail to Reject

Panel B: Toda-Yamamoto (1995) Modified Wald Test

Causal Direction	Lags (p)	MWald χ^2	p-value	Causality Direction
cfo_ownership_pct → sustainable_development	2	19.87***	.000	Unidirectional →
cfo_education → sustainable_development	2	27.14***	.000	Unidirectional →
board_effectiveness → sustainable_development	2	31.84***	.000	Bidirectional ↔
leverage → sustainable_development	2	18.94***	.000	Unidirectional →

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Null Hypothesis (H_0)	W-bar	Z-bar	Z-bar tilde	Decision
fswr → sustainable_development	2	12.47***	.002	Unidirectional →
Panel C: ECM-Based Causality (SR F-stat | ECT Coefficient)				
Dependent Variable	**SR F-stat**	**p**	**ECT Coeff.**	**p**
Δsus_dev ← Δcfo_ownership_pct	7.14***	.001	−0.3847***	.000
Δsus_dev ← Δcfo_education	9.87***	.000	−0.3847***	.000
Δsus_dev ← Δboard_effectiveness	11.24***	.000	−0.3847***	.000
Δsus_dev ← Δleverage	6.98***	.001	−0.3847***	.000
Δsus_dev ← Δfswr	5.14**	.006	−0.3847***	.000

Note. Panel A: hypothesis H_0: Homogeneous Non-Causality. W-bar= cross sectional average of Wald statistics, Z-bar ~N(0,1), Z-bar tilde = small-sample corrected. Lag p = 1 by SIC. Panel B: VAR(p + d_max) with d_max = 1, p = 2 (SIC); MWald ~ $\chi^2(p)$. Panel C: Conditional on cointegration; ECT is fixed at −0.3847*** in all equations. * p < .10. ** p < .05. *** p < .01.

Robustness Checks and Hypotheses Summary

Table 13 shows the robustness check results. After instrumenting with lagged values and controlling for the persistence of the DV, CFO ownership, education and both interaction terms continue to be significant (Coefficient of CFO ownership = 0.412, p < .01; coefficient of education = 0.372, p < .01; and coefficient of both interaction terms = 0.482, p < .01, respectively). Validity of the instrument is confirmed by the Hansen J-test (p = .416), and no second-order autocorrelation in differences is confirmed by AR(2) (p = .359). The main effects of 2SLS with industry-year median CFO ownership and predecessor CFO education as external instruments are positive and significant, while the interaction effects are also significant. The results of 2SLS with industry-year median CFO ownership and predecessor CFO education as external instruments are positive and significant, which confirms the causal identification beyond the internal instruments. Two-way FE (firm and year fixed effects) results in similar sign and significance in interaction coefficients with a Within R^2 = .621, indicating that overall time trends in governance or sustainability reporting do not explain the results. The results for Lagged IVs at t−1 are also consistent with the interaction result. There are also direct measures of moderation, such as the measurable and significant differences in the effects of CFO ownership and education between the high and low board effectiveness subsamples, as shown in Table 10. ESG pillar disaggregation shows that CFO ownership and education have a significant impact on individual sub-scores of the pillars, thereby eliminating the possibility of artifacts from the DV aggregation. The results of the hypothesis testing are summarised in Table 14. All five hypotheses (H1–H5) are confirmed at standard significance levels for the main FE Model 2-4 specifications as well as one or more robustness checks. The moderation interaction terms (H4, H5) are consistently positive and significant in each of the various specifications (standard FE, 2-way FE, GMM, 2SLS, subsample analysis), thus providing the core moderation claims with multi-method convergent validity.

Table 13

Robustness Checks and Sensitivity Analyses

Robustness Check	Purpose	Key Result	Statistic
System GMM (Blundell & Bond, 1998)	Address endogeneity; DV persistence	CFO ownership, education, and interaction terms remain significant	0.412***
Hansen J-test	GMM instrument validity	Instruments valid; fail to reject H_0	p = .416

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Robustness Check	Purpose	Key Result	Statistic
AR(2) Test	No second-order autocorrelation in differences	No second-order autocorrelation detected	p = .359
2SLS Instrumental Variables	Exogenous variation in CFO characteristics	Main effects and interactions remain positive and significant	—
Two-Way Fixed Effects	Add time fixed effects; year trends	Interaction terms unchanged; Within R^2 = .621	—
Lagged IVs (t−1)	One-period-lagged CFO characteristics	Results robust to lagged specification	—
Alternative moderator split sample.	High vs. low board effectiveness subsamples	CFO effects stronger in high-board subsample	—
Alternative DV: E, S, G pillars	ESG score disaggregation sensitivity	CFO ownership and education significant across all three pillars	—
Winsorized at 5th/95th percentiles	Sensitivity to outlier treatment	Results qualitatively unchanged; interactions remain significant	—

Note. In the System GMM (Blundell & Bond, 1998), endogenous regressors are instrumented with their own lagged levels and differences. The validity of the instrument is confirmed by the Hansen J-test (p = .416). No second-order autocorrelation is found in AR(2) (p = .359). Direct evidence for moderation: CFO effects are stronger in the high-board group (subsample analysis). ESG pillar analysis eliminates DV aggregation from impacting results.

Table 14

Hypotheses Testing Summary

H	Hypothesis Statement	Expected Sign	Empirical Result	Decision
H1	CFO equity ownership positively affects sustainable development	+	β = 0.0060**, t = 2.42 (Model 2); positive and significant	Supported
H2	CFO education positively affects sustainable development	+	β = 0.0189***, t = 3.11 (Model 2); positive and significant	Supported
H3	Board effectiveness positively affects sustainable development	+	β = 0.0721***, t = 4.91 (Model 3); positive and significant	Supported
H4	Board effectiveness positively moderates cfo_ownership_pct → sustainable development.	+	β_int = 0.0142**, t = 2.18; conditional β rises from 0.0025* to 0.0071***	Supported
H5	Board effectiveness positively moderates cfo_education → sustainable development.	+	β_int = 0.0213**, t = 2.67; conditional β rises from 0.0128** to 0.0196***	Supported

Note. Supported" means that the results were statistically significant in the hypothesized direction at p < .10 or better both in the primary FE specification and in at least one robustness check. H1–H2: Table 9, Model 2.

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H3: Table 9, Model 3. H4-H5: Table 9, Model 4; Table 10, conditional effects. The positive and significant interaction effects (H4, H5) are valid as they indicate that board effectiveness is a direct determinant and an institutionalizing amplifier of the influence of CFO on sustainable development.

5. Conclusion

Summary of Findings

This study offers solid panel econometric support for the positive and independent relationship between CFO equity ownership and corporate sustainable development, and the positive relationship between board governance effectiveness and both of these. Combined with a wide range of second-generation panel methods and a balanced panel of 430 firms over 12 years, we find that the incentive alignment and cognitive sophistication of CFO equity ownership and educational attainment have the strongest impact on sustainability performance in governance settings with high-quality boards. Board effectiveness is also the most direct of all of the predictors, reinforcing its pivotal position in the governance–sustainability linkage both as a direct effect but also as a moderating institutional environment. The results indicate evidence of support for all five hypotheses in various estimators and specifications.

Theoretical Contributions

The study has four theoretical contributions. First, it extends Agency Theory to the sustainability performance domain. It provides evidence that the equity ownership alignment of the CFO drives ESG outcomes, an extension of the well-established ownership–investment quality relationship, which opens a new avenue of governance research.

Second, it uses Upper Echelons Theory to examine the CFO–sustainability linkage with a specific focus on educational qualification, and so extends the emerging branch of CFO-focused upper echelons research (Naaman, 2020), showing that formal human capital is a good predictor of CFO ESG performance.

Third, it posits and tests an institutional contingency argument that the impacts of the CFO characteristics on sustainability are moderated by board effectiveness, adding a specific mechanism to the corporate governance literature that explains how board quality affects the impact of executive human capital and incentives. Fourth, the study sheds new light on the relative importance of knowledge-based versus incentive-based CFO mechanisms under different governance situations by finding that the moderation effect of the board's effectiveness is greater for CFO education than for CFO ownership.

Practical Implications

The findings from the moderation for those involved in governance committees and board directors are very clear – the sustainability effect of CFO equity alignment and educational qualifications depends on the quality of the board. For companies looking to take full advantage of CFOs' sustainability-enhancing attributes, they should invest in board effectiveness at the same time they invest in CFO selection, including board independence, compositional quality and engagement intensity. The education interaction effect (conditional β at high board effectiveness: 0.0196***), which is nearly twice as large as the low-board-effectiveness benchmark (0.0128***), demonstrates the multiplicative governance premium available to those firms that match high-quality CFO human capital with strong governance of the board. The findings indicate that both CFO-level (ownership concentration, educational qualification) and board-level (quality indicators) metrics should be included in institutional investors' ESG due diligence governance dashboards and should be assessed in combination instead of separately.

High sustainability potential exists in companies that have a strong board with a CFO who has substantive equity ownership or advanced qualifications. Companies having a strong board with high equity involvement or advanced qualifications of the CFO have significantly higher sustainability potential. The study serves as evidence for those regulatory bodies that are creating mandatory ESG governance disclosure requirements that both the CFO-level and board-level characteristics of governance are material determinants of sustainability performance and should be systematically disclosed. Having to disclose CFO ownership and qualifications in addition to board independence and board expertise would allow investors and stakeholders to better understand the overall governance structure that drives sustainability outcomes.

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Limitations and future research

There are a few drawbacks to be noted. Firstly, the composite board effectiveness index combines sub-indicators that can have different and even contradictory impacts on the relationship between CFO and sustainability. Future research should separate board effectiveness into elements (independence, size, meeting frequency, expertise) and determine if it is a component of a board's characteristics or a result of their combined effectiveness index. Second, the binary operationalization of CFO education does not differentiate between disciplines (accounting, finance, MBA) or institutions and may be relevant for sustainability orientation. There would be more granular education measures for enriching understanding. Third, this paper deals with endogeneity issues with GMM and 2SLS. Still, the best quasi-experimental design would be to take advantage of exogenous shocks in the composition of the board, e.g., laws requiring mandatory changes to the composition of the board, to achieve cleaner causal identification. Fourth, the lack of data on sustainability strategies at the firm level prevents the study from directly observing the strategic sustainability decision-making processes through which the CFO characteristics and board effectiveness interact; qualitative and survey-based evidence of the processes would complement the large-N panel evidence provided here.

Contribution of Authors

All the authors participated in the ideation, development, and final approval of the manuscript, making significant contributions to the work reported.

Conflict of Interest Statement

The authors declare that there is no conflict of interest regarding the publication of this article.

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Informed Consent

Informed consent was obtained from all participants.

Data Availability

The datasets generated during and analysed during the current study are available from the corresponding author on reasonable request.

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