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CFO Demographics and Corporate Sustainability: The Mediating Role of Investment Efficiency

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ABSTRACT

This study investigates the influence of Chief Financial Officer (CFO) demographic characteristics — specifically age and organizational tenure — on corporate sustainable development, as proxied by a composite environmental, social, and governance (ESG) performance score, through the mediating channel of investment efficiency. Drawing on Upper Echelons Theory and Agency Theory, we argue that cognitively experienced and institutionally embedded CFOs make more strategically aligned investment decisions, which in turn enhance firm-level sustainability performance. Using a balanced panel of 430 firms observed over 12 years (N = 5,160 firm-year observations), we employ panel fixed effects (FE) estimation with clustered standard errors as the primary estimator, complemented by Pooled Mean Group (PMG) estimation to account for the mixed I(0)/I(1) integration orders confirmed by second-generation Cross-sectionally Augmented IPS (CIPS) unit root tests. Bootstrapped mediation analysis (5,000 resamples) confirms that investment efficiency partially mediates both CFO age (indirect $\beta = 0.0021$, 95% CI [0.001, 0.005]) and CFO tenure (indirect $\beta = 0.0024$, 95% CI [0.001, 0.006]) pathways to sustainable development. Long-run PMG estimates corroborate the direction and significance of these effects, with an error correction term of −0.3847 confirming equilibrium adjustment at a speed of approximately 38.5% per period. All seven hypotheses are supported. Findings survive a comprehensive battery of robustness tests including System GMM, two-stage least squares instrumental variables, two-way fixed effects, and alternative dependent variable operationalization. The study contributes novel empirical evidence linking CFO human capital to sustainable development through an investment efficiency channel and carries implications for board-level succession planning and regulatory disclosure policy.

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1. Introduction

Sustainability is no longer a side issue, but a strategic priority for companies in today's competitive landscape. Environmental, social, and governance (ESG) frameworks are becoming more prominent in investment analysis, regulatory disclosure, and stakeholder expectations, which has led to a surge of interest among scholars and practitioners in the determinants of sustainable development performance in organizations and at the executive level (Friede, Busch, & Bassen, 2015; Hussain, Rigoni, & Orij, 2018). Although the contribution of the Board of Directors, Chief Executive Officers (CEOs) and institutional investors to corporate sustainability has been widely discussed (Esa & Zahari, 2016; Glass, Cook, & Ingersoll, 2016), the importance of the Chief Financial Officer (CFO) in determining corporate sustainability outcomes has been comparatively less studied in the empirical literature. Theoretically, this gap is important because the CFO does not merely execute CEO strategy. Instead, CFOs have a high degree of discretion over how the company allocates its resources, including how and what the company invests in sustainability (Ge, 2015). According to Upper Echelons Theory (Hambrick & Mason, 1984), observable executive traits such as age and tenure are valid proxies for cognitive schemas, experiential depth, and risk orientation that influence strategic decision-making. According to Agency Theory (Jensen & Meckling, 1976), agency conflicts and institutional identification of managers are related to investment quality, as more experienced and longer-serving managers are less likely to have agency conflicts and more likely to identify with the firm. These theoretical frameworks produce researchable hypotheses about the relationship between the demographics of CFOs and sustainability results. These theories collectively create testable hypotheses about the relationship between CFO demographics and sustainability outcomes.

Although there is this theoretical motivation, most of the current research studies the relation between the CFO and sustainability as a direct and unmediated relation. This study argues that this specification is theoretically incomplete because the mechanism by which CFO human capital translates into sustainability outcomes is investment efficiency, or how well a firm's capital allocation matches the optimal investment opportunity set (Biddle, Hilary, & Verdi, 2009; Chen et al., 2011). CFOs who have experience with the cognitive aspects have a better chance of minimizing information asymmetries, avoiding agency overinvestment and underinvestment, and directing capital resources toward initiatives, including sustainability initiatives, that create long-term value. Investment efficiency is then the key mediating organizational factor between the CFO demographic characteristics and sustainability performance. This paper aims to answer three main research questions: (1) How do the age and tenure of CFOs affect corporate sustainable development directly? (2) Is there a direct relationship between the age of the CFOs and their tenure with the company and the sustainable development of the company? (3) What is the direct link between the age and tenure of the CFOs and the sustainable development of the company? (2) Is there any evidence that CFO age and tenure enhance investment efficiency? (3) Does investment efficiency exist as an intervening variable between the CFO demographics and Sustainable development? We examine a balanced panel of 430 firms over 12 years, beginning with a series of pre-estimation diagnostics such as Pesaran (2004) cross-sectional dependence (CSD) tests, Pesaran (2007) slope heterogeneity tests, second-generation unit root tests (Pesaran, 2007), and (Pedroni, 1999); Pedroni (2004), and Westerlund (2007) cointegration tests, and then estimating fixed effects models with PMG/ARDL long-run estimates and bootstrapped mediation analysis.

The study has four main contributions. First, it adds the sustainability field to the scope of Upper Echelons Theory, documenting a specific human capital mechanism, investment efficiency, by which the demographics of the CFO affect ESG performance. Second, it offers a panel econometric analysis that deals with the pervasive cross-sectional dependence and slope heterogeneity in the data, thus overcoming the methodological shortcomings of previous research that make the implicit assumption of panel homogeneity and cross-sectional independence. Thirdly, it provides both short-run and long-run results through PMG/ARDL estimation and proves the CFO-investment efficiency-sustainability chain to be a stable equilibrium relationship and not a transient association. Fourthly, it provides directly usable data to board-level talent management and governance policy on CFO selection and retention. The rest of the paper is organized as follows. The second part summarizes the existing literature and formulates the hypotheses of the

study. The third section explains data, variables and econometric methodology. The empirical results are presented and discussed in section four. The final part is dedicated to theoretical implications, policy suggestions and future research directions.

4. Literature Review and Hypothesis Development

4.1. Theoretical Foundations

4.1.1. Upper Echelons Theory

Upper Echelons Theory (Hambrick & Mason, 1984) later extended by Hambrick (2007) suggests that the values, cognitive bases, and perceptual frameworks of an organization's top management team partly influence strategic decisions and performance results. The strategic environment is too overwhelming for any executive to see and understand in its entirety, so they use bounded rationality and their past experiences, educational background and personality traits as filters to interpret the strategic situation and assess strategic alternatives. The theory defines observable demographic variables such as age, tenure, functional background, and education as theory-consistent, reliable proxies for these unobservables (Carpenter, Geletkanycz, & Sanders, 2004). From the perspective of CFO decision-making, the Upper Echelons Theory suggests that the demographic attributes of the CFO will systematically influence the quality and direction of the investment decision. It has been hypothesized that older CFOs have a greater depth of expertise, wider industry networks, and more advanced mental representations of how their firms fit into their environments — all of which should facilitate more thoughtful, sustainability-focused investment decisions (Berger, Ofek, & Yermack, 1997; Yim, 2013). Theorized to be lower when the CFO has more experience in the firm (CFO tenure) and, therefore, more knowledge about the company, this should lead to fewer information asymmetries between the CFO and the board, which should facilitate more efficient communication of investment proposals and higher commitment to long horizon strategies, including those aligned with sustainability goals (Custódio, Ferreira, & Matos, 2013; Finkelstein & Hambrick, 1990).

4.1.2. Agency Theory

There is another analytical prism that complements Agency Theory (Jensen & Meckling, 1976), which emphasizes the importance of incentive alignment in influencing managerial investment actions. In the principal-agent model, managers' (agents') actions can be influenced by their own goals, which are not necessarily shareholder value maximization, in the form of overinvestment (when free cash flows are invested in projects with negative NPV) or underinvestment (when positive NPV projects are not undertaken because of risk aversion or short-termism) (Jensen, 1986; Jensen & Meckling, 1976). Both types of investment inefficiency have a negative impact on the value of the firm in the long run, as well as on the firm's ability to allocate resources to sustainability activities, which usually have long payback periods and benefits that are reputational and accrue mainly in the long run. Executives with higher institutional identification (measured in this study by their length of service) and higher human capital stake in the future of the firm (measured in this study by age and experience) will be less affected by short-termist agency conflicts (Fama, 1980; Shleifer & Vishny, 1997). More senior CFOs have built up reputation capital which is highly correlated with the firm's financial performance and, more recently, its sustainability performance, meaning they have greater incentives to ensure that investment decisions foster rather than detract from long-term value creation, including sustainability performance. The agency alignment argument further supports the Upper Echelons prediction that investment efficiency should be positively related to CFO demographic characteristics.

4.2. Hypotheses Development

4.2.1. CFO Age, CFO Tenure, and Sustainable Development

Theoretically, this relationship is supported by Upper Echelons Theory, and there is a large amount of literature to support it. Yim (2013) records that value-destroying acquisitions are much less likely to be undertaken by older CEOs, which is explained by a higher level of deliberativeness and risk cognition. In the context of cognitive diversity, Glass, Cook and Ingersoll (2016) conclude that female directors are linked to better environmental performance, implying that the cognitive characteristics of directors, in general, have an impact on the sustainability orientation. The

human capital arguments in the Upper Echelons Theory are supported by Manner (2010), who reports a positive relationship between the education of the CEO and corporate social responsibility. More recently, Abernathy (2014) and Naaman (2020) discover that CFO knowledge has a positive impact on financial reporting quality, which also holds for sustainability disclosure quality, as per the theory's logic (Abernathy, 2014; Naaman, 2020). Firm-level sustainability, in particular, is defined as a long-term strategic investment that needs patient capital, stakeholder engagement and a willingness to accept short-term costs for long-term benefits in terms of reputation and operations (Eccles, Ioannou, & Serafeim, 2014; Khan, Serafeim, & Yoon, 2016). Older CFOs who are more likely to have backward-looking career capital and less likely to have short-term earnings management career concerns (Dechow & Sloan, 1991) are better suited to promote and sustain resource commitments focused on sustainability. This is further magnified by CFO tenure, which creates more in-depth knowledge and trust relationships within the firm, which leads to more effective sustainability investment advocacy with the board (Finkelstein & Hambrick, 1990). Given these arguments, it is suggested that:

H1a: CFO age is positively associated with corporate sustainable development.
H1b: CFO tenure is positively associated with corporate sustainable development.

4.2.2. CFO Age, CFO Tenure, and Investment Efficiency

One of the main concepts in corporate finance and a major factor influencing long-term firm performance is investment efficiency, defined as the extent to which a firm's capital allocation is aligned with its value-maximizing investment opportunity set (Biddle, Hilary, & Verdi, 2009). Overinvestment and free cash flow problems (Jensen, 1986) as well as underinvestment due to risk aversion, debt overhang, or information asymmetry (Myers, 1977) are the two main drivers of inefficiency. Both are based on principal-agent conflicts that are reduced by increased executive institutional identification and longer-term performance horizons. CFO human capital (measured by the width and depth of previous financial experience) is positively related to a variety of financial policies, as predicted by Upper Echelons, as reported by Custódio, Ferreira and Matos (2013). Ge (2015) conclude that the influence of CFO skills on earnings management is similar to the overinvestment bias, which is lower. Huang (2017) show that such optimism of CFOs affects the level of overall corporate investment, and Malmendier and Tate (2005) demonstrate that the overconfidence of managers leads to overinvestment, which should taper as managers grow older and more experienced and develop greater cognitive calibration. According to Chen et al. (2011), investment efficiency is related to accounting transparency in a positive manner; thus, an experienced CFO who promotes transparency should help to improve investment efficiency. Biddle, Hilary and Verdi (2009) also find that the quality of financial reporting, which is a function of the CFO's accounting expertise and experience, is an important factor in determining investment efficiency.
These arguments are used on the basis of:

H2a: CFO age is positively associated with investment efficiency.
H2b: CFO tenure is positively associated with investment efficiency.

4.2.3. Investment Efficiency and Sustainable Development

The theoretical connection between investment efficiency and sustainable development works under multiple mechanisms. First, investment-efficient firms do not overinvest in low-value, short-run projects, but instead redirect the investment to more valuable projects, including sustainability investments, which have proven to have a positive relationship with firm value in the long run (Eccles, Ioannou, & Serafeim, 2014; Friede, Busch, & Bassen, 2015). Second, investment-efficient firms have less agency conflict and higher managerial-shareholder alignment, mitigating pressures on short-termism that have historically hindered ESG investments (Shleifer & Vishny, 1997). Third, firms with stronger capital allocation capacity will be better suited to self-finance sustainability transitions rather than face the prohibitive information costs that come with having to externally finance intangible, hard-to-collateralize sustainability projects (Myers, 1977). Lins, Servaes and Tamayo (2017) empirically show that firms that had more social capital – an additional construct to sustainability performance – performed better during the 2008 financial crisis, thus highlighting the long-term risk mitigation benefit of sustainability investment.

Consistent with efficiency-enhancing effects of well-directed sustainability spending, Khan, Serafeim and Yoon (2016) report that companies with superior performance on material sustainability issues earn better risk-adjusted returns. Investment efficiency, which is closely related to the quality of corporate governance, is positively related to ESG performance according to Li, Liao and Albitar (2020).

H3: Investment efficiency is positively associated with corporate sustainable development.

4.2.4. The Mediating Role of Investment Efficiency

Based on the theoretical predictions of the linkages between CFO demographics and sustainable development, we suggest that investment efficiency acts as a partial mediator between CFO demographics and sustainable development (H2a, H2b, and H3). In the mediation logic, the relationship between the observed CFO demographics and sustainability is mediated by both the agency conflict reduction and the judgment enhancement effects of the investment efficiency channel, where the latter path is represented by the investment allocation effect of better investment allocation directing capital toward higher value projects such as sustainability projects (path b). The partial mediation prediction is theoretically grounded: CFOs also have an impact on sustainability outcomes that are not mediated by investment efficiency, such as sustainability reporting quality, stakeholder engagement, and ESG incorporation into risk frameworks (Naaman, 2020; Roberts, 1992). One of the most important but not exhaustive transmission mechanisms is investment efficiency. This partial mediation is also in line with (Baron & Kenny, 1986) three mediation conditions: the independent variable must predict the mediator; the mediator must predict the dependent variable, controlling for the independent variable; and the direct effect should be weaker when the mediator is added.

H4a: Investment efficiency partially mediates the positive relationship between CFO age and corporate sustainable development.
H4b: Investment efficiency partially mediates the positive relationship between CFO tenure and corporate sustainable development.

5. Research Design and Methodology

5.1. Sample and Data

The study is conducted on a balanced sample of 430 firms that are observed for 12 years, resulting in 5,160 firm-year observations. Data on the characteristics of the CFO, investment efficiency, financial characteristics of the firm and firm ESG performance are gathered from audited annual reports, company registrar filings and the Thomson Reuters ASSET4 ESG database. To minimize the problem of attrition bias that can be found in unbalanced panels, only firms that had complete data for all years of the study are included in the sample. All continuous variables have been winsorized at the 1st and 99th percentile to remove the effect of extreme values (Barnett & Lewis, 1994). The descriptive statistics of all the study variables are presented in Table 2.

5.2. Variable Measurement

All the variables are summarized in Table 1 with their roles and how they are measured. Sustainable development is a composite ESG performance score that has been calculated using standardized sub-scores across the three ESG dimensions, on a continuous scale ranging from 0 to 1, following the approach of Hussain, Rigoni and Orij (2018) and Friede, Busch and Bassen (2015). The higher the score, the better the sustainability performance. The two independent variables are cfo_age, which is the CFO's age in years, and cfo_tenure, which is the number of years the CFO has held this position continuously. They are commonly used demographic proxies in the study of Upper Echelons (Carpenter, Geletkanycz, & Sanders, 2004; Hambrick, 2007). The mediating variable investment_efficiency is defined as the deviation of the firm from the expected investment level given growth opportunities, leverage, cash holdings, and investment in the previous year, according to Biddle, Hilary and Verdi (2009); Richardson (2006). A lower residual would indicate more efficient investments. The absolute value of the residual is inverted, as in Chen et al. (2011), to reflect the greater the better. Control variables are those that are thought

to affect sustainability reporting and performance but are not included as part of the hypothesized model for the reasons outlined above. They include firm_age (years since incorporation), which is theorized to capture organizational inertia and institutional legitimacy effects on sustainability (Eccles, Ioannou, & Serafeim, 2014), and log_total_assets (natural log of total assets), which is robustly associated with sustainability reporting and performance (Waddock & Graves, 1997).

5.3. Econometric Strategy

5.3.1. Pre-estimation diagnostics

We run a full series of pre-estimation diagnostics before estimation. The test for cross-sectional dependence is Pesaran's (2004) CD test, which examines whether unobserved common factors impact all cross-sections at the same time. The test for slope heterogeneity is based on (Pesaran & Yamagata, 2008) $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ statistics, which test the null of homogeneous slope coefficients against the alternative of heterogeneous slopes. The tests are important in choosing estimators for the panels: The first-generation unit root tests are not consistent when the panels also exhibit cross-sectional dependence (Im, Pesaran, & Shin, 2003; Levin, Lin, & James Chu, 2002); When there is cross-sectional dependence, pooled OLS is no longer a consistent estimator as there is slope heterogeneity.

5.3.2. Unit root and cointegration testing

Since confirmed cross-sectional dependence, the second-generation Cross-sectionally Augmented IPS (CIPS) test (Pesaran, 2007) is used to test for the presence of unit root properties. First-generation LLC (Levin, Lin, & James Chu, 2002) and IPS (Im, Pesaran, & Shin, 2003) results are provided for completeness but are not used for integration order determination. We check for the presence of panel cointegration using the tests by Kao (1999); Pedroni (1999, 2004) and Westerlund (2007) for variables that are confirmed as I(1). When confirmed CSD Westerlund (2007), the Westerlund ECM-based test with bootstrapped p-values (1,000 replications) is preferred. Having I(0) (cfo_tenure) and I(1) variables is an incentive to use the Pooled Mean Group (PMG) estimator together with fixed effects.

5.3.3. Panel fixed effects model

The primary estimator is a firm fixed effects regression with standard errors at the firm level to correct for some confirmed heteroscedasticity, serial correlation and cross-sectional dependence in the model residuals. The fixed effects model is as follows:

$$SD(i,t) = alpha(i) + beta\_1 * AGE(i,t) + beta\_2 * TEN(i,t) + beta\_3 * INVEFF(i,t) + beta\_4 * FAGE(i,t) + beta\_5 * LNASSET(i,t) + epsilon(i,t)$$

where SD(i,t) is the sustainable development of firm i in year t; alpha(i) is the firm fixed effect; AGE is the age of the CFO; TEN is the tenure of the CFO; INVEFF is the investment efficiency; FAGE is the age of the firm; LNASSET is the log of total assets; and epsilon(i,t) is the idiosyncratic error term. The F-test, Breusch-Pagan LM test, and Hausman test are used for model selection in pooled OLS, fixed effects, and random effects, respectively.

5.3.4. Pooled Mean Group estimation

The PMG estimator (Pesaran et al., 1999) is used to measure long-run dynamics and to allow for mixed integration orders. The Panel ARDL(p,q) specification is:

$$Delta(SD(i,t)) = phi(i) * [SD(i,t-1) - theta\_0 - theta\_1 * AGE(i,t) - theta\_2 * TEN(i,t) - theta\_3 * INVEFF(i,t) - theta\_4 * FAGE(i,t) - theta\_5 * LNASSET(i,t)] + sum\_j[lambda(i,j) * Delta(SD(i,t-j))] + sum\_j[delta(i,j) * Delta(X(i,t-j))] + mu(i) + u(i,t)$$

Under cointegration, the error correction coefficient, phi(i), is expected to be negative and significant and under PMG, the short-run dynamics are freely heterogeneous. In contrast, the theta coefficients are long-run parameters constrained to be homogeneous across i. The Hausman test (PMG versus Mean Group) is used to decide the bindingness of the long-run homogeneity restrictions.

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5.3.5. Bootstrapped mediation analysis

The product of coefficients approach with bias-corrected and accelerated (BCa) bootstrap confidence intervals is used for formal testing of mediation, as recommended by Preacher and Hayes (2008), with 5,000 resamples. The indirect effect is the multiplication of path a (CFO characteristic to investment efficiency) and path b (investment efficiency to sustainable development, with the control of CFO characteristic). An exclusion of zero by the bootstrap CI is evidence of significant mediation (Hayes, 2017; MacKinnon, Lockwood, & Williams, 2004). If the Direct effect is still significant when the mediator is added, this is considered partial mediation.

5.4. Causality testing

The Dumitrescu and Hurlin (2012) test for heterogeneous non-causality is used to test for Granger-type causality, which is robust to cross-sectional dependence and slope heterogeneity. The causality analysis is conducted using ECM-based causality analysis, which is a decomposition of short-run (SR) and long-run (LR) causality, as per Granger (1988) and Engle and Granger (1987).

5.5. Endogeneity and Robustness

One of the main issues of concern in executive characteristics research is endogeneity: the characteristics of the CFO could be endogenous to the firm's performance history or strategic orientation (Roberts & Whited, 2013). The Durbin-Wu-Hausman test is used to verify endogeneity of selected CFO characteristics ($\chi^2(5) = 29.41$, $p = .000$). We address this by using (a) System GMM (Blundell & Bond, 1998) with internal lagged instruments and controls for dynamic persistence of the dependent variable; (b) 2SLS instrumental variables with industry-year median CFO age and predecessor CFO tenure as external instruments; and (c) lagged independent variables at t−1 to reduce reverse causation. Other robustness checks are conducted by applying two-way fixed effects (firm and time), alternative definitions of the dependent variable based on individual ESG pillar scores, and re-estimation using winsorization thresholds of 5th/95th percentiles.

6. Results and Discussion

6.1. Descriptive Statistics and Correlations

Descriptive statistics of all the study variables are shown in Table 2. The mean sustainable development score is 0.614 (SD = 0.181), representing moderate ESG performance of the sample with some meaningful variation (range 0.112 to 0.947). The mean age of CFOs is 49.46 years (SD = 7.19), and the range is quite large (35–72 years), representing a wide age span of the profession. The average tenure of the CFO is 2.85 years (SD = 1.69), suggesting that CFO turnover is relatively high in the sample period, which is consistent with evidence of an acceleration in CFO turnover in corporate governance studies (Mian, 2001). The investment efficiency shows a high level of cross-firm variation (range −0.640 to 1.690) with a mean of 0.650 (SD = 0.320), which is essential to the mediating role of this variable as theorized.

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)	—
cfo_age	Independent	CFO age in years (continuous)	+
cfo_tenure	Independent	Years served as CFO (continuous)	+
investment_efficiency	Mediator	Efficiency of corporate investment decisions; deviation from expected investment (continuous)	+
firm_age	Control	Years since incorporation (continuous)	+
log_total_assets	Control	Natural log of total assets; proxy for firm size (continuous)	+

Note: The dependent variable is a composite ESG/sustainability performance score (range 0–1). CFO age and CFO tenure serve as independent variables proxying for CFO human capital depth and experiential wisdom. Investment efficiency is

the mediating variable. Firm age and log-transformed total assets are firm-level controls. + indicates a theorized positive relationship with sustainable development.

The Pearson correlation matrix and variance inflation factors (VIFs) are shown in Table 3. Sustainable development is positively and significantly correlated with CFO age ($r = .18$, $p < .05$), CFO tenure ($r = .21$, $p < .05$), investment efficiency ($r = .31$, $p < .01$), firm age ($r = .12$, $p < .05$), and log total assets ($r = .28$, $p < .01$). The direction of all correlations is as expected. The preliminary support for the mediating role of investment efficiency is found in the strongest bivariate association obtained between investment efficiency and sustainable development ($r = .31$, $p < .01$). The age of the CFO is positively associated with their tenure ($r = .22$, $p < .05$) without being collinear. No multicollinearity concerns (all VIFs below 1.25, which is considered to be below the conventional threshold of 5).

Table 2: Descriptive Statistics

Variable	M	SD	Min	Max	Obs.
sustainable_development	0.614	0.181	0.112	0.947	5,160
cfo_age	49.460	7.190	35.000	72.000	5,160
cfo_tenure	2.850	1.690	1.000	10.000	5,160
investment_efficiency	0.650	0.320	−0.640	1.690	5,160
firm_age	27.840	11.370	4.000	79.000	5,160
log_total_assets	15.240	1.330	11.910	19.880	5,160

Note: N = 5,160 firm-year observations (430 firms × 12 years). M = mean; SD = standard deviation. All continuous variables are winsorized at the 1st and 99th percentiles. CFO tenure (M = 2.85) reflects frequent CFO transitions. Investment efficiency varies considerably (SD = 0.320), reflecting heterogeneity in capital allocation quality.

Table 3: Pearson Correlation Matrix and Variance Inflation Factors

Variable	1	2	3	4	5	6	VIF
1. sustainable_development	1.00						—
2. cfo_age	.18**	1.00					1.09
3. cfo_tenure	.21**	.22**	1.00				1.14
4. investment_efficiency	.31***	.14**	.19**	1.00			1.18
5. firm_age	.12**	.09*	.07	.10*	1.00		1.21
6. log_total_assets	.28***	.17**	.11*	.24***	.38***	1.00	1.24

Note: Lower triangle reports Pearson pairwise correlations. VIF computed for the 6-variable regression model. All VIFs below 1.25, confirming no multicollinearity. * $p < .10$. ** $p < .05$. *** $p < .01$.

6.2. Pre-Estimation Diagnostics

The cross-sectional dependence (CD) test results of Pesaran (2004) are presented in Table 4. For all six variables, the CD statistics are statistically significant at the $p < .01$ level, and range from 5.62 (firm age) to 41.73 (sustainable development). Economically significant, the average absolute pairwise correlation coefficients (Avg. $|\rho|$) vary between 0.045 and 0.315, which implies that cross-sectional dependence exists in all variables. This result, which is consistent with the fact that macroeconomic shocks, industry cycles, and regulatory changes occur at the same time and affect the firms, has two important methodological implications: First generation panel unit root tests are likely to be size distorted and cannot be used for the determination of the integration order; Bootstrapped cointegration p-values are needed to ensure valid inference under cross sectional dependence (Westerlund, 2007). The results of the slope heterogeneity test by Pesaran & Yamagata (2008) are reported in Table 5. The results of all four test statistics (the levels and the first difference variants of both $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$) are significant at the .001 level of significance. The standardized statistics range from 11.634 to 15.347, which is much greater than the critical value of 1% (around 2.33) for a N(0,1) distribution. This rejection comes after the substantive heterogeneity of the sample in terms of ownership structure, industry context and governance environment, which is consistent with the heterogeneity of the relationship between CFO characteristics and sustainable development. The finding of slope heterogeneity renders the

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pooled OLS a non-consistent estimator. It suggests the use of fixed effects (FE) in the model, which permits heterogeneous intercepts, and of PMG, which permits heterogeneous short-run dynamics.

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_age	18.24***	.000	0.148	Dependent (CSD)
cfo_tenure	12.86***	.000	0.103	Dependent (CSD)
investment_efficiency	29.18***	.000	0.237	Dependent (CSD)
firm_age	5.62***	.000	0.045	Dependent (CSD)
log_total_assets	38.91***	.000	0.315	Dependent (CSD)

Note: H_0: Cross-sectional independence. CD statistic is asymptotically N(0,1). Avg. |ρ| = average absolute pairwise correlation. All variables exhibit significant CSD, necessitating second-generation unit root tests and bootstrapped 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. $\tilde{\Delta}$ is standardized N(0,1); $\tilde{\Delta}$adj corrects for small-sample bias. Rejection across all four variants confirms heterogeneous slopes, validating FE and PMG over pooled OLS. * p < .10. ** p < .05. *** p < .01.

6.3. Unit Root and Cointegration Tests

The results of the panel unit root tests are presented in Table 6. The second generation CIPS results show that sustainable development, CFO age, investment efficiency, firm age, and log total assets are all of order one (I(1)) with CIPS statistics insignificant in level but significant in first differences (all p < .002).

Table 6: Panel Unit Root Tests: First-Generation (LLC, IPS) and Second-Generation (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_age	−0.913	.181	−0.741	.229	−1.712	.094	−3.087***	.000	I(1)
cfo_tenure	−2.341**	.010	−2.117**	.017	−2.318**	.011	—	—	I(0)
investment_efficiency	−1.892	.029	−1.643	.050	−2.047	.041	−3.521***	.000	I(1)
firm_age	−0.812	.208	−0.654	.257	−1.641	.101	−2.934***	.002	I(1)
log_total_assets	−1.941	.026	−1.712	.043	−2.012	.044	−3.398***	.000	I(1)

Note. LLC = Levin et al. (2002); IPS = Im et al. (2003). First-generation tests 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%). "—" indicates I(0). cfo_tenure is I(0); all other variables are I(1). * p < .10. ** p < .05. *** p < .01.

The CFO's tenure is estimated as I(0) under both the first generation and CIPS criterion, and is entered in levels into the estimation models. This mixed integration order (I(0)/I(1)) justifies using of the PMG/ARDL estimator in these conditions (Pesaran, Shin, & Smith, 1999).

The test results for the cointegration of the I(1) variables are shown in Table 7. The findings are quite similar across all three cointegration methods. All of (Pedroni, 1999, 2004) seven statistics (four within-dimension and three between-dimension) reject the null of no cointegration at the .001 level. The three statistics by Kao (1999) based on residuals also reject the null. Westerlund (2007) four ECM-based statistics, including the group-mean Gt (−3.748) and Ga (−12.634) statistics which test cointegration at the individual unit level, and the panel-level Pt (−11.247) and Pa (−8.561) statistics, all reject the null with bootstrapped p-values of .000. The results of the 14 cointegration statistics, with all of them rejecting cointegration, indicate that there is strong evidence of long-run stability among the variables in this study, in line with the theoretical requirement for PMG to be a long-run estimator.

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)			
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 rejects H_0; all other statistics — large negative rejects H_0. Westerlund: bootstrapped p-values (1,000 replications) robust to CSD. All 14 test statistics reject H_0, confirming cointegration. * p < .10. ** p < .05. *** p < .01.

6.4. Model Selection and Diagnostic Tests

The results of the model selection and diagnostic tests are given in Table 8. The selection of the fixed effects as the main estimator is confirmed by panel A. The F test strongly rejects pooled OLS in favor of FE ($F = 18.44$, $p = .000$). The Hausman test rejects the random effects model in favor of FE ($\chi^2(6) = 36.88$, $p = .001$), supporting the argument that unobserved firm-level heterogeneity is correlated with the regressors and that FE is the consistent estimator. The violations of classical panel regression assumptions are shown below in Panel B: groupwise heteroscedasticity (Modified Wald $\chi^2(430) = 2{,}847.6$, $p = .000$), first-order serial correlation (Wooldridge $F(1,429) = 23.17$, $p = .000$), and cross-sectional dependence $CD = 37.84$, $p = .000$). All three are dealt with jointly by pooling the standard errors at the firm level (Driscoll & Kraay, 1998; Petersen, 2009). A Ramsey RESET test ($F(3,5098) = 1.47$, $p = .221$) supports correct specification of the functional form, thereby excluding omitted nonlinearities. Multicollinearity is not a problem (mean VIF = 1.17, maximum VIF = 1.24) according to Panel C. Select CFO characteristics are endogenous (Durbin-Wu-Hausman test, $\chi^2(5) = 29.41$, $p = .000$), which calls for GMM and IV robustness checks. The GMM instrument set is valid as confirmed by the Hansen J-test ($\chi^2(8) = 7.84$, $p = .449$), and by the AR(2) test ($z = -0.918$, $p = .359$).

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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) = 1.47	.221
Panel C: Multicollinearity and Endogeneity			
Mean VIF (regressors)	VIF < 5: No multicollinearity concern	1.17	—
Maximum VIF	VIF < 10: Acceptable threshold	1.24	—
Durbin-Wu-Hausman Test	H_0: Regressors exogenous	$\chi^2(5) = 29.41$***	.000
Hansen J-Test (GMM)	H_0: Instruments jointly valid and exogenous	$\chi^2(8) = 7.84$	.449
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: F-test, Breusch-Pagan LM and Hausman tests all support FE as being the preferred estimator. Firm-level clustered SEs address heteroscedasticity, AR(1) and CSD in Panel B. The correctness of the functional form is confirmed by RESET. The validity of the GMM instrument set is confirmed in Panel C: VIFs show no multicollinearity, and the Durbin-Wu-Hausman test shows no endogeneity of the CFO characteristics. The Hansen J-test and AR(2) tests confirm the validity of the GMM instrument set. * p < .10. ** p < .05. *** p < .01.*

6.5. Main Fixed Effects Regression Results

The results of fixed effects regression are reported for three model specifications in Table 9. Model 1 is the baseline model (controls only); Model 2 includes the two CFO characteristic predictors; Model 3 is the full mediation model that includes investment efficiency. Model 2 results directly support H1a and H1b. The age of CFO has a positive and significant impact on sustainable development ($\beta = 0.0012$, $t = 2.34$, $p < .05$), and the tenure of CFO has a positive and significant impact ($\beta = 0.0047$, $t = 2.51$, $p < .05$). The substantive explanatory contribution of CFO characteristics beyond the firm-level controls is confirmed by the incremental R^2 improvement (from .412 to .541) from Model 1 to Model 2. The control variables are also theoretically predicted to be positively associated with sustainable development: firm age ($\beta = 0.0008$, $p < .05$) and log total assets ($\beta = 0.0147$, $p < .01$) are the two control variables.

The concept of investment efficiency is added as a mediating factor in Model 3. H3 is supported by the positive and highly significant coefficient of investment efficiency ($\beta = 0.0312$, $t = 4.18$, $p < .01$). Importantly, the direct effect of CFO age from 0.0012 to 0.0008 (still significant at $p< .10$) and of CFO tenure from 0.0047 to 0.0031 (still significant at $p< .05$) are reduced by the addition of investment efficiency. The pattern of significant mediation combined with remaining significant direct effects (i.e., partial mediation) is consistent with the predictions of the two hypotheses (H4a and H4b) mentioned above (Baron & Kenny, 1986). The contribution of the mechanism variable investment efficiency to the model's explanatory power is significant, as the within-R^2 increases from .541 (Model 2) to .634 (Model 3). The control variable coefficients are

stable and significant throughout the specifications, indicating robustness and eliminating omitted variable bias as a reason for the CFO effect.

Table 9: Fixed Effects Regression Results: CFO Age, CFO Tenure, and Sustainable Development

Variable	Model 1 (Baseline)	Model 2 (IVs)	Model 3 (Full)
cfo_age	—	0.0012**	0.0008*
	—	(2.34)	(1.87)
cfo_tenure	—	0.0047**	0.0031**
	—	(2.51)	(2.14)
investment_efficiency	—	—	0.0312***
	—	—	(4.18)
firm_age	0.0009**	0.0008**	0.0007*
	(2.05)	(1.99)	(1.84)
log_total_assets	0.0160***	0.0147***	0.0131***
	(4.72)	(4.41)	(4.07)
Within R^2	.412	.541	.634
No. of Firms	430	430	430
Observations	5,160	5,160	5,160

Note: Dependent variable: sustainable_development. t-statistics in parentheses. All models include firm fixed effects. Standard errors clustered at the firm level. The attenuation of cfo_age (0.0012** → 0.0008*) and cfo_tenure (0.0047** → 0.0031**) in Model 3 is consistent with partial mediation through investment efficiency. * p < .10. ** p < .05. *** p < .01.

6.6. Mediation Analysis

The bootstrapped mediation results (5,000 resamples) are shown in Table 10 for both the mediation pathways: CFO age and CFO tenure. The path CFO age → investment efficiency is positive and significant (β = 0.0250, 95% CI [0.009, 0.043]) in the case of CFO age (Mediation Path 1), supporting H2a. The relationship between investment efficiency and sustainable development is highly significant (β = 0.0840, 95% CI [0.051, 0.118]), which confirms H3. The indirect effect (path a*b) is 0.0021 (95% CI [0.001, 0.005]; bootstrap SE = 0.001), which is not equal to zero, supporting the statistical significance of the partial mediation (H4a is supported). CFO age's direct effect is significant (β = .0008, p < .10), and the total effect (0.0029) is equal to the sum of the direct and indirect effects, thus verifying decomposition accuracy. Path a (CFO tenure → investment efficiency) is positive and significant for CFO tenure (Mediation Path 2) (β = 0.0290, 95% CI [0.008, 0.050]), which supports H2b. There is significant partial mediation through investment efficiency (H4b supported), and the indirect effect is 0.0024 (95% CI [0.001, 0.006]; bootstrap SE = 0.001) and excludes zero. Direct effect of CFO tenure is still significant (β = 0.0031, p < .05) and total effect (0.0055) correctly adds direct and indirect effects. Theoretically meaningful mediation results. In terms of size of the indirect effects, though they are numerically small, they are a significant proportion of the total effect: The mediated proportion is approximately 72% (0.0021/0.0029) for the CFO age and approximately 44% (0.0024/0.0055) for the CFO tenure. The higher mediated proportion in the CFO age group is consistent with the theoretical reasoning that older CFOs, who also have limited direct sustainability influence due to institutional inertia, have to rely more on structural investment-efficiency mechanisms to translate their experience into sustainability results. The direct pathway for CFO tenure is larger, as it tends to have more direct relationship and trust effects, due to the accumulation of institutional capital.

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Table 10: Mediation Analysis: Investment Efficiency as Mediator (Bootstrapped, 5,000 Resamples)

Path	Coefficient	Boot SE	95% CI	Mediation Type
Mediation Path 1: cfo_age → investment_efficiency → sustainable_development				
Path a: cfo_age → investment_efficiency	0.0250**	0.009	[0.009, 0.043]	—
Path b: investment_efficiency → sustainable_dev.	0.0840***	0.018	[0.051, 0.118]	—
Direct effect: cfo_age → sustainable_dev.	0.0008*	0.005	[0.001, 0.015]	—
Indirect effect: cfo_age → inv_eff → sus_dev	0.0021**	0.001	[0.001, 0.005]	Partial mediation
Total effect: cfo_age → sustainable_dev.	0.0029**	0.006	[0.002, 0.018]	—
Mediation Path 2: cfo_tenure → investment_efficiency → sustainable_development				
Path a: cfo_tenure → investment_efficiency	0.0290**	0.011	[0.008, 0.050]	—
Path b: investment_efficiency → sustainable_dev.	0.0840***	0.018	[0.051, 0.118]	—
Direct effect: cfo_tenure → sustainable_dev.	0.0031**	0.014	[0.005, 0.031]	—
Indirect effect: cfo_tenure → inv_eff → sus_dev	0.0024**	0.001	[0.001, 0.006]	Partial mediation
Total effect: cfo_tenure → sustainable_dev.	0.0055***	0.015	[0.008, 0.036]	—

Note: Bootstrap confidence intervals based on 5,000 resamples (bias-corrected and accelerated). CI excluding zero indicates significant mediation. Partial mediation is confirmed for both CFO age and CFO tenure: direct effects are attenuated but remain significant after controlling for investment efficiency. Path a = IV → mediator; Path b = mediator → DV (controlling for IV); Indirect = a × b. * p < .10. ** p < .05. *** p < .01.

6.7. Long-Run Dynamics: PMG Estimation

The long-term and short-term estimates are given in Table 11. The long-run coefficients support and bolster the FE results. Both the CFO age (β_LR = 0.0021, t = 3.62, p < .01) and the CFO tenure (β_LR = 0.0078, t = 3.94, p < .01) are positively and significantly related to sustainable development in the long run, with the long-run coefficient for CFO tenure being particularly large, indicating that institutional capital accumulation over time has a compounding effect on sustainable development that is larger than the annual FE model captures. Among the major variables, investment efficiency is the most important long-run coefficient with β_LR = 0.0847, t = 6.23, p < .01. The positive and significant long-run control variable effects are also confirmed: firm age (β_LR = 0.0014, p < .05) and log total assets (β_LR = 0.0241, p < .01) are both positive and significant. The error correction term (ECT = −0.3847, t = −8.21, p < .001) is negative and highly significant, and thus indicates that the system is mean-reverting toward the long-run equilibrium at a rate of approximately 38.5% per period.

The speed of adjustment suggests that the cointegrating relationship is empirically stable in that respect, as deviations from the long-run equilibrium, such as those from the composition of CFOs or changes in investment levels in firms, are corrected fairly quickly within one year. The Hausman test ($\chi^2(5) = 6.12$, p = .294) does not reject the null of long-run slope homogeneity. It thus confirms the validity of PMG's pooled long-run parameters as opposed to the unrestricted Mean Group estimator. There is also significant short-run heterogeneity: the short-run effects of CFO age and tenure are smaller than their long-run effects, as would be expected, since the human capital benefits of experience are likely to be greater in the long-run with their associated strategic commitments. In addition, investment efficiency (β_SR = 0.0341, p < .01) also has a significant short-run impact, which is consistent with the theoretical finding that the efficient

allocation of investments has a positive short- and long-term impact. The small short-run coefficient for Δfirm_age (β = 0.0003, p > .10) is consistent with firm age being a slow-moving institutional variable that has a sustainability effect primarily through long-run accumulation of reputation and legitimacy.

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_age	0.0021***	—	3.62
cfo_tenure	0.0078***	—	3.94
investment_efficiency	0.0847***	—	6.23
firm_age	0.0014**	—	2.28
log_total_assets	0.0241***	—	5.02
Short-Run Estimates (Error Correction Model — ECM)			
ECT (Error Correction Term)	—	−0.3847***	−8.21
Δcfo_age	—	0.0008*	1.87
Δcfo_tenure	—	0.0019**	2.21
Δinvestment_efficiency	—	0.0341***	3.87
Δfirm_age	—	0.0003	0.91
Δlog_total_assets	—	0.0098**	2.31
Model Preference Test			
Hausman Test (PMG vs. MG)	$\chi^2(5) = 6.12$	p = .294	PMG preferred

Note: PMG estimator applied given mixed I(0)/I(1) variables. Long-run slopes constrained homogeneous across firms; short-run dynamics are freely heterogeneous. ECT = −0.3847*** confirms mean reversion at 38.5% per period. Hausman test (p = .294) confirms PMG preference over MG. "—" indicates coefficient not applicable to that estimation horizon. * p < .10. ** p < .05. *** p < .01.

6.8. Panel Causality Analysis

The results of panel causality tests are shown in Table 12. The results of heterogeneous non-causality tests (Panel A) confirm that there is no reverse causality between sustainable development and the other variables and that the causality is unidirectional: from CFO age (Z-bar = 6.214, p < .01) to sustainable development and from CFO tenure (Z-bar = 7.341, p < .01) to sustainable development. In the same way, unidirectional causality is found from CFO age (Z-bar = 5.487, p < .01) and CFO tenure (Z-bar = 6.314, p < .01) to investment efficiency, as well as from investment efficiency to sustainable development (Z-bar = 7.147, p < .01). The small reverse causality from sustainable development to investment efficiency (Z-bar = 2.547, p < .05) does not contradict the main causal path; the robustness analysis in the GMM also tackles this. If we assume that the series are cointegrated (as suggested by both ST and LT causality tests), then the results of the ECM-based causality tests (Panel B) suggest that there are no significant causality links in the short-run or long-run in any of the hypothesized directions. The short-run F-statistics are between 5.41 (Δinvestment efficiency ← Δcfo_age) and 9.87 (Δsustainable development ← Δinvestment efficiency), and they are all significant at p < .01. The sign of the ECT coefficient is always negative: −0.3847 is significant in all equations, indicating the long run Granger causality in both directions. Both causal directions from the two causality approaches are consistent with the full architecture of the theoretical model, that is, CFO demographics → investment efficiency → sustainable development, and some direct effects of CFO demographics on sustainable development.

Table 12: Panel Causality Tests: Dumitrescu-Hurlin (2012) and ECM-Based Causality

Null Hypothesis (H_0)	W-bar	Z-bar	Z-bar tilde	Decision
Panel A: Dumitrescu-Hurlin (2012) Heterogeneous Non-Causality Test				
cfo_age does not cause sustainable_development	3.847	6.214***	5.981***	Reject H_0

sustainable_development does not cause cfo_age	1.124	0.841	0.798	Fail to Reject
cfo_tenure does not cause sustainable_development	4.213	7.341***	7.084***	Reject H_0
sustainable_development does not cause cfo_tenure	1.247	1.134	1.072	Fail to Reject
cfo_age does not cause investment_efficiency	3.214	5.487***	5.241***	Reject H_0
investment_efficiency does not cause cfo_age	1.147	0.924	0.871	Fail to Reject
cfo_tenure does not cause investment_efficiency	3.687	6.314***	6.087***	Reject H_0
investment_efficiency does not cause cfo_tenure	1.284	1.214	1.147	Fail to Reject
investment_efficiency does not cause sustainable_dev.	4.124	7.147***	6.894***	Reject H_0
sustainable_development does not cause inv_efficiency	1.874	2.547**	2.434**	Reject H_0
log_total_assets does not cause sustainable_development	3.621	6.187***	5.947***	Reject H_0
sustainable_development does not cause log_total_assets	1.421	1.547	1.487	Fail to Reject
firm_age does not cause sustainable_development	2.314	3.847***	3.714***	Reject H_0
sustainable_development does not cause firm_age	1.087	0.714	0.671	Fail to Reject

Panel B: ECM-Based Causality (Short-Run F-stat | ECT Coefficient)

Dependent Variable	SR F-stat	p	ECT Coeff.	p
Δsustainable_dev. ← Δcfo_age	6.24***	.001	−0.3847***	.000
Δsustainable_dev. ← Δcfo_tenure	7.14***	.001	−0.3847***	.000
Δsustainable_dev. ← Δinvestment_efficiency	9.87***	.000	−0.3847***	.000
Δsustainable_dev. ← Δlog_total_assets	5.87***	.003	−0.3847***	.000
Δinvestment_eff. ← Δcfo_age	5.41***	.004	−0.2941***	.000
Δinvestment_eff. ← Δcfo_tenure	6.84***	.001	−0.2941***	.000

Note: Panel A: 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: Conditional on confirmed cointegration. SR F-stat = short-run Granger causality; ECT = long-run causality coefficient. * p < .10. ** p < .05. *** p < .01.

6.9. Robustness Checks and Hypotheses Summary

Results of the robustness check are presented in Table 13. System GMM (Blundell & Bond, 1998) estimates confirm that the age of CFO and tenure of the CFO are still positive and significant, even after controlling for endogeneity with lagged instruments and dynamic persistence in sustainable development (age CFO coefficient = 0.412, p < .01; tenure CFO coefficient = 0.028, p < .05). The instrument set is validated by the Hansen J-test (p = .449), which indicates instrument validity, and the AR(2) test (p = .359) which indicates that there is no second-order autocorrelation. Significant positive effects are also obtained with the 2SLS instrumental variables estimator, with industry-year median CFO age and predecessor CFO tenure as instruments (coefficient = 0.015, p < .05). The results of the two-way fixed effects (firm and year fixed effects) and lagged independent variables at t−1 are qualitatively similar to the main specification. Sensitivity analyses with each ESG pillar score as a separate dependent variable further show that the characteristics of the CFOs are all significant when measured on their

respective sub-scores, demonstrating that the weights assigned to the ESG pillars in the composite score are not the source of the results. Re-estimation using winsorization at 5th/95th percentiles leads to the same results. The results of the hypothesis testing are summarized in Table 14. All seven hypotheses (H1a, H1b, H2a, H2b, H3, H4a, H4b) are confirmed at conventional levels of significance for multiple estimators and specifications. The direction and significance of the results in the FE primary model, PMG long-run estimates, bootstrapped mediation, and robustness tests give significant multi-method support to the theoretical model.

Table 13: Robustness Checks and Sensitivity Analyses

Robustness Check	Purpose	Key Result	Statistic
System GMM (Blundell & Bond, 1998)	Address endogeneity; lagged DV	cfo_age and cfo_tenure positive and significant	0.412***
Hansen J-test	Instrument validity under GMM	Instruments valid; fail to reject H_0	p = .449
AR(2) Test	No second-order autocorrelation in differences	No second-order autocorrelation detected	p = .359
2SLS Instrumental Variables	Exogenous variation in CFO characteristics	Coefficients remain positive and significant	0.015**
Two-Way Fixed Effects	Control for firm and time effects	Main results unchanged	—
Lagged IVs (t−1)	Use one-period-lagged CFO characteristics	Coefficients robust to lagged specification	—
Alternative DV: ESG pillar scores	Sensitivity of DV operationalization	cfo_age and cfo_tenure significant across pillars	—
Winsorized at 5th/95th percentiles	Sensitivity to outlier threshold	Results unchanged under stricter winsorization	—

Note: System GMM uses lagged levels and differences as instruments. Hansen J-test confirms instrument validity (p = .449). AR(2) failure to reject (p = .359) confirms no second-order autocorrelation. 2SLS uses industry-year median CFO age and predecessor CFO tenure as instruments. All specifications confirm the positive and significant effects of CFO demographics on sustainable development.

Table 14: Hypotheses Testing Summary

H	Hypothesis Statement	Expected Sign	Empirical Result	Decision
H1a	CFO age positively affects sustainable development	+	β = 0.0012**, t = 2.34; positive and significant	Supported
H1b	CFO tenure positively affects sustainable development	+	β = 0.0047**, t = 2.51; positive and significant	Supported
H2a	CFO age positively affects investment efficiency	+	β = 0.0250**, Boot CI [0.009, 0.043] excludes zero	Supported
H2b	CFO tenure positively affects investment efficiency	+	β = 0.0290**, Boot CI [0.008, 0.050] excludes zero	Supported
H3	Investment efficiency positively affects sustainable development	+	β = 0.0312***, t = 4.18; positive and significant	Supported
H4a	Investment efficiency mediates cfo_age → sustainable development	Indirect (+)	Indirect = 0.0021**, CI [0.001, 0.005]; partial mediation	Supported
H4b	Investment efficiency mediates cfo_tenure → sustainable development	Indirect (+)	Indirect = 0.0024**, CI [0.001, 0.006]; partial mediation	Supported

Note: "Supported" indicates statistical significance in the theorized direction at p < .10 or better, confirmed across the primary FE model and at least one robustness specification. H1a–H1b: Table 9. H2a–H2b: Table 10, Path a. H3: Table 10, Path b. H4a–H4b: Table 10, indirect effects. * p < .10. ** p < .05. *** p < .01.

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7. Conclusion

7.1. Summary of Findings

This study systematically presents empirical evidence indicating that the demographic characteristics of CFOs (age and organizational tenure) are important positive factors for the sustainable development of companies, both directly and indirectly via the intermediary of investment efficiency. We find that experienced and institutionally embedded CFOs help to increase the quality of investment allocation, and that this increase in investment efficiency further contributes to better ESG performance, using a balanced panel of 430 firms over 12 years and a strict sequence of second-generation panel econometric methods. The findings are replicated using panel fixed effects, PMG long-run estimation, bootstrapped mediation analysis, and a full robustness battery of various specifications, such as System GMM, 2SLS, two-way fixed effects, and alternate dependent variable operationalization.

7.2. Theoretical Contributions

The study contributes to the overall theoretical literature in three main ways. First, it applies Upper Echelons Theory to a new area of study, sustainability, and shows the systematic link between CFO demographic characteristics and the outcome variable of ESG performance, which is under-explored in the upper echelons literature (Hambrick, 2007). Second, it introduces investment efficiency as a specific organizational mechanism that mediates the relationship between CFO human capital and sustainability outcomes, filling the theoretical need for more specificity on the processes by which executive characteristics lead to firm outcomes (Carpenter, Geletkanycz, & Sanders, 2004). Third, it enriches Agency Theory's understanding of investment quality by documenting that the experiential and institutional dimensions of CFO tenure both independently contribute to reducing agency-related investment inefficiency, and that the two dimensions have synergistic effects which can result in greater reductions in inefficiency (Jensen, 1986; Myers, 1977).

7.3. Practical Implications

The study has direct implications for corporate governance practice. Given the positive impact of CFO age and tenure on investment efficiency and sustainability, boards and nomination committees need to consider CFO human capital characteristics, such as prior experience depth and organizational tenure, in succession planning processes, especially for companies with sustainability commitments. The partial mediation finding also means that the contribution of CFOs to sustainability is not just structural (through investment decisions) but direct, which means that the CFO input into the ESG strategy (over and above the financial gating of sustainability proposals) drives independent sustainability benefits. The results indicate that stability and depth of CFO experience are informative signals of sustainability performance, and should be incorporated in CFO-level governance evaluations together with other factors that are typically measured, such as CFO compensation structure and board tenure. The study's empirical evidence suggests that disclosure of a CFO's tenure and experience may also be included in the ESG report, as it is considered material governance information. The study's empirical evidence suggests that disclosure of a CFO's tenure and experience may also be included in the ESG report, as it is considered material governance information.

7.4. Limitations and Future Research

There are a number of caveats to be noted. First, the composite ESG score, which is used in the literature (Friede, Busch, & Bassen, 2015; Hussain, Rigoni, & Orij, 2018), may hide within the sub-dimensions of the ESG score. This should be further investigated in future research to determine if the demographical impact on various ESG aspects varies in size and impact. Second, the relationships found in the study are strong and are consistent with the theory. Still, the causal identification strategy, though supported by System GMM and IV estimation, assumes that the internal and external instruments are valid, which may not be sufficient to rule out all endogeneity concerns. More causal identification could be achieved using quasi-experimental designs that take advantage of exogenous transitions in CFOs (e.g., resulting from health shocks, mandatory retirement). Third, the time window for the sample is 12 years, which may not fully reflect the total duration of tenure effects of long-term serving CFOs. Long-term studies of individual CFOs'

careers in different companies would yield more data about the career dynamics of CFO influence and sustainability. Fourth, the study fails to consider the relationship between CFO demographics and the composition of the CEO-CFO team. This area is growing in importance, as noted by Upper Echelons research (Hambrick, 2007). Future research should investigate whether the sustainability impacts found in this study are strengthened or weakened when there is a match on CFO-CEO age and tenure.

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