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Research Paper

Green Accounting, Eco-Innovation, and ESG Performance: Dynamic Effects, Mediation, and Threshold Evidence

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ABSTRACT

This study examines the dynamic and non-linear relationships among green accounting (GA), eco-innovation (EI), and ESG performance. Drawing on Legitimacy Theory and the Natural Resource-Based View, the study investigates whether GA and EI independently contribute to ESG performance, whether EI mediates the GA–ESG relationship, and whether a critical level of EI changes the contribution of GA to ESG performance. The analysis uses an unbalanced panel of 500 multinational corporations observed between 2015 and 2025. Two-Step System Generalized Method of Moments (GMM) is employed to address dynamic persistence and potential endogeneity, while Panel Threshold Analysis is used to identify regime-dependent effects. The findings indicate that both GA and EI are positively associated with ESG performance, with EI also functioning as an important transmission mechanism between GA and ESG. Furthermore, the positive contribution of GA becomes substantially stronger when firms exceed a critical eco-innovation threshold of approximately ten green patents per year. ESG performance also demonstrates significant intertemporal persistence. These findings highlight the importance of integrating environmental accounting with substantive innovation capabilities rather than treating sustainability disclosure as an isolated practice. The study offers theoretical implications for sustainability and resource-based perspectives and practical implications for corporate strategy and green policy design.

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Introduction

The global business landscape has undergone a substantial transformation as sustainability imperatives increasingly converge with market accountability and corporate governance. Environmental, Social, and Governance (ESG) considerations have moved beyond their traditional role as reputational instruments to become increasingly embedded in investment decisions, regulatory requirements, and long-term corporate strategies (Kim & Yang, 2026; Ozata Canli & Sercemeli, 2026; Wu et al., 2025). This transformation reflects growing recognition that financial performance and environmental responsibility are not necessarily competing objectives but may develop in mutually reinforcing ways (Ainorrofiqie & Santoso, 2026). Across both emerging and advanced economies, ESG considerations are becoming increasingly institutionalized within capital allocation and corporate disclosure systems. The introduction of the IFRS Sustainability Disclosure Standards, particularly IFRS S1 and S2, further demonstrates the institutionalization of sustainability reporting and signals a broader restructuring of expectations concerning corporate accountability and transparency (Albitar et al., 2020). Consequently, understanding the organizational mechanisms that translate sustainability commitments into superior ESG outcomes has become increasingly important.

Within this evolving sustainability architecture, green accounting (GA) and eco-innovation (EI) represent two important mechanisms through which firms can operationalize environmental commitments. Green accounting provides an informational infrastructure for measuring, recognizing, disclosing, and managing environmental assets, liabilities, and costs, thereby connecting environmental responsibility with organizational decision-making and performance outcomes (Alodat & Dong, 2026; Bonsu et al., 2024; Schaltegger & Burritt, 2018). Eco-innovation complements this function by representing firms' capacity to develop environmentally superior products, processes, technologies, and organizational practices (Chen et al., 2023; Huang, 2021; Radzi et al., 2026). The relationship between these mechanisms is increasingly relevant because accounting information alone may not generate substantive environmental improvements unless firms possess the capacity to translate information into innovative action. Existing evidence indicates that environmental disclosure and research and development commitments can jointly stimulate eco-innovation, although the strength of these relationships may depend on organizational characteristics and institutional conditions (Cai & Li, 2018; Casciello et al., 2024). Thus, GA and EI should be considered complementary components of the sustainability-performance process.

Importantly, the relationship among GA, EI, and ESG performance may not operate through a simple additive or linear mechanism. From the perspective of the Natural Resource-Based View (NRBV), environmentally oriented capabilities may generate increasing returns as they become embedded within organizational resources, routines, and strategic processes (Hart & Dowell, 2011). Legitimacy Theory similarly suggests that sustainability practices become meaningful when organizational actions demonstrate alignment with societal expectations and stakeholder norms (Bhattacharyya, 2016) Accordingly, the benefits generated by green accounting may depend on whether firms possess sufficient eco-innovation capabilities to transform environmental information into substantive improvements (Lopes & Basso, 2025; Wang et al., 2025). Emerging evidence points to non-linear and threshold-dependent relationships in the sustainability domain,

suggesting that ESG gains may become more pronounced after firms reach particular levels of environmental capability or institutionalization (Nguyen, 2025; Trumpp & Guenther, 2017; Van et al., 2025). Such possibilities challenge conventional linear approaches and raise an important empirical question concerning whether the ESG returns associated with GA change once eco-innovation reaches a critical intensity.

Despite increasing scholarly attention to green accounting, eco-innovation, and ESG performance, several important gaps remain. First, much of the existing literature examines GA and EI separately or focuses on individual countries, potentially limiting the generalizability of findings and obscuring cross-national heterogeneity (Atif & Ali, 2021; Hussin & Mohammad, 2026). Second, although non-linear relationships have been theoretically recognized, empirical applications of panel threshold approaches remain relatively limited within sustainability accounting research (Hansen, 1999, 2000; Nguyen, 2025; Trumpp & Guenther, 2017). Third, the dynamic nature of ESG performance has received insufficient attention because many previous studies rely on static OLS or fixed-effects estimators that may not adequately address persistence and simultaneity between ESG outcomes, corporate practices, and institutional conditions (Aboud & Diab, 2018; Atif & Ali, 2021). Finally, the combined influence of GA and EI on aggregate ESG performance remains insufficiently examined at the global level. These limitations indicate the need for an analytical framework that simultaneously considers direct effects, non-linear relationships, dynamic persistence, and cross-firm heterogeneity.

Drawing on this background, this study investigates the dynamic and non-linear relationships among green accounting, eco-innovation, and ESG performance using a global panel of 500 firms over the 2015–2025 period. The study pursues three objectives. First, it examines the individual and combined effects of GA and EI on aggregate ESG performance. Second, it investigates whether a critical level of eco-innovation exists beyond which the contribution of green accounting to ESG performance becomes stronger. Third, it accounts for the dynamic and potentially endogenous nature of ESG performance by employing Two-Step System GMM alongside Panel Threshold Analysis. This design enables the study to move beyond conventional linear specifications and examine whether the effectiveness of green accounting depends on the intensity of eco-innovation. By integrating these dimensions, the study seeks to provide a more nuanced explanation of how accounting-based environmental information and innovation capabilities jointly contribute to corporate sustainability performance within a globally heterogeneous business environment.

The study contributes to the literature in three complementary respects. Theoretically, it integrates Legitimacy Theory and the Natural Resource-Based View to explain both the organizational motivation for green accounting and the capability-based process through which environmental resources and innovation can generate ESG outcomes. This integration allows the study to distinguish between green accounting as a mechanism for communicating and institutionalizing environmental responsibility and eco-innovation as a capability for translating that commitment into substantive organizational outcomes. Methodologically, the study combines Two-Step System GMM and Panel Threshold Analysis to address dynamic persistence, endogeneity, and potential non-linearity within a global panel setting. Practically, the findings provide implications for managers seeking to align environmental accounting with innovation strategies while reducing the risk of symbolic sustainability practices and greenwashing. They also offer insights for policymakers designing green-transition incentives, sustainability-oriented taxation, and

regulatory frameworks that encourage firms to develop substantive rather than purely disclosure-based environmental capabilities.

Theoretical Foundation and Hypotheses Development

Legitimacy Theory and the Natural Resource-Based View

This study draws on Legitimacy Theory and the Natural Resource-Based View (NRBV) as complementary theoretical perspectives for explaining the relationships among green accounting, eco-innovation, and ESG performance. Legitimacy Theory proposes that organizations operate within an implicit social contract and must demonstrate conformity with prevailing social values, norms, and stakeholder expectations to maintain their legitimacy and continued right to operate (Deegan, 2014; Suchman, 1995). From this perspective, green accounting can function as a legitimating mechanism because transparent environmental measurement and disclosure allow firms to communicate their environmental responsibilities and responses to stakeholder expectations (Ogunode, 2022; Schaltegger & Burritt, 2018). The NRBV extends the conventional resource-based perspective by emphasizing environmentally oriented organizational capabilities as sources of sustained competitive advantage (Hart & Dowell, 2011; Barney, 1991). Within this framework, eco-innovation represents an important knowledge-intensive capability through which firms can transform environmental commitments into superior organizational outcomes (Acar et al., 2025; Roșu et al., 2026). Together, these perspectives explain both why firms engage in green accounting and how environmental capabilities may convert such commitments into ESG performance.

Green Accounting and ESG Performance

Green accounting refers to the systematic measurement, recognition, and disclosure of environmental costs, liabilities, and assets within corporate accounting systems (Maneekul, 2024). By translating environmental impacts into financially and organizationally relevant information, it enables firms to incorporate ecological considerations into managerial decision-making and stakeholder communication (Schaltegger & Burritt, 2018). From a legitimacy perspective, comprehensive green accounting can signal environmental accountability, enhance transparency, and reduce information asymmetry between firms and stakeholders, thereby strengthening institutional trust (Albitar et al., 2020; Deegan, 2014). Firms that provide credible sustainability information may consequently achieve stronger ESG evaluations and more favorable financial conditions because stakeholders can better assess their environmental and social commitments (Pratiwi & Nuswantara, 2026; Wu et al., 2026). Recent evidence further indicates that the depth of sustainability accounting is positively associated with aggregate ESG performance (Casciello et al., 2024; Khanchel et al., 2023). Therefore, firms with more developed green accounting practices are expected to demonstrate stronger ESG performance because accounting systems can institutionalize environmental accountability and make sustainability practices more visible and actionable.
H_1: Green accounting has a positive effect on ESG performance.

Eco-Innovation and ESG Performance

Eco-innovation encompasses the development or modification of products, processes, organizational practices, and marketing approaches that reduce environmental harm relative to existing alternatives (Gregán et al., 2026; Juracka et al., 2024). Although the literature distinguishes eco-innovation from related concepts such as green innovation, substantial conceptual and operational overlap exists, particularly in relation to environmental technologies, green patents, and environmental research and development (Shaukat et al., 2026). Accordingly, this study adopts eco-innovation as its primary terminology, consistent with contemporary sustainability research (Cai & Li, 2018; Wang & Qiu, 2025). From the NRBV perspective, eco-innovation represents a firm-specific and knowledge-intensive capability through which organizations can internalize environmental externalities while simultaneously developing competitive advantages (Domaracká et al., 2023; Portillo-Tarragona et al., 2025). Empirical evidence associates eco-innovation with improved environmental outcomes, corporate reputation, and ESG performance (Cai & Li, 2018; Wang & Qiu, 2025). Moreover, embedding eco-innovation within corporate strategy can provide an important foundation for long-term sustainability outcomes (Nguyen, 2025; Wu et al., 2025). Thus, stronger eco-innovation capabilities are expected to enhance firms' ability to achieve superior ESG performance.

H_2: Eco-innovation has a positive effect on ESG performance.

Eco-Innovation as a Mediating Mechanism

Green accounting and eco-innovation are not necessarily independent mechanisms in the process of generating ESG performance. Green accounting provides information concerning environmental costs, impacts, and opportunities, thereby creating an informational and managerial foundation through which firms can identify, prioritize, and allocate resources toward eco-innovation initiatives (Schaltegger & Burritt, 2018). Eco-innovation subsequently translates this informational capacity into new products, processes, technologies, and organizational practices capable of generating substantive environmental improvements (Bonsu et al., 2024; Van et al., 2025). This suggests that green accounting may have both an informational function and an action-oriented function, with eco-innovation representing the mechanism through which accounting information can be converted into observable sustainability outcomes. Without such a conversion mechanism, green accounting may risk becoming primarily symbolic disclosure rather than substantive environmental action, potentially contributing to the conditions associated with greenwashing (Marquis et al., 2016). Accordingly, eco-innovation is expected to transmit at least part of the effect of green accounting to ESG performance.

H_3: Eco-innovation mediates the relationship between green accounting and ESG performance.

Eco-Innovation as a Threshold Condition

The relationship between green accounting and ESG performance may also vary according to the intensity of eco-innovation. NRBV reasoning suggests that environmental capabilities can generate increasing returns as firms accumulate sufficient knowledge, complementary assets, organizational routines, and strategic commitment (Hart & Dowell,

2011). Eco-innovation requires absorptive capacity and complementary capabilities before environmental information can be effectively transformed into measurable improvements in sustainability outcomes (Derlukiewicz et al., 2026; Juracka et al., 2024). Consequently, firms operating below a critical level of eco-innovation may possess green accounting information without having sufficient capabilities to convert it into substantive ESG improvements. Once eco-innovation exceeds such a level, however, the same accounting practices may generate stronger returns because innovation capabilities amplify the usefulness of environmental information. Prior research provides evidence of non-linear relationships in the environmental-performance domain, while more recent studies suggest that eco-innovation intensity may strengthen the marginal contribution of green accounting (Fülöp & Cifuentes-Faura, 2025; Trumpp & Guenther, 2017; Wang & Qiu, 2025). This reasoning supports a threshold rather than a conventional linear moderation specification.
H4: The positive effect of green accounting on ESG performance is stronger above the eco-innovation threshold.

Dynamic Persistence of ESG Performance

ESG performance is unlikely to be determined entirely by contemporaneous corporate practices because sustainability outcomes may reflect accumulated investments in disclosure systems, governance structures, environmental capabilities, and stakeholder relationships. Historical organizational choices can create path dependence, whereby established routines and stakeholder expectations constrain the trajectory of subsequent organizational outcomes (Aboud & Diab, 2018; Albitar et al., 2020; Wu et al., 2025). From a dynamic capabilities perspective, ESG performance reflects the cumulative development of organizational routines for sensing environmental risks, seizing sustainability opportunities, and reconfiguring resources over time (Alodat & Dong, 2026). Organizational inertia may reinforce these trajectories because established routines and reputational commitments are not easily created or dismantled (Huang, 2021). Consequently, current ESG performance is expected to depend partly on previous ESG performance. Recognizing this temporal persistence is also important econometrically because omitting lagged performance may generate dynamic endogeneity and biased estimates when static estimators are used (Kim & Yang, 2026). Therefore, the dynamic specification explicitly incorporates lagged ESG performance.
H5: Previous-period ESG performance positively influences current ESG performance.

The dynamic nature of ESG performance requires an estimation approach capable of addressing persistence and potential endogeneity. This study therefore employs the Two-Step System Generalized Method of Moments (System GMM) estimator (Ozata Canli & Sercemeli, 2026). Compared with Difference GMM, System GMM is particularly appropriate when the dependent variable is highly persistent because lagged levels may constitute weak instruments for the differenced equation when the autoregressive parameter approaches unity (Radzi et al., 2026; Van et al., 2025). By combining moment conditions from the levels and first-differenced equations, System GMM can mitigate this weak-instrument problem and improve estimation efficiency. It is also suitable for unbalanced panels characterized by a relatively short time dimension, as is relevant to the global firm-level sample examined in this study (Wu et al., 2025). The two-step estimator is

selected for its asymptotic efficiency. This methodological framework complements the theoretical argument concerning ESG persistence and provides an appropriate basis for examining the dynamic relationship proposed in H5.

The five hypotheses collectively establish the proposed relationships among green accounting, eco-innovation, and ESG performance by integrating direct effects, mediation, threshold effects, and dynamic persistence. Specifically, the framework proposes that green accounting and eco-innovation positively influence ESG performance, while eco-innovation mediates the relationship between green accounting and ESG performance. It further posits that the positive effect of green accounting becomes stronger when eco-innovation exceeds a critical threshold and that previous-period ESG performance positively influences current ESG performance. Firm size, leverage, and profitability are included as control variables to account for differences in firms' financial and organizational characteristics. The conceptual relationships underpinning these hypotheses are summarized in Figure 1, which presents the integrated research framework guiding the empirical analysis.

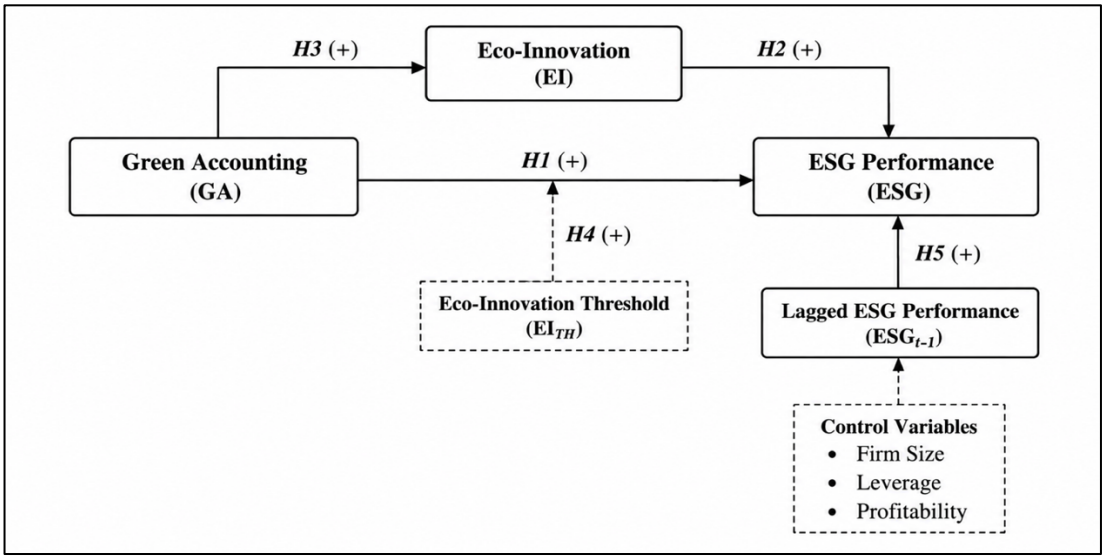


Figure 1. Research Framework

Method

Research Design

This study employs a quantitative research design using dynamic panel-data analysis to examine the relationships among green accounting (GA), eco-innovation (EI), and Environmental, Social, and Governance (ESG) performance. The empirical strategy is designed to capture both the direct relationships among the principal variables and the dynamic and non-linear characteristics of the proposed model. Specifically, the study employs the Two-Step System Generalized Method of Moments (System GMM) to account for the persistence of ESG performance and potential endogeneity, while Panel Threshold Analysis is used to identify whether the effect of green accounting on ESG performance changes after eco-innovation reaches a critical level. The combined application of these approaches enables the analysis to move beyond static linear estimation by simultaneously considering dynamic dependence, potential reverse causality, and threshold effects. This

methodological design is consistent with the theoretical argument that ESG performance develops cumulatively over time and that the contribution of green accounting may depend on the intensity of firms' eco-innovation capabilities.

Data and Sample

The study examines 500 multinational corporations operating in emissions-intensive sectors across international markets during the 2015–2025 period. The firms were selected using purposive sampling based on the availability and completeness of the information required for the analysis, including ESG performance data, annual reports containing environmental cost and sustainability disclosures, and information on eco-innovation activity. The principal data sources comprise Refinitiv Eikon, Bloomberg, Capital IQ, and the World Intellectual Property Organization (WIPO) Green Patent Mapping database. The resulting dataset forms an unbalanced firm-level panel, reflecting differences in data availability across firms and years. The focus on multinational corporations in emissions-intensive sectors is intended to provide a relevant setting for examining green accounting and eco-innovation because firms operating in these sectors face substantial environmental pressures and sustainability expectations. The 2015–2025 observation period also captures a period of increasing institutionalization of ESG reporting and sustainability-oriented corporate practices.

Variable Definition and Measurement

The study includes ESG performance as the dependent variable, green accounting (GA) as the principal independent variable, and eco-innovation (EI) as both a mediating mechanism and a threshold variable. Three firm-level characteristics, firm size, leverage, and profitability, are included as control variables to account for differences in organizational resources and financial conditions that may influence ESG performance. ESG performance is measured using a composite score covering the environmental, social, and governance dimensions based on Refinitiv Eikon and Bloomberg data. Green accounting is operationalized through an index of environmental cost disclosure and green investment derived from firms' annual reports aligned with the Global Reporting Initiative (GRI). Eco-innovation is measured by the annual number of patents associated with environmentally friendly technologies identified through WIPO Green Patent Mapping. Firm size is measured as the natural logarithm of total assets, leverage as total debt divided by total equity, and profitability as return on assets. The operational definitions, measurement indicators, and primary data sources for all variables are summarized in Table 1.

Table 1 shows that the study combines sustainability-related indicators with firm-level financial controls to construct the empirical dataset. The use of a composite ESG score captures sustainability performance across its three principal dimensions, while the green accounting index reflects the extent to which environmental costs and green investments are incorporated into corporate reporting. Eco-innovation is represented by green patent activity, providing a quantifiable indicator of firms' environmentally oriented technological output. The inclusion of firm size, leverage, and profitability helps account for differences in resource availability, financing structure, and financial capacity that may independently affect ESG performance. These operationalizations provide the basis for the subsequent dynamic panel estimation and threshold analysis.

Table 1. Variable Operational Definition

Variable	Code	Operational Definition	Data Source (2026)
ESG Performance	ESG	Composite score (Environment, Social, Governance).	Refinitiv Eikon / Bloomberg
Green Accounting	GA	Environmental cost disclosure index & green investment.	Annual Report (GRI-indexed)
Eco Innovation	EI	Number of environmentally friendly patent applications per year.	WIPO Green Patent Mapping
Firm Size	SIZE	The natural logarithm of total assets.	Refinitiv
Leverage	LEV	Total Debt / Total Equity.	Bloomberg
Profitability	LONG	Net Income / Total Assets.	Capital IQ

Econometric Model Specification

The empirical model is specified as a dynamic panel framework in which current ESG performance is explained by its lagged value, green accounting, eco-innovation, the interaction between green accounting and eco-innovation, and the control variables. The model also incorporates firm-specific and time effects to account for unobserved heterogeneity and common temporal influences. The basic specification can be represented conceptually as follows:

$$ESG_{it} = \alpha + \beta_1 ESG_{it-1} + \beta_2 GA_{it} + \beta_3 EI_{it} + \beta_4 (GA \times EI)_{it} + \sum_k \phi_k X_{kit} + \eta_i + \delta_t + \epsilon_{it}$$

where ESG_{it} represents the ESG performance of the company in the given period, GA_{it} is green accounting, EI_{it} denotes Eco Innovation, $(GA \times EI)_{it}$ is the product of green accounting and Eco Innovation, X_{kit} is the control variable, η_i is the company's fixed effect, δ_t is the time effect, and ϵ_{it} is the error term.

Technical Estimation

In order to solve problems of endogeneity, heteroskedasticity, and the time-varying nature of the ESG variables, this study uses the xtabond2 command in STATA 19 to implement the two-step system GMM method. When using the System GMM, the endogeneity of the independent and error variables is differentiated, and the lagged independent and lagged dependent variables are presented as appropriate instruments to address the reverse causality problem. The basic model is presented below:

$$ESG_{it} = \alpha + \beta_1 ESG_{it-1} + \beta_2 GA_{it} + \beta_3 EI_{it} + \beta_4 (GA \times EI)_{it} + \sum_k \phi_k X_{kit} + \eta_i + \delta_t + \epsilon_{it}$$

Where ESG_{it} is the company's ESG performance for that period, GA_{it} is green accounting, EI_{it} is Eco Innovation, $(GA \times EI)_{it}$ is the interaction of green accounting and Eco Innovation, X_{kit} is the control variable (firm size, leverage, profitability).

Moreover, to determine the instrument's validity, Hansen's test formula is used:

$$J = n \cdot \bar{g}(\hat{\theta})' W_n \bar{g}(\hat{\theta}) \sim \chi^2$$

Initially, this test verified that the instrument employed was not incorporated in the error term. Following this, an Arellano-Bond second-order test (AR2) was performed to test for second-order autocorrelation of the error terms. If AR(2) is not statistically significant, then the GMM estimate is regarded as consistent.

In addition to the GMM System, this study employs the Panel Threshold Analysis to estimate how much Eco Innovation is necessary for Eco Innovation to influence green accounting on ESG performance. The threshold model permits the examination of the GA–ESG relationship under the condition of exceeding a given boundary. The threshold model can be expressed as follows:

$$ESG_{it} = \alpha + \beta_1 GA_{it} + \beta_2 EI_{it} + \beta_3 (GA \times EI)_{it} \cdot I(EI_{it} > \gamma) + \sum_k \phi_k X_{kit} + \eta_i + \delta_t + \epsilon_{it}$$

This function determines whether Eco Innovation surpasses a specified intensity threshold. The value of this function is 1 when the threshold is surpassed. If the threshold is met or not surpassed, the value is 0. Thus, the function assesses the effect of Eco Innovation intensity moderation on green accounting (GA) at the highest level of satisfaction possible.

In order to maximize the reliability of the output, standard Driscoll-Kraay errors, which are robust to a case of heteroscedasticity, cross-sectional, and time-based correlations, were used to adjust standard errors. This adjustment is vital due to the cross-country time series challenges that arise with multinational panel data.

Diagnostic and Robustness Tests

Several diagnostic tests and robustness checks were conducted to assess the validity, consistency, and reliability of the econometric estimates. Given the use of the Two-Step System Generalized Method of Moments (System GMM), particular attention was paid to instrument validity, serial correlation, and the consistency of the estimated relationships across alternative model specifications.

First, Hansen's J-test was employed to assess the joint validity of the instruments used in the System GMM estimation. The test evaluates the null hypothesis that the instruments are jointly valid and uncorrelated with the error term. Its general formulation is expressed as follows:

$$J = n \cdot \bar{g}(\hat{\theta})' W_n \bar{g}(\hat{\theta}) \sim \chi^2$$

where (J) denotes the Hansen test statistic, n represents the number of observations, $\bar{g}(\hat{\theta})'$ is the vector of sample moment conditions evaluated at the estimated parameter vector, and (W_n) is the weighting matrix. Under the null hypothesis, the test statistic asymptotically follows a chi-squared distribution, with degrees of freedom determined by the number of overidentifying restrictions. A p-value greater than 0.05 indicates that the null hypothesis cannot be rejected, providing no evidence against the joint validity of the instruments. This test is particularly important in System GMM estimation because lagged variables are commonly employed as instruments to address potential endogeneity.

Second, the Arellano–Bond test for second-order serial correlation, commonly referred to as the AR(2) test, was conducted to examine whether the differenced residuals exhibit second-order autocorrelation. The test statistic can be expressed as:

$$AR(2) = \frac{\hat{\rho}_2}{SE(\hat{\rho}_2)}$$

where $AR(2)$ denotes the estimated second-order autocorrelation coefficient and $SE(\hat{\rho}_2)$ represents its standard error. The null hypothesis states that no second-order serial correlation exists in the differenced residuals. A p-value greater than 0.05 indicates that the null hypothesis cannot be rejected, supporting the consistency of the GMM estimator, provided that the other specification and instrument-validity conditions are also satisfied. The absence of second-order serial correlation is important because its presence may undermine the validity of the lagged instruments used in the estimation.

To further assess the robustness of the findings, the baseline System GMM estimates were compared with results obtained using the fixed-effects and difference GMM estimators. The fixed-effects model accounts for unobserved, time-invariant firm-specific heterogeneity, while difference GMM provides an alternative dynamic panel specification based on first-differenced equations. Consistency in the direction and statistical significance of the estimated coefficients across these alternative specifications would provide additional evidence that the findings are not driven solely by the choice of estimator. Nevertheless, differences across estimators were also considered in light of their respective assumptions and limitations.

Finally, Driscoll–Kraay standard errors were employed in the relevant panel estimations to address potential heteroskedasticity, serial correlation, and cross-sectional dependence. This adjustment is particularly relevant to multinational firm-level panel data, in which firms may be exposed to common economic shocks and interconnected market conditions. By accounting for these potential sources of dependence in the estimated standard errors, the procedure helps improve the reliability of statistical inference. Collectively, these diagnostic tests and robustness checks provide a systematic assessment of instrument validity, serial-correlation properties, and the stability of the empirical findings across alternative estimation approaches.

Results

Descriptive Statistics and Sample Characteristics

The descriptive statistics provide an overview of the distribution and variability of the study variables across 500 multinational corporations observed during 2015–2025. As presented in Table 2, the analysis covers ESG performance, green accounting, eco-innovation, and three firm-level control variables: firm size, leverage, and profitability. These statistics characterize the sample and provide an empirical foundation for the subsequent correlation analysis and dynamic panel estimation.

As shown in Table 2, ESG performance has a mean of 62.45 and a standard deviation of 12.30, with scores ranging from 30 to 95. The distribution indicates substantial variation in ESG performance across the sampled firms. This variation suggests that the firms differ considerably in their sustainability performance, providing a relevant basis for examining whether green accounting practices and eco-innovation are associated with differences in ESG outcomes. Green accounting has a mean of 0.58 and a standard deviation of 0.21, with values ranging from 0.10 to 0.95. These figures indicate considerable variation in the measured extent of green accounting practices across firms. The observed distribution

provides an opportunity to investigate whether differences in environmental cost disclosure and green investment are associated with ESG performance. However, these descriptive statistics alone do not establish the direction or magnitude of the relationship.

Table 2. Descriptive Statistics of the Variables

Variable	Mean	Std. Dev	Minimum	Maximum
ESG Performance (ESG)	62.45	12.30	30.00	95.00
Green Accounting (GA)	0.58	0.21	0.10	0.95
Eco-Innovation (EI)	12.40	8.50	1.00	45.00
Firm Size (SIZE)	15.20	1.80	12.00	19.00
Leverage (LEV)	0.65	0.30	0.10	1.80
Profitability (LONG)	0.08	0.05	−0.10	0.25

Eco-innovation has a mean of 12.40 patents per year and a standard deviation of 8.50, with values ranging from 1 to 45 patents. The relatively wide distribution indicates substantial heterogeneity in firms' environmentally oriented technological activity. While some firms exhibit comparatively limited green patent activity, others demonstrate considerably higher levels of innovation output. This variation is particularly relevant to the subsequent threshold analysis, which examines whether the relationship between green accounting and ESG performance changes across different levels of eco-innovation.

The control variables also demonstrate variation in firms' organizational and financial characteristics. Firm size has a mean of 15.20 and a standard deviation of 1.80, with values ranging from 12 to 19, indicating differences in the scale of the sampled corporations. Leverage has a mean of 0.65 and a standard deviation of 0.30, with values ranging from 0.10 to 1.80, reflecting differences in firms' financial structures. Profitability, reported under the variable code LONG, has a mean of 0.08 and a standard deviation of 0.05, with values ranging from −0.10 to 0.25. The negative minimum indicates that some observations record negative profitability, whereas the positive maximum reflects higher profitability among other observations.

Overall, the descriptive statistics in Table 2 demonstrate considerable variation in ESG performance, green accounting, eco-innovation, and firm-level financial characteristics. This variation provides the empirical foundation for investigating the relationships proposed in the research framework. The following subsection examines the preliminary associations among these variables using the correlation matrix.

Preliminary Correlation Analysis

The correlation analysis examines the preliminary associations among ESG performance, green accounting, eco-innovation, and the firm-level control variables. As presented in Table 3, the correlation matrix provides an initial assessment of the direction and strength of the bivariate relationships before the multivariate dynamic panel estimation. These associations help identify broad patterns in the data, although they should not be interpreted as evidence of causality.

Table 3. Correlation Matrix

Variable	ESG	GA	EI	SIZE	LEV	LONG
ESG	1.00					
GA	0.45	1.00				
EI	0.52	0.48	1.00			
SIZE	0.30	0.25	0.35	1.00		
LEV	-0.20	-0.15	-0.18	0.40	1.00	
LONG	0.40	0.22	0.28	0.15	-0.35	1.00

According to Table 3, ESG performance is positively correlated with both green accounting (r=0.45) and eco-innovation (r=0.52). The correlation with eco-innovation is comparatively stronger, suggesting that firms with greater green patent activity tend to exhibit higher ESG performance. Similarly, the positive association between green accounting and ESG performance indicates that firms with more developed environmental accounting practices tend to report higher ESG scores. These preliminary patterns are consistent with the proposed relationships in H_1 and H_2, although their statistical significance and independent effects must be established through the subsequent regression analysis.

The correlation matrix also indicates a positive association between green accounting and eco-innovation (r=0.48). This finding suggests that firms with more developed environmental accounting practices tend to exhibit greater eco-innovation activity. Such an association is relevant to the proposed mediation mechanism in H3 because it indicates that the two principal explanatory variables are related. However, the correlation coefficient alone cannot establish whether eco-innovation mediates the relationship between green accounting and ESG performance; this requires a separate empirical assessment of the indirect effect.

Regarding the control variables, firm size is positively correlated with ESG performance (r=0.30), suggesting that larger firms tend to have higher ESG scores in the sample. Firm size is also positively associated with green accounting (r=0.25) and eco-innovation (r=0.35). These patterns indicate that organizational scale may be relevant to firms' sustainability practices and innovation activities. In contrast, leverage exhibits negative correlations with ESG performance (r=-0.20), green accounting (r=-0.15), and eco-innovation (r=-0.18). These associations suggest that firms with higher leverage tend to exhibit lower values for these sustainability-related variables, although the correlations do not establish that debt exposure causes weaker sustainability performance.

Profitability, represented by LONG, is positively correlated with ESG performance (r=0.40), green accounting (r=0.22), and eco-innovation (r=0.28). These findings indicate that more profitable firms tend to exhibit stronger sustainability performance and greater engagement in environmental accounting and innovation. Profitability is also negatively correlated with leverage (r=-0.35), while its correlation with firm size is relatively weak and positive (r=0.15). Collectively, these relationships suggest that firms' financial characteristics may be relevant to the observed patterns of sustainability performance, supporting the inclusion of firm size, leverage, and profitability as control variables in the subsequent econometric models.

To sum up, the correlation matrix in Table 3 reveals positive preliminary associations among ESG performance, green accounting, and eco-innovation, alongside differing relationships with the financial control variables. None of the reported pairwise correlations exceeds an absolute value of 0.52, suggesting that the matrix does not display extremely high pairwise correlations among the variables. Nevertheless, correlation coefficients alone cannot rule out multicollinearity, which should be assessed using appropriate diagnostic procedures where applicable. The analysis therefore provides an initial empirical foundation for the dynamic panel estimation, which examines the relationships while accounting for lagged ESG performance, other explanatory variables, and potential endogeneity.

Dynamic Panel Estimation and Hypothesis Testing

The dynamic panel estimation examines the relationships between green accounting, eco-innovation, and ESG performance while accounting for the persistence of ESG outcomes over time and controlling for firm-level characteristics. Table 4 reports the Two-Step System Generalized Method of Moments (System GMM) estimates, including the lagged dependent variable, the two principal explanatory variables, their interaction term, and the control variables. The results provide evidence concerning the direct relationships proposed in H1 and H_2, the dynamic persistence specified in H_5, and the interaction between green accounting and eco-innovation. The interaction coefficient should, however, be distinguished from the mediation mechanism proposed in H_3 and the threshold effect examined separately in H_4.

Table 4. System GMM Estimation Results

Variable	Coefficient	Std. Error	z-statistic	Significance
ESG (t-1)	0.42	0.008	5.25	***
Green Accounting (GA)	0.28	0.10	2.80	**
Eco-Innovation (EI)	0.35	0.12	2.92	**
GA x EI	0.18	0.07	2.57	**
Firm Size (SIZE)	0.12	0.05	2.40	**
Leverage (LEV)	-0.20	0.09	-2.22	**
Profitability (LONG)	0.25	0.11	2.27	**

Note: *** p<0.01; ** p<0.05.

The coefficient for lagged ESG performance is positive and statistically significant (beta=0.42), SE = 0.08, (z=5.25), indicating that ESG performance in the previous period is positively associated with current ESG performance, conditional on the other variables in the model. This finding supports H_5 and suggests that sustainability performance exhibits temporal persistence. Firms with stronger prior ESG performance tend to maintain stronger performance in subsequent periods, consistent with the possibility that sustainability outcomes reflect accumulated organizational practices, governance arrangements, and environmental capabilities. Nevertheless, the coefficient should be interpreted as evidence

of persistence within the estimated dynamic model rather than as proof of a specific causal mechanism.

Green accounting has a positive and statistically significant coefficient (beta=0.28), SE = 0.10, (z=2.80). This result supports H_1, indicating that green accounting is positively associated with ESG performance after accounting for lagged ESG, eco-innovation, their interaction, and the firm-level controls. The finding suggests that environmental cost disclosure and green investment practices are associated with stronger sustainability performance. Importantly, because the model includes the interaction between green accounting and eco-innovation, the coefficient of 0.28 represents the estimated effect of green accounting when eco-innovation equals zero, subject to the model's specification. It should not automatically be interpreted as the average effect of green accounting across all firms.

Eco-innovation also exhibits a positive and statistically significant coefficient (beta=0.35), SE = 0.12, (z=2.9). This finding supports H_2 and indicates that firms with greater environmentally oriented innovation activity tend to demonstrate stronger ESG performance, conditional on the other explanatory variables. The result is consistent with the view that green patent activity may reflect firms' capacity to develop and implement environmentally beneficial technologies. However, the coefficient represents the estimated effect of eco-innovation when green accounting equals zero in the interaction model; the marginal effect of eco-innovation therefore depends on the level of green accounting.

The interaction between green accounting and eco-innovation is positive and statistically significant (beta=0.18), SE = 0.07, (z=2.57). This result indicates that the estimated association between green accounting and ESG performance becomes more positive as eco-innovation increases, within the specified linear interaction model. In other words, environmental accounting practices may be more strongly associated with ESG performance when firms also demonstrate greater eco-innovation activity. This finding provides preliminary evidence of a complementary relationship between accounting practices and innovation capabilities. However, the interaction term does not by itself establish the mediation hypothesis in H3, nor does it demonstrate the threshold effect proposed in H_4. Those hypotheses require separate assessments using the relevant mediation and threshold analyses.

The estimated coefficients for the control variables also reveal meaningful associations with ESG performance. Firm size has a positive and statistically significant coefficient (beta=0.12), SE = 0.05, (z=2.40), suggesting that larger firms tend to exhibit stronger ESG performance after accounting for the other model variables. Leverage has a negative and statistically significant coefficient (beta=-0.20), SE = 0.09, (z=-2.22), indicating that higher leverage is associated with lower ESG performance, conditional on the other variables. Profitability, measured by return on assets and represented by the code LONG, has a positive and statistically significant coefficient (beta=0.25), SE = 0.11, (z=2.27). This suggests that more profitable firms tend to exhibit stronger ESG performance. These findings underscore the relevance of accounting for firms' organizational scale and financial characteristics when examining sustainability outcomes, although the estimated relationships should not be interpreted as definitive causal effects.

The System GMM estimates in Table 4 provide support for H_1, H_2, and H_5, based on the positive and statistically significant coefficients for green accounting, eco-innovation, and lagged ESG performance, respectively. The positive interaction coefficient further indicates

a complementary relationship between green accounting and eco-innovation within the estimated model. However, H3 cannot be confirmed from these estimates alone, because the table does not report the indirect effect of green accounting through eco-innovation. Similarly, H4 must be assessed using the separate threshold analysis rather than inferred solely from the interaction coefficient. The subsequent subsection examines whether the relationship between green accounting and ESG performance changes when eco-innovation exceeds the identified threshold.

Eco-Innovation Threshold Analysis

This section examines whether the relationship between green accounting and ESG performance changes when firms reach a critical level of eco-innovation. Unlike the linear interaction model reported in Table 4, the threshold analysis distinguishes between firms operating below and above a specified level of eco-innovation. This approach directly addresses H4, which proposes that the positive effect of green accounting on ESG performance is stronger above the eco-innovation threshold.

Table 5. Threshold Analysis Results

EI Threshold (γ)	GA → ESG (below γ)	GA → ESG (above γ)
10 patents	0.15 (ns)	0.40 (***)

As reported in Table 5, the estimated threshold is ten green patents per year. For firms with ten or fewer green patents annually, the estimated coefficient for green accounting is 0.15 and is not statistically significant. This result suggests that, below the identified threshold, the relationship between green accounting and ESG performance is not statistically distinguishable from zero at conventional significance levels. Thus, the presence of environmental accounting practices alone may not be sufficient to produce a measurable improvement in ESG performance when eco-innovation activity remains relatively limited. In contrast, for firms generating more than ten green patents per year, the estimated coefficient for green accounting increases to 0.40 and is statistically significant at the 1% level. The larger coefficient indicates that green accounting is more strongly associated with ESG performance among firms operating above the estimated eco-innovation threshold. This pattern is consistent with the proposition that eco-innovation capability enhances the contribution of environmental accounting practices to sustainability outcomes. Firms with stronger innovation activity may be better positioned to translate environmental information into technological improvements, more efficient resource use, and stronger environmental and governance practices.

The difference between the estimated coefficients below and above the threshold, 0.15 versus 0.40, provides preliminary evidence of a regime-dependent relationship between green accounting and ESG performance. Accordingly, the findings are consistent with H4, which proposes that the positive effect of green accounting on ESG performance is stronger above the eco-innovation threshold. Nevertheless, the difference between the two coefficients should be formally tested to establish whether it is statistically significant; the significance of the coefficient above the threshold alone does not establish that the two coefficients differ significantly. The threshold estimate should also be interpreted as a

sample-specific empirical boundary rather than a universal benchmark applicable to all firms or industries.

In conclusion, Table 5 suggests that the relationship between green accounting and ESG performance varies with firms' eco-innovation intensity. The findings reinforce the importance of examining environmental accounting alongside firms' innovation capabilities rather than treating green accounting as an isolated sustainability practice. The next subsection evaluates the robustness of these findings by comparing the principal estimates across alternative econometric specifications.

Diagnostic Tests and Robustness Analysis

This section evaluates the reliability of the principal findings by examining the diagnostic tests for the System GMM estimator and comparing the estimated relationships across alternative econometric specifications. The diagnostic analysis focuses on instrument validity and second-order serial correlation, while the robustness analysis assesses whether the relationships between green accounting, eco-innovation, and ESG performance remain consistent when using System GMM, fixed-effects, and difference GMM estimators.

Table 6. Robustness Check Results

Model	GA	EI	GA × EI	ESG (t–1)
System GMM	0.28**	0.35**	0.18**	0.42***
Fixed Effects	0.25**	0.30**	0.15**	0.40***
Difference GMM	0.27**	0.33**	0.16**	0.41***

Note: *** p<0.01; ** p<0.05.

As reported in Table 6, the estimated coefficients for green accounting are positive across all three specifications, ranging from 0.25 to 0.28. Similarly, the coefficients for eco-innovation range from 0.30 to 0.35, while those for the interaction between green accounting and eco-innovation range from 0.15 to 0.18. All these coefficients are reported as statistically significant at the 5% level. The consistency in their direction and reported significance suggests that the positive relationships observed in the baseline model are not exclusive to the System GMM specification.

The coefficient for lagged ESG performance is also positive and statistically significant across the three models, ranging from 0.40 to 0.42. This consistency reinforces the baseline finding that ESG performance exhibits temporal persistence. The comparatively small differences in the estimated coefficients across specifications indicate that the principal associations remain similar when alternative estimators are applied. Nevertheless, these comparisons should be interpreted cautiously because the estimators differ in their assumptions and treatment of unobserved heterogeneity and endogeneity. The robustness results therefore provide supplementary evidence of consistency rather than definitive proof that all potential sources of estimation bias have been eliminated.

Moreover, Table 7 presents the diagnostic results for the System GMM estimation. The Hansen test yields a statistic of 18.5 with a p-value of 0.27. Because this p-value exceeds the conventional 5% significance level, the null hypothesis of joint instrument validity cannot be rejected. This result provides no statistical evidence against the validity of the instrument set, although it does not conclusively establish that every instrument is valid.

Table 7. Diagnostic Tests Summary

Test	Statistical Value	Probability	Reported Interpretation
Hansen test	X^2=18.5	0.27	Instrument validity not rejected
Arellano–Bond AR(2) test	Z=-0.85	0.39	No evidence of second-order serial correlation
Number of instruments	35	-	Instrument count reported

The Arellano–Bond AR(2) test produces a statistic of −0.85 with a p-value of 0.39. The null hypothesis of no second-order serial correlation in the differenced residuals cannot be rejected at the 5% level. This finding is consistent with the serial-correlation condition required for the validity of the lagged instruments commonly employed in dynamic panel GMM estimation. However, the absence of detected second-order serial correlation should be considered alongside the other specification and instrument-validity diagnostics.

The estimation uses 35 instruments. This figure provides information about the size of the instrument set, but the instrument count alone is insufficient to determine whether instrument proliferation is a concern. Its adequacy should be assessed relative to the number of firms in the panel and the instrument-generation procedure. Given the reported results, the Hansen and AR(2) tests do not identify an evident violation of these two diagnostic conditions. Nevertheless, the findings should be interpreted as diagnostic support for the estimated model rather than definitive proof of its overall validity.

The robustness comparisons in Table 6 and the diagnostic results in Table 7 provide complementary evidence regarding the consistency of the estimated relationships and the suitability of the System GMM specification. The positive coefficients across alternative estimators reinforce the stability of the principal associations, while the diagnostic tests do not indicate rejection of the instrument-validity null or evidence of second-order serial correlation. The subsequent analysis examines whether these relationships differ across the energy, manufacturing, and technology sectors.

Sectoral Heterogeneity Analysis

This analysis examines whether the relationships between green accounting, eco-innovation, and ESG performance differ across the energy, manufacturing, and technology sectors. The analysis extends the preceding results by considering whether the associations between sustainability-related accounting practices, innovation activities, and ESG performance vary across industry contexts. Table 8 presents the reported sector-specific coefficients for the direct relationships of green accounting and eco-innovation with ESG performance, as well as their interaction.

Based on Table 8, the estimated relationships between green accounting, eco-innovation, and ESG performance vary across the three sectors. The energy sector exhibits the largest coefficients for all three relationships: 0.35 for green accounting, 0.40 for eco-innovation, and 0.22 for their interaction. All three coefficients are statistically significant, with the direct relationships significant at the 1% level and the interaction significant at the 5% level. These results indicate that green accounting and eco-innovation have relatively strong positive associations with ESG performance in the energy sector. One possible

explanation is that energy firms face substantial environmental scrutiny and regulatory expectations, potentially increasing the relevance of environmental accounting and innovation to their sustainability outcomes. However, this explanation should be treated as a plausible interpretation rather than a directly tested finding.

Table 8. Sectoral Differences in the Relationships between Green Accounting, Eco-Innovation, and ESG Performance

Sector	GA → ESG	EI → ESG	GA × EI → ESG
Energy	0.35***	0.40***	0.22**
Manufacturing	0.20**	0.28**	0.15**
Technology	0.25**	0.35***	0.18**

Note: *** p<0.01; ** p<0.05.

The manufacturing sector exhibits comparatively smaller coefficients: 0.20 for green accounting, 0.28 for eco-innovation, and 0.15 for the interaction term. All are reported as statistically significant at the 5% level. These results suggest that both environmental accounting practices and eco-innovation are positively associated with ESG performance in manufacturing, although their estimated relationships are weaker than those reported for the energy sector. The interaction coefficient also indicates a positive association between the combined presence of green accounting and eco-innovation and ESG performance. The relatively smaller coefficients may reflect differences in firms' production processes, investment requirements, or approaches to environmental management, although these explanations cannot be confirmed from the sectoral coefficients alone.

In the technology sector, the estimated coefficients are 0.25 for green accounting, 0.35 for eco-innovation, and 0.18 for their interaction. Green accounting and the interaction term are significant at the 5% level, while eco-innovation is significant at the 1% level. The comparatively strong eco-innovation coefficient suggests that environmentally oriented innovation is particularly relevant to ESG performance in this sector. This pattern may reflect the role of technological development in supporting resource efficiency, cleaner production processes, and environmentally oriented products. Nevertheless, the table does not directly measure these mechanisms, so they should be explored as possible explanations in the Discussion rather than presented as established empirical findings.

Comparing the three sectors, the energy sector has the largest reported coefficients, followed by the technology sector and then manufacturing. This pattern is consistent across green accounting, eco-innovation, and their interaction. The findings therefore suggest that the associations between sustainability-related accounting practices, innovation capabilities, and ESG performance may vary with industry context. However, differences in coefficient magnitude do not, by themselves, establish statistically significant differences between sectors. Formal cross-sector coefficient tests or a pooled model with sector-interaction terms would be required to establish whether these differences are statistically significant.

To sum up, Table 8 provides supplementary evidence that the relationships examined in this study are not uniform across the energy, manufacturing, and technology sectors. The consistently positive and statistically significant coefficients suggest that green accounting, eco-innovation, and their interaction are positively associated with ESG performance in all three sectors, although the estimated magnitudes differ. These findings highlight the

potential importance of industry context when examining corporate sustainability practices and provide a basis for further discussion of how sectoral characteristics may shape the relationship between environmental accounting, innovation, and ESG outcomes.

Discussion

The positive relationship between green accounting (GA) and ESG performance supports H_1 and indicates that environmental accounting can function as more than a reporting mechanism. From the perspective of Legitimacy Theory, the systematic identification and disclosure of environmental costs and investments provide stakeholders with observable evidence that firms recognize and respond to environmental responsibilities. Such transparency can strengthen stakeholder trust and organizational reputation by reducing uncertainty concerning the firm's sustainability commitments. The finding is consistent with Thanh Thuy Ngoc (2025) and Van et al. (2025), who demonstrate that environmental management accounting and green practices can contribute to sustainability-related outcomes through more transparent and informative accounting systems. However, the finding should not be interpreted as evidence that disclosure automatically produces substantive sustainability improvements. Rather, GA appears to provide an organizational infrastructure through which environmental priorities become visible, measurable, and potentially actionable. Its contribution to ESG performance therefore depends on whether accounting information is incorporated into managerial processes rather than being used primarily for symbolic compliance.

The positive effect of eco-innovation (EI) on ESG performance supports H_2 and suggests the importance of innovation capability in converting environmental commitment into observable sustainability outcomes. From the Resource-Based View, eco-innovation represents a knowledge-intensive organizational capability that can generate value because environmentally oriented technologies, products, and processes are not necessarily easily replicated by competitors. The finding is consistent with Casciello et al. (2024) and Khanchel et al. (2023), who demonstrate the importance of green innovation, research and development, and ESG-related practices for sustainability and financial performance. At the same time, the relationship may be more appropriately understood as potentially reciprocal rather than strictly one-directional. Wu et al. (2025) argue that stronger ESG performance can itself encourage firms to increase eco-innovation. Thus, while the present findings support the proposed positive relationship, they also suggest that ESG and EI may reinforce one another over time. This interpretation strengthens the dynamic perspective of the study and cautions against viewing innovation merely as a one-time technological investment.

The mediation result provides further insight into the relationship between green accounting and ESG performance. Supporting H_3, the findings indicate that eco-innovation constitutes an important pathway through which green accounting can be translated into broader sustainability outcomes. Green accounting generates information concerning environmental costs, investments, and responsibilities, but information alone does not necessarily improve organizational performance. Its value becomes more substantive when firms use that information to identify opportunities, allocate resources, and develop environmentally oriented products, processes, or technologies. In this sense, eco-innovation represents a conversion mechanism between environmental information and ESG outcomes. This interpretation is consistent with Bonsu et al. (2024), who identify a mediating

role for green innovation between corporate social responsibility and environmental performance, and with Nguyen (2025), who emphasizes the mediating role of green product innovation in the relationship between accounting and finance innovations. The present finding therefore shifts attention from whether firms disclose environmental information to whether they possess the innovative capacity to act upon that information.

The threshold analysis provides an important refinement of the preceding relationships by demonstrating that the contribution of green accounting is not uniform across levels of eco-innovation. Supporting H_4, the effect of GA on ESG performance becomes significantly stronger when firms exceed the identified threshold of ten green patents per year. This result suggests that eco-innovation should not be understood simply as another independent predictor of ESG performance; rather, a sufficient level of innovation capability may determine the extent to which accounting-based environmental information can generate sustainability benefits. Below the threshold, firms may possess environmental accounting systems without having sufficient technological, organizational, or absorptive capacity to transform information into substantive outcomes. Above the threshold, stronger innovation capability appears to amplify the value of GA. This finding is consistent with the sustainability-oriented arguments of Fülöp and Cifuentes-Faura (2026) and Wang and Qiu (2025). Importantly, the threshold should be interpreted as an empirical regime boundary rather than as a universal benchmark applicable to all firms or industries.

The finding concerning H_5 demonstrates that ESG performance possesses a substantial dynamic component. The positive and significant lagged ESG coefficient indicates that firms' current sustainability performance is partly conditioned by their previous performance, suggesting that ESG outcomes accumulate over time rather than being determined entirely by contemporaneous managerial decisions. This pattern is consistent with the notion of organizational path dependence, whereby established routines, capabilities, stakeholder expectations, and sustainability commitments create continuity in organizational behavior. The interpretation is also consistent with Sasongko et al. (2021), who emphasize the importance of long-run trajectories in economic and sustainability systems, and with Bawono (2026), who discusses persistence and dynamic processes in broader economic systems. The implication is important for both theory and empirical modelling: ESG performance should be understood as a cumulative organizational state. Firms that have already developed sustainability capabilities may possess advantages in maintaining and extending their ESG performance, whereas firms starting from lower levels may require sustained investment before comparable improvements become visible.

The findings provide a more integrated explanation of the GA–EI–ESG relationship than is offered by studies examining these variables through isolated or static associations. Existing research, including Kanchel et al. (2023) and Casciello et al. (2024), has provided important evidence concerning the relationship between eco-innovation and ESG performance, but the present study emphasizes that the value of green accounting depends partly on firms' capacity to convert environmental information into innovative action. The findings are also consistent with Van et al. (2025) and Thanh Thuy Ngoc (2025), which highlight the role of environmental management accounting in supporting green innovation and environmental performance. More broadly, the significant lagged ESG effect suggests that the GA–EI–ESG relationship should be understood within a dynamic rather than purely contemporaneous framework. By employing System GMM, the study therefore contributes methodologically as well as theoretically: it recognizes persistence and potential

endogeneity while demonstrating that sustainability outcomes evolve through accumulated organizational capabilities and practices rather than through isolated annual interventions.

The findings generate both theoretical and practical implications. Theoretically, the study strengthens the integration of Legitimacy Theory and the Resource-Based View by showing that green accounting can be understood as a mechanism for establishing environmental transparency and legitimacy, while eco-innovation represents a capability through which such commitments are converted into ESG outcomes. The threshold finding further suggests that the effectiveness of accounting-based environmental practices depends on the accumulation of sufficient innovation capability, while the persistence of ESG performance highlights the importance of organizational history and path dependence. Practically, managers should therefore avoid treating green accounting as a stand-alone reporting requirement and instead connect environmental information with innovation strategy, investment decisions, and technological development. Firms should build eco-innovation capabilities alongside sustainability accounting to ensure that environmental information produces substantive outcomes. For policymakers, the findings support integrated sustainability policies that combine environmental reporting requirements with incentives for green innovation, including fiscal measures and support for green technologies. Such an approach may be more effective than policies that encourage disclosure without strengthening firms' capacity to implement meaningful environmental innovation.

Conclusion

This study demonstrates that green accounting and eco-innovation are complementary mechanisms for strengthening corporate Environmental, Social, and Governance (ESG) performance. Green accounting contributes by enhancing environmental transparency, accountability, and the integration of sustainability considerations into organizational decision-making, while eco-innovation provides the technological and organizational capacity to translate these commitments into substantive sustainability outcomes. The findings further indicate that the contribution of green accounting becomes stronger when firms attain a sufficient level of eco-innovation, highlighting the importance of integrating accounting practices with green technologies, products, and processes rather than treating sustainability reporting as a stand-alone activity. The significant influence of previous ESG performance also demonstrates that sustainability outcomes have a dynamic and cumulative character. Theoretically, these findings strengthen the integration of Legitimacy Theory and the Resource-Based View by showing how legitimacy-oriented accounting practices and resource-based innovation capabilities jointly contribute to ESG performance over time. Managerially, firms should align green accounting, sustainability reporting, and eco-innovation strategies to strengthen competitiveness and stakeholder trust. From a policy perspective, governments can support this transition through fiscal incentives, green-technology investment, patent-related incentives, and stronger sustainability reporting requirements.

This study should nevertheless be interpreted within several deliberate boundaries. First, the analysis covers 500 multinational enterprises during 2015–2025, meaning that the findings primarily reflect the sustainability and green-innovation behavior of relatively large firms operating in an international context and may not fully represent small and

medium-sized enterprises, particularly resource-constrained businesses. Future research should therefore examine whether similar relationships, thresholds, and dynamic patterns emerge among SMEs and across different industries, institutional environments, and geographical settings. Second, the study relies on Two-Step System GMM and Panel Threshold Analysis; although these approaches allow the analysis to account for dynamic persistence, potential endogeneity, and non-linear relationships, future studies could employ alternative approaches, including Bayesian dynamic panel models and advanced machine-learning techniques, to investigate more complex forms of non-linearity and heterogeneity. Third, eco-innovation is measured primarily through green patents, which provide a quantifiable indicator but may not capture the full breadth, quality, or organizational consequences of innovation. Future research should incorporate broader indicators, including sustainable process improvements, green technologies, emission-reduction practices, and organizational innovation. Such extensions would provide a more comprehensive understanding of how firms transform environmental information and innovation capabilities into sustained ESG performance.

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AI Use Declaration

Artificial intelligence (AI) tool [*ChatGPT*] was used solely to assist with language enhancement, including improving grammar, clarity, readability, and academic expression. AI tools were not used to generate, analyze, or interpret the research data, determine the

findings, or make substantive research decisions. The authors remain fully responsible for the content, accuracy, interpretation, and conclusions of the manuscript.

Conflict of Interest

The authors declare that they have no conflicts of interest related to the research, authorship, or publication of this paper.

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