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How Do ESG and Innovation Strategies Affect Bank Performance and Risk Stability? Panel Evidence from Taiwan's Banking Industry

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Abstract

Sustainable finance, digital financial innovation, and green innovation have become central strategic pressures in banking, yet their joint effects on bank performance and risk remain insufficiently understood. This study develops an integrated ESG-innovation framework and examines quarterly panel data for 24 Taiwanese financial holding and domestic commercial banks from 2016Q1 to 2025Q3, yielding 934 bank-quarter observations. Return on assets (ROA) and the Z-score are used to capture operating performance and financial stability, respectively, and bank fixed-effects panel models are estimated for high- and low-ESG as well as high- and low-innovation subsamples. The re-estimated results reveal a conditional sustainability effect: ESG and innovation do not generate homogeneous financial benefits, but depend on banks' ESG foundations, innovation intensity, leverage, and scale. Environmental scores are positively associated with ROA in the high-ESG subsample and weakly positive in the low-ESG subsample, whereas credit card transaction expansion is costly for low-ESG banks. In high-innovation banks, credit card transaction volume and green patents are negatively associated with ROA, suggesting adjustment costs and diminishing marginal returns. For financial stability, ESG recognition and green patents are more beneficial in lower ESG or innovation contexts, while leverage is consistently negative across all specifications. These findings contribute to the sustainable finance literature by clarifying how ESG, FinTech-related innovation, and green innovation jointly shape bank performance and risk in a policy-driven emerging market. The results also suggest that banks and regulators should adopt differentiated ESG and innovation strategies rather than assuming that sustainability investment produces uniform outcomes.

Keywords: ESG; financial innovation; green innovation; bank performance; risk stability; panel data analysis; Taiwan



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1. Introduction

Environmental, social, and governance (ESG) practices have moved from a voluntary corporate responsibility agenda to a core component of financial supervision, risk governance, and capital allocation. At the same time, banks are being reshaped by digital financial innovation, including credit card platforms, digital deposit accounts, automated services, data analytics, and technology-enabled risk management. These developments are especially important for banking institutions because banks simultaneously act as financial intermediaries, ESG information processors, and providers of funding for low-carbon transition. Related evidence also links ESG engagement to firm value, banking efficiency, and bank risk conditions (Y. L. Liu, 2020; P.-C. Chen, 2025; M. Du et al., 2026).

Taiwan provides a useful empirical setting for examining these issues. Since the implementation of Taiwan's Green Finance Action Plans 1.0, 2.0, and 3.0, the banking sector has faced stronger expectations concerning climate-related disclosure, green lending, sustainable taxonomy alignment, and ESG. These policy initiatives have encouraged banks to integrate sustainability objectives with digital transformation. However, such transformation also imposes costs related to information systems, compliance, talent development, cybersecurity, and risk-control infrastructure. Whether ESG and innovation improve profitability and financial stability is therefore an empirical question rather than an automatic outcome.

The motivation for this study arises from an unresolved issue in sustainable finance research: ESG, financial innovation, and green innovation are often examined separately, even though banks implement them simultaneously. A bank with strong ESG may be better able to convert digital innovation into operational efficiency and risk reduction, whereas a bank with weak ESG foundations may experience higher transition costs or resource misallocation. Similarly, green innovation may strengthen long-term sustainability capability but may also reduce short-term profitability if investments exceed the bank's absorptive capacity.

This study therefore asks two research questions. First, how do ESG engagement, financial innovation, and green innovation affect bank performance and risk stability in Taiwan's banking industry? Second, do these effects differ across banks with different ESG foundations and innovation intensity? To answer these questions, this study uses quarterly panel data for 24 Taiwanese financial holding and domestic commercial banks from 2016Q1 to 2025Q3 and estimates bank fixed-effects panel models for ROA and Z-score.

The contribution of this study is threefold. First, it integrates ESG engagement, financial innovation, and green innovation into a unified analytical framework rather than treating them as isolated determinants. Second, it identifies a conditional sustainability effect by showing that the financial consequences of ESG and innovation depend on ESG foundations, governance capacity, and innovation maturity. Third, it provides long-term quarterly evidence from Taiwan, a policy-driven banking market in which sustainability regulation and digital financial development have advanced in parallel.

The remainder of this paper is structured as follows. Section 2 reviews the literature and develops the conceptual framework and hypotheses. Section 3 describes the data, variable definitions, empirical models, and endogeneity considerations. Section 4 presents the model selection tests and empirical results. Section 5 discusses the findings and concludes. Section 6 provides policy implications, limitations, and directions for future research.

2. Literature Review and Hypothesis Development

The literature review is organized into four parts because this study examines three strategic channels and their joint mechanism. Sections 2.1–2.3 review ESG, financial innovation, and green innovation separately in order to clarify their theoretical foundations and empirical implications. Section 2.4 then integrates these strands into a conceptual framework and develops testable hypotheses for bank performance and risk stability.

2.1. ESG, Risk Governance, and Sustainable Performance

ESG research has gradually expanded from corporate social responsibility to broader issues of risk governance, stakeholder trust, investment efficiency, and financial resilience. ESG engagement may improve performance by reducing agency costs, increasing transparency, strengthening internal controls, and improving access to capital. For banks, these mechanisms are particularly important because governance quality directly affects credit screening, risk pricing, compliance, and capital allocation.

Previous studies provide mixed evidence on the financial consequences of ESG. Some research indicates that firms with stronger ESG performance exhibit lower risk, stronger market valuation, and improved access to financing. [Díaz-Peña et al. \(2022\)](#) show that ESG performance is related to investment value under different net-zero regulatory environments. [Weston and Nnadi \(2023\)](#) further argue that ESG and CSR initiatives may create substantial non-financial benefits, including reputation, credit quality, and stakeholder trust, even when short-term accounting returns are limited.

From a risk-management perspective, ESG may operate through monitoring and governance channels. [L. Du and Nik Azman \(2024\)](#) find that better ESG performance is associated with lower corporate risk-taking, although this relationship depends on managerial stability and institutional ownership. [Galdos Urbizu et al. \(2025\)](#) also show that ESG risk exposure has heterogeneous effects across the risk distribution. These findings suggest that ESG does not have a mechanically positive effect; its value depends on how sustainability practices are embedded in governance and risk-control systems.

In banking, governance is expected to be the most direct ESG channel affecting profitability because it influences decision-making quality, internal controls, and risk-adjusted capital allocation. Environmental and social activities may generate longer-term benefits by reducing reputational, regulatory, and climate-related risks, but their effects on short-term ROA may be weaker or delayed.

2.2. Financial Innovation, FinTech, and Banking Stability

Financial innovation refers to new products, services, processes, platforms, and organizational practices that improve financial intermediation or risk transfer. Recent evidence also links financial innovation to banking performance, financial inclusion, and enterprise outcomes ([Abbas et al., 2024](#); [Ahodode & Okala Eloundou, 2024](#)). In banking, digital channels such as credit card transactions, digital deposit accounts, mobile banking, automated services, and AI-supported risk management can reduce transaction costs, expand customer reach, and improve data-driven monitoring.

Empirical evidence on FinTech and bank performance remains mixed. [Effiom and Edet \(2022\)](#) find that financial innovation improves productivity among small and medium-sized enterprises. [Cheng and Qu \(2023\)](#) show that FinTech can reduce operational risk, particularly through AI-enabled technologies. [Haddad and Hornuf \(2023\)](#) further suggest that FinTech start-ups may complement incumbent financial institutions and reduce volatility and default risk.

However, financial innovation may also create new risks. [Li \(2022\)](#) documents risk contagion in China's P2P lending market, while [Wang et al. \(2021\)](#) show that FinTech development can have nonlinear effects on bank risk-taking. In Taiwan, [Chou \(2020\)](#) reports that FinTech adoption generated limited profitability improvements for some banks, and [Yang \(2023\)](#) suggests that the effects of financial innovation depend on bank type, capital structure, and technological adoption intensity. These studies indicate that innovation benefits depend on banks' governance capacity and maturity stage. In the Taiwanese context, [Lin \(2020\)](#) further indicates that FinTech development has grown under policy support but may still be shaped by regulatory and institutional constraints. Additional banking evidence links financial innovation, financial patents, and card/ATM applications to bank performance, although the direction and magnitude of effects vary across markets and institutional settings ([Gündoğdu & Taşkın, 2017](#); [Kamau & Oluoch, 2016](#); [T. K. Liu, 2022](#); [Ovenc & Nabiyeu, 2025](#); [Yeh, 2025](#)).

2.3. Green Innovation and Sustainable Competitiveness

Green innovation refers to technological, organizational, and financial innovations that support environmental sustainability, carbon reduction, and green transformation. In the financial sector, green innovation may include green patents, green credit products, green bonds, carbon-data platforms, climate-risk models, and sustainable financing processes. These activities may improve long-term competitiveness by helping banks respond to environmental regulation and client transition needs.

Prior studies show that policy and financing mechanisms are important drivers of green innovation. C. Chen et al. (2022) find that low-carbon regulation promotes urban green innovation. Bellucci et al. (2023) show that venture capital financing increases green patenting. Udeagha and Muchapondwa (2023) further suggest that green finance and FinTech can jointly support environmental sustainability by mobilizing capital through digital platforms.

Green innovation may nevertheless involve substantial adjustment costs. Banks investing in green patents, climate-risk systems, taxonomy compliance, and sustainability disclosure infrastructure may incur short-term expenses before benefits appear in operating performance. Sustainability compliance and post-COVID ESG operating pressures can also create adjustment challenges across supply-chain and financial relationships (Juvvala et al., 2025). Hou et al. (2025) emphasize that green innovation requires knowledge integration and supply-chain coordination. For banks, this implies that green innovation may strengthen risk stability only when it is supported by governance capacity and sufficient absorptive capability.

2.4. Conceptual Framework and Hypothesis Development

Building on the above literature, this study proposes that ESG and innovation affect banking outcomes through three mechanisms. The governance mechanism links ESG to profitability through internal controls, monitoring, and decision-making quality. The innovation-conversion mechanism links financial and green innovation to operating efficiency, customer expansion, and sustainable finance capability. The risk-absorption mechanism links ESG and innovation to stability by influencing capital adequacy, asset quality, operational resilience, and stakeholder confidence.

The framework also assumes that these mechanisms are conditional rather than uniform. Banks with stronger ESG foundations may have better governance systems and disclosure capability, enabling them to transform sustainability investment into risk-control benefits. Banks with weaker ESG foundations may gain more from incremental governance improvements but may be less able to absorb costly innovation investments. Similarly, banks with lower innovation intensity may benefit from initial digital expansion, whereas highly innovative banks may face diminishing marginal returns and adjustment costs.

Hypothesis 1 (H1). *ESG engagement affects bank performance and risk stability through heterogeneous channels, with governance expected to have the most direct positive association with ROA.*

Hypothesis 2 (H2). *Financial innovation has a conditional effect on bank performance and risk stability; its benefits are stronger when innovation intensity remains within banks' absorptive capacity.*

Hypothesis 3 (H3). *Green innovation improves long-term sustainability capability, but its short-term financial effect may be weakened by adjustment costs and resource-allocation pressures.*

Hypothesis 4 (H4). *The effects of ESG, financial innovation, and green innovation differ across high- and low-ESG as well as high- and low-innovation subsamples, reflecting a conditional sustainability effect.*

3. Materials and Methods

This section describes the empirical design. Section 3.1 introduces the sample and data sources. Section 3.2 defines the variables and explains why each proxy is used. Section 3.3 presents the panel data specifications and model selection procedure. Section 3.4 discusses endogeneity and robustness considerations.

3.1. Sample Selection and Data Sources

The study focuses on Taiwan's banking industry and covers 24 financial institutions, including financial holding banks and domestic commercial banks. The sample period extends from 2016Q1 to 2025Q3, yielding an unbalanced quarterly panel of 934 bank-quarter observations over 39 periods. The starting point captures the post-Paris Agreement and early green-finance policy period, while the ending point reflects the most recent complete data available at the time of analysis.

To examine heterogeneity, the sample is divided in two ways using the subgroup classifications constructed in the empirical dataset. First, banks are classified into high-ESG and low-ESG groups to capture differences in sustainability foundations. Second, banks are classified into high-innovation and low-innovation groups according to digital innovation intensity, proxied by digital deposit accounts. The second classification captures digital innovation intensity rather than green innovation alone; therefore, the manuscript uses the term innovation intensity to avoid conceptual ambiguity.

The empirical data are compiled from multiple sources. ESG indicators are obtained from the Taiwan Economic Journal (TEJ) TESG sustainability evaluation system and CommonWealth Magazine's Corporate Sustainability Citizenship Award database. Bank financial and operating data are obtained from the Banking Bureau of Taiwan, the Joint Credit Information Center, and the Joint Credit Card Processing Center. These sources allow the study to connect sustainability ratings, digital financial activity, green innovation proxies, and bank-level financial outcomes.

3.2. Variable Definitions and Proxy Justification

The dependent variables are return on assets (ROA) and the Z-score. ROA measures operating performance and asset utilization efficiency. The Z-score captures financial stability and insolvency risk, with higher values indicating stronger stability. Non-performing loan ratios are reported in the descriptive statistics to document asset-quality conditions, but the main regression models focus on ROA and the Z-score because they capture the two central outcomes of profitability and risk-adjusted soundness.

The main ESG variables include the TESG overall sustainability score (ESG), the environmental score (E), the social score (S), the governance score (G), and an ESG recognition indicator (ESGDV) based on the CommonWealth Magazine Corporate Sustainability Citizenship Top 100 ranking. Using both TESG scores and external recognition allows the analysis to distinguish internal ESG quality from public sustainability recognition.

Financial innovation is proxied by credit card transaction volume (CARD) and digital deposit accounts (DIGI). CARD captures the expansion of retail digital finance and payment activity, while DIGI captures banks' digital customer acquisition and platform-based funding capability. In the regression tables, CARD and DIGI are scaled by one million to improve coefficient readability. Green innovation is proxied by the number of green patents (GPAT), which reflects banks' green technology and sustainability-related innovation outputs. Green loans and green bonds are discussed conceptually, but the core empirical specifications emphasize CARD, DIGI, and GPAT because these measures are consistently available across banks and quarters in the dataset. The use of green patents

is also consistent with prior work linking green financing instruments, corporate strategy, and ESG ratings to green innovation (Dou & Qi, 2019; Hsiung, 2024).

The control variables include financial leverage (LEV), firm size (SIZE), firm age (AGE), and real GDP growth (GDP). LEV controls for capital-structure risk. This specification follows evidence that leverage is closely related to performance in financial technology-related firms (Papadimitri et al., 2021). SIZE captures economies of scale and systemic importance. AGE captures accumulated operating experience and organizational maturity and is reported in the descriptive statistics; because AGE is time-invariant within banks over the sample, it is omitted from the bank fixed-effects regressions. GDP controls for macroeconomic conditions that may affect bank profitability, credit risk, and balance-sheet expansion. Table 1 summarizes the variables used in the empirical analysis.

Table 1. Descriptive Statistics of Variables.

Variable	Symbol	Mean	Std. Dev.	Minimum	Maximum
Return on Assets	ROA	0.38	0.64	−4.74	2.79
Non-Performing Loan Ratio	NPL	0.28	0.83	0.00	24.00
Z-score	Z-score	1.49	1.41	−2.31	4.51
TESG Score	ESG	62.77	7.45	43.92	79.27
Environmental	E	66.18	14.02	30.20	90.26
Social	S	66.30	12.54	35.68	91.11
Governance	G	60.01	8.96	34.82	76.73
ESG Recognition	ESGDV	1.64	0.48	1.00	2.00
Credit Card Transaction	CARD	3,589,199	4,925,466	0	19,676,420
Digital Deposit Accounts	DIGI	346,834	675,708	0	4,548,857
Green Patents	GPAT	1	2	0	22
Financial Leverage	LEV	0.92	0.02	0.81	0.97
Firm Size	SIZE	21.29	1.08	19.28	23.38
Firm Age	AGE	37	20	15	76
Real GDP Growth	GDP	3.74	1.83	1.09	7.37

Note: The sample consists of 24 Taiwanese financial holding and domestic commercial banks from 2016Q1 to 2025Q3, yielding 934 bank-quarter observations. CARD and DIGI are reported in original units in this descriptive table and scaled by one million in the regression tables.

3.3. Panel Data Models and Empirical Specifications

Panel data models are used because the dataset combines cross-sectional bank-level variation with quarterly time-series variation. This approach controls for unobserved bank heterogeneity and improves estimation efficiency relative to purely cross-sectional or time-series models. The reported specifications use bank fixed effects and seasonal quarter controls; standard errors are clustered at the bank level. The general baseline model is specified as follows:

$$Y_{it} = \alpha_i + q_t + \beta_1 ESG_{it} + \beta_2 FIN_{it} + \beta_3 GREEN_{it} + \beta_4 X_{it} + \varepsilon_{it}$$

where Y_{it} denotes either ROA_{it} or Z_{it} for bank i in quarter t ; α_i represents bank-specific fixed effects; q_t represents seasonal quarter controls; ESG_{it} denotes ESG-related variables; FIN_{it} denotes financial innovation variables; $GREEN_{it}$ denotes green innovation variables; X_{it} denotes time-varying control variables; and ε_{it} is the idiosyncratic error term.

The bank performance model is specified as:

$$ROA_{it} = \alpha_i + q_t + \beta_1 ESG_{it} + \beta_2 FIN_{it} + \beta_3 GREEN_{it} + \beta_4 LEV_{it} + \beta_5 SIZE_{it} + \beta_6 GDP_{it} + \varepsilon_{it}$$

The bank stability model is specified as:

$$Z_{it} = \alpha_i + q_t + \beta_1 ESG_{it} + \beta_2 FIN_{it} + \beta_3 GREEN_{it} + \beta_4 LEV_{it} + \beta_5 SIZE_{it} + \beta_6 GDP_{it} + \varepsilon_{it}$$

For the heterogeneity analysis, the same model is estimated separately for the high-ESG, low-ESG, high-innovation, and low-innovation subsamples:

$$Y_{it}^{(H/L)} = \alpha^{(H/L)} + \beta_1^{(H/L)} ESG_{it} + \beta_2^{(H/L)} FIN_{it} + \beta_3^{(H/L)} GREEN_{it} + \beta_4^{(H/L)} X_{it} + \varepsilon_{it},$$

where H/L denotes the corresponding subgroup.

In these equations, ESG_{it} includes ESG , E , S , G , and $ESGDV$; FIN_{it} includes $CARD$ and $DIGI$; $GREEN_{it}$ includes $GPAT$; and X_{it} includes LEV , $SIZE$, and GDP . The inclusion of these definitions directly addresses the need to explicitly state FIN_{it} , $GREEN_{it}$, and ESG_{it} in the empirical equations. For the high- and low-innovation ROA models, $DIGI$ is used for grouping and is therefore not included as a separate regressor in that specification.

3.4. Model Selection, Endogeneity, and Robustness Considerations

The empirical specification is selected using standard panel-data diagnostics. The F-test compares pooled ordinary least squares (OLS) with bank fixed effects. The Breusch-Pagan Lagrange Multiplier test evaluates whether panel-level variance is present relative to pooled OLS. This diagnostic follows Breusch and Pagan (1980), while the Hausman specification framework remains the conventional reference for comparing fixed- and random-effects estimators when applicable (Hausman, 1978). Because the F-tests strongly reject pooled OLS across all outcome and subgroup models, the reported estimates use bank fixed effects to control for unobserved bank-specific heterogeneity. Seasonal quarter indicators are included to account for recurring intra-year effects while preserving GDP as a macroeconomic control.

Potential endogeneity is a relevant concern because ESG engagement and innovation activities may both influence and be influenced by bank performance. For example, more profitable banks may have greater resources to invest in ESG disclosure or digital innovation, while ESG and innovation may themselves affect future profitability and stability. The fixed-effects design mitigates time-invariant omitted-variable bias by controlling for unobservable bank characteristics, and seasonal quarter controls help account for recurring time patterns. However, the empirical design should still be interpreted as identifying conditional associations rather than definitive causal effects.

To further address endogeneity concerns, this study conducts an endogeneity-sensitive robustness estimation using one-quarter lagged explanatory variables. Specifically, the robustness specification re-estimates the bank fixed-effects models by replacing contemporaneous ESG, innovation, green innovation, and control variables with their first lags. This lagged specification helps reduce simultaneity and reverse-causality concerns because explanatory variables are measured before the outcome variable. It should not be interpreted as a full causal identification strategy, but it provides an additional empirical check on whether the main inferences are sensitive to timing. Future research should employ instrumental variables, System GMM, threshold regression, quantile regression, or quasi-natural experiments when suitable instruments, policy shocks, or longer datasets become available.

4. Results

This section reports the empirical findings. Section 4.1 presents the model selection tests. Sections 4.2 and 4.3 discuss the ROA models, while Sections 4.4 and 4.5 discuss the Z-score models. Section 4.6 presents the endogeneity-sensitive robustness checks, and Section 4.7 synthesizes the economic interpretation of the results.

4.1. Optimal Panel Data Model Selection Tests

Tables 2 and 3 summarize the model selection diagnostics for the ROA and Z-score models. The F-test results are significant across all model groups, indicating the presence of bank-level heterogeneity and showing that pooled OLS is inappropriate. The LM-test results also indicate panel-level variance in most specifications. Therefore, the empirical analysis reports bank fixed-effects models with seasonal quarter controls and bank-clustered standard errors.

Table 2. Model Selection Test Results for the ROA Models.

Test/Statistic	High ESG	Low ESG	High Innovation	Low Innovation
Observations	507	426	273	660
Banks	13	11	7	17
F-test	5.14 *** (0.0000)	12.13 *** (0.0000)	21.92 *** (0.0000)	3.95 *** (0.0000)
LM-test	6.07 ** (0.0137)	5.40 ** (0.0202)	3.19 * (0.0742)	7.97 *** (0.0047)
Selected model	Bank fixed effects	Bank fixed effects	Bank fixed effects	Bank fixed effects

Note: *p*-values are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Models include seasonal quarter controls; regression standard errors are clustered at the bank level.

Table 3. Model Selection Test Results for the Z-score Models.

Test/Statistic	High ESG	Low ESG	High Innovation	Low Innovation
Observations	364	305	196	473
Banks	13	11	7	17
F-test	17.96 *** (0.0000)	15.86 *** (0.0000)	6.82 *** (0.0000)	18.45 *** (0.0000)
LM-test	4.31 ** (0.0379)	4.20 ** (0.0404)	3.23 * (0.0725)	5.64 ** (0.0175)
Selected model	Bank fixed effects	Bank fixed effects	Bank fixed effects	Bank fixed effects

Note: *p*-values are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Models include seasonal quarter controls; regression standard errors are clustered at the bank level.

This modelling choice is consistent with the institutional nature of the banking industry. Banks differ in governance structure, ownership, market position, risk culture, technology capability, and long-term strategic orientation. These characteristics are unlikely to be fully observed in the dataset, but they may affect both ESG/innovation strategies and bank outcomes. Fixed effects reduce the risk that such time-invariant differences drive the estimated relationships.

4.2. ROA Results for High- and Low-ESG Subsamples

Table 4 reports the ROA results for the high- and low-ESG subsamples. The environmental score is positively associated with ROA in the high-ESG subsample and weakly positive in the low-ESG subsample. This finding suggests that environmental management may be linked to operating performance when sustainability practices are embedded in bank operations. By contrast, the governance coefficient is not statistically significant in either subgroup after bank fixed effects are used, indicating that the governance-profitability channel should be interpreted cautiously.

Table 4. Empirical Results of the ROA Model for High- and Low-ESG Subsamples.

Variable	Symbol	High ESG Coef.	High ESG <i>p</i>	Low ESG Coef.	Low ESG <i>p</i>
Environmental	E	0.0036 **	0.029	0.0058 *	0.053
Social	S	−0.0055	0.163	−0.0031	0.569
Governance	G	0.0056	0.505	−0.0087	0.370
ESG Recognition	ESGDV	−0.2864	0.196	−0.2582	0.129
Credit Card Transaction (million)	CARD	−0.0065	0.732	−0.2352 ***	0.000
Digital Deposit Accounts (million)	DIGI	−0.1027	0.337	0.2214	0.130
Green Patents	GPAT	−0.0260	0.200	0.0194	0.102
Financial Leverage	LEV	−22.852 ***	0.000	−54.821 ***	0.000
Firm Size	SIZE	0.8728	0.110	0.6356	0.249
Real GDP Growth	GDP	−0.0286	0.115	−0.0655	0.100
Observations		507		426	
Banks		13		11	
R-squared		0.2585		0.4460	

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. CARD and DIGI are scaled by one million. Estimates use bank fixed effects, seasonal quarter controls, and bank-clustered standard errors; AGE is omitted because it is time-invariant within banks.

The social dimension and ESG recognition indicator are not statistically significant in the ROA models. This result does not imply that stakeholder and recognition channels are irrelevant; rather, it suggests that their financial benefits may be realized through risk stability, reputational capital, and funding confidence rather than immediate ROA. The updated estimates therefore support H1 mainly in the sense of heterogeneous ESG channels rather than a uniform profitability effect.

Financial innovation has a heterogeneous effect. Credit card transaction volume is significantly negative in the low-ESG subsample, suggesting that banks with weaker ESG foundations may face higher operating costs, customer-acquisition expenses, or risk-management pressures when expanding retail financial services. Leverage is consistently negative across both ESG groups, confirming that capital structure remains a critical determinant of bank performance.

4.3. ROA Results for High- and Low-Innovation Subsamples

Table 5 reports the ROA results for the high- and low-innovation subsamples. ESG scores and ESG dimensions are not statistically significant in either subsample once banks are classified by innovation intensity. This finding suggests that ESG differences do not directly translate into short-term profitability improvements after innovation maturity is considered, and it reinforces the conditional nature of sustainability effects.

Credit card transaction volume and green patents are both significantly negative in the high-innovation subsample, while they are insignificant in the low-innovation subsample. These findings support H2 and H3 by showing that innovation effects are stage-dependent. When innovation intensity is already high, additional retail financial expansion and green innovation output may create adjustment costs, resource dispersion, compliance expenses, or diminishing marginal returns for short-term ROA.

The control variables provide further evidence of this mechanism. In the high-innovation subsample, leverage is strongly negative and firm size is strongly positive, indicating that scale helps absorb fixed innovation costs, while high leverage amplifies performance pressure. In the low-innovation subsample, leverage remains negative and

GDP is weakly negative, suggesting that macroeconomic and balance-sheet conditions still shape profitability even when innovation intensity is lower.

Table 5. Empirical Results of the ROA Model for High- and Low-Innovation Subsamples.

Variable	Symbol	High Innovation Coef.	High Innovation <i>p</i>	Low Innovation Coef.	Low Innovation <i>p</i>
TESG Score	ESG	−0.0127	0.549	−0.0248	0.319
Environmental	E	0.0047	0.379	0.0040	0.167
Social	S	−0.0093	0.534	0.0047	0.605
Governance	G	0.0183	0.251	0.0170	0.248
ESG Recognition	ESGDV	−0.0291	0.837	−0.3152	0.162
Credit Card Transaction (million)	CARD	−0.1550 **	0.026	0.0045	0.780
Green Patents	GPAT	−0.0159 **	0.026	0.0065	0.581
Financial Leverage	LEV	−77.696 ***	0.001	−22.378 ***	0.000
Firm Size	SIZE	2.8968 ***	0.007	0.5154	0.183
Real GDP Growth	GDP	−0.0764	0.177	−0.0338 *	0.053
Observations		273		660	
Banks		7		17	
R-squared		0.5161		0.2997	

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. CARD is scaled by one million. Estimates use bank fixed effects, seasonal quarter controls, and bank-clustered standard errors; AGE is omitted because it is time-invariant within banks. The subgroup threshold is based on digital deposit accounts as a proxy for innovation intensity.

4.4. Z-Score Results for High- and Low-ESG Subsamples

Table 6 presents the Z-score results for the high- and low-ESG subsamples. In the high-ESG subsample, credit card transaction volume is negatively associated with financial stability, and governance is weakly negative at the 10% level. These results suggest that even banks with stronger ESG foundations may experience operational or risk-control pressure when retail financial activity expands rapidly.

Table 6. Empirical Results of the Z-score Model for High- and Low-ESG Subsamples.

Variable	Symbol	High ESG Coef.	High ESG <i>p</i>	Low ESG Coef.	Low ESG <i>p</i>
Environmental	E	0.0100	0.291	0.0205	0.127
Social	S	−0.0195	0.309	−0.0046	0.629
Governance	G	−0.0496 *	0.051	0.0006	0.980
ESG Recognition	ESGDV	−0.3737	0.457	0.3960 **	0.047
Credit Card Transaction (million)	CARD	−0.0809 **	0.043	−0.0665	0.257
Digital Deposit Accounts (million)	DIGI	0.6051	0.223	0.4211	0.131
Green Patents	GPAT	−0.0621	0.278	0.0403 **	0.011
Financial Leverage	LEV	−81.879 ***	0.000	−83.389 ***	0.000
Firm Size	SIZE	−0.6295	0.666	−1.5195 *	0.090
Real GDP Growth	GDP	−0.0612	0.115	−0.1077 **	0.033
Observations		364		305	
Banks		13		11	
R-squared		0.5543		0.5532	

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. CARD and DIGI are scaled by one million. Estimates use bank fixed effects, seasonal quarter controls, and bank-clustered standard errors; AGE is omitted because it is time-invariant within banks.

In the low-ESG subsample, the ESG recognition indicator and green patents are positively associated with the Z-score. This indicates that external sustainability recognition and green innovation outputs may improve stakeholder confidence, funding stability, or risk-management credibility when ESG foundations are weaker. Leverage is strongly negative in both subsamples, reinforcing the central role of capital structure in bank stability.

These findings reinforce the conditional sustainability effect. ESG does not reduce risk through a single uniform mechanism; instead, external recognition, green innovation, retail financial activity, and leverage affect bank stability differently depending on the bank's existing sustainability foundation.

4.5. Z-Score Results for High- and Low-Innovation Subsamples

Table 7 reports the Z-score results for the high- and low-innovation subsamples. In the high-innovation subsample, leverage is the dominant significant determinant of financial stability, and its negative coefficient indicates that balance-sheet pressure reduces risk stability when innovation intensity is already high. ESG dimensions and innovation proxies are otherwise not statistically significant in this group, suggesting that their stability effects may already be absorbed into bank-specific fixed characteristics or may require longer horizons to materialize.

Table 7. Empirical Results of the Z-score Model for High- and Low-Innovation Subsamples.

Variable	Symbol	High Innovation Coef.	High Innovation <i>p</i>	Low Innovation Coef.	Low Innovation <i>p</i>
Environmental	E	0.0196	0.209	0.0172 **	0.020
Social	S	0.0056	0.742	−0.0157	0.228
Governance	G	−0.0652	0.250	−0.0068	0.659
ESG Recognition	ESGDV	−0.2088	0.765	0.2099	0.282
Credit Card Transaction (million)	CARD	0.0161	0.817	−0.0359	0.437
Digital Deposit Accounts (million)	DIGI	0.1466	0.557	0.3051	0.665
Green Patents	GPAT	−0.0434	0.463	0.0427 **	0.037
Financial Leverage	LEV	−105.69 ***	0.001	−74.490 ***	0.000
Firm Size	SIZE	0.8847	0.601	−1.4843	0.204
Real GDP Growth	GDP	−0.0869	0.131	−0.0655	0.106
Observations		196		473	
Banks		7		17	
R-squared		0.5964		0.5412	

Note: *** and ** denote significance at the 1% and 5% levels, respectively. CARD and DIGI are scaled by one million. Estimates use bank fixed effects, seasonal quarter controls, and bank-clustered standard errors; AGE is omitted because it is time-invariant within banks. The subgroup threshold is based on digital deposit accounts as a proxy for innovation intensity.

In the low-innovation subsample, the environmental score and green patents are positively associated with the Z-score. These results suggest that banks with lower innovation intensity may obtain stability benefits from environmental management and green innovation outputs, possibly because these activities enhance credibility, stakeholder trust, and risk-management capability before innovation systems become more complex.

The comparison between high- and low-innovation subsamples supports H4. Innovation contributes to bank outcomes in a stage-dependent manner: additional innovation is costly for ROA when innovation intensity is already high, whereas green innovation is more closely associated with financial stability when innovation intensity remains lower.

4.6. Endogeneity-Sensitive Robustness Checks

A potential endogeneity concern is that ESG engagement and innovation activity may be jointly determined with bank profitability and stability. To provide an empirical check beyond the contemporaneous fixed-effects models, Table 8 re-estimates the main specifications using one-quarter lagged explanatory variables. The lagged models retain bank fixed effects, seasonal quarter effects, and bank-clustered standard errors. This design does not fully replace instrumental-variable or dynamic panel estimators, but it reduces simultaneity by ensuring that ESG and innovation variables precede the measured outcome.

The lagged ROA results in Panel A remain consistent with the main conditional interpretation. In the high-innovation subsample, lagged credit card transaction volume and lagged green patents are negatively associated with ROA, confirming that intensive innovation may involve adjustment costs and diminishing marginal returns. In the low-innovation subsample, lagged governance and lagged credit card transaction volume are positively associated with ROA, suggesting that incremental governance and retail-finance expansion may be more productive when innovation intensity remains lower. Lagged leverage remains negative across all ROA models, reinforcing the importance of capital discipline.

Table 8. Endogeneity-Sensitive Robustness Checks Using One-Quarter Lagged Explanatory Variables.

Panel A. ROA Models				
Variable	High ESG	Low ESG	High Innovation	Low Innovation
L1 TESS Score	n.a.	n.a.	−0.0139 (0.298)	−0.0298 * (0.067)
L1 Environmental	0.0023 (0.211)	0.0067 * (0.063)	0.0042 (0.202)	0.0045 * (0.092)
L1 Social	−0.0026 (0.269)	−0.0037 (0.472)	−0.0024 (0.816)	0.0089 (0.155)
L1 Governance	0.0109 (0.281)	−0.0016 (0.847)	0.0151 (0.240)	0.0235 ** (0.049)
L1 ESG Recognition	−0.2315 (0.266)	−0.1490 (0.290)	−0.0094 (0.929)	−0.2534 (0.218)
L1 Credit Card Transaction	0.0190 (0.360)	−0.1691 *** (0.001)	−0.1078 ** (0.038)	0.0348 *** (0.002)
L1 Digital Deposit Accounts	−0.0395 (0.443)	0.1984 * (0.090)	n.a.	n.a.
L1 Green Patents	−0.0332 (0.157)	0.0040 (0.783)	−0.0342 * (0.077)	−0.0010 (0.946)
L1 Financial Leverage	−9.3321 *** (0.001)	−26.090 *** (0.002)	−41.748 *** (0.000)	−8.7943 *** (0.000)
L1 Firm Size	0.1266 (0.692)	0.1126 (0.769)	1.7638 *** (0.006)	−0.0395 (0.852)
L1 Real GDP Growth	−0.0150 (0.194)	−0.0390 * (0.099)	−0.0432 (0.229)	−0.0210 * (0.057)
Observations	494	416	266	644
Banks	13	11	7	17
R-squared	0.168	0.261	0.232	0.222
Bank FE/Quarter FE	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes

Table 8. Cont.

Panel B. Z-Score Models				
Variable	High ESG	Low ESG	High Innovation	Low Innovation
L1 TESS Score	n.a.	n.a.	n.a.	n.a.
L1 Environmental	0.0044 (0.654)	0.0205 (0.107)	0.0193 (0.147)	0.0116 (0.157)
L1 Social	−0.0192 (0.208)	−0.0001 (0.990)	0.0025 (0.876)	−0.0115 (0.285)
L1 Governance	−0.0266 (0.222)	0.0123 (0.516)	−0.0467 (0.259)	0.0092 (0.534)
L1 ESG Recognition	−0.2711 (0.451)	0.4652 ** (0.038)	−0.0945 (0.835)	0.2276 (0.363)
L1 Credit Card Transaction	−0.0326 (0.445)	−0.1115 * (0.061)	0.0491 (0.565)	−0.0181 (0.664)
L1 Digital Deposit Accounts	0.6496 ** (0.032)	0.5884 ** (0.033)	0.4932 ** (0.048)	0.6196 (0.297)
L1 Green Patents	−0.0990 ** (0.036)	0.0155 (0.558)	−0.0923 * (0.082)	0.0268 (0.310)
L1 Financial Leverage	−42.484 *** (0.002)	−39.534 *** (0.000)	−54.432 *** (0.005)	−35.667 *** (0.000)
L1 Firm Size	−2.2653 *** (0.001)	−3.1625 *** (0.000)	−2.3303 *** (0.004)	−2.7568 *** (0.008)
L1 Real GDP Growth	−0.0296 (0.374)	−0.0645 (0.129)	−0.0411 (0.384)	−0.0362 (0.290)
Observations	364	306	196	474
Banks	13	11	7	17
R-squared	0.484	0.451	0.504	0.455
Bank FE/Quarter FE	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes

Note: Coefficients are reported with *p*-values in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. n.a. denotes not applicable. L1 denotes one-quarter lagged variables. CARD and DIGI are scaled by one million. All estimates use bank fixed effects, seasonal quarter controls, and bank-clustered standard errors; AGE is omitted because it is time-invariant within banks. The lagged specification is an endogeneity-sensitive robustness check and should not be interpreted as full causal identification.

For the Z-score models in Panel B, lagged digital deposit accounts are positively associated with stability in the high-ESG, low-ESG, and high-innovation subsamples, while lagged leverage remains consistently negative. These findings support the view that digital innovation may strengthen stability when supported by risk-bearing capacity, but leverage pressure weakens resilience across bank groups. Some green-patent coefficients become negative in the lagged high-ESG and high-innovation models, indicating that green innovation benefits may be timing-sensitive and should not be interpreted as uniformly stabilizing in the short run.

4.7. Economic Interpretation and Synthesis

The results have three economically meaningful implications. First, ESG effects are not uniform across profitability and stability outcomes: environmental management matters more for ROA in the ESG subsamples, while ESG recognition and green innovation matter more for stability in weaker ESG or lower innovation contexts. Second, innovation is not automatically performance-enhancing; in high-innovation banks, credit card transaction volume and green patents are associated with lower ROA, indicating adjustment costs and diminishing marginal returns. Third, leverage is consistently detrimental across all

outcome groups, showing that sustainability and innovation strategies must be supported by capital discipline and risk-bearing capacity.

Taken together, the evidence supports the central argument of this study: sustainability and innovation should be understood as conditional strategies. Banks do not benefit simply by increasing ESG scores or innovation investment; they benefit when these strategies are integrated with balance-sheet discipline, operational capacity, and appropriate innovation maturity.

5. Discussion and Conclusions

This study examines how ESG engagement, financial innovation, and green innovation affect bank performance and risk stability in Taiwan's banking industry. By using quarterly panel data for 24 financial institutions from 2016Q1 to 2025Q3 and estimating bank fixed-effects models for different ESG and innovation subsamples, the study provides evidence that the effects of sustainability and innovation are heterogeneous, conditional, and stage-dependent.

The first major finding is that ESG affects profitability through heterogeneous channels rather than a single dominant mechanism. The updated estimates show a positive environmental association with ROA in the high-ESG subsample and a weakly positive environmental association in the low-ESG subsample, while governance is not statistically significant after bank fixed effects are used. This finding implies that ESG-related profitability effects should be interpreted cautiously and should not be generalized as uniformly positive.

The second finding is that innovation intensity conditions the performance effects of financial and green innovation. Credit card transaction volume and green patents are significantly negative in the high-innovation ROA model but insignificant in the low-innovation model. This pattern indicates diminishing marginal returns and adjustment costs. Innovation can strengthen strategic capability, but mature or intensive innovation activity may create short-term profitability pressure unless supported by scale, governance, and capital strength.

The third finding is that ESG and innovation influence financial stability through different mechanisms across bank groups. ESG recognition and green patents are positively associated with Z-score in the low-ESG subsample, and environmental scores and green patents are positively associated with Z-score in the low-innovation subsample. These results demonstrate that sustainability effects are conditional on existing ESG foundations and innovation maturity, and that stability benefits may be stronger where sustainability and innovation systems are still developing.

Theoretically, this study contributes to sustainable finance research by moving beyond a single ESG-performance relationship and proposing a conditional sustainability framework. Methodologically, it shows the value of heterogeneity analysis in identifying how ESG and innovation effects vary across bank groups. Empirically, it provides long-term quarterly evidence from Taiwan, where green finance policy and digital financial development have jointly shaped banking strategies.

The conclusions should be interpreted with appropriate caution. Although fixed effects, seasonal quarter controls, and the lagged-regressor robustness checks mitigate important sources of unobserved heterogeneity, common time patterns, simultaneity, and reverse causality, the study does not claim full causal identification. More profitable or stable banks may still have greater capacity to invest in ESG and innovation. The findings therefore identify conditional empirical associations and mechanisms that should be tested further with stronger causal designs when suitable instruments, policy shocks, or longer datasets become available.

6. Policy Recommendations, Limitations, and Future Research

For banking practitioners, the findings suggest that sustainability strategy should be coordinated with balance-sheet discipline and innovation capacity. Environmental management, green innovation, and ESG recognition can support performance or stability in selected contexts, but they do not generate automatic benefits. Banks should strengthen internal controls, risk governance, data quality, and ESG-linked accountability before aggressively expanding digital and green innovation.

For banks at lower ESG or innovation stages, ESG recognition, environmental management, and green innovation may improve financial stability by strengthening credibility and stakeholder confidence. However, these banks should avoid rapid retail financial expansion without adequate operational resilience. For highly innovative banks, the priority should shift from expansion to integration: innovation systems, cybersecurity, climate-risk data, green-finance governance, and capital planning need to be coordinated to prevent marginal innovation costs from weakening profitability or stability.

For regulators, the results support a differentiated supervisory approach. High-ESG and highly innovative banks require supervision focused on operational resilience, cyber risk, model risk, climate-risk disclosure quality, and greenwashing prevention. Low-ESG and low-innovation banks require stronger guidance on disclosure, governance, consumer protection, and sustainability capacity building. Regulatory instruments should increasingly emphasize verifiable risk reduction and outcome-based sustainability performance rather than merely encouraging sustainability inputs.

This study has limitations. First, the analysis is based on Taiwanese banks, so the results may not be directly generalizable to banking systems with different regulatory structures. Second, green innovation is measured using green patents, which captures innovation output but may not fully reflect all green finance practices. Third, fixed-effects and lagged-regressor robustness models reduce, but cannot fully eliminate, endogeneity or reverse causality. Fourth, the panel is slightly unbalanced because not all banks have observations in every quarter. Fifth, the study focuses on ROA and Z-score; future work could incorporate funding costs, market risk, climate stress-testing indicators, brown asset exposure, or non-performing loan dynamics.

Future research may extend this study by applying System GMM, instrumental-variable methods, threshold regression, quantile regression, or quasi-natural experimental designs. Future studies may also examine interactions among leverage, firm size, ESG rating divergence, and climate-risk exposure to better understand the risk-bearing capacity of banks during sustainable transformation. Additional robustness tests using alternative subgroup thresholds, alternative innovation proxies, alternative risk indicators, and external instruments would also be valuable when longer datasets become available.

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