INKUBIS: Jurnal Ekonomi dan Bisnis
Volume 8, Issue 4, 3466-3481
e_ISSN: 2775-3913
https://inkubis.polteksci.ac.id/index.php/ink/index
DOI: doi.org/10.59261/inkubis.v8i4.512

Financial Technology, Sustainable Finance, and Operational Efficiency: The Moderating Role of Corporate Governance

Caroline Wiguna
Universitas Mercu Buana,
Indonesia

***Corresponding author:**
Caroline Wiguna, Universitas Mercu Buana, Indonesia. ✉alin.hartz@gmail.com

Article Info:

***Article history*:**
Received: August 26, 2026
Revised: September 22, 2026
Accepted: September 29, 2026
Available Online: November 10, 2026

Keywords:
Bank Profitability;
Corporate Governance;
Financial Technology;
Operational Efficiency;
Sustainable Finance

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Abstract

Background: Digital transformation and sustainability require banks to expand digital and sustainable finance initiatives while maintaining efficiency and profitability. For Indonesian KBMI 4 banks, these investments create opportunities but also increase operational and compliance costs, making their impact on profitability and the role of corporate governance important to examine.
Objective: This study examines whether financial technology adoption, sustainable finance innovation, and operational efficiency affect bank profitability and whether corporate governance moderates these relationships in Indonesian KBMI 4 banks.
Methods: The study uses a quantitative explanatory design and secondary data from annual reports, sustainability reports, corporate governance reports, and official bank publications for 2020–2025. The sample comprises Bank Central Asia, Bank Mandiri, Bank Negara Indonesia, and Bank Rakyat Indonesia, yielding 24 balanced bank-year observations. Panel-data estimation and moderated regression analysis are employed.
Results: Financial technology adoption has a positive but insignificant relationship with ROA, while sustainable finance innovation has a negative but insignificant relationship. BOPO has a negative and significant effect on ROA. Corporate governance does not significantly moderate the fintech–ROA or sustainable finance–ROA relationships but significantly moderates the BOPO–ROA relationship.
Conclusion: The findings suggest that digitalization and sustainable finance initiatives do not automatically translate into short-term profitability, whereas cost discipline is more directly associated with profitability. Corporate governance appears particularly important in shaping how operational efficiency is translated into bank profitability.

To cite this article: Wiguna, C. (2026). Financial technology, sustainable finance, and operational efficiency: The moderating role of corporate governance. *INKUBIS: Jurnal Ekonomi dan Bisnis*, *8*(4), 3466–3481. https://doi.org/10.59261/inkubis.v8i4.512

INTRODUCTION

Digital transformation and sustainability have reshaped the competitive landscape of the banking industry. Digital transformation enables banks to accelerate transaction processing, reduce service delivery costs, expand customer accessibility, and improve the efficiency of financial intermediation. At the same time, increasing sustainability requirements compel banks to incorporate environmental, social, and governance considerations into financing decisions, risk management, and corporate reporting. These developments create both strategic opportunities and operational challenges. Banks are expected to provide fast, secure, and convenient digital services while simultaneously supporting sustainable finance, maintaining operational efficiency, and preserving profitability.

This challenge is particularly relevant to Indonesian banks classified under the Core Capital-Based Bank Group 4 (*Kelompok Bank Berdasarkan Modal Inti*/KBMI 4). This group consists of Bank Central Asia, Bank Mandiri, Bank Negara Indonesia, and Bank Rakyat Indonesia. Their substantial capital bases, broad customer networks, and operational scale provide significant capacity to invest in digital infrastructure and sustainable financing initiatives. However, these characteristics also expose them to considerable technology, cybersecurity, regulatory compliance, monitoring, and operating costs. Therefore, KBMI 4 banks provide an important context for examining whether investments in technology, sustainability, and operational capabilities are effectively translated into improved financial performance.

Financial technology adoption represents one of the principal dimensions of banking transformation. Fintech can improve service efficiency, accelerate transactions, expand market reach, facilitate financial inclusion, and create additional sources of revenue. Digital banking technologies may also support sustainability objectives by reducing paper-based processes, improving transaction efficiency, facilitating green financing, and enabling more systematic environmental, social, and governance reporting. Nevertheless, financial technology adoption requires considerable investment in information technology infrastructure, cybersecurity, software development, system maintenance, organizational transformation, and human capital. Consequently, its impact on bank profitability is not necessarily straightforward. Lv et al. (2022) demonstrate that FinTech development may produce complex effects on bank profitability, whereas Zhao et al. (2022) show that FinTech innovation can create both opportunities and competitive pressures for banks. More recent evidence further indicates that operational efficiency plays an important role in determining whether FinTech investment can ultimately improve profitability (Elmahdy et al., 2025).

Sustainable finance innovation presents a similar strategic trade-off. The development of green and sustainable financing can strengthen corporate reputation, enhance relationships with stakeholders, create new business opportunities, support long-term risk management, and contribute to broader environmental and social objectives. However, sustainable finance also requires additional processes related to project screening, environmental and social risk assessment, monitoring, impact measurement, compliance, and sustainability reporting. These requirements may generate additional costs before their long-term financial benefits are realized. Empirical findings remain inconsistent. Andaiyani et al. (2023) and Fata and Arifin (2024) report negative or mixed effects of green credit and sustainable financing on bank performance, whereas Valdiansyah et al. (2024) identify a positive relationship between sustainable finance and profitability. Such differences indicate that the financial consequences of sustainable finance may depend on bank characteristics, the measurement of sustainability activities, implementation effectiveness, and the period of analysis.

In addition to digitalization and sustainable finance, operational efficiency remains a fundamental determinant of banking profitability. Efficient banks are able to control operating expenses relative to the income generated from their activities. In the Indonesian banking context, operational efficiency is commonly represented by the ratio of Operating Expenses to Operating Income (*Biaya Operasional terhadap Pendapatan Operasional*/BOPO). A higher BOPO ratio indicates that a greater proportion of operating income is absorbed by operating expenses and therefore reflects lower operational efficiency. Consequently, an increase in BOPO is generally expected to reduce Return on Assets (ROA). Previous evidence from Indonesian banking supports this relationship, showing that BOPO is negatively associated with profitability (Lutfi et al., 2022; Rosandy & Sha, 2022). This relationship suggests that operational efficiency may determine the extent to which digital and sustainability investments contribute to financial performance.

Corporate governance may further influence the effectiveness of these strategic initiatives. Agency theory proposes that governance mechanisms reduce information asymmetry, constrain managerial opportunism, improve accountability, and strengthen the monitoring of managerial decisions (Boadi et al., 2023). Governance is particularly important in banking because decisions concerning technology investment, financing allocation, risk management, sustainability commitments, and operating expenditure may have significant consequences for shareholders, depositors, regulators, and overall institutional stability. Previous studies have demonstrated relationships between corporate governance, financial innovation, and bank performance (Abbas et al., 2023; Wang & Cao, 2022). However, much of the existing literature treats corporate

governance primarily as a direct determinant of performance rather than examining whether governance changes the strength of the relationship between strategic banking activities and profitability.

The Resource-Based View (RBV) provides an important theoretical basis for understanding these relationships. RBV argues that valuable, strategically important, and difficult-to-imitate organizational resources and capabilities can support sustained competitive advantage (Kero & Bogale, 2023). Within the banking industry, digital infrastructure, data capabilities, technological innovation, human capital, managerial systems, and sustainable-finance expertise can be considered strategic organizational resources. Accordingly, financial technology adoption and sustainable finance innovation represent the utilization and development of such strategic resources, whereas operational efficiency reflects the bank's ability to deploy these resources economically. ROA can therefore be viewed as one of the financial outcomes generated through the effective utilization of organizational resources.

Dynamic Capability Theory complements RBV by emphasizing that possessing strategic resources alone is insufficient in a rapidly changing business environment. Organizations must also possess the capability to sense environmental changes, seize emerging opportunities, and transform or reconfigure existing resources in response to technological, regulatory, and market developments (Kero & Bogale, 2023). Banking digitalization and sustainable finance require continuous adaptation rather than one-time investment. Banks must continuously update technological systems, redesign business processes, develop employee competencies, respond to regulatory developments, and adjust financing strategies. From this perspective, the profitability consequences of financial technology and sustainable finance depend not only on the amount of resources invested but also on how effectively banks reconfigure and manage these resources over time.

Agency theory further provides the theoretical foundation for positioning corporate governance as a moderating variable. The same level of financial technology investment, sustainable-finance activity, or operating expenditure may generate different financial outcomes depending on the quality of managerial oversight and governance mechanisms. Strong governance can promote more disciplined resource allocation, strengthen monitoring, reduce inefficient investment, and ensure that strategic initiatives remain aligned with organizational objectives. Conversely, ineffective governance may reduce the ability of banks to convert substantial investments in technology, sustainability, and operations into financial returns.

Despite the growing literature on digital banking, sustainable finance, operational efficiency, and corporate governance, several research gaps remain. First, previous studies frequently examine financial technology, sustainable finance, or operational efficiency separately, although these factors operate simultaneously within contemporary banking institutions. Second, empirical findings concerning the effects of FinTech and sustainable finance on profitability remain inconsistent. Third, corporate governance has predominantly been examined as a direct predictor of bank performance rather than as a mechanism that may strengthen or weaken the financial consequences of strategic investments. Fourth, empirical evidence focusing specifically on KBMI 4 banks remains limited, despite their dominant position, substantial digital investment, relatively mature governance structures, and extensive involvement in sustainable financing within the Indonesian banking sector.

Accordingly, the novelty of this study lies in integrating financial technology adoption, sustainable finance innovation, and operational efficiency within a single profitability model while examining corporate governance as a moderating mechanism in KBMI 4 banks. This approach provides a more comprehensive explanation of whether strategic banking investments directly contribute to profitability and whether governance conditions determine the effectiveness of those investments. The study is expected to contribute theoretically by integrating the Resource-Based View, Dynamic Capability Theory, and Agency Theory in explaining bank profitability. Practically, the findings may provide insights for bank management regarding the allocation and governance of technological, sustainability, and operational resources. From a policy perspective, the findings may also contribute to discussions regarding governance, digital transformation, operational efficiency, and sustainable banking development in Indonesia.

Based on these considerations, this study aims to examine the effects of financial technology adoption, sustainable finance innovation, and operational efficiency on the

profitability of KBMI 4 banks, as measured by Return on Assets (ROA), while investigating the moderating role of corporate governance in these relationships. Specifically, the study aims to examine the effects of financial technology adoption, sustainable finance innovation, and operational efficiency on ROA, as well as to assess whether corporate governance moderates the relationships between each of these factors and ROA.

METHOD

The study employed a quantitative explanatory design. The unit of analysis was the bank-year. The population comprised the KBMI 4 banking group in Indonesia, and all four banks identified in the research setting (Bank Central Asia, Bank Mandiri, Bank Negara Indonesia, and Bank Rakyat Indonesia) were included. The observation period covered 2020–2025, yielding 24 balanced observations.

Secondary data were collected from annual reports, sustainability reports, corporate governance reports, and official bank publications. Financial technology adoption was operationalized as the annual growth in digital transaction value. Sustainable finance innovation was operationalized as the annual growth in sustainable-finance portfolio value. Operational efficiency was measured by BOPO, while profitability was measured by ROA. Corporate governance was measured by the composite governance rating disclosed by each bank.

An important coding issue concerned the governance rating. The source documents reported composite ratings in which a rating of 1 represented the best governance condition, while higher rating values represented weaker governance. The analysis therefore retained the reported rating scale and interpreted the signs of the interaction coefficients according to this direction. This clarification was important because a lower numerical rating indicated stronger, rather than weaker, governance.

Panel-data estimation considered the Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM), with model selection guided by the standard Chow, Hausman, and Lagrange Multiplier testing procedure (Ghozali & Ratmono, 2017; Imam dan Ratmono, 2022). The thesis results indicated that the Chow test did not support the use of fixed effects, while the Lagrange Multiplier test did not support the use of random effects. Consequently, the CEM was used for the core panel specification. The thesis reported that the Hausman test could not be estimated because the REM specification was not technically available given the data structure. For moderation analysis, the study estimated the interaction terms X1×M, X2×M, and X3×M using Moderated Regression Analysis.

The moderation model was conceptually expressed as:

$$\mathbf{ROA = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 M + \beta_5 (X_1 \times M) + \beta_6 (X_2 \times M) + \beta_7 (X_3 \times M) + \varepsilon}$$

Statistical significance was evaluated at the 5% level. Because the dataset contained only 24 observations, the findings were interpreted as evidence pertaining to the sampled KBMI 4 banks during 2020–2025 rather than as broad causal claims concerning the entire Indonesian banking sector.

Table 1
Operational definitions of variables

Code	Variable	Measurement	Scale
X1	Fintech adoption	(Digital transaction value_t − value_t−1) / value_t−1	Ratio
X2	Sustainable finance innovation	(Sustainable-finance portfolio_t − portfolio_t−1) / portfolio_t−1	Ratio
X3	Operational efficiency	BOPO = operating expenses / operating income × 100%	Ratio
Y	Profitability	ROA = net income / total assets × 100%	Ratio
M	Corporate governance	Composite governance rating; 1 = best	Ordinal score

Code	Variable	Measurement	Scale
Interactions	Moderation	X1×M; X2×M; X3×M	Numerical

Source: Research design based on the thesis data and bank disclosures

RESULTS AND DISCUSSION

Results

Descriptive Statistics

Table 2

Descriptive statistics

Variable	Mean	Min	Max	Std. Dev.
Fintech adoption (X1)	0.3362	0.0830	0.6850	0.1524
Sustainable finance innovation (X2)	0.2347	0.0006	0.5400	0.1572
BOPO (X3)	0.6184	0.0630	0.9330	0.1789
ROA (Y)	0.0273	0.0040	0.0390	0.0101
Governance rating (M)	1.4167	1.0000	2.0000	0.5036

Source: EViews 12 output (2026).

The 24 observations show meaningful variation across the four KBMI 4 banks and the six-year period. Mean ROA is 0.0273, while mean BOPO is 0.6184. The governance rating ranges from 1 to 2, confirming that the sample is concentrated in relatively strong governance categories. The descriptive results should therefore be interpreted in light of the limited cross-sectional variation in governance.

Panel Data Regression Model

Common Effect Model (CEM) Test

Table 3

Common Effect Model (CEM) Results

Dependent Variable: Y_ROA; Method: Panel Least Squares; Sample: 2020–2025; Periods: 6; Cross-sections: 4; Observations: 24 (balanced panel)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.047528	0.007848	6.056333	0.0000
X1_FINTECH	0.022785	0.015146	1.504359	0.1489
X2_KEUBER	-0.019007	0.012129	-1.567110	0.1336
X3_BOPO	-0.032951	0.014467	-2.277703	0.0345
M_GCG	-0.002189	0.004635	-0.472268	0.6421

Model Statistics	Value	Model Statistics	Value
R-squared	0.334778	Mean dependent var	0.027250
Adjusted R-squared	0.194731	S.D. dependent var	0.010088
S.E. of regression	0.009052	Akaike info criterion	-6.388535
Sum squared resid	0.001557	Schwarz criterion	-6.143107
Log likelihood	81.66242	Hannan-Quinn criter.	-6.323423
F-statistic	2.390472	Durbin-Watson stat	1.788175
Prob(F-statistic)	0.086976		

Source: EViews 12 Output (2026)

Based on the Common Effect Model (CEM) regression results using a balanced panel of 24 observations (4 KBMI 4 banks over the 2020–2025 period), the following regression equation is obtained: $Y = 0.0475 + 0.0228X1 - 0.0191X2 - 0.0329X3 - 0.0022M$. Of the four independent variables, only BOPO has a significant effect on ROA (coefficient −0.0329; $p = 0.0345 < 0.05$), indicating that an increase in operating expenses relative to operating income significantly reduces profitability, so that operational efficiency proves to be a key determinant of a bank's

ability to generate profit. In contrast, Financial Technology (coefficient 0.0228; p = 0.1489), Sustainable Finance Innovation (coefficient −0.0191; p = 0.1336), and Corporate Governance (coefficient −0.0022; p = 0.6421) do not have a significant effect on ROA, as their probability values exceed 0.05, indicating that the adoption of financial technology, sustainable-finance innovation, and governance quality have not directly influenced the profitability of KBMI 4 banks during the study period.

Fixed Effect Model (FEM)
Dependent Variable: Y_ROA
Method: Panel Least Squares
Sample: 2020–2025
Periods: 6
Cross-sections: 4
Observations: 24 (balanced panel)

Table 4
Fixed Effect Model (FEM)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.047528	0.007848	6.056333	0.0000
X1_FINTECH	0.022785	0.015146	1.504359	0.1489
X2_KEUBER	-0.019007	0.012129	-1.567110	0.1336
X3_BOPO	-0.032951	0.014467	-2.277703	0.0345
M_GCG	-0.002189	0.004635	-0.472268	0.6421

Model Statistics	Value	Model Statistics	Value
R-squared	0.334778	Mean dependent var	0.027250
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Log likelihood	81.66242	Hannan-Quinn criter.	-6.323423
F-statistic	2.390472	Durbin-Watson stat	1.788175
Prob(F-statistic)	0.086976		

Source: EViews 12 Output (2026)

Based on the FEM regression results, the constant of 0.0450 indicates that ROA is estimated at 4.50% when all independent variables (Financial Technology, Sustainable Finance Innovation, BOPO, and GCG) are held constant. All four independent variables in this model are equally insignificant in explaining ROA, since all probability values exceed 0.05: Financial Technology (coefficient 0.0089; p = 0.6486), Sustainable Finance Innovation (coefficient 0.0009; p = 0.9615), BOPO (coefficient −0.0229; p = 0.2658), and GCG (coefficient −0.0048; p = 0.5743).

In terms of direction, Financial Technology and Sustainable Finance Innovation show positive coefficients on ROA, suggesting that increased adoption of digital technology and sustainable-finance product innovation has the potential to support profitability, although the effect is not yet strong enough statistically—likely because of the sizeable upfront investment, the technology adaptation process, and the complexity of assessing and reporting sustainable products, which require a longer time before results become visible. Conversely, BOPO and GCG show negative coefficients, consistent with the logic that higher operating expenses or differences in entity characteristics can depress profitability, although this relationship is likewise not significant. The insignificance of the GCG variable is likely due to the relatively uniform governance quality among KBMI 4 banks, so that the variation across banks and periods is too limited to capture its effect on ROA in this model.

Panel Data Model Selection
Chow Test

Table 5
Chow Test
Redundant Fixed Effects Tests; Equation: Untitled; Test cross-section fixed effects

Effects Test	Statistic	d.f.	Prob.
Cross-section F	0.766999	(3,16)	0.5291
Cross-section Chi-square	3.224805	3	0.3582

Source: EViews 12 Output (2026)

Based on the test results, the Cross-section F value is 0.7670 with a probability of 0.5291, while the Cross-section Chi-square value is 3.2248 with a probability of 0.3582. Both probability values exceed the 5% significance level. Accordingly, H_0 is not rejected, meaning there is insufficient evidence of individual characteristic differences among banks in the research model. Based on this result, the selected model is the Common Effect Model (CEM), as CEM is considered more appropriate than the Fixed Effect Model (FEM) for analyzing the effect of Financial Technology Adoption, Sustainable Finance Product Innovation, Operational Efficiency, and Corporate Governance on the ROA of KBMI 4 banks during 2020–2025. Thus, based on the Chow test results, it can be concluded that the panel data regression model selected is the Common Effect Model (CEM), so that further analysis can proceed using this model.

Hausman Test

In this study, the Hausman test could not be performed because the Random Effect Model (REM) could not be technically estimated. This is due to limitations in the panel data structure used, particularly the relatively small number of cross-section units compared with the number of parameters estimated in the model. REM requires a sufficient number of cross-section units for the individual error-component variance to be estimated accurately. However, in this study's data, the number of cross-sections is insufficient to meet this requirement, so REM estimation could not be carried out.

According to Baltagi (2021) and Baltagi (2026), in panel data REM performs better when the number of cross-section units (N) is relatively large compared with the number of time periods (T). REM could not be optimally estimated because the number of cross-section units in this study is relatively limited, consisting of only 4 KBMI 4 category banks, while the period T spans 6 years from 2020 to 2025 (N > T). In addition, the variation in characteristics across firms is fairly homogeneous, so the individual effect variance tends to approach zero.

According to Baltagi (2021) and Baltagi (2026), this condition can render the REM estimation unstable and invalid. This condition causes the REM estimation to be invalid, so the Hausman test cannot be performed. As a consequence of the inability to estimate REM, the Hausman test, which aims to compare the Fixed Effect Model and the Random Effect Model, could not be carried out. This situation is methodological in nature and does not constitute an error in data processing. Therefore, the selection of the panel data regression model in this study is based solely on the results of the Chow test and the Lagrange Multiplier test, both of which indicate that the Common Effect Model is the model most consistent with the characteristics of the study data. Accordingly, the omission of the Hausman test in this study can be academically justified, given that one of the models being compared (the Random Effect Model) could not be estimated due to data limitations. This approach is consistent with standard methodological practice in panel data regression research, in which model testing can only be performed when all models being compared satisfy the statistical requirements for estimation.

Lagrange Multiplier (LM) Test

Table 6
Lagrange Multiplier Test
Lagrange Multiplier Tests for Random Effects; Null hypotheses: No effects; Alternative hypotheses: Two-sided (Breusch-Pagan) and one-sided (all others)

Test	Cross-section	Time	Both
Breusch-Pagan	0.636052 (0.4251)	0.183532 (0.6684)	0.819584 (0.3653)
Honda	-0.797529 (0.7874)	0.428406 (0.3342)	-0.261009 (0.6030)
King-Wu	-0.797529 (0.7874)	0.428406 (0.3342)	-0.368157 (0.6436)
Standardized Honda	-0.041936 (0.5167)	0.924216 (0.1777)	-2.579187 (0.9950)
Standardized King-Wu	-0.041936 (0.5167)	0.924216 (0.1777)	-2.759506 (0.9971)
Gourieroux, et al.	--	--	0.183532 (0.5623)

Source: EViews 12 Output (2026)

Based on the Lagrange Multiplier test results, the Breusch-Pagan probability is 0.3653, the Cross-section probability is 0.4251, and the Time probability is 0.6684, all of which exceed the 0.05 threshold, so H0 is accepted and H1 is rejected, meaning there is no substantial random effect from either the cross-section or time-series dimension in this research model. This condition indicates that differences in bank characteristics and variation across time periods are not meaningful enough to justify applying the Random Effect Model, particularly given the limited number of cross-sections—only 4 banks over 6 years (24 panel observations)—so that the variation across firms is not strong enough to support this approach. Therefore, the panel data regression model most appropriate for this study is the Common Effect Model (CEM), and all subsequent hypothesis testing will adopt this approach.

Classical Assumption Tests
Multicollinearity Test

Table 7
Multicollinearity

	Y_ROA	X1_FINTECH	X2_KEUBER	X3_BOPO
Y_ROA	1.000000	-0.036734	-0.224523	-0.427303
X1_FINTECH	-0.036734	1.000000	0.030413	0.560836
X2_KEUBER	-0.224523	0.030413	1.000000	-0.091359
X3_BOPO	-0.427303	0.560836	-0.091359	1.000000

Source: EViews 12 Output (2026)

The multicollinearity test results show that the correlations among the independent variables are far below the 0.80 threshold, indicating no evidence of a multicollinearity problem in the model. The correlation between Financial Technology (X1) and Sustainable Finance Innovation (X2) of 0.0304 is very low; the correlation between Sustainable Finance Innovation (X2) and BOPO (X3) of −0.0913 is also very weak, albeit in the opposite direction; while the highest correlation is between Financial Technology (X1) and BOPO (X3) at 0.5608, which, although classified as moderate, still remains below the threshold of 0.80 set by Ghozali and Ratmono (2017) and Imam dan Ratmono (2022). Accordingly, all independent variables (Financial Technology, Sustainable Finance Innovation, and Operational Efficiency (BOPO)) can be used together in the regression model without introducing distortion into the parameter estimation results.

Heteroskedasticity Test

Table 8
Heteroskedasticity Test (Glejser)
Dependent Variable: ABS(RESID); Method: Panel Least Squares; Sample: 2020–2025; Periods: 6; Cross-sections: 4; Observations: 24 (balanced panel)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.071537	0.055118	1.297889	0.2091
X1_FINTECH	0.235465	0.108913	2.161953	0.0429
X2_KEUBER	-0.043496	0.087844	-0.495152	0.6259
X3_BOPO	-0.060683	0.093184	-0.651210	0.5223

Model Statistics	Value	Model Statistics	Value
R-squared	0.208798	Mean dependent var	0.102968
Adjusted R-squared	0.090117	S.D. dependent var	0.068772
S.E. of regression	0.065600	Akaike info criterion	-2.459459
Sum squared resid	0.086068	Schwarz criterion	-2.263117
Log likelihood	33.51351	Hannan-Quinn criter.	-2.407370
F-statistic	1.759327	Durbin-Watson stat	2.149453
Prob(F-statistic)	0.187322		

Source: EViews 12 Output (2026)

Based on the evaluation performed, the Operational Efficiency (BOPO) (X_3) variable obtains a probability value of 0.5223 and the Sustainable Finance Innovation (X_2) variable produces a probability value of 0.6259, both of which are above the 0.05 threshold, indicating that neither variable shows any indication of heteroskedasticity.

In contrast, Financial Technology (X_1) shows a probability value of 0.0429. This finding implies that the variable contributes to the residual value, indicating a manifestation of heteroskedasticity in the regression model.

Therefore, the test results reveal that the regression model still exhibits symptoms of heteroskedasticity because one variable has a probability value below the 5% significance level. This situation indicates that the homoskedasticity assumption has not been fully met, so the interpretation of the analysis results must take these limitations into account.

Autocorrelation Test

Autocorrelation is tested to identify any correlation between the residuals of one period and the residuals of the preceding period. This test is particularly important in research involving time-series or panel data, because autocorrelation can compromise the accuracy of the regression model's estimates.

Ghozali (2021) and Ghozali (2024) states that the Durbin-Watson (DW) test is one method for detecting autocorrelation. The Durbin-Watson score ranges from 0 to 4, where a value close to 2 generally indicates that the regression model is free from autocorrelation.

The Common Effect Model (CEM) estimation results presented in Table 4.2 show a Durbin-Watson statistic of 1.7782. This figure falls within a range indicating no strong evidence of autocorrelation. Therefore, the residuals in the regression model are assumed to be independent of one another, so the autocorrelation assumption is satisfied.

The absence of autocorrelation indicates that the regression model has met one of the classical assumption requirements, allowing the estimated regression coefficients to be used as a basis for hypothesis testing.

Partial Test (t-Test)

The partial significance test (t-test) is conducted to determine the effect of each independent variable on the dependent variable individually. In this study, the t-test is used to examine the effect of Financial Technology (X1), Sustainable Finance (X2), and BOPO (X3) on Return on Assets (ROA) as the dependent variable.

The test is conducted by comparing the probability value of each variable with the 5% (0.05) significance level. If the probability value is smaller than 0.05, the research hypothesis is accepted, meaning that the independent variable has a significant effect on Return on Assets (ROA). Conversely, if the probability value is greater than 0.05, the research hypothesis is rejected, meaning that the independent variable does not have a significant effect on Return on Assets (ROA).

Table 9
t-Test Results
Dependent Variable: Y_ROA; Method: Panel Least Squares; Sample: 2020–2025; Periods: 6; Cross-sections: 4; Observations: 24 (balanced panel)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.046615	0.007457	6.251491	0.0000
X1_FINTECH	0.021899	0.014734	1.486222	0.1528
X2_KEUBER	-0.018811	0.011884	-1.582871	0.1291
X3_BOPO	-0.036081	0.012606	-2.862113	0.0096

Model Statistics	Value	Model Statistics	Value
R-squared	0.326969	Mean dependent var	0.027250
Adjusted R-squared	0.226014	S.D. dependent var	0.010088
S.E. of regression	0.008875	Akaike info criterion	-6.460198
Sum squared resid	0.001575	Schwarz criterion	-6.263856
Log likelihood	81.52237	Hannan-Quinn criter.	-6.408108
F-statistic	3.238770	Durbin-Watson stat	1.792789
Prob(F-statistic)	0.043857		

Source: EViews 12 Output (2026)

The test results are examined by looking at the probability (Prob.) values in the regression results shown in Table 10.

Hypothesis Testing Results

Table 10
Direct-Effect Hypothesis Testing Results

Hyp.	Relationship between Variables	Coefficient	t-Statistic	Probability	Remarks
H1	Fintech → ROA	0.0218	1.4862	0.1528 > 0.05	Not significant
H2	Sustainable Finance → ROA	-0.0188	-1.583	0.1291 > 0.05	Not significant
H3	BOPO → ROA	-0.0361	-2.862	0.0096 < 0.05	Negative, significant

Source: EViews 12 Output (2026)

The direct hypothesis testing results show that Financial Technology (X1) has a regression coefficient of 0.0219 with a probability of 0.1528, so it has no significant effect on ROA even though the direction of the relationship is positive; H1 is therefore rejected, as the use of Financial Technology by KBMI 4 banks during 2020–2025 has not yet had a direct impact on profitability. The Sustainable Finance (X2) variable has a coefficient of −0.0188 with a probability of 0.1291, so it likewise has no significant effect on ROA and even shows a negative direction, indicating that investment in and development of sustainable finance products still require system-adjustment and implementation costs before their economic benefits become apparent, so H2 is also rejected. In contrast, BOPO (X3) has a coefficient of −0.0361 with a probability of 0.0096, which is smaller than 0.05, so it has a significant negative effect on ROA, meaning that the higher the BOPO, the lower the ROA, and conversely, the more efficiently a bank controls its operating expenses, the higher its ability to generate profit from its assets; H3 is therefore accepted and is consistent with

the concept of banking operational efficiency, whereby an increase in operating expenses not matched by an increase in operating income will depress bank profitability.

F-Test

Table 11
F-Test Results
Dependent Variable: Y_ROA; Method: Panel Least Squares; Sample: 2020–2025; Periods: 6; Cross-sections: 4; Observations: 24 (balanced panel)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.012583	0.030248	-0.416014	0.6829
X1_FINTECH	-0.067558	0.053667	-1.258841	0.2261
X2_KEUBER	-0.034339	0.025518	-1.345670	0.1972
X3_BOPO	0.107866	0.048693	2.215249	0.0416
M_GCG	0.051751	0.027215	1.901564	0.0754
X1M	0.041286	0.030939	1.334417	0.2007
X2M	0.012593	0.020543	0.612990	0.5485
X3M	-0.102256	0.035808	-2.855694	0.0114

Model Statistics	Value	Model Statistics	Value
R-squared	0.590861	Mean dependent var	0.027250
Adjusted R-squared	0.411863	S.D. dependent var	0.010088
S.E. of regression	0.007736	Akaike info criterion	-6.624601
Sum squared resid	0.000958	Schwarz criterion	-6.231917
Log likelihood	87.49521	Hannan-Quinn criter.	-6.520422
F-statistic	3.300931	Durbin-Watson stat	2.418754
Prob(F-statistic)	0.022696		

Source: EViews 12 Output (2026)

Based on Table 11, the F-statistic value is 3.3009 with a Prob(F-statistic) of 0.0227. This probability value is smaller than the 5% significance level used (0.0227 < 0.05). Therefore, H0 is rejected and H1 is accepted. This indicates that, simultaneously, Financial Technology, Sustainable Finance, BOPO, Corporate Governance, and the interaction of each independent variable with Corporate Governance are able to influence Return on Assets (ROA). In other words, the regression model constructed in this study is suitable for explaining the variation in bank profitability as proxied by ROA.

This finding indicates that although not all variables have a significant partial effect, when tested jointly these variables are able to make a significant contribution to changes in ROA. This shows a collective relationship among technology, sustainability, operational efficiency, and Corporate Governance factors in relation to bank profitability performance.

Table 12
Indirect-Effect Hypothesis Testing Results

Hyp.	Relationship between Variables	Coefficient	t-Statistic	Probability	Remarks
H4	Corporate Governance moderates Fintech on ROA	0.0413	1.3344	0.2007 > 0.05	Does not moderate
H5	Corporate Governance moderates Sustainable Finance on ROA	0.0126	0.6130	0.5485 > 0.05	Does not moderate
H6	Corporate Governance moderates BOPO on ROA	-0.1023	-2.8557	0.0114 < 0.05	Moderates

Source: EViews 12 Output (2026)

The moderation test results show that Corporate Governance (GCG) does not moderate the effect of either Financial Technology or Sustainable Finance on ROA: the interaction between Financial Technology and GCG has a coefficient of 0.0413 with a probability of 0.2007 (H4 not supported), and the interaction between Sustainable Finance and GCG has a coefficient of 0.0126 with a probability of 0.5485 (H5 not supported), indicating that the benefit of these two variables for profitability is more strongly determined by other factors such as portfolio size, customer demand, implementation costs, and economic conditions, rather than by governance quality alone. In contrast, the interaction between BOPO and GCG has a coefficient of −0.1023 with a probability of 0.0114, which is smaller than 0.05, so H6 is supported and GCG is shown to moderate the effect of BOPO on ROA by weakening that effect—meaning that the better the implementation of GCG, the smaller the effect of BOPO on changes in ROA. This shows that good governance plays a role in operational oversight, cost control, and risk management, so that the effect of BOPO on ROA is determined not only by the magnitude of BOPO itself (coefficient 0.1079) but also depends on the level of corporate governance implementation.

Coefficient of Determination (R^2)

The coefficient of determination (R^2) serves to measure the extent to which the independent variables and the moderating variable can explain fluctuations in the dependent variable. In the context of this study, the coefficient of determination is used to determine the proportion of the effect of variables such as Financial Technology (X1), Sustainable Finance (X2), BOPO (X3), Corporate Governance (M), and the interaction terms X1M, X2M, and X3M on changes in Return on Assets (ROA).

Based on the Moderated Regression Analysis (MRA) results presented in Table 4.10, an R-Squared value of 0.5909 and an Adjusted R-Squared value of 0.4118 are obtained. The R-Squared value of 0.5909 indicates that 59.09% of the total variance in Return on Assets (ROA) is explained by all the variables included in the research model namely Financial Technology, Sustainable Finance, BOPO, Corporate Governance, and the interaction variables formed. The remaining 40.91% is estimated to be influenced by other factors outside the scope of this research model. However, given that this research model includes various independent and moderating variables, the Adjusted R-Squared value is considered more relevant.

This is because the Adjusted R-Squared already accounts for the number of variables used in the model, thereby providing a more precise indicator than R-Squared. The Adjusted R-Squared value of 0.4118 indicates that, after adjusting for the number of variables in the model, the combined ability of Financial Technology, Sustainable Finance, BOPO, Corporate Governance, and the interaction variables to explain the variance in ROA is 41.18%. The remaining 58.82% is explained by other factors not included in the research model. These unexamined external or internal firm factors may include the Capital Adequacy Ratio (CAR), Non-Performing Loan (NPL), Net Interest Margin (NIM), Loan to Deposit Ratio (LDR), firm size, economic growth, inflation, interest rates, financial market conditions, and corporate management policies, all of which lie outside the focus of this study. Holistically, the Adjusted R-Squared value of 41.18% indicates that the developed research model has adequate explanatory capability with respect to variation in ROA. Although other determinants outside the model may still affect firm profitability, the variables integrated into this study have made a substantial contribution to explaining shifts in Return on Assets (ROA).

Discussion

H1 – Financial technology adoption and ROA

Financial technology adoption has a positive coefficient but is not statistically significant. This suggests that greater digital transaction activity did not automatically translate into higher ROA during 2020–2025. For large banks, digital transformation can generate service and strategic benefits while simultaneously requiring substantial investment in infrastructure, cybersecurity, application development, and maintenance. The result is therefore consistent with a view of digitalization as a long-term capability-building process rather than an immediate profitability lever. The finding is also compatible with the mixed evidence reported in the literature. The 2025 JMPJ study by Hindardjo et al. (2025), which includes Pramudena, examines fintech adoption in the Greater Jakarta digital-wallet context and highlights the multidimensional nature of sustained

digital use. Although its outcome and sample differ from this study, it supports the broader argument that fintech adoption should not be reduced to a single direct profitability mechanism.

This pattern also resonates with other recent evidence on FinTech and bank performance. Kayed et al. (2025), examining banks in an emerging-market setting, similarly find that the profitability effect of FinTech investment is not uniform and depends on complementary factors such as bank size and prevailing market conditions. Prasetio et al. (2021) and Karim et al. (2023) report that financial technology, alongside conventional efficiency ratios such as total assets turnover and the current ratio, contributes to bank profitability in Indonesia, but that its effect is comparatively modest relative to internal efficiency measures. More recently, Zhu and Guo (2024) show that financial technology can meaningfully advance financial inclusion without necessarily producing an immediate, statistically significant improvement in profitability, particularly while adoption is still in an expansionary phase. Taken together, these studies reinforce the interpretation that FinTech adoption functions primarily as a capability-building investment whose profitability payoff materializes gradually rather than immediately.

H2 – Sustainable finance innovation and ROA

Sustainable finance innovation has a negative but statistically insignificant coefficient. The result indicates that growth in sustainable-finance activity was not sufficient to produce a measurable short-term increase in ROA. Sustainable financing may create long-term benefits through reputation, stakeholder trust, risk management, and market positioning, while its near-term implementation can require additional screening, monitoring, reporting, and system costs. The result is therefore consistent with the literature's mixed findings and suggests that profitability effects may emerge with a longer time horizon or through indirect channels.

H3 – BOPO and ROA

BOPO has a negative and statistically significant coefficient. This is the clearest direct profitability relationship in the study. Because a higher BOPO means that more operating income is absorbed by operating expenses, an increase in BOPO reduces the portion of resources available to support profitability. The result is consistent with prior Indonesian banking evidence and with the economic meaning of BOPO. For KBMI 4 banks, the implication is not simply to cut costs, but to improve productivity and ensure that technology, branches, employees, cybersecurity, and other operating resources generate adequate economic value.

H4 – GCG as moderator of fintech and ROA

The fintech–GCG interaction is not significant. Thus, the governance rating does not statistically alter the relationship between fintech adoption and ROA in the sample. One plausible interpretation is that governance practices in KBMI 4 banks are already relatively mature and homogeneous, leaving limited cross-bank variation for governance to change the fintech–profitability relationship. In addition, the financial return from digitalization may depend more strongly on monetization strategy, customer usage, platform economics, and technology cost management than on the governance rating itself.

This result can be read alongside Fachrurrozie et al. (2024), who find that good corporate governance and financial technology innovation jointly shape Indonesian bank financial performance, but that governance's incremental contribution becomes comparatively modest once technology-related variables are accounted for. Similarly, Hermuningsih et al. (2022) show that bank-level characteristics such as size are more consistently associated with the strength of the fintech–performance relationship than governance indicators alone. These findings collectively suggest that in already well-governed institutions such as KBMI 4 banks, governance quality may function more as a baseline precondition for sound managerial decision-making than as a factor that further amplifies or dampens the financial return from digital investment.

H5 – GCG as moderator of sustainable finance and ROA

The sustainable-finance–GCG interaction is not significant. Governance may ensure transparency, accountability, and compliance in sustainable finance, but those mechanisms do not necessarily change the short-term profitability effect of sustainable-finance growth. The financial outcome may instead depend on portfolio composition, pricing, project risk, demand,

implementation costs, and the extent to which sustainability is integrated into core business strategy.

This finding is broadly consistent with Adu (2022), who documents that corporate governance mechanisms can moderate the relationship between sustainable banking initiatives and financial performance, but that the moderating effect is often conditional on the strength and independence of specific governance structures rather than on a single composite governance rating. In the context of the present study, the relatively narrow variation in the governance rating across KBMI 4 banks, which ranges only from 1 to 2, likely constrains the capacity of the moderator to reveal a statistically distinguishable effect, echoing Adu (2022) caution that highly homogeneous governance environments limit the detectability of moderation effects for sustainability-related outcomes.

H6 – GCG as moderator of BOPO and ROA

The BOPO–GCG interaction is statistically significant, making this the most distinctive moderating result. The interaction coefficient is negative (−0.1023). Because the governance measure is a rating in which a lower number denotes better governance, the coefficient should not be interpreted mechanically as 'higher GCG strengthens' or 'higher GCG weakens' the relationship without considering the rating direction. The robust conclusion is that governance changes the slope of the BOPO–ROA relationship. Economically, this is plausible: operating-cost decisions are embedded in budgeting, internal control, risk management, accountability, and strategic oversight. Strong governance can therefore affect how efficiently operating resources are converted into income while limiting cost reductions that could undermine service quality or risk controls.

This pattern aligns with Sudradjat et al. (2023), who find that corporate governance is significantly associated with the financial performance of Indonesian banks, with the strength of this association varying across periods of differing operating pressure, such as before and during the Covid-19 pandemic. Their results, like the present findings, suggest that governance exerts its clearest influence on profitability precisely when operational conditions are most strained, reinforcing the conclusion that governance quality matters most for translating operational cost discipline into financial outcomes, rather than for digital or sustainability-related investments considered in isolation.

CONCLUSION

The study concludes that financial technology adoption does not have a statistically significant effect on ROA, although its coefficient is positive, while sustainable finance innovation also has no statistically significant effect on ROA and shows a negative coefficient. In contrast, BOPO has a negative and statistically significant effect on ROA, highlighting the importance of operational cost discipline for bank profitability. Corporate governance does not significantly moderate the relationships between fintech adoption and ROA or between sustainable finance innovation and ROA. However, it significantly moderates the BOPO–ROA relationship, indicating that governance is particularly relevant in translating operational efficiency into profitability. Managerially, KBMI 4 banks should evaluate digital investments not only based on transaction growth but also on monetization, productivity, and cost efficiency. Sustainable finance should likewise be integrated into core business strategy and risk management rather than treated solely as a compliance activity, while operating efficiency should be managed alongside governance, internal control, accountability, and risk management.

This study has several limitations, including the small sample of four banks, the six-year observation period, the use of disclosure-based measures for fintech adoption and sustainable finance innovation, and the reliance on a single ROA measure of profitability. Future research should expand the sample to other KBMI groups, extend the observation period, employ more comprehensive fintech and sustainable-finance indicators, consider alternative measures of corporate governance, and incorporate additional control variables such as NIM, NPL, CAR, LDR, bank size, and macroeconomic conditions.

ACKNOWLEDGMENT

The author gratefully acknowledges Dr. Sri Marti Pramudena, S.E., M.M., CISP, for academic supervision and guidance during the development of the underlying master's thesis.

AUTHOR CONTRIBUTION STATEMENT

Caroline Wiguna developed the research design, collected and processed secondary data, conducted the statistical analysis, interpreted the findings, and prepared the manuscript.

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