



Effects of Digital Transformation, GCG, and CAR on NPL in Indonesian Banks with Profitability as Moderator

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ABSTRACT

Keywords:

Digital Transformation; Good Corporate Governance; Capital Adequacy Ratio; Non-Performing Loans

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This study aims to examine the relationships between digital transformation, Good Corporate Governance (GCG), Capital Adequacy Ratio (CAR), and non-performing loans (NPLs), while assessing the moderating role of profitability in these relationships. A quantitative research design was employed using panel data obtained from official reports covering the 2020–2024 period. The data were analyzed using panel data regression and Moderated Regression Analysis (MRA) to examine both the direct effects of digital transformation, GCG, and CAR on NPLs and the moderating effect of profitability. The findings indicate that digital transformation significantly reduces NPLs, suggesting that the adoption of digital technologies, including artificial intelligence, big data, and real-time monitoring, can improve credit assessment and facilitate earlier identification of credit risk. GCG and adequate capital also contribute to strengthening credit risk management. However, profitability does not significantly moderate the relationships between digital transformation, GCG, CAR, and NPLs. These findings highlight the importance of integrating digital capabilities, effective governance, and capital resilience into banking risk-management strategies to support more effective and sustainable credit risk management.

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INTRODUCTION

Digital transformation in banking has become an important societal issue because banks increasingly determine how efficiently households and businesses access financial services, credit, and secure transactions. Rapid adoption of artificial intelligence, cloud computing, blockchain, and digital platforms can improve service efficiency while strengthening credit assessment and risk monitoring. Anshul Vyas et al. (2025) reports expanding use of artificial

intelligence in financial risk management, while Tedi and Wiyono (2025) emphasize artificial intelligence, real-time data integration, and predictive analytics for improving credit assessment. For society, stronger credit-risk management is important because excessive non-performing loans can weaken bank stability and ultimately affect access to finance. Aji and Manda (2021) and Arthur-Sam (2025) link credit risk with bank profitability. Therefore, understanding whether digital transformation can reduce credit risk is important for strengthening banking resilience and protecting broader economic activity across Indonesia today and nationally.

The study integrates three theoretical perspectives to explain its variables and relationships. Dynamic Capabilities Theory views digital transformation as an organizational capability that enables banks to sense technological changes, seize opportunities, and reconfigure resources, potentially improving credit-risk management (Teece et al., 1997). Resource-Based View explains Good Corporate Governance as an internal organizational resource that can strengthen monitoring, accountability, and responsible lending. Capital adequacy is considered a financial resource that provides capacity to absorb losses and maintain stability, making CAR relevant to credit-risk management. Profitability, measured by ROA, is positioned as a moderator because financially stronger banks may possess greater resources to implement technology, governance mechanisms, and risk-control systems. This framework is supported by research linking profitability with banking risk and governance (Safitri & Nur, 2024; Yubileus et al., 2025). Thus, the theories provide complementary foundations for testing the proposed relationships.

Despite technological progress, the Indonesian banking sector continues to face credit-risk challenges. Non-performing loans can reduce profitability, weaken asset quality, and constrain banks' financial resources. Aji and Manda (2021) demonstrate the relevance of credit risk to profitability, while Rahmawati et al. (2021) identify NPL as an important factor associated with bank profitability. The challenge becomes more complex for digital banks because rapid technological adoption does not automatically guarantee effective risk control or improved financial outcomes. Novanti (2025) examines digitalization and NPL in relation to bank performance, while Murtopo and Setyawan (2024) examine NPL alongside other determinants of digital-bank profitability. Meanwhile, Daeli and Wedari (2025) show that digital transformation can have varied implications for bank profitability. These conditions create a practical problem: banks must pursue digital innovation while ensuring that governance, capital strength, and profitability support effective credit-risk management in practice.

Previous studies provide substantial evidence concerning individual determinants of banking risk, but their findings remain fragmented. Research on digital transformation generally emphasizes efficiency, financial performance, or risk-taking, while studies on NPL frequently focus on conventional financial determinants. Daeli and Wedari (2025) examine digital transformation and profitability, whereas Hakim and Fauzi (2025) investigate digital transformation and bank risk-taking. Chai and Sun (2024) and Yang and Masron (2024) provide evidence that financial technology and digital transformation can contribute to mitigating credit risk. However, these studies do not consistently integrate digital transformation with GCG and CAR in explaining Net NPL. Similarly, studies concerning GCG, CAR, and banking performance often emphasize profitability rather than credit risk as the principal outcome. Consequently, the literature provides limited integrated evidence regarding how technological, governance, and capital dimensions jointly explain credit risk in Indonesian digital banking.

A further gap concerns the role of profitability. Existing research frequently treats profitability as an outcome of credit risk, governance, capital, or digitalization rather than as a condition that may change their effects on credit risk. Safitri and Nur (2024) examine profitability with credit risk as a moderating variable, while Sriyono and Nabellah (2022) investigate credit quality as a moderator of profitability relationships. Yubileus et al. (2025) similarly connect profitability with risk, capital, governance, and efficiency. These studies specifically provide foundations but leave limited evidence whether profitability moderates the effects of Digital Transformation, GCG, and CAR on Net NPL. This distinction is important because profitability may provide resources for technological investment and risk management, yet it may also reflect outcomes rather than mechanisms alone. Therefore, examining profitability as a moderator offers an opportunity to address an unresolved relationship in Indonesian banking.

The state of the art of this study lies in integrating technological transformation with internal governance and capital strength within one credit-risk framework, while explicitly testing profitability as a moderating condition. Rather than examining digitalization, GCG, CAR, and profitability as isolated banking indicators, the study evaluates their relationships with Net NPL simultaneously. The research also focuses specifically on digital-oriented banks, where technological capability is central to business operations and risk management. This configuration provides a more focused assessment of whether digital transformation represents a stable credit-risk management mechanism and whether profitability changes the effectiveness of organizational and financial resources. The novelty is therefore positioned in the integrated model,

the digital-banking context, and the moderation mechanism. Resolving this issue is important because banking strategies increasingly require simultaneous technological investment, governance quality, adequate capitalization, and sustainable financial performance.

This research addresses whether Digital Transformation, GCG, and CAR reduce Credit Risk measured by Net NPL, and whether profitability changes these relationships. The central argument is that stronger digital capabilities, governance mechanisms, and capital positions should be associated with better credit-risk conditions because they can strengthen monitoring, decision-making, accountability, and loss-absorption capacity. Profitability is expected to condition these relationships because banks with stronger financial performance may have greater capacity to support technology, governance, and risk-management investments. The study contributes by empirically testing these relationships together rather than considering them independently. Using panel observations from Indonesian digital banks during 2020–2024, the research provides evidence on whether these proposed mechanisms operate consistently across banks and years. The results are expected to clarify which organizational and financial factors are most relevant to credit-risk management and whether profitability functions as an effective boundary condition.

RESEARCH METHODS

This study employed a quantitative causal research design to examine the effects of digital transformation, Good Corporate Governance (GCG), and Capital Adequacy Ratio (CAR) on Net Non-Performing Loans (Net NPL), with profitability (ROA) tested as a moderating variable. The quantitative design was selected because it enables objective measurement of variables and statistical testing of causal relationships, consistent with Putra et al. (2025) and Novanti (2025). Panel data regression was selected because it combines cross-sectional observations across banks with time-series observations across five years. This approach provides greater information and estimation efficiency for examining relationships among variables, including interaction effects. Its selection is also supported by Yubileus et al. (2025) and Sriyono and Nabellah (2022). The research location is the Indonesian banking sector, using data accessed through the IDX because it provides publicly available, standardized corporate disclosures for listed banking companies.

The population comprised all banking sector companies listed on the Indonesia Stock Exchange (IDX). Purposive sampling was applied because the study required banks with complete and consistent information on digital transformation, GCG, CAR, ROA, and Net NPL throughout the observation period. The sampling criteria included continuous listing during 2020–2024,

availability of annual financial and corporate governance reports, and classification as digital banks or banks with a fully digital service focus. Based on these criteria, seven banks were selected from the initial population of 47 listed banking companies. The resulting sample generated 35 observations, calculated from seven banks observed over five consecutive years. The detailed sample selection process, including the number of excluded banks at each stage, is presented in Table 1. This purposive sampling procedure ensured that the selected observations contained the data required for the regression and moderation analyses.

Table 1. Sample Selection Criteria		
No.	Sample Selection Criteria	Number of Banks
1	Banking sector companies listed on the Indonesia Stock Exchange (IDX) as of 2024	47
2	Banks that were not continuously listed during the 2020–2024 observation period	-4
3	Banks that did not consistently provide financial statements or data on ROA, Net NPL, and CAR	-2
4	Banks that did not regularly publish Corporate Governance (GCG) reports	-3
5	Banks that were not categorized as digital banks or did not have a fully digital service focus	-31
Total Number of Banks Meeting the Criteria		7
Total Observations (7 Banks × 5 Years)		35

Source: Data processed by the author (2026).

Data were collected using documentary techniques from secondary quantitative sources. The dataset consisted of annual financial reports, sustainability reports, and corporate governance disclosures published by the sampled banks for 2020–2024. Data were obtained primarily from the official Indonesia Stock Exchange (IDX) website and the respective banks’ reports. The collected information was organized into panel data containing cross-sectional and time-series dimensions. Data analysis was conducted using panel regression and Moderated Regression Analysis (MRA). Model selection was performed initially using the Chow Test to compare the Common Effect Model (CEM) and Fixed Effect Model (FEM), followed by the Lagrange Multiplier Test to compare the CEM and Random Effect Model (REM). Classical assumption testing included multicollinearity and heteroskedasticity assessments. Three regression models were estimated to examine the direct effects, the role of profitability, and the interaction effects between profitability and the independent variables.

RESULTS AND DISCUSSION

Results

Panel Data Selection

Panel data model selection was conducted using the Chow Test and Lagrange Multiplier (LM) Test. The Chow Test was used to compare the Common Effect Model (CEM) and Fixed Effect Model (FEM), while the LM Test was used to compare the CEM and Random Effect Model (REM).

Chow Test Results

Table 2. Chow Test Results

Effects Test	Statistic	d.f.	Prob.
Cross-section F	0.572500	-6, 1	0.7445
Cross-section Chi-square	6.200844	6	0.4011

Source: EViews 12 output, processed by the author (2026).

As shown in Table 2, the Cross-section F statistic is 0.572500 with a probability value of 0.7445. The Cross-section Chi-square statistic is 6.200844 with a probability value of 0.4011. Both probability values are greater than 0.05.

Lagrange Multiplier Test Results

Table 3. Lagrange Multiplier Test Results

Test Hypothesis	Cross-section	Time	Both
Breusch-Pagan	1.053301 (0.3047)	0.024429 (0.8758)	1.077729 (0.2992)
Honda	-1.026304 (0.8476)	-0.156297 (0.5621)	-0.836225 (0.7985)
King-Wu	-1.026304 (0.8476)	-0.156297 (0.5621)	-0.753381 (0.7744)
Standardized Honda	-0.603736 (0.7270)	0.374878 (0.3539)	-3.745504 (0.9999)
Standardized King-Wu	-0.603736 (0.7270)	0.374878 (0.3539)	-3.460868 (0.9997)
Gourieroux, et al.	—	—	0.000000 (1.0000)

Source: EViews 12 output, processed by the author (2026).

As reported in Table 2.2, the Breusch-Pagan Cross-section statistic is 1.053301 with a probability value of 0.3047, while the probability value for the Both component is 0.2992. The remaining reported probability values are also greater than 0.05. Based on the panel model selection results, the CEM was retained for the subsequent analysis.

Classical Assumption Testing

Classical assumption testing was conducted using multicollinearity and heteroskedasticity tests.

Multicollinearity Test Results

Table 4. Multicollinearity Test Results			
Variable	X1	X2	X3
X1	1.000000	0.123079	0.065932
X2	0.123079	1.000000	-0.282728
X3	0.065932	-0.282728	1.000000

Source: EViews 12 output, processed by the author (2026).

As presented in Table 4, the correlation coefficient between Digital Transformation (X1) and Good Corporate Governance (X2) is 0.123079. The correlation coefficient between Digital Transformation (X1) and Capital Adequacy Ratio (X3) is 0.065932, while the correlation coefficient between Good Corporate Governance (X2) and Capital Adequacy Ratio (X3) is -0.282728. The absolute correlation coefficients among the independent variables are below 0.85.

Heteroskedasticity Test Results

Graph 3.1 Heteroskedasticity Test Results

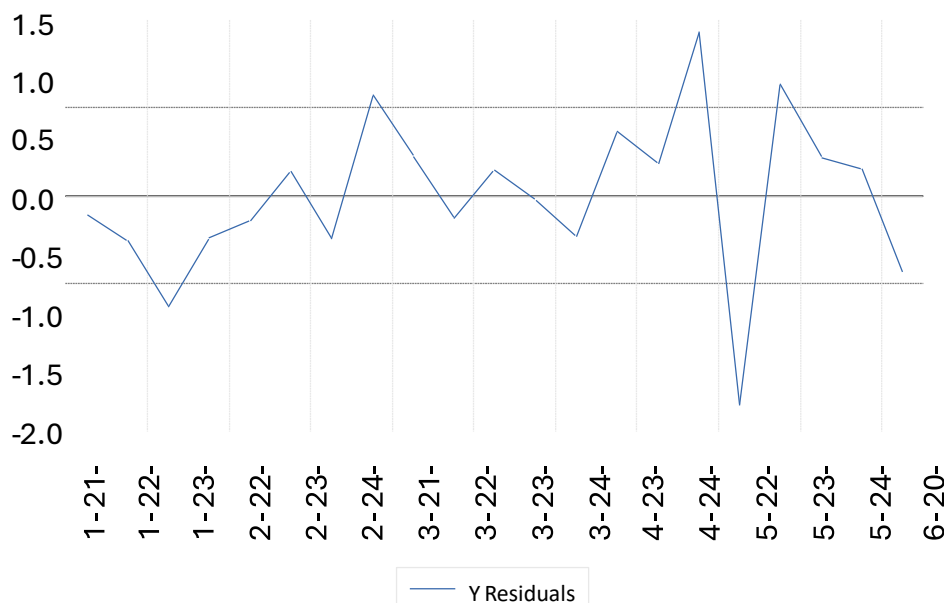


Figure 1. Heteroskedasticity Test Results

Source: EViews 12 output, processed by the author (2026).

As shown in Figure 1, the residual observations are distributed around the center line without a visible systematic pattern. The residual distribution does not display an apparent funnel-shaped or widening pattern.

Moderated Regression Analysis

Moderated Regression Analysis (MRA) was conducted through three regression models. Model 1 included Digital Transformation (X1), Good Corporate Governance (X2), and Capital Adequacy Ratio (X3). Model 2 added

Profitability (Z), measured by Return on Assets (ROA). Model 3 additionally included the interaction terms between Profitability and each independent variable.

Model 1 Test Results

Table 5. Model 1 Test Results

Variable	Coefficient	t-Statistic	Prob.
C	7.398424	6.295692	0.0000
X1	-0.252478	-3.823656	0.0014
X2	-3.223446	-2.337710	0.0319
X3	-0.011756	-2.513310	0.0223
Model Statistic		Value	
R-squared		0.643560	
Adjusted R-squared		0.580659	
F-statistic		10.23131	
Prob(F-statistic)		0.000441	

Source: EViews 12 output, processed by the author (2026).

According to Table 5, the model produces an R-squared value of 0.643560 and an Adjusted R-squared value of 0.580659. The F-statistic is 10.23131 with a probability value of 0.000441.

The coefficient of Digital Transformation (X1) is -0.252478, with a t-statistic of -3.823656 and a probability value of 0.0014. Good Corporate Governance (X2) has a coefficient of -3.223446, a t-statistic of -2.337710, and a probability value of 0.0319. Capital Adequacy Ratio (X3) has a coefficient of -0.011756, a t-statistic of -2.513310, and a probability value of 0.0223.

Model 2 Test Results

Table 2.5. Model 2 Test Results

Variable	Coefficient	t-Statistic	Prob.
C	7.330908	5.655382	0.0000
X1	-0.256265	-3.519158	0.0028
X2	-3.059167	-1.686536	0.1111
X3	-0.011303	-1.970158	0.0664
Z	-0.008767	-0.145622	0.8860
Model Statistic		Value	
R-squared		0.644032	
Adjusted R-squared		0.555040	
F-statistic		7.236973	
Prob(F-statistic)		0.001586	

Source: EViews 12 output, processed by the author (2026).

As reported in Table 2.5, the model has an R-squared value of 0.644032 and an Adjusted R-squared value of 0.555040. The F-statistic is 7.236973, with a probability value of 0.001586.

Digital Transformation (X1) has a coefficient of -0.256265, a t-statistic of -3.519158, and a probability value of 0.0028. Good Corporate Governance (X2) has a coefficient of -3.059167, a t-statistic of -1.686536, and a probability value of 0.1111. Capital Adequacy Ratio (X3) has a coefficient of -0.011303, a t-statistic of -1.970158, and a probability value of 0.0664. Profitability (Z) has a coefficient of -0.008767, a t-statistic of -0.145622, and a probability value of 0.8860.

Model 3 Test Results

Table 2.6. Model 3 Test Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	7.295951	1.412385	5.165696	0.0002
X1	-0.250285	0.080193	-3.121035	0.0081
X2	-3.173853	2.006534	-1.581759	0.1377
X3	-0.011888	0.006764	-1.757505	0.1023
Z	-0.292009	1.089150	-0.268107	0.7928
X1Z	0.013848	0.061298	0.225909	0.8248
X2Z	-0.185612	0.401081	-0.462779	0.6512
X3Z	0.002178	0.002769	0.786754	0.4455
Model Statistic		Value		
R-squared		0.663881		
Mean dependent var		1.181905		
Adjusted R-squared		0.482893		
S.D. dependent var		1.154082		
S.E. of regression		0.829902		
Akaike info criterion		2.747314		
Sum squared resid		8.953592		
Schwarz criterion		3.145227		
Log likelihood		-20.84680		
Hannan-Quinn criter.		2.833672		
F-statistic		3.668104		
Durbin-Watson stat		3.177290		
Prob(F-statistic)		0.020746		

Source: EViews 12 output, processed by the author (2026).

As shown in Table 2.6, Model 3 has an R-squared value of 0.663881 and an Adjusted R-squared value of 0.482893. The F-statistic is 3.668104 with a probability value of 0.020746.

The coefficient of Digital Transformation (X1) is -0.250285, with a t-statistic of -3.121035 and a probability value of 0.0081. Good Corporate Governance (X2) has a coefficient of -3.173853, a t-statistic of -1.581759, and a probability value of 0.1377. Capital Adequacy Ratio (X3) has a coefficient of -0.011888, a t-statistic of -1.757505, and a probability value of 0.1023. Profitability (Z) has a coefficient of -0.292009, a t-statistic of -0.268107, and a probability value of 0.7928.

The interaction term between Digital Transformation and Profitability (X1Z) has a coefficient of 0.013848, a t-statistic of 0.225909, and a probability value of 0.8248. The interaction term between Good Corporate Governance and Profitability (X2Z) has a coefficient of -0.185612, a t-statistic of -0.462779, and a probability value of 0.6512. The interaction term between Capital Adequacy Ratio and Profitability (X3Z) has a coefficient of 0.002178, a t-statistic of 0.786754, and a probability value of 0.4455.

Discussion

The finding that Digital Transformation significantly reduces Credit Risk (Net NPL) is consistent with evidence that digitalization can improve banking risk management and reduce non-performing loans. Chai and Sun (2024) demonstrate that fintech development can mitigate NPL risk, while Yang and Masron (2024) identify digital transformation as an important factor in bank credit-risk management. Shneiwer et al. (2026) similarly associate digital transformation with financing and NPL conditions. The present result further supports these findings because Digital Transformation remains significant across Models 1, 2, and 3. This consistency differs from the less stable effects observed for GCG and CAR. Moreover, Hakim and Fauzi (2025) and Zheng et al. (2025) emphasize that digital transformation can alter banking risk-taking through improved management efficiency and credit structures. Thus, this study reinforces the growing evidence that digital capability has an independent role in controlling banking credit risk.

The significant negative effect of Good Corporate Governance (GCG) on Net NPL in Model 1 is consistent with Mohammad et al. (2024), who highlight the relationship between governance, credit risk, and financial performance. It also corresponds with Kushwaha et al. (2025), who emphasize the importance of corporate governance and risk-management mechanisms in commercial banking. Similarly, Diansari et al. (2025) demonstrate that corporate governance is connected with financial stability. However, the present finding differs in an important respect because GCG becomes statistically insignificant after Profitability is introduced in Model 2 and remains insignificant in Model 3. This difference indicates that the governance–credit-risk relationship is not equally stable across model specifications. The finding contributes to previous research by showing that the apparent effect of governance on Net NPL may depend on the inclusion of additional financial variables rather than operating as a uniformly significant relationship.

Capital Adequacy Ratio (CAR) has a significant negative effect on Net NPL in Model 1, supporting the view that stronger capitalization is associated with improved capacity to manage credit-related risk. This finding is consistent

with Busari (2023), who examines the relationship between credit-risk management, CAR, and banking performance. It also corresponds with Sulbahri et al. (2023), who identify CAR and NPL as important banking-related variables. Pili and Fadrianto (2025) further demonstrate the relevance of governance in the relationship between credit risk and capital adequacy. However, CAR becomes insignificant in Models 2 and 3. This differs from findings suggesting a more persistent role of capital adequacy. The contribution of this study is therefore to demonstrate that the negative CAR–Net NPL relationship is specification-sensitive, while its novelty lies in examining this instability alongside digital transformation and profitability within an integrated banking-risk framework.

Profitability (ROA) does not significantly affect Net NPL in Model 2. This finding differs from research that associates banking profitability with credit-risk conditions. Dea et al. (2024) examine credit-risk management in relation to bank financial performance, while Hartanto et al. (2024) demonstrate the relevance of NPL, agency cost, GCG, and credit policy to profitability. Zafir and Sudarjah (2025) also investigate the relationship between credit risk and bank profitability in Indonesian conventional banks. The absence of a significant direct ROA effect in this study suggests that profitability does not automatically correspond to lower Net NPL. This result may reflect differences in model structure, banking characteristics, or the role of profitability within the observed period. Accordingly, this study contributes by showing that ROA does not provide additional explanatory power for Net NPL after the principal banking variables are considered.

The moderation results provide a further distinction from studies that examine profitability primarily as a direct determinant of banking outcomes. In Model 3, none of the interaction terms—Digital Transformation $\times$ Profitability, GCG $\times$ Profitability, or CAR $\times$ Profitability—is statistically significant. Therefore, profitability does not alter the relationships between the principal explanatory variables and Net NPL. This finding contrasts with Aryani and Assegaf (2026), who specifically examine moderating effects related to bank profitability, lending, and credit risk in Indonesia. It also differs from studies emphasizing the interconnected effects among credit risk, governance, capital adequacy, and financial performance. The present result contributes by testing profitability as a boundary condition rather than merely as an explanatory variable. Its novelty lies in demonstrating that the effectiveness of digital transformation, governance, and capital adequacy in relation to credit risk does not statistically depend on the bank's profitability level.

The differences across Models 1–3 provide an important empirical contribution. Digital Transformation remains statistically significant in all specifications, whereas GCG and CAR are significant only in Model 1, and ROA

is insignificant in Model 2. These findings suggest that Digital Transformation has greater statistical consistency than the conventional banking variables examined in this study. The result complements Chai and Sun (2024), Yang and Masron (2024), and Zheng et al. (2025), which emphasize the increasing relevance of digital transformation to banking risk. At the same time, the findings extend Hakim and Fauzi (2025) by showing that the negative association between digital transformation and credit risk persists even after profitability and interaction terms are incorporated. This cross-model stability constitutes a key contribution of the study and provides a more differentiated perspective on which banking factors demonstrate robust associations with Net NPL.

Overall, this study contributes to the literature by integrating Digital Transformation, GCG, CAR, and Profitability into a single moderated panel-data framework for explaining Credit Risk. Previous studies have generally examined these factors separately or emphasized their direct relationships with banking performance and risk. The present findings provide a different empirical pattern: Digital Transformation consistently demonstrates a significant negative relationship with Net NPL, while GCG and CAR lose significance after additional variables are incorporated, and Profitability neither directly affects Net NPL nor moderates the relationships examined. This combination represents the principal novelty of the study. The findings also complement the evidence of Lan (2026) and Shneiwer et al. (2026) concerning banking risks in the digital-transformation era, while extending existing research by demonstrating the absence of a profitability-based moderation mechanism in the observed banking context.

CONCLUSION

This study concludes that digital transformation, Good Corporate Governance (GCG), and adequate capital play important roles in strengthening credit risk management and reducing non-performing loans (NPLs) in the Indonesian banking sector. The most important lesson is that digital transformation provides banks with greater capacity to improve credit assessment, monitor borrower conditions in real time, and identify potential default risks at an earlier stage, while strong GCG and sufficient capital remain essential institutional foundations for maintaining financial stability. Theoretically, this study contributes to the banking and financial risk literature by integrating digital transformation, GCG, and Capital Adequacy Ratio (CAR) into a unified framework for explaining NPLs, while also demonstrating that profitability measured by Return on Assets (ROA) does not significantly moderate these relationships. This finding provides evidence that profitability alone may not determine the effectiveness of risk-management mechanisms. However, the study is limited by its reliance on secondary data and the specific

context of the Indonesian banking sector, which may restrict the generalizability of the findings. Future research should therefore incorporate broader samples, longer observation periods, and additional moderating or mediating variables, such as bank size, liquidity, technological capability, or macroeconomic conditions, to provide a more comprehensive understanding of the determinants of credit risk.

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