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Digital Transformation and Bank Performance: The Moderating Role of Risk in Indonesian Commercial Banks

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ABSTRACT

This study analyzes the effect of digital transformation on the performance of Indonesian commercial banks, with financial risk measured by the Z-Score as a moderating variable. Using panel data regression on 21 listed banks from 2019 to 2023, the findings reveal that digital transformation has a positive and significant impact on Net Interest Margin (NIM), reflecting improved efficiency and profitability. However, when financial risk is considered, the direct effect of digital transformation becomes insignificant, suggesting that risk conditions may hinder the optimal benefits of digital initiatives. Interestingly, the interaction term between digital transformation and Z-Score is positive and significant, indicating that banks with higher financial stability are better positioned to leverage digital technologies. Furthermore, leverage and Non-Performing Loans (NPLs) show significant effects, while macroeconomic factors such as inflation and GDP growth are insignificant. These results highlight that the success of digital transformation depends not only on technology adoption but also on financial soundness and effective risk management. The findings provide practical implications for regulators and banking practitioners in designing sustainable digital transformation strategies that enhance competitiveness in the digital era.

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INTRODUCTION

The era of globalization has witnessed the rapid advancement of digital technology, bringing transformative changes to various aspects of life, including in Indonesia. The development of information and communication technology (ICT) has penetrated nearly all sectors ranging from communication, the economy, and education to culture (We Are Social and Hootsuite, 2024). The internet, as the backbone of the digital era, enables individuals and communities across the country to connect, interact, collaborate, and exchange information without geographical limitations.

This phenomenon has significantly impacted how Indonesians live, work, and access information. The ease of accessing information through the internet has created new opportunities for the public to learn, innovate, and participate actively in the digital society. However, it also presents new challenges, such as the digital divide, cybersecurity risks, and the spread of misinformation (Kompas.com, 2023).

In the national banking sector, digital transformation has become imperative to maintain competitiveness amid increasing industry rivalry and growing customer expectations. This transformation involves the adoption of advanced technologies, changes in business models, and innovations in digital-based products and services OJK (2022).

According to the report by (We Are Social and Hootsuite, 2024), device ownership rates in Indonesia are exceptionally high, indicating the population's readiness to access digital banking services: 99.4% of internet users own a mobile phone, 99.3% own a smartphone, 57.8% own a laptop, and 14.6% own a tablet. This condition facilitates wider access to digital financial services, including banking applications.

The use of banking applications in Indonesia has shown a positive growth trend. Data from the OJK (2022) revealed that the percentage of users aged 16 – 64 who use banking apps increased from 33% in 2020 to 39.2% in 2022 although still lagging behind other application categories such as social media and online shopping, which have user rates above 90%. This indicates a significant opportunity to expand the user base of banking applications in Indonesia.

The increasing adoption of digital services is also reflected in transaction volumes. According to (Bank Indonesia, 2024), the average daily value of BI-RTGS transactions grew by 13.42% year-on-year, reaching IDR 42,008.08 trillion. BI-FAST transactions rose by 67.79%, totaling 785.95 thousand transactions, while digital banking transactions surged by 34.49%, amounting to 5.363 billion transactions. Electronic money transactions increased sharply by 39.24% (3.958 billion transactions), while the use of QRIS grew spectacularly by 226.54%, reaching 50.50 million active users and 32.71 million merchants.

Furthermore, data from (Bank Indonesia, 2020) show that e-wallet top-up services were the most popular, with a usage rate of 81%, followed by money transfers (78%), bill payments such as electricity, water, and internet (64%), mobile credit purchases (56%), and virtual account payments for services such as online games (52%). This surge reflects the massive adoption of electronic money, which grew more than 200-fold from IDR 981.3 billion in 2011 to IDR 204,909.17 billion in 2020.

However, a high level of digitalization does not automatically lead to increased banking profitability. Net Interest Margin (NIM), a key indicator of profitability, rose from 4.63% in 2020 to 5.24% in 2022 but declined slightly to 5.15% in 2023 (Bank Indonesia, 2024). Moreover, the average Z-Score of Indonesian banks, which reflects financial stability, remains lower than in neighboring countries such as Malaysia, although it has shown a gradual upward trend (Fahmi, 2018). The decline in NIM is suspected to be influenced by increasing competition among banks, a shift in customer preferences toward non-bank investment instruments, and the suboptimal use of customer data for product innovation (Hang & Trang, 2023; Nguyen et al., 2023).

Conceptually, digital transformation is believed to enhance efficiency, expand services, and create new business opportunities. However, several studies have noted that the benefits of digitalization are not instantaneous. (Kriebel & Debener, 2021) stated that the positive impacts of digitalization are typically felt five years after implementation, and may even turn negative if not supported by adequate IT infrastructure and strong organizational readiness. Additionally, other key challenges include cybersecurity threats, the

need for substantial investment, and organizational culture shifts (Kriebel & Debener, 2021).

Therefore, this research is highly relevant in analyzing the impact of digital transformation on the performance of commercial banks in Indonesia. The study aims to identify key digital transformation factors that significantly affect banks' financial performance and examine the moderating role of risk, which may strengthen or weaken these effects. The results are expected to provide valuable insights for regulators, bank management, and academics in formulating effective, measurable, and sustainable digital transformation strategies and policies in the national banking industry.

LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

Bank Performance

A bank is a financial institution whose main activities involve collecting funds from the public in the form of savings and redistributing them as credit or other financial products to improve the standard of living in society (Law of the Republic of Indonesia No. 10 of 1998 on Banking). As both a fund collector and distributor, banks play a crucial role in stimulating economic growth and enhancing the quality of life (Jumingan, 2009). Banks do not only absorb funds through savings, deposits, and current accounts but also provide credit to support both consumption and production activities. In addition, banks offer supporting services such as credit cards, money transfers, and investment services, which facilitate daily economic activities.

Bank performance reflects the achievements made in carrying out banking operations over a specific period. It encompasses financial aspects, fund collection and distribution, technology utilization, and human resource management (Jumingan, 2009). Strong bank performance demonstrates the institution's ability to manage customer funds safely, efficiently, and profitably fostering customer trust and loyalty. Solid bank performance can be seen in responsive services, product innovation, operational efficiency, and the ability to adapt to market dynamics (Fahmi, 2014; Zarrouk et al., 2016). Conversely, poor performance can reduce the trust of the public, investors, and regulators, which is why banks must consistently work to improve their performance (Secchi & Tamagni, 2008).

The factors influencing bank performance are categorized into internal factors (such as managerial decisions, portfolio strategies, and cost control quality) and external factors (such as inflation and macroeconomic conditions) (Staikouras & Wood, 2004; Zimmerman, 1996). Management quality is considered essential, as it reflects how effectively bank leadership controls policies and maintains organizational performance.

One of the main indicators of bank performance is profitability, often measured using financial ratios such as Net Interest Margin (NIM). NIM is the ratio of net interest income (interest revenue minus interest expense) to average earning assets (Slamet, 2006). According to Bank Indonesia standards, a good NIM is above 6%. This ratio reflects a bank's ability to generate interest income from its productive assets; the higher the NIM, the lower the probability of the bank experiencing financial distress (Mudjijah et al., 2019).

The formula for Net Interest Margin (NIM) is:

$$NIM = \frac{(Interest\ Revenue - Interest\ Expenses)}{(Average\ Earning\ Assets)}\ x\ 100\%$$

Digital Transformation

Digital transformation refers to the use of technology to enhance productivity, create added value, and strengthen organizational competitiveness (Ebert & Duarte, 2018; Henriette et al., 2015). It involves the utilization of information, communication, and interaction technologies to improve quality of life and business operations (Naveen, 2022; Vial, 2019). Digital transformation goes beyond the adoption of technologies such as artificial intelligence (AI), cloud computing, and the Internet of Things (IoT); it also encompasses the transformation of business processes, organizational structures, and management strategies (Libert et al., 2016; Matt et al., 2015).

According to Khattak et al. (2023), digital transformation in the banking sector occurs through two pathways: (1) external pressure from fintech companies offering similar digital services, and (2) internal transformation through the adoption of advanced technologies within the bank. The implementation of digital transformation is measured by indicators such as the availability of mobile banking, internet banking, digital products

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(e-wealth management, online accounts, internet loans, e-commerce payments), digital architecture (digital finance departments, fintech subsidiaries), the proportion of executives with IT backgrounds, and bank collaborations with tech companies (Chen & Volve, 1998; Shanti, Siregar, et al., 2023).

Digital transformation has had a significant impact on the banking industry, contributing to operational efficiency, product innovation, cost savings, and improved customer experience through data-driven personalized services (Khattak et al., 2023). However, it also poses major challenges such as cybersecurity risks, high investment requirements, cultural changes within organizations, and increasing competition from fintech players (Kriebel & Debener, 2021; Nguyen et al., 2021).

Recent studies show that digitalization can enhance bank efficiency and profitability, but these positive effects typically emerge in the medium to long term and are highly dependent on the bank's internal readiness (T. D. Do et al., 2022; L. Nguyen et al., 2023). Technological advancement has fundamentally reshaped banking operations. In today's context, technology plays not only a supportive role but also a driving force in accelerating, streamlining, and simplifying the services provided by banks (OJK, 2022). According to (OJK, 2025), banking activities are inherently technological and mathematical, meaning that most operational functions can be transformed into technology based digital services. From front-end services (such as customer service) to back-end processes (such as internal data processing), banking functions can now be automated, reducing reliance on human labor. Thus, digital banking presents a strategic opportunity for banks to enhance competitiveness through operational efficiency.

Economic theory also states that technological advancement can improve productivity and increase company efficiency (OJK, 2022). The more efficient and productive a company is, the greater its capacity to compete and dominate the market. Empirical findings also show that most banks have adopted digital banking technology as a core strategy to strengthen their position in the banking industry.

Furthermore, (Chen et al., 2023) emphasize that digital transformation can significantly improve bank operational efficiency. A key example is the widespread use of digital channels, such as mobile and internet banking, which reduce reliance on traditional physical branches. This directly impacts the reduction of operational costs, including branch maintenance and human resource expenditures. Additionally, digitalization enables banks to deliver real-time, on-demand services, enhancing customer satisfaction and optimizing internal resource allocation.

Digital transformation has become an urgent necessity for Indonesia's banking sector, in response to shifting customer behavior toward digital services and growing market competition. Through digital technology, banks can automate and standardize business processes, reduce dependence on human resources, lower operational costs, and ultimately increase profitability (Z. Chen et al., 2023). Several studies have even shown that profitability can serve as a key mediating variable that strengthens the impact of digital transformation on bank performance (Xie & Wang, 2023).

The implementation of digital transformation involves various technological innovations, such as mobile banking, internet banking, artificial intelligence (AI), big data, and blockchain. Mobile and internet banking provide customers with anytime-anywhere banking services, while AI and big data support more personalized services and data-driven decision-making (Vial, 2019). Meanwhile, blockchain enhances security and transaction transparency, supporting the creation of a more reliable banking system.

In Indonesia, digital transformation also plays a key role in promoting financial inclusion. The availability of digital services has improved public access to financial services, including in remote areas that were previously underserved. For banks, adopting digital technology not only improves internal efficiency but also opens up new revenue opportunities through the development of innovative products tailored to market needs.

Nevertheless, the literature presents mixed findings. Some studies have found that digital transformation may negatively affect profitability, particularly when facing challenges such as infrastructure limitations, high initial investment costs, or organizational unpreparedness (Kriebel & Debener, 2021; Nguyen et al., 2020). In fact, some findings indicate that the benefits of digital

transformation become significantly evident only in the medium to long term approximately five years after implementation.

Considering these previous findings, the first hypothesis proposed in this study is:

H1: Digital transformation has a significant effect on the performance of commercial banks in Indonesia.

This hypothesis is based on the assumption that the higher the level of digitalization adopted by a bank, the better its financial and non-financial performance outcomes. However, the effectiveness of this impact depends on the bank's internal readiness, implementation strategies, and adequate infrastructure support (Agboola et al., 2019; Tran et al., 2022)

Risk (Z-Score)

According to Government Regulation No. 60, risk is defined as an event that may occur and, if it does, could negatively impact the achievement of an institution's objectives. The Indonesian Dictionary (KBBI, n.d.) defines risk as an unfavorable (harmful or dangerous) consequence of an action or behavior. International standards such as (BS ISO 31000;2018, 2018) define risk as the effect of uncertainty on the achievement of organizational goals. In a business context, this uncertainty can arise from various unpredictable factors ranging from market changes and technological failures to natural disasters that can result in financial losses, reputational damage, or customer attrition.

The impact of risk on organizational goals can be significant, as it affects operational aspects such as efficiency, effectiveness, and security. For example, data security risks may result in financial losses due to misuse of sensitive data, while operational risks can disrupt business processes and delay strategic decision-making. Therefore, it is essential for organizations, including banks, to proactively identify, assess, and manage risks to minimize their negative impact.

Banking stability can be defined as the condition in which a bank can effectively perform its three primary functions: facilitating the allocation of resources between depositors and borrowers, proactively managing financial risks, and withstanding economic shocks without significant disruptions (Aroghene et al., 2022) In other words, banking stability refers to the absence of unexpected disturbances in credit distribution, the payment system, and banking services (Aroghene et al., 2022).

Furthermore, a well-functioning financial system is characterized by effective price-setting mechanisms, risk management, and fund allocation, all of which support economic growth (Fajriani & Sudarmawan, 2022) Financial stability reflects the banking sector's ability to absorb potential losses or crises. Banking instability often arises when banks fail to manage liquidity risks, which may trigger systemic shocks and reduce the overall efficiency of the economy.

In the context of Indonesian regulations, Law No. 10 of 1998 on Banking requires banks to maintain their soundness by fulfilling capital adequacy, asset quality, management soundness, liquidity, profitability, and solvency requirements, while also applying the principles of prudence. A stable bank is not only capable of sustaining adequate profitability but also maintaining sufficient capital reserves to anticipate potential losses. This enables banks to manage the risks inherent in their operations while continuing to provide optimal services to the public, ultimately contributing positively to the national economy.

Through comprehensive risk analysis, organizations can understand the likelihood of risk events and their potential impacts. The results of such analysis serve as the foundation for developing appropriate mitigation strategies, such as formulating internal policies, conducting employee training, or investing in security technologies. This approach enhances an organization's adaptability to environmental changes, ensuring more stable, effective, and sustainable goal achievement.

Recent studies have revealed that the relationship between digital transformation (DT) and the performance of commercial banks is not always linear, but often moderated by risk factors. Digital transformation has emerged as a key strategy adopted by banks to remain competitive amid an increasingly complex and fast-changing financial landscape (Cheng et al., 2024). However, the influence of digital transformation on a bank's risk profile is not consistent across different contexts. Some studies have found that DT can reduce risk under certain conditions such as in the context of climate transition risks, particularly for smaller

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banks or those with high-carbon loan portfolios (Otoritas jasa Keuangan, 2024)

A study by (Do et al., 2022) in Vietnam found that digital transformation had a positive effect on bank performance, especially for larger banks. However, other studies identified short-term challenges stemming from high investment costs and limited IT infrastructure (Nguyen et al., 2023; Shanti et al., 2023). Nevertheless, in the long term, DT has been proven to enhance bank efficiency and profitability (Kriebel & Debener, 2021), with success largely depending on factors such as bank size, IT infrastructure readiness, technology governance, and human capital capacity (Kudratovna, 2024).

Interestingly, financial inclusion has also been identified as a moderating variable that strengthens the impact of DT on bank performance (Fan & Masron, 2023). This suggests that the success of digital transformation is not merely about technology implementation, but also about how well banks manage emerging risks and leverage technology to strengthen their competitiveness.

Considering these findings, this study proposes the following second hypothesis:

H2: Digital transformation significantly affects the performance of commercial banks in Indonesia, moderated by risk.

This hypothesis is based on the assumption that a bank's level of risk may strengthen or weaken the influence of digital transformation on its performance. When risks are well managed, digital transformation is expected to improve efficiency, expand financial inclusion, and enhance profitability. Conversely, if risks are poorly managed, DT may impose additional burdens that hinder bank performance especially in the short term.

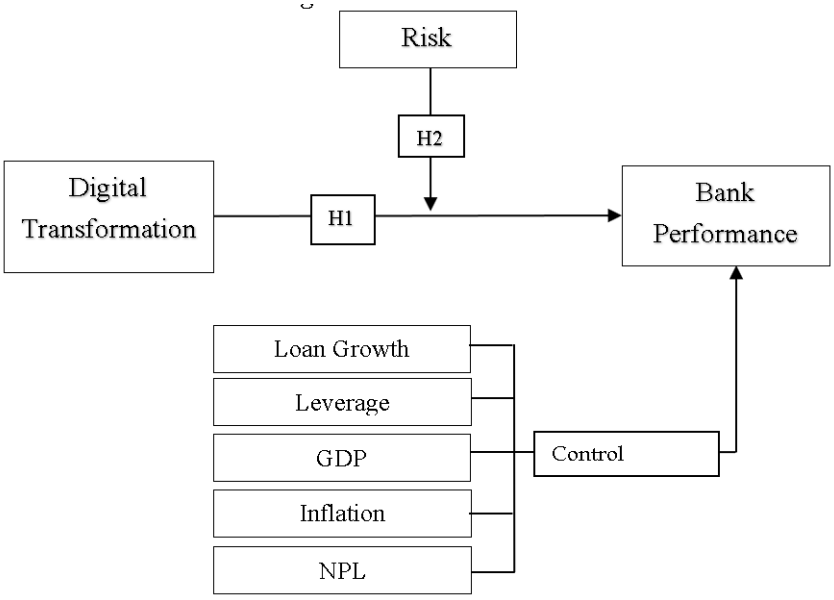

Figure 1 Research Model

RESEARCH METHODS

Type of Research

This study employs a quantitative approach using a comparative method. According to (Sugiyono, 2018), quantitative research is based on positivist philosophy and is used to examine populations or samples through measurable research instruments, with data analyzed statistically to test hypotheses. The comparative method is used to compare the performance of commercial banks in Indonesia in relation to digital transformation.

Population and Sample

The population in this study consists of all commercial banks in Indonesia listed on the Indonesia Stock Exchange (IDX) during the 2019 – 2023 period, totaling 47 banks. The sample was selected using purposive sampling based on the following criteria:

1. Banks listed on the IDX during the 2019 – 2023 period.
2. Banks that have implemented digital transformation since 2019.

3. Banks with complete annual report data for the entire study period.

Based on these criteria, a total of 21 banks were selected as the sample. Therefore, the number of observations for Indonesia is 105 data points (21 banks × 5 years).

Types and Sources of Data

This study uses secondary data, obtained from the annual reports of the respective banks for the 2019 – 2023 period, as well as official publications from the Financial Services Authority (OJK), Bank Indonesia, and other public sources such as the Central Statistics Agency (BPS) and credible online media. The data collection process involved accessing resources from the Indonesia Stock Exchange (IDX), OJK reports, and official banking documents. The research was conducted between December 2024 and February 2025.

Research Variables

Independent Variable (X):

Digital Transformation, measured using the Digitalization Index of Chinese Commercial Banks, focusing on two key dimensions: Business Transformation (e.g., mobile banking, internet banking, e-wealth management, online deposit accounts, online loans, e-commerce payments). Management Transformation (e.g., digital organizational structures, proportion of IT-experienced directors/executives, digital collaborations), adapted from (Xie & Wang, 2023)

Dependent Variable (Y):

Bank Performance, measured using Net Interest Margin (NIM), with the following formula:

$$\text{NIM} = (\text{Net Interest Income} / \text{Average Earning Assets}) \times 100$$

$$\frac{(\text{Interest Revenue} - \text{Interest Expenses})}{(\text{Average Earning Assets})} \text{ x } 100\%.$$

Risk, measured using the Z-Score, which reflects the financial stability of a bank. The Z-Score indicates a bank's ability to withstand shocks and avoid insolvency by capturing the combined effect of profitability, leverage, and volatility.

The Z-Score is calculated using the following formula:

$$\frac{(\text{Return On Asset (ROA)} + \text{CAR})}{\text{Standar Deviasi ROA}}$$

In addition to the main variables, this study incorporates several control variables to ensure a more accurate estimation of the relationship between digital transformation and bank performance. These control variables are selected based on their theoretical and empirical relevance to banking performance in existing literature. Loan Growth is included to capture the expansion rate of a bank's lending activities. A higher loan growth rate may signal aggressive credit expansion, which can potentially increase interest income. However, it can also be associated with higher credit risk if loan quality is not adequately maintained. Leverage refers to the proportion of a bank's assets that are financed through debt. It serves as an indicator of financial structure and risk exposure. While leverage can enhance returns during periods of growth, excessive leverage may increase the likelihood of financial distress. Non-Performing Loans (NPLs) are used to assess the quality of a bank's loan portfolio. A high NPL ratio suggests that a significant portion of loans are not generating expected returns, which could negatively affect profitability and overall performance. Inflation is considered a key macroeconomic variable that can influence banking operations. Fluctuations in inflation rates may affect interest margins, the real value of assets and liabilities, and the behavior of borrowers and savers. Gross Domestic Product (GDP) Growth represents the overall economic environment. Positive economic growth tends to create more lending and investment opportunities for banks, reduce credit risk, and enhance bank profitability. By controlling for these variables, the study aims to isolate the specific effect of digital transformationboth directly and through risk moderation on the financial performance of commercial banks in Indonesia.

Data Analysis Method

This study employs a quantitative approach using panel data analysis, which combines time-series and cross-sectional observations to examine the impact of digital transformation on the performance of commercial banks in Indonesia. Data analysis was conducted using EViews version 12, a statistical software widely used for econometric

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modeling. The initial stage of analysis involved descriptive statistics to present an overview of the data characteristics, including the mean, maximum, minimum, and standard deviation of each variable, in order to understand the distribution and variation of the dataset throughout the study period.

Following the descriptive analysis, the study proceeded with panel regression analysis using three primary estimation models: the Common Effect Model (CEM), the Fixed Effect Model (FEM), and the Random Effect Model (REM). The Common Effect Model treats the data as a pooled structure and assumes that there are no significant individual differences across entities. In contrast, the Fixed Effect Model acknowledges individual heterogeneity by allowing different intercepts for each bank, assuming that these differences are constant over time. Meanwhile, the Random Effect Model also accounts for individual variability, but assumes that such variability is random and uncorrelated with the independent variables.

To determine the most appropriate model for estimating the regression and testing the hypotheses, the study employed a series of model selection tests. The Chow test was used to compare the Common Effect and Fixed Effect models, while the Hausman test was conducted to choose between the Fixed Effect and Random Effect models. In addition, the Lagrange Multiplier test was applied to evaluate the suitability of the Random Effect Model compared to the Common Effect Model. These model selection procedures were essential in identifying the most statistically appropriate estimation method for the data structure and research objectives.

Once the most suitable model was selected, classical assumption tests were conducted to ensure the validity and reliability of the regression results. The Jarque-Bera test was used to assess the normality of the residuals, the Variance Inflation Factor (VIF) was calculated to detect potential multicollinearity among the independent variables, the White test was applied to test for heteroskedasticity, and the Lagrange Multiplier test was used again to examine the presence of autocorrelation. The combination of these tests allowed for a rigorous evaluation of model assumptions and improved the robustness of the findings. Through this structured analytical process, the study aimed to generate scientifically valid and empirically grounded conclusions that contribute to understanding the relationship between digital transformation, risk, and bank performance in the Indonesian context.

Testing Model

The empirical testing of this study is based on three regression models developed to evaluate the effect of digital transformation on bank performance, particularly measured by Net Interest Margin (NIM), with and without the moderating role of financial risk (Z-Score).

Model

$$Y = \alpha + \beta 1X + \beta 2C1 + \beta 3C2 + \beta 4C3 + \beta 5C4 + \beta 6C5 + \varepsilon \quad (1)$$

Model 2

$$Y = \alpha + \beta 1X + \beta 2Z + \beta 3C1 + \beta 4C2 + \beta 5C6 + \beta 7C4 + \beta 8C5 + \varepsilon \quad (2)$$

Model 3 applies Moderated Regression Analysis (MRA) to examine the interaction effect between digital transformation and risk. The interaction term (X × Z) is introduced to determine whether risk (Z-Score) moderates the relationship between digital transformation and bank performance.

$$Y = \alpha + \beta 1X + \beta 2Z + \beta 3 (X *Z) + \beta 4C1 + \beta 5C2 + \beta 6C7 + \beta 8C9 + \beta 10C5 + \varepsilon \quad (3)$$

Where:

Y : Net Interesrt Margin (NIM)
α : Constant Term
β : Koefisien Regresi DT
X : Digital Trasformation (DT)
Z : Risk (Z-Score)
βX*Z : Interaction term between digital transformation and risk (moderating effect)
C1 : Gross Domestik Product (GDP)
C2 : Inflation
C3 : Leverage
C4 : Loan Growth
C5 : Non-Performing Loans (NPL)
ε : error

Subsequently a t-test was conducted to examine the partial effect of each independent variable on the dependent variable. In addition, the coefficient of determination (R^2) was used to assess the overall

explanatory power of the independent variables in predicting the variation in the dependent variable.

RESULTS AND DISCUSSION

The descriptive statistical analysis in this study covers eight key variables, focusing on Net Interest Margin (NIM) as the primary indicator of bank performance. The supporting variables include Digital Transformation (DT), Z-Score (as a measure of bankruptcy risk), Loan Growth, Leverage, Non-Performing Loans (NPL), Inflation, and GDP Growth. In the case of Indonesia, the average NIM was recorded at 0.0107, although a notable outlier with a minimum value of -3.52 indicates that some banks experienced severely negative net interest income performance. The average score for Digital Transformation was 0.6101, reflecting a moderate level of digital adoption with considerable variation across banks. The average Z-Score stood at 3.79, suggesting a broad range in financial resilience, with some banks even posting negative values signaling a serious risk of insolvency. The average Loan Growth reached 11.5%, though it exhibited extreme fluctuations across institutions. Meanwhile, Leverage averaged 80.53%, highlighting a high dependence on debt financing. The average NPL ratio was 2.98%, which remains within the acceptable limit set by the Financial Services Authority (OJK). Inflation was relatively stable, averaging 2.87%, while GDP growth averaged 3.4%, although it experienced sharp contractions during certain periods.

Determining the Best Model

To determine the most appropriate panel regression model, this study conducted a series of model specification tests, namely the Chow Test, the Hausman Test, and the Breusch-Pagan Lagrange Multiplier (BP-LM) Test. The Chow Test was used to decide between the Common Effect Model (CEM) and the Fixed Effect Model (FEM), the Hausman Test was applied to choose between FEM and the Random Effect Model (REM), and the BP-LM Test was used to compare CEM and REM. The results of the Chow Test yielded a probability value of 0.7879 (greater than 0.05), indicating that the Common Effect Model is more appropriate than the Fixed Effect Model. Similarly, the BP-LM Test produced a probability value of 0.1050 (also greater than 0.05), suggesting that the Common Effect Model is preferable to the Random Effect Model. Based on these results, it can be concluded that the Common Effect Model is the most suitable specification for the panel regression, as there is no significant variation across observational units.

To ensure the reliability of the regression estimates, the study also performed a multicollinearity test. The results show that all independent variables in the Indonesian banking model have Variance Inflation Factor (VIF) values below 2, with the highest values observed for Leverage (1.689), Loan Growth (1.667), and Inflation (1.469). These results indicate that multicollinearity is not present (VIF < 10), and that each variable is sufficiently independent from the others. In addition, the heteroskedasticity test was conducted using the ARCH method, which produced an Obs*R-squared value of 0.7446, below the critical value at the 5% significance level. This finding suggests the absence of heteroskedasticity in the regression model for Net Interest Margin (NIM). Therefore, the residuals are considered homoscedastic, fulfilling one of the classical assumptions of regression. As a result, the model can be regarded as efficient, and the estimation results are deemed statistically reliable.

Regression Test Results

The regression results of this study highlight the significant role of digital transformation in improving bank performance. In both Model 1 and Model 2, the Digital Transformation (DT) variable exhibits a positive and statistically significant coefficient with respect to Net Interest Margin (NIM). This indicates that the adoption of digital technologies directly contributes to improved efficiency and profitability in the banking sector. These findings align with previous studies by Vial (2019) and Susanti et al. (2023), which argue that digitalization enables automation of business processes, enhances service delivery, and reduces operational costs, thereby strengthening financial performance.

Model 1

$$\text{Bank Performance} = \alpha + 0{,}469328\ (\text{DT}) - 0{,}004419\ (\text{GDP}) + 0{,}020493\ (\text{Inflation}) - 0{,}926695\ (\textit{Leverage}) - 0{,}074104\ (\textit{Loan Growth}) + 4{,}103243(\text{NPL}) + \varepsilon \quad (1)$$

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Model 2

Bank Performance = α + 0,482202 (DT) – 0,030198 (Risk) – 0,004255 (GDP) + 0,021295 (Inflation) – 0,819472 (*Leverage*) – 0,068723 (*Loan Growth*) + 3,592561(NPL) + ε (2)

Model 3

Bank Performance = α – 1,434874(DT) – 0,307572 (Risiko)+ 0,471147 (DT*Risk) – 0,006003 (GDP) + 0,026784 (Inflation) – 0,520930 (*Leverage*) – 0,054148 (*Loan Growth*) + 1,443914(NPL)+ ε (3)

However, when risk (measured by the Z-Score) is introduced into Model 3 as a moderating variable, the direct effect of digital transformation on bank performance becomes insignificant and even changes direction to negative. Interestingly, the interaction term between digital transformation and Z-Score (DT × Z) shows a positive and significant relationship. This suggests that the effect of digital transformation on bank performance is highly contingent on the internal financial stability of the institution. In other words, banks with higher Z-Scores indicating stronger financial resilience are more likely to benefit from digital transformation initiatives (Barney, 1991; Utami & Alamanos, 2025)

The Risk variable, measured by the Z-Score, shows a significant negative effect on bank performance in Model 3. This implies that a higher level of bankruptcy risk is associated with poorer performance. This finding reinforces the argument that financial stability is a critical prerequisite for the successful implementation of digital transformation. From a macroeconomic perspective, both Gross Domestic Product (GDP) growth and inflation fail to show a statistically significant impact on bank performance across all three models. The small and insignificant coefficients suggest that these macroeconomic factors do not exert a direct effect on NIM in the short term. This may be attributed to banks' ability to dynamically adjust their policies in response to macroeconomic changes, such as interest rate revisions and cost structure realignments (Athanasoglou et al., 2008).

Table 5 Regression Test Results

Variable	Test Results		
	Model 1	Model 2	Model 3
Digital Transformation	0,469328*** (0,0081)	0,482202*** (0,0069)	-1,434874 (0,1256)
Gross Domestic Product	-0,004419 (0,7544)	-0,004255 (0,7635)	-0,006003 (0,6665)
Inflation	0,020493 (0,4778)	0,021295 (0,4616)	0,026784 (0,3486)
Leverage	-0,926695** (0,0461)	-0,819472* (0,0875)	-0,520930 (0,2882)
Loan Growth	-0,074104 (0,5361)	-0,068723 (0,5670)	-0,054148 (0,6468)
Non-Performing Loans	4,103243** (0,0445)	3,592561* (0,0901)	1,443914 (0,5320)
Risk (Z-Score)	-	-0,030198 (0,3763)	-0,307572** (0,0262)
(X*Z)	-	-	0,471147** (0,0383)
Obs, (Bank)	21	21	21
N	105	105	105
R-squared	0,1284	0,1354	0,1734

Source: Processed data

Meanwhile, the leverage variable demonstrates a significant negative effect in both Model 1 and Model 2. This indicates that a capital structure heavily reliant on debt may reduce bank performance, primarily due to the high cost of interest payments and elevated financial risk. These findings are consistent with prior research suggesting that higher leverage levels increase financial pressure and reduce bank profitability (Ghosh, 2021).

The Loan Growth variable does not show a statistically significant effect on Net Interest Margin (NIM). Although credit growth is often viewed as an indicator of business expansion in banking, it does not automatically translate into higher net interest margins unless it is accompanied by effective credit risk management. Rapid loan disbursements without rigorous credit screening may lead to a future increase in non-performing loans (NPLs), which could negatively affect long-term performance.

An interesting result emerges from the Non-Performing Loans (NPL) variable. In both

Model 1 and Model 2, NPLs exhibit a positive and statistically significant effect on bank performance. This unexpected finding may be explained by the possibility that banks impose higher interest rates on riskier borrowers to compensate for potential default, thereby temporarily boosting interest margins. Alternatively, it may reflect a lag effect, where the rise in NPLs has not yet been realized as actual financial loss in the current reporting period (Albertazzi & Gambacorta, 2009). Nonetheless, this result should be interpreted with caution, as persistently high NPLs represent a long-term threat to the financial health and stability of banks..

CONCLUSION

This study concludes that digital transformation has a significant positive impact on bank performance, particularly in terms of improving the Net Interest Margin (NIM). The adoption of digital banking technologies such as mobile banking, internet banking, and AI-based systems has proven effective in enhancing operational efficiency and strengthening banks' competitiveness in the digital era.

However, when considering bankruptcy risk, as measured by the Z-Score, the positive effect of digital transformation becomes statistically insignificant. This suggests that in high-risk conditions, digital transformation alone may not be sufficient to optimally enhance financial performance. Interestingly, the interaction effect between digital transformation and Z-Score is positive and significant, indicating that banks with strong financial stability are better positioned to capitalize on the benefits of digital initiatives. This finding supports the Resource-Based View (RBV), which emphasizes the importance of leveraging internal resources and managerial capabilities to achieve superior performance.

On the other hand, the leverage variable exhibits a significant negative effect on bank performance, suggesting that a capital structure overly reliant on debt may hinder profitability. Meanwhile, macroeconomic variables such as GDP growth and inflation do not show any significant influence on NIM, implying that internal factors are more dominant in shaping banks short-term performance. The loan growth variable also shows no significant effect, indicating that credit expansion does not necessarily improve NIM unless it is supported by sound credit quality.

The findings on Non-Performing Loans (NPLs), which demonstrate a positive effect on performance, must be interpreted with caution. This may reflect pricing strategies where higher interest rates are charged to compensate for credit risk, or it could be the result of a lag effect, where the negative impact of rising NPLs has not yet materialized during the observed period. Overall, the study reaffirms that the success of digital transformation in improving bank performance is not determined by technology alone. It is highly dependent on internal conditions, such as financial stability and a sound capital structure. Therefore, banks must strengthen their financial foundations and integrate effective risk management practices to fully realize the benefits of digitalization initiatives.

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