“Banking innovation and digital transformation as catalysts of infrastructure financing: Evidence from Indonesian banking”

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BANKING INNOVATION AND DIGITAL TRANSFORMATION AS CATALYSTS OF INFRASTRUCTURE FINANCING: EVIDENCE FROM INDONESIAN BANKING

Abstract

Digital transformation in the banking sector increasingly determines the direction of financial intermediation, including infrastructure financing, which requires long-term commitment. This study analyzes the influence of digitalization, digital security, and banking product innovation on infrastructure financing. This study uses banking data from the Indonesia Stock Exchange. The data were sourced from published quarterly bank financial reports. The study uses 1,980 observations from the 2014–2024 period. The data are analyzed using panel data regression with a fixed-effects model. The results show that banking product innovation consistently has a significant positive impact on infrastructure financing. Innovation enables the development of new financing instruments, increases intermediation flexibility, and expands access to long-term funding sources – conversely, digitalization in banking yields contradictory findings. In the initial model, digitization had a positive effect on intermediation efficiency. However, the advanced model showed a significant negative impact, indicating a trade-off: short-term digital transaction efficiency can reduce banks' orientation towards long-term infrastructure project financing.

Keywords digitalization, banking innovation, digital security, financial intermediation, infrastructure financing

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INTRODUCTION

The banking sector's contribution to economic development in Indonesia is increasingly crucial, particularly in supporting infrastructure financing, which is the foundation for long-term growth. Adequate infrastructure is needed to promote connectivity, logistical efficiency, and equitable regional development. However, to date, infrastructure financing remains heavily reliant on state budgets and debt issuance, with the banking sector's participation considered suboptimal. Amid increasing financing needs, there is an urgent need to strengthen banks' role in supporting the national development agenda through long-term financing mechanisms. Digital transformation in the financial sector presents strategic opportunities for banks to increase their financing capacity, including in the infrastructure sector. Digital technology enables banks to streamline operational processes, expand market access, and create innovative products more suited to development financing needs. However, adopting this technology also presents new challenges, including cybersecurity risks and disparities in readiness across financial institutions. These challenges are even more complex in Indonesia, which has a dual banking system.

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In addition, when adopting digital technologies to enhance competitiveness, banks must ensure compliance with Sharia principles that emphasize fairness, transparency, and the prohibition of usury in all activities and product innovations. This means that banks must balance technological innovation and Sharia compliance, as this raises scientific questions about the extent to which digitalization, digital security, and product innovation can strengthen infrastructure financing capacity within the Sharia banking system. Therefore, the main issue that underpins this study is the interaction among digitization, digital security risks, and product innovation in shaping the ability of both the conventional and Sharia banking sectors to support infrastructure financing. The analysis focuses on the impact of integrating digitization, banking product innovation, and Sharia compliance to strengthen the banking sector's role in infrastructure financing in Indonesia. The role of digitization in increasing infrastructure financing capacity is evident: it boosts operational efficiency, enhances transparency, and expands financial inclusion, thereby supporting sustainable economic development.

1. LITERATURE REVIEW AND HYPOTHESES

The development of digitalization in the financial and banking systems has become a significant determinant of the transformation of infrastructure financing. Classical financial intermediation theory posits that banks act as intermediaries between surplus and deficit funds. However, this process is often hampered by transaction costs, information asymmetry, and limited access (Allen & Santomero, 1997). Infrastructure is a sector with long-term financing needs and complex risks, making intermediation efficiency crucial. In this context, digitalization serves as a mechanism to reduce these costs, increase processing speed, and expand access for economic actors who were previously marginalized (Adel, 2024; Karosas, 2024). More efficient intermediation functions are crucial, given that infrastructure projects require long-term financing and complex risks that necessitate technology-based management.

The theory of financial intermediation emphasizes the role of banks as intermediaries that connect surplus-fund holders with those who need financing. Banks play an essential role because infrastructure projects require long-term funding and entail complex risks. Digitalization expands intermediation capabilities by reducing transaction costs, accelerating risk assessment, and increasing access to alternative funding sources, for example, through collaboration with fintech platforms or digital bond instruments (Ozili, 2018). Previous literature emphasizes that digitization is not merely operational modernization, but a prerequisite for increasing infrastructure financing capacity through efficiency (He et al., 2024; Mavlutova et al., 2022; Zhang et al., 2024), increased inclusion (Guo et al., 2023; Zhang et al., 2023), and diversification of funding sources (Liu et al., 2025; Mou, 2024). Empirical studies show that banking digitization can increase banks' capacity to channel infrastructure financing. Digital financial infrastructure in Nigeria has been shown to correlate positively with commercial bank growth and long-term project financing capacity (Iwedi, 2024). Similar research in India found that integrating digital public infrastructure expands financial access and enables accelerated infrastructure-based economic development (Sarma & Pais, 2011). In addition, digitization also promotes financial inclusion and economic growth in the Asia-Pacific by opening access to financial services for previously underserved groups (Basnayake et al., 2024). This expands the deposit base and increases banking liquidity, which can be allocated for infrastructure financing.

Digital financial inclusion not only increases access to banking services but also strengthens the stability of the banking sector, which has distinct risk exposures from conventional banking (Banna et al., 2022). Digital financial inclusion increases access to banking services and strengthens the stability of Sharia banking, which has different risk exposures compared to conventional banking. Other research warns that digitization that is overly focused on short-term efficiency could shift banks' funding priorities. Gao and Wang (2023) found that digital finance intensifies competition among banks in China, creating a "catfish" effect that accelerates innovation. However, this increased competition sometimes focuses on

consumer services rather than productive sector financing. Therefore, the role of policy is crucial to ensure that the benefits of digitization are truly directed towards long-term infrastructure financing.

One of the main challenges of digitization is cybersecurity risk. Banna et al. (2022) highlight that, in the context of the COVID-19 pandemic, digitalization of the banking sector increases the financial system's resilience while also increasing exposure to cyber risks. Digital security has become a strategic issue, particularly for banking, which relies on trust grounded in ethical and just principles. Billah et al. (2025) show that digital risks are closely related to financial system stability; therefore, digital risk management warrants serious attention in the dual banking system. The risk of cyberattacks, data breaches, and regulatory noncompliance can undermine public confidence and institutional investor confidence. Hu et al. (2023) emphasize that digitization may increase systemic risks that hinder long-term financing in the absence of an adequate regulatory framework. In the context of infrastructure, which requires long-term contracts and funding, digital security is a technical issue and a strategic element that determines investment feasibility. Strengthening digital security is expected to increase public trust, thereby enabling the smooth operation of digital financial intermediation. Windasari et al. (2022) found that younger generations (Gen Y and Gen Z), despite being more open to digital-only banking, still consider transaction security guarantees a key factor in loyalty. A similar point was made by Adel (2024), which shows that digital literacy and trust in technology security play an important role in increasing financial inclusion in developing countries.

Financial innovation theory highlights the role of product and service innovation in improving banks' ability to channel funds more effectively (Abbas et al., 2024). Digital innovations such as mobile banking, digital lending, and fintech collaboration create new infrastructure financing instruments while expanding the investor base through digital bonds and crowdfunding. Therefore, digitization is seen as a factor of efficiency and a driver of financial inclusion and sustainable development (Banna et al., 2022). In addition, innovation diffusion theory and the technology acceptance model provide theoretical foundations for why digitization and the adoption of financial technology are essential to accelerating infrastructure financing. Digital infrastructure encompasses transaction speed, secure verification, and new channels that enable banks and non-bank financial institutions to channel funding for large-scale projects (Ajupov et al., 2019).

Security is an important aspect of digital product innovation. Strengthening digital security enables banks to innovate in creating technology-based infrastructure financing products, such as digital sukuk or blockchain-based infrastructure bonds (Khan et al., 2022). Without security guarantees, the adoption of these digital instruments will be hampered due to low investor and public confidence. In addition, Gyau et al. (2024) highlight that AI-based innovation in banking can improve financial performance. However, its effectiveness depends on protection against data risks and digital security. This aligns with Hoque et al. (2024), who found that digital transformation can reduce the risk of bank decision-making when supported by a robust security system. In other words, digital security is a key factor linking digital innovation to outcomes, including increased infrastructure financing capacity. When banks can guarantee digital security, public participation in the financial system increases, ultimately expanding the third-party funding base. This is important because the greater the amount of funds collected, the greater the bank's capacity to channel long-term financing, including infrastructure projects (Basnayake et al., 2024). Thus, digital security serves as a protective mechanism and a strategic instrument for building trust, thereby increasing financing capacity.

Banking product innovation is the development of new financial services and instruments that leverage digital technologies and innovative financial approaches to expand intermediation functions, enhance efficiency, and deepen market penetration (Abbas et al., 2024). Diffusion of Innovation Theory (Dearing, 2009) explains that the adoption of innovation in the financial system depends not only on technological factors but also on organizational readiness and institutional incentives. In the banking context, product innovation includes digital-only banking services (Windasari et al.,

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2022), mobile banking (Abdurrahman, 2024), asset tokenization (Khan et al., 2025), and peer-to-peer financing based on Sharia fintech (Marhadi et al., 2024). All of these innovations expand the capacity of banking intermediation by increasing financial inclusion. (Basnayake et al., 2024), providing long-term financing alternatives and reducing information asymmetry in fund distribution.

Infrastructure financing requires stable, long-term, and diversified funding sources. Banking product innovation can support this need by providing new instruments better suited to the characteristics of infrastructure projects. For example, green sukuk-based financing and asset tokenization (Khan et al., 2022) enable more efficient, transparent, and integrated capital raising aligned with global investor preferences. Thus, banking product innovation strengthens traditional intermediary functions and creates a new ecosystem that can support sustainable infrastructure development. Furthermore, this dynamic is consistent with the argument (Abdurrahman et al., 2024), which emphasizes the importance of dynamic capabilities in the digital transformation of banking to strengthen competitiveness. When banks develop innovative technology-based products (such as digital payment services, AI-based credit scoring, and digital sukuk), access to infrastructure financing can expand because risk-evaluation mechanisms become more efficient (Hoque et al., 2024). Lower transaction costs, and the potential mismatch between short-term and long-term funding can be minimized. Thus, banking product innovation is an enabler that strengthens the connection between the financial system and infrastructure development needs.

Banking product innovations support the diversification of infrastructure financing sources. Abbas et al. (2024) show that the interaction between financial innovation, digitalization, and green technology contributes to the growth of sustainability-oriented businesses. This is reflected in applying green financing products such as green bonds and sukuk, which are widely used to fund renewable energy and environmentally friendly infrastructure projects. These innovations enable mobilizing funds from global investors who prefer sustainable instruments (Feng et al., 2022). In addition, banking product innovation can strengthen risk management and financing resilience. By utilizing AI-driven financial products and fintech collaboration, banks can improve the quality of risk assessment and minimize the potential for non-performing loans (Gyau et al., 2024; Hoque et al., 2024) and enhance intermediation stability in supporting infrastructure financing. Khan et al. (2023) added that adopting fintech in banking also strengthens financial system stability through more adaptive supervision of new risks.

Based on the literature review, this study aims to examine the effects of digitalization, digital security, and innovations in banking products on infrastructure financing. Thus, the following hypotheses are formulated:

H1: *Banking digitalization has a positive effect on infrastructure financing.*

H2: *Digital security has a positive effect on infrastructure financing.*

H3: *Banking innovation has a positive effect on infrastructure financing.*

2. METHODOLOGY

This study employs a quantitative, explanatory design to examine the effects of banking digitalization, digital security, and innovation on infrastructure financing. A quantitative approach was chosen because it enables empirical analysis of numerical and inferential data, thereby facilitating the testing of formulated hypotheses. An explanatory design was used because this study describes the relationship between variables and tests causal relationships using a panel-data econometric model.

The primary data source for this study is secondary data, specifically quarterly financial reports of 46 Indonesian banks. The data were obtained from official annual bank reports and publications from regulators (the Financial Services Authority and Bank of Indonesia). The study period covers 2014–2024 using quarterly data. The sample selection used purposive sampling, which is selecting banks that meet the following criteria:

1) have complete financial reports during the observation period;

2) are active in channeling infrastructure financing; and

3) have digitalization initiatives documented in their annual reports. Banks that are inconsistent in publishing reports or do not have complete data are excluded from the sample (exclusion criteria).

The data analysis employs a panel data regression model with a Fixed-Effects Model (FEM). This model was chosen because it allows control of unobserved heterogeneity among banks that may affect the relationships among variables. The Hausman test was used to determine whether FEM was more appropriate than REM in this study. The operational definitions and variable measurements are presented in Appendix A.

3. RESULTS AND DISCUSSION

The descriptive analysis presented in Table 1 provides an overview of the characteristics of the research variables used in this study. The dependent variable, Infrastructure Financing (Infra), has an average bank infrastructure financing of 6.63 million, with a very high standard deviation (19.13 million) from the total bank infrastructure financing, indicating substantial variation in infrastructure financing across banks and periods. The digitization variable (Digital) has a mean of 0.786 on a binary (0-1) scale, indicating that most observations in the sample use digital banking services. This illustrates a strong trend towards the digitization of the banking sector in the last decade. However, the digital security variable (Digsecur) exhibits a more variable distribution, with a mean of 8,099 and a standard deviation of 41,247. This high variation reflects substantial differences in the capacity and intensity of digital security investment across banks, likely influenced by asset size, digitization levels, and the regulatory policies applicable to each institution. Additionally, the innovation variable (Inov) has a relatively low mean of 2.45, with a standard deviation of 2.97 and a maximum of 47, suggesting that while most banks engage in limited innovative activities, some actively pursue product and service innovation.

The correlation test presented in Table 2 shows different patterns of relationships between the independent and dependent variables in this study. First, the main variable of focus, namely digital banking (Digital), shows a moderate positive correlation with infrastructure financing (Lninfra) of 0.271. Conversely, the digital security variable (Digsecur) weakly correlates with infrastructure financing (0.053). These results indicate that, although the literature emphasizes the importance of digital security in building trust in digital banking systems, this factor has not been significantly internalized in banks' capacity to channel

Table 1. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Infra	1808	6639877.3	19129767	5000	6.323e+08
Lninfra	1808	13.934	2.419	5.70	20.265
Digital	1980	.786	.41	0	1
Digsecur	1553	8098.718	41246.717	1	660275
Shariacomp	1929	2.017	.499	1	4
Inov	1760	2.453	2.977	1	47
ROA	1980	1.174	2.817	–29.19	17.23
LDR	1980	13.328	144.095	0.01	4246.69
Size	1980	1.494e+08	3.127e+08	174533	3.579e+09
Lnsize	1980	17.29	1.838	12.07	22
Lev	1980	.803	.243	–1	8.27
Age	1980	45.883	21.881	15	129
Jobless	1980	5.568	.552	4.82	7.07
Inf	1980	3.623	1.761	1.33	8.36
GDP	1980	4.683	1.481	–2.19	7.07

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Table 2. Matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) Lninfra	1												
(2) Digital	0.271	1											
(3) Digsecur	0.053	0.072	1										
(4) Syariacomp	−0.395	−0.236	−0.013	1									
(5) Inov	0.079	0.092	0.358	−0.023	1								
(6) ROA	0.366	0.167	0.011	−0.362	0.041	1							
(7) LDR	−0.107	0.059	0.071	0.065	0.14	−0.062	1						
(8) Lnsize	0.85	0.342	0.065	−0.476	0.105	0.426	−0.028	1					
(9) Lev	0.356	0.03	0.032	0.003	0.022	0.11	0.208	0.348	1				
(10) Age	0.404	0.203	0.009	−0.203	0.046	0.235	−0.099	0.553	0.057	1			
(11) Jobless	−0.002	−0.037	−0.079	−0.002	0.026	−0.115	0.05	−0.002	0.032	−0.015	1		
(12) Inf	−0.048	−0.3	−0.086	−0.043	−0.105	0.122	0.019	−0.028	0.115	−0.082	−0.064	1	
(13) GDP	−0.013	−0.014	0.009	−0.019	−0.014	0.063	0.016	−0.005	−0.022	−0.013	−0.392	0.216	1

funds to the infrastructure sector. However, the moderate positive correlation between Digsecur and innovation (0.358) confirms that any increase in digital innovation in the banking sector tends to go hand in hand with an increase in system security, so both play a more indirect role in shaping long-term trust in infrastructure financing instruments. Table 2 shows that almost all variables have weak and moderate correlations in the study.

The results of the panel data model estimation presented in Table 3 show interesting dynamics regarding the determinants of infrastructure financing in the banking context. In model (1), the Digital variable shows a positive and significant effect ($\beta = 0.356$; $t = 5.85$; $p < 0.01$), confirming that banking digitalization plays an important role in driving infrastructure financing. This finding aligns with the literature emphasizing that digital transformation improves intermediation efficiency and expands banks' capacity to channel productive credit (Ozili, 2018). This finding also reinforces the argument that banking digitization can expand intermediation capacity by reducing transaction costs, increasing the speed of risk assessment, and diversifying access to financing sources (Khera et al., 2022).

However, the results from Table 3 in models (2) to (4) show a change in the direction of the relationship, where Digital actually has a significant negative effect on infrastructure financing, with the largest coefficient in model (4) ($\beta = -0.532$; $t = -4.99$; $p < 0.01$). This shift in the direction of the relationship indicates a trade-off in the banking digitalization process. Intensified digital adoption may encourage banks to focus on short-term transaction-based retail products, such as digital payment services or consumer credit, which generate margins more quickly. As a result, the orientation towards long-term, capital-intensive, and high-risk infrastructure projects is reduced. This phenomenon is consistent with research findings that the growth of digital credit from fintech actually suppresses the profitability of traditional banks and reduces incentives to support long-term financing, especially in developing countries with weak regulations (Basnayake et al., 2024).

These contrasting results can be explained by the Too Much Finance theory (Arcand et al., 2015), which states that excessive financial growth can be detrimental to long-term economic development. When digitalization in banking drives the aggressive expansion of consumer credit, it distorts capital allocation, diverting funds from productive investments, including infrastructure, to short-term or even speculative activities. Alzarooni et al. (2024) emphasize that banking stability in a dual system is strongly influenced by regulatory structures and the institutional environment; therefore, digitization without a robust policy framework can create imbalances in the financing portfolio.

Digitalization offers a significant opportunity to enhance infrastructure by integrating big data, artificial intelligence, and blockchain into the risk assessment of large-scale projects. Gyau et al. (2024) show that AI-based innovation can improve the accuracy of risk assessment and the efficiency of capital allocation in the banking sector. However, without a focused implementation strat-

Table 3. Results of independent variable hypothesis testing on infrastructure financing

Variable	Infrastructure Financing			
	(1)	(2)	(3)	(4)
Digital	0.356***	−0.387***	−0.383***	−0.532***
	(5.85)	(−6.78)	(−5.96)	(−4.99)
Digsecur	0.00000132**	−4.79E−09	6.62E−07	6.8E−07
	(3.01)	(−0.01)	(1.56)	(1.27)
Inov	0.0546***	0.0166**	−0.00523	0.0230***
	(8.69)	(3.11)	(−0.44)	(4.88)
ROA	–	−0.00821	0.0278*	−0.0107
		(−0.88)	(2.53)	(−0.64)
LDR	–	−0.138***	−0.178***	−0.179***
		(−7.72)	(−6.93)	(−8.56)
Lnsize	–	0.587***	1.087***	0.173**
		(12.82)	(15.36)	(2.96)
Lev	–	1.777***	0.923**	0.692*
		(7.38)	(2.79)	(1.98)
Age	–	0.0725***	0.0426***	0.0726***
		(10.19)	(4.45)	(7.37)
Jobless	–	0.0342	0.0709*	0.005
		(1.32)	(2.28)	(0.13)
Inf	–	−0.0363***	−0.0248*	−0.0478**
		(−3.75)	(−2.17)	(−3.31)
GDP	–	0.000047	0.00189	0.00616
		(0)	(0.17)	(0.45)
_cons	13.99***	−0.68	−7.445***	7.753***
	(247.79)	(−0.98)	(−7.71)	(7.42)
Number of obs	1385	1385	1033	352
R-squared	0.0394	0.4272	0.6052	0.4526
F test	51.93	104.37	80.77	61.63
Prob > F	0.0000	0.0000	0.0000	0.0000
Hausman	0.0000	0.0118	0.0000	0.0000

Note: ***, **, and * denote statistically significant variables at 0.1%, 1%, and 5% levels, respectively, with t-statistics in parentheses.

egy, this potential will not automatically translate into infrastructure financing. In fact, fierce digital competition among banks may lead them to prefer developing low-risk retail digital services rather than channeling credit to the uncertain infrastructure sector.

These results also indicate that large banks with more mature capital and digital infrastructure capabilities can integrate digital transformation into their infrastructure financing agenda. Conversely, small banks often lack the flexibility to bear long-term risks, prompting them to maximize transaction-volume-oriented digital services. Study Yao and Song (2023) shows that the benefits of digitization in reducing systemic risk are greater for large banks, while small banks face pressures that can limit their intermediation capacity.

In addition, the results of this study indicate that digitization needs to be viewed as a double-edged sword. On the one hand, it increases efficiency, expands access, and promotes financial inclusion. However, it has the potential to shift the focus of financing from the long-term productive sector to short-term financial activities. This means that digitization cannot stand alone as a driver of infrastructure financing. Synergy with public policy, regulatory designs that promote sustainability, and adequate incentives are necessary for digitalization to truly support the infrastructure development agenda.

The results of the panel data model estimation indicate that digital security (Digsecur) has a positive and significant effect on the first model ($\beta = 1.32e\text{-}06$; $t = 3.01$; $p < 0.05$), although the coefficient is small. This indicates that investment in digital security – even if limited – can strengthen system trust and contrib-

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ute to banking intermediation capacity. From an intermediation economics perspective, trust is the primary foundation for channeling funds. Digital literacy and security help ensure the reliability of the financial system, thereby maintaining continuity of long-term credit flows, including for infrastructure projects (Jafri et al., 2024).

However, in models (2)-(4), this positive effect is no longer significant, indicating that digital security functions more as a secondary supporting factor than a primary driver in intermediation decisions. In the macro-financial framework, cybersecurity is an important component in ensuring operational resilience and data integrity. However, it is not the only determinant of stability, as digital finance is highly dependent on the overall financial ecosystem and regulatory readiness (Khan & Malaika, 2021).

IMF (2024) reports that cyberattacks on the banking sector can trigger a domino effect through cyber runs, defined as massive withdrawals of funds due to a loss of public trust. In the context of infrastructure financing, this condition is crucial because infrastructure projects require long-term financing stability. If public trust is undermined by digital vulnerabilities, long-term credit flows are at risk of being hampered. The finding that digital security has a significant impact only in the early stages can be interpreted as an initial credibility effect: banks that invest in digital security gain public trust. However, in the long term, other factors such as macroprudential policy regulations, capital costs, and banks' preferences for liquid assets are more decisive in determining the sustainability of infrastructure financing (Hoque et al., 2024).

The results of this study also show that investment in digital security increases credibility but also incurs high costs that can reduce the capacity for productive credit expansion. Wang et al. (2024) emphasize that banks undergoing digital transformation often face a dilemma between investing in cybersecurity compliance and supporting long-term credit. The costs of implementing security technologies such as real-time monitoring, zero-trust architecture, and AI-driven fraud detection are relatively high and short-term, while infrastructure financing requires a long-term horizon and capital patience. This situation shows that although digital security is important, it does not always directly accelerate infrastructure financing. Instead, it can create a substitution effect where banks prefer to channel capital into short-term instruments that are more compatible with their digital strategies.

The Invasion variable (Inov) consistently shows a significant positive effect on most models. In model (1), innovation substantially increases infrastructure financing ($\beta = 0.0546$; $t = 8.69$; $p < 0.01$), and although its significance declines in model (3), the positive effect returns strongly in model (4) ($\beta = 0.0230$; $t = 4.88$; $p < 0.01$). These findings confirm that innovation is a key catalyst in strengthening financial intermediation. Innovation enables banks to expand access to funding, improve the efficiency of credit distribution, and develop new financing products that meet long-term needs, such as infrastructure projects.

These results are in line with the study by Abbas et al. (2024), which states that digital-based financial innovation strengthens the ability of companies, including the banking sector, to access resources more flexibly, increase productivity, and expand investment capacity. This means that innovation not only supports internal efficiency but also strengthens the capacity of banks as financial intermediaries capable of mobilizing funds for productive projects.

Infrastructure financing often entails significant risks, including cash-flow uncertainty, contract complexity, and macroeconomic volatility. Innovation in financial instruments enables banks to develop risk-mitigation mechanisms through portfolio diversification, risk-sharing instruments, and technology-based financing models. Billah et al. (2025) emphasize that the development of digital-based instruments, including Decentralized Finance (DeFi), plays an important role in reducing tail risk and expanding access to hedging instruments. Thus, innovation enables banks to be more daring in entering infrastructure sectors previously considered too risky.

Innovation can also be viewed as a dynamic capability that enables banks to respond quickly and effectively to external changes. Abdurrahman et al. (2024) emphasize that dynamic capabilities related to digital innovation play an important role in strengthening banking performance. In the context of infrastructure financing, banks' ability to adopt new technolo-

gies, integrate big data analytics, and develop digital project risk assessment models enhances the credibility of infrastructure project feasibility assessments. In other words, innovation not only improves operational efficiency but also strengthens the due diligence function in long-term financing. This is particularly important given that infrastructure projects have long gestation periods and require certainty in risk assessment.

One important impact of innovation is its capacity to expand financial inclusion, thereby increasing banks' funding bases. Previous studies have shown that the adoption of digital innovation significantly expands financial inclusion in various developing countries (Adel, 2024; Basnayake et al., 2024). In the context of infrastructure financing, this creates a new funding pool that banks can utilize to support large-scale projects. In addition, digitally enabled financial inclusion strengthens the stability of the banking sector amid the COVID-19 pandemic (Banna et al., 2022). The important implication is that innovation expands the base of stable long-term liquidity, thereby encouraging banks to be more willing to extend credit to infrastructure projects that require sustainable financing.

The effectiveness of innovation in promoting infrastructure financing also depends heavily on regulation. Previous studies emphasize that banking stability in a dual banking system is greatly influenced by external policies, including foreign investment flows and financial regulation (Alzarooni et al., 2024). Banking innovations will have a positive impact on infrastructure financing only if supported by regulations that encourage long-term funding. This is consistent with the findings. Alkhowaiter (2020) shows that the adoption of digital payments in Gulf countries is highly dependent on government policy support and regulatory frameworks. Thus, the role of innovation cannot be separated from the policy ecosystem that directs banks to use innovation not only for retail services but also for productive financing, such as infrastructure.

Further analysis using a split-sample design between Islamic banks (model 1) and conventional banks (model 2) in Table 4 reveals interesting dynamics when the variables of digitization, sharia compliance, and banking product innovation are considered simultaneously in their influence on infrastructure financing. Digitization partially shows an opposite effect in the two models tested. In model (1), digitization has a positive and significant effect on infrastructure financing, indicating that the application of digital technology can improve the efficiency of banking intermediation and expand access to financing. However, in model (2), digitization actually shows a significant negative effect. This difference indicates that digitization does not always foster long-term financing capacity; rather, it can give rise to a short-term orientation that is less consistent with the characteristics of infrastructure financing, which is capital-intensive and long-term.

Table 4. Results of the moderation test of independent variables in infrastructure financing

Variable	Infrastructure Financing	
	(1)	(2)
Digital	1.331**	−0.354**
	(2.68)	(−2.66)
Syariacomp	0.973***	–
	(5.55)	
Digital x Syariacomp	−0.886***	–
	(−3.67)	
Inov	0.0278***	−0.212***
	(5.48)	(−4.05)
Inov x Digital	–	0.226***
		(4.25)
ROA	−0.0259	0.0407*
	(−1.61)	(2.35)
LDR	−0.151***	−0.0892*
	(−6.88)	(−2.51)
Lnsize	0.306***	1.197***
	(4.57)	(15.57)
Lev	0.0414	0.0511
	(0.95)	(0.48)
Age	0.0660***	0.00532
	(6.21)	(0.41)
Jobless	−0.0457	0.0235
	(−1.18)	(0.48)
Inf	−0.0574***	−0.0337
	(−3.87)	(−1.87)
GDP	0.00132	−0.00933
	(0.09)	(−0.51)
_cons	4.642***	−6.782***
	(3.65)	(−5.82)
Number of obs	400	1684
R–squared	0.3432	0.6613
F test	51.60	62.44
Prob > F	0.0000	0.0000
Hausman	0.0000	0.0000

Note: ***, **, and * denote statistically significant variables at 0.1%, 1%, and 5% levels, respectively, with t-statistics in parentheses.

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Sharia compliance (Syariacomp) consistently has a positive and significant effect on infrastructure financing. This confirms that Islamic banking instruments can be a credible alternative source of financing aligned with sustainability principles, particularly through infrastructure sukuk schemes and partnership-based contracts. However, when digitalization interacts with Sharia compliance, the research results show a significant negative coefficient. This finding indicates a potential trade-off between digital orientation and Sharia principles, where overly dominant digital penetration may not be fully compatible with a more conservative and prudential Sharia compliance model. This condition underscores the importance of harmonizing digitalization policies in banking with Sharia finance principles to enable synergies that strengthen infrastructure financing.

Banking product innovation shows quite complex results. In model (1), product innovation has a positive and significant effect, confirming that the development of new financial instruments such as project finance, infrastructure bonds, and sharia-based products can expand long-term financing capacity. However, in model (2), the product innovation coefficient becomes negative and significant. This shift in direction indicates that not all forms of product innovation have a constructive impact on infrastructure financing; some new products may be merely commercial or consumptive, thereby providing less support for productive investment in the infrastructure sector. Interestingly, the interaction between product innovation and digitalization produces a significant positive effect. This means that product innovation enabled by digitalization can strengthen banks' role in infrastructure financing, for example, through digital syndicated loan platforms or the issuance of technology-based bonds (e.g., blockchain-based bonds), which reduce transaction costs and increase transparency.

These findings make an important academic contribution by showing that the relationship between digitization, product innovation, and sharia compliance in infrastructure financing is not linear but contextual. Digitization can either support or hinder infrastructure financing, depending on the extent to which it is integrated with appropriate financial instruments. Sharia compliance provides a strong basis for sustainability but requires an integration strategy to ensure compatibility with the digital ecosystem. Meanwhile, banking product innovation has proven effective when directed toward long-term, productive instruments and is more effective when synergized with digitization. Thus, this study not only enriches the literature on the role of the banking sector in infrastructure development but also provides policy implications that digitization and product innovation strategies must be designed in an integrated manner, taking into account the Sharia regulatory framework and Sustainable Development Goals.

CONCLUSION

The purpose of the study is to analyze the impact of digitalization, digital security, and banking product innovation on infrastructure financing. The results of this study confirm that innovation, digitization, and digital security are important determinants of infrastructure financing, although their effects exhibit distinct dynamics. Digital security has a positive but inconsistent influence, functioning more as a factor supporting system trust than as a key driver of intermediation decisions. Banking product innovation has been proven to have a consistent, positive, and significant effect on increasing infrastructure financing. In addition, sharia compliance consistently strengthens infrastructure financing capacity, confirming the important role of sharia-based instruments in supporting sustainable financing.

This study contributes to the literature on financial intermediation by integrating perspectives on digital transformation, digital security, and innovation in the context of infrastructure financing. These findings enrich our understanding of financial intermediation theory and dynamic capability theory by showing that innovation serves not only as an instrument of efficiency but also as a strategic mechanism for strengthening banks' role in sustainable development. Furthermore, findings regarding the ambiguity of the impact of digitalization provide a basis for developing a theory on the trade-off between a

digital retail-based service orientation and a long-term productive financing agenda. From a practical standpoint, this study has important implications for policymakers, regulators, and the banking industry. For regulators, policies are needed that balance the promotion of retail service digitalization with the strengthening of incentives for long-term financing, particularly for infrastructure projects. For banks, the results of this study emphasize the importance of innovation strategies that target not only transaction-based services but also the development of products that support infrastructure financing, including green technology-based instruments, digital sukuk, and collaboration schemes with fintech. For development policymakers, these findings indicate that the success of mobilizing infrastructure financing through the banking sector depends not only on fiscal capacity but also on the extent to which innovation and digital transformation can be strategically managed to support sustainable development.

AUTHOR CONTRIBUTIONS

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REFERENCES

1. Abbas, J., Balsalobre-Lorente, D., Amjid, M. A., Al-Sulaiti, K., Al-Sulaiti, I., & Aldereai, O. (2024). Financial innovation and digitalization promote business growth: The interplay of green technology innovation, product market competition and firm performance. *Innovation and Green Development, 3*(1), 100111. https://doi.org/10.1016/j.igd.2023.100111
2. Abdurrahman, A. (2024). Investigating the impact of digital business ecosystem in enhancing Islamic mobile banking adoption through the TOE framework. *Digital Business, 4*(2), 100096. https://doi.org/10.1016/j.digbus.2024.100096
3. Abdurrahman, A., Gustomo, A., & Prasetio, E. A. (2024). Impact of dynamic capabilities on digital transformation and innovation to improve banking performance: A TOE framework study. *Journal of Open Innovation: Technology, Market, and Complexity, 10*(1), 100215. https://doi.org/10.1016/j.joitmc.2024.100215
4. Adel, N. (2024). The Impact of Digital Literacy and Technology Adoption on Financial Inclusion: Evidence from Emerging Economies in Africa, Asia, and Latin America. *Heliyon, 10*(24), e40951. https://doi.org/10.1016/j.heliyon.2024.e40951
5. Ajupov, A. A., Ahmadullina, A. A., Belyaev, R. M., & Sizova, A. I.

http://dx.doi.org/10.21511/bbs.21(1).2026.21

(2019). Assessment of the Level of Development of Digital Technologies in the Banking Sector. *HELIX, 9*(4), 5248-5251. https://doi.org/10.29042/2019-5248-5251

6. Alkhowaiter, W. A. (2020). Digital payment and banking adoption research in Gulf countries: A systematic literature review. *International Journal of Information Management, 53,* 102102. https://doi.org/10.1016/j.ijinfomgt.2020.102102
7. Allen, F., & Santomero, A. M. (1997). The theory of financial intermediation. *Journal of Banking & Finance, 21*(11-12), 1461-1485. https://doi.org/10.1016/S0378-4266(97)00032-0
8. Alzarooni, L., Al-Shboul, M., & Maghyereh, A. (2024). The influence of foreign direct investment on banking stability in a dual banking system during the COVID-19 pandemic and the global financial crisis. *Borsa Istanbul Review, 24*(5), 1046-1058. https://doi.org/10.1016/j.bir.2024.06.001
9. Arcand, J. L., Berkes, E., & Panizza, U. (2015). Too much finance? *Journal of Economic Growth, 20*(2), 105-148. https://doi.org/10.1007/s10887-015-9115-2
10. Banna, H., Hassan, M. K., Ahmad, R., & Alam, M. R. (2022). Islamic banking stability amidst the COVID-19 pandemic: the role of digital financial inclusion. *International Journal of Islamic and Middle Eastern Finance and Management, 15*(2), 310-330. https://doi.org/10.1108/IMEFM-08-2020-0389
11. Basnayake, D., Naranpanawa, A., Selvanathan, S., & Bandara, J. S. (2024). Financial inclusion through digitalization and economic growth in Asia-Pacific countries. *International Review of Financial Analysis, 96*(PA), 103596. https://doi.org/10.1016/j.irfa.2024.103596
12. Bhattacharyya, A., Wright, S., & Rahman, M. L. (2021). Is better banking performance associated with financial inclusion and mandated CSR expenditure in a developing country? *Accounting and Finance, 61*(1), 125-161. https://doi.org/10.1111/acfi.12560
13. Billah, M., Enamul Hoque, M., Hadhri, S., & Do, H. X. (2025). Tail risk connectedness between DeFi and Islamic assets and their determinants. *International Review of Economics and Finance, 97*(December 2024), 103789. https://doi.org/10.1016/j.iref.2024.103789
14. Dearing, J. W. (2009). Applying Diffusion of Innovation Theory to Intervention Development. *Research on Social Work Practice, 19*(5), 503-518. https://doi.org/10.1177/1049731509335569
15. Feng, S., Chong, Y., Yu, H., Ye, X., & Li, G. (2022). Digital financial development and ecological footprint: Evidence from green-biased technology innovation and environmental inclusion. *Journal of Cleaner Production, 380*(P2), 135069. https://doi.org/10.1016/j.jclepro.2022.135069
16. Gao, C., & Wang, Q. (2023). Does digital finance aggravate bank competition? Evidence from China. *Research in International Business and Finance, 66,* 102041. https://doi.org/10.1016/j.ribaf.2023.102041
17. Ghaemi Asl, M., Ben Jabeur, S., Hosseini, S. S., & Tajmir Riahi, H. (2024). Fintech's impact on conventional and Islamic sustainable equities: Short- and long-term contributions of the digital financial ecosystem. *Global Finance Journal, 62*(December 2023), 101022. https://doi.org/10.1016/j.gfj.2024.101022
18. Goetz, M. R. (2018). Competition and Bank Stability. *Journal of Financial Intermediation, 35*(Part A), 57-69. https://doi.org/10.1016/j.jfi.2017.06.001
19. Guo, B., Feng, Y., & Lin, J. (2023). Digital inclusive finance and digital transformation of enterprises. *Finance Research Letters, 57,* 104270. https://doi.org/10.1016/j.frl.2023.104270
20. Gyau, E. B., Appiah, M., Gyamfi, B. A., Achie, T., & Naeem, M. A. (2024). Transforming banking: Examining the role of AI technology innovation in boosting banks financial performance. *International Review of Financial Analysis, 96*(PB), 103700. https://doi.org/10.1016/j.irfa.2024.103700
21. Haile, M. A., M.K., J., & Mulugeta, W. (2025). Does regulatory convergence shape banking resilience in Africa? *Heliyon, 11*(1), e41347. https://doi.org/10.1016/j.heliyon.2024.e41347
22. Haruna, A., Oumbé, H. T., Kountchou, A. M., & Pilag Kakeu, C. B. (2024). Can Islamic finance enhance the innovation capacity of Cameroonian SMEs? Empirical evidence based on a multivariate probit approach. *Borsa Istanbul Review, 24*(1), 187-200. https://doi.org/10.1016/j.bir.2023.11.006
23. Hazaea, S. A., Tabash, M. I., Zhu, J., Khatib, S. F. A., & Farhan, N. H. S. (2021). Internal audit and financial performance of Yemeni commercial banks: Empirical evidence. *Banks and Bank Systems, 16*(2), 137-147. https://doi.org/10.21511/bbs.16(2).2021.13
24. He, J., Du, X., & Tu, W. (2024). Can corporate digital transformation alleviate financing constraints? *Applied Economics, 56*(20), 2434-2450. https://doi.org/10.1080/00036846.2023.2187037
25. Hoque, A., Le, D. T., & Le, T. (2024). Does digital transformation reduce bank's risk-taking? evidence from Vietnamese commercial banks. *Journal of Open Innovation: Technology, Market, and Complexity, 10*(2), 100260. https://doi.org/10.1016/j.joitmc.2024.100260
26. Hu, S., Zhu, Q., Zhao, X., & Xu, Z. (2023). Digital Finance and Corporate Sustainability Performance: Promoting or Restricting? Evidence from China's Listed Companies. *Sustainability, 15*(13), 9855. https://doi.org/10.3390/su15139855
27. IMF. (2024). *Cyber Risk: A Growing Concern for Macrofinancial Stability* (Issue April). Retrieved from https://www.imf.org/-/media/files/publications/gfsr/2024/april/english/ch3.pdf
28. Iwedi, M. (2024). Digital finance infrastructure and growth of commercial banking firms in Nigeria. *Discover Analytics, 2*(1), 16. https://doi.org/10.1007/s44257-024-00022-1

29. Jafri, J. A., Mohd Amin, S. I., Abdul Rahman, A., & Mohd Nor, S. (2024). A systematic literature review of the role of trust and security on Fintech adoption in banking. *Heliyon, 10*(1), e22980. https://doi.org/10.1016/j.heliyon.2023.e22980

30. Karosas, K. (2024). Digitalization in Finance and Banking. *SSRN Electronic Journal.* https://doi.org/10.2139/ssrn.4723084

31. Kashi, A., Laallam, A., Mansour Nomran, N., Azmi Abumughli, A., & Al-Binali, T. (2024). Do institutional environment and corporate governance structures determine Islamic Banks' sustainability performance? Evidence across key jurisdictions in Islamic finance industry. *Borsa Istanbul Review, 24*(6), 1088-1100. https://doi.org/10.1016/j.bir.2024.06.005

32. Khan, A., & Malaika, M. (2021). *Monetary and Capital Markets Department and Information Technology Department* (IMF Working Paper WP/21/105). Retrieved from https://www.imf.org/en/publications/miscellaneous-publications/issues/2022/01/18/monetary-and-capital-markets-department-technical-assistance-handbook

33. Khan, F., Bartáková, G. P., Almadhor, A., Qayyum, A., Abeer, K., & Durrani, A. (2025). Evaluating the capacity and limitations of generative AI in financial decision making. *Computer Standards and Interfaces, 93*(December 2024). https://doi.org/10.1016/j.csi.2024.103965

34. Khan, H. H., Khan, S., & Ghafoor, A. (2023). Fintech adoption, the regulatory environment and bank stability: An empirical investigation from GCC economies. *Borsa Istanbul Review, 23*(6), 1263-1281. https://doi.org/10.1016/j.bir.2023.10.010

35. Khan, N., Kchouri, B., Yatoo, N. A., Kräussl, Z., Patel, A., & State, R. (2022). Tokenization of sukuk: Ethereum case study. *Global Finance Journal, 51*(April 2020), 1-16. https://doi.org/10.1016/j.gfj.2020.100539

36. Khera, P., Ng, S., Ogawa, S., & Sahay, R. (2022). Measuring Digital Financial Inclusion in Emerging Market and Developing Economies: A New Index. *Asian Economic Policy Review, 17*(2), 213-230. https://doi.org/10.1111/aepr.12377

37. Liu, H., Wu, S., Zhong, C., & Liu, Y. (2020). The sustainable effect of operational performance on financial benefits: Evidence from Chinese quality awards winners. *Sustainability (Switzerland), 12*(5). https://doi.org/10.3390/su12051966

38. Liu, Y., Ma, S., & Sun, M. (2025). Digital infrastructure policies, local fiscal and financing constraints of Non-SOEs: Evidence from China. *PLOS One, 20*(7), e0327294. https://doi.org/10.1371/journal.pone.0327294

39. Mallinguh, E., Wasike, C., & Zoltan, Z. (2020). The business sector, firm age, and performance: the mediating role of foreign ownership and financial leverage. *International Journal of Financial Studies, 8*(4), 1-16. https://doi.org/10.3390/ijfs8040079

40. Marhadi, M., Fathoni, A. F., Setiawan, B., Pratiwi, D., Hayati, R., Boros, A., & Sudibyo, N. A. (2024). Continuance intention of Fintech Peer-to-Peer (P2P) financing Shariah: Moderation role of brand schematicity and digital financial literacy. *Journal of Open Innovation: Technology, Market, and Complexity, 10*(2), 100301. https://doi.org/10.1016/j.joitmc.2024.100301

41. Mavlutova, I., Spilbergs, A., Verdenhofs, A., Natrins, A., Arefjevs, I., & Volkova, T. (2022). Digital Transformation as a Driver of the Financial Sector Sustainable Development: An Impact on Financial Inclusion and Operational Efficiency. *Sustainability, 15*(1), 207. https://doi.org/10.3390/su15010207

42. Mawardi, I., Al Mustofa, M. U., Widiastuti, T., & Ghozali, M. (2024). The influence of institutional quality, economic freedom, and technological development on Islamic financial development in OIC countries. *Journal of Open Innovation: Technology, Market, and Complexity, 10*(2), 100279. https://doi.org/10.1016/j.joitmc.2024.100279

43. Mou, Y. (2024). The impact of digital finance on technological innovation across enterprise life cycles in China. *Heliyon, 10*(14), e33965. https://doi.org/10.1016/j.heliyon.2024.e33965

44. Nguyen, L., Tran, S., & Ho, T. (2021). Fintech credit, Bank Regulations and Bank Performance: A Cross-country Analysis. *Asia-Pacific Journal of Business Administration, 14*(4), 445-466. https://doi.org/10.1108/APJBA-05-2021-0196

45. Ozili, P. K. (2018). Impact of digital finance on financial inclusion and stability. *Borsa Istanbul Review, 18*(4), 329-340. https://doi.org/10.1016/j.bir.2017.12.003

46. Rabbani, M. R., Bashar, A., Nawaz, N., Karim, S., Ali, M. A. M., Rahiman, H. U., & Alam, M. S. (2021). Exploring the role of Islamic fintech in combating the aftershocks of COVID-19: The open social innovation of the Islamic financial system. *Journal of Open Innovation: Technology, Market, and Complexity, 7*(2), 136. https://doi.org/10.3390/joitmc7020136

47. Sarma, M., & Pais, J. (2011). Financial Inclusion and Development. *Journal of International Development, 23*(5), 613-628. https://doi.org/10.1002/jid.1698

48. Sha'ban, M., Ayadi, R., Forouheshfar, Y., Challita, S., & Sandri, S. (2024). Digital and traditional financial inclusion: Trends and drivers. *Research in International Business and Finance, 72*(PB), 102528. https://doi.org/10.1016/j.ribaf.2024.102528

49. Tian, G., Wang, K. T., & Wu, Y. (2023). Does the market value the green credit performance of banks? Evidence from bank loan announcements. *British Accounting Review, 57*(5), 101282. https://doi.org/10.1016/j.bar.2023.101282

50. Ullah, S., Liew, C. Y., & Nobanee, H. (2025). Digital transactions and financial development: The moderating role of global integra-

http://dx.doi.org/10.21511/bbs.21(1).2026.21

tion across income levels. *International Review of Economics and Finance, 98,* 103861. https://doi.org/10.1016/j.iref.2025.103861

51. Usman, B., Hasnam, M. G., Nurazi, R., Baihaqi, & Aujirapongpan, S. (2024). Exploring investor attention in Shariah markets, macroeconomic influences, and corporate performance: Insights from Indonesia. *Social Sciences and Humanities Open, 10,* 101015. https://doi.org/10.1016/j.ssaho.2024.101015

52. Wang, S., Asif, M., Shahzad, M. F., & Ashfaq, M. (2024). Data privacy and cybersecurity challenges in the digital transformation of the banking sector. *Computers and Security, 147,* 104051. https://doi.org/10.1016/j.cose.2024.104051

53. Windasari, N. A., Kusumawati, N., Larasati, N., & Amelia, R. P. (2022). Digital-only banking experience: Insights from gen Y and gen Z. *Journal of Innovation and Knowledge, 7*(2), 100170. https://doi.org/10.1016/j.jik.2022.100170

54. Yao, T., & Song, L. (2023). Can digital transformation reduce bank systemic risk? Empirical evidence from listed banks in China. *Economic Change and Restructuring, 56*(6), 4445-4463. https://doi.org/10.1007/s10644-023-09560-2

55. Zhang, R., Gao, W., Chen, S., Zhou, L., & Li, A. (2024). Does digital transformation contribute to improving financing efficiency? Evidence and implications for energy enterprises in China. *Energy, 300,* 131271. https://doi.org/10.1016/j.energy.2024.131271

56. Zhang, X., Li, J., Xiang, D., & Worthington, A. C. (2023). Digitalization, financial inclusion, and small and medium-sized enterprise financing: Evidence from China. *Economic Modelling, 126,* 106410. https://doi.org/10.1016/j.econmod.2023.106410

57. Zou, F., Huang, L., Ghaemi Asl, M., Delnavaz, M., & Tiwari, S. (2023). Natural resources and green economic recovery in responsible investments: Role of ESG in context of Islamic sustainable investments. *Resources Policy, 86*(PA), 104195. https://doi.org/10.1016/j.resourpol.2023.104195

APPENDIX A

Table A1. Operational definitions and variable measurements

Variable	Definition	Measurement	Reference
Infrastructure financing (Infra)	A number of loans are provided by banks to support infrastructure development	The natural logarithm of the sum of bank credits allocated for infrastructure development	Haile et al. (2025), Usman et al. (2024), Zou et al. (2023)
Digitization (Digital)	Level of digital technology implementation in banking services. Proportion of Digital transactions to total bank transactions	The proportion of digital transactions to total bank transactions	Adel (2024), Basnayake et al. 2(024)
Digital security (Digsecur)	The ability of banks to maintain the security of customer digital data and protect financial transactions from cyber threats. The number of reported digital security breaches per year.	Number of reported digital security breaches per year	Sha'ban et al. (2024), Wang et al. (2024)
Product Innovation (Inov)	Development of new technology-based services or products in bank operations. Number of new technology-based products launched in one year	The number of new technology-based products launched in a year	Ghaemi Asl et al. 2024), Rabbani et al. (2021)
Sharia Compliance (Shariacomp)	The level of banks' operational compliance with Sharia principles. Annual sharia audit score	Annual Sharia audit value	Kashi et al. (2024), Mawardi et al. (2024)
Return on Asset (ROA)	The rate of return on total assets owned by the company	$Net\ Profit_t$ / $Total\ Asset_t$	Haruna et al. (2024)
Efisiensi (BOPO)	The level of a bank's operational efficiency in managing operating income and expenses	BOPO ratio = Operating expenses divided by operating income	Abdurrahman et al. (2024)
Bank stability (ZSCORE)	A bank's financial condition	Z-score is the ratio of return on assets (ROA) and capital to assets (CA) to the standard deviation of return on assets	Ullah et al. (2025), Zou et al. (2023)
Loan to Deposit Ratio (LDR)	Bank deposit-to-loan ratio	Total bank deposits divided by total loans	Tian et al. 2023)
Bank Size (SIZE)	Bank asset value	Natural logarithm of total bank assets	Bhattacharyya et al. (2021), Liu et al. (2020)
Leverage (LEV)	The proportion of debt borne by banks relative to their total assets	Debt-to-asset ratio	Goetz (2018), Mallinguh et al. (2020)
Age	Bank age	Age of the bank since its establishment	Tian et al. (2023)
Unemployment (Jobless)	Percentage of the labor force that is unemployed but actively seeking work	The open unemployment rate in one year	Feng et al. (2022), Zou et al. (2023)
Inflation (INF)	Annual inflation rate	The annual inflation rate	Hazaea et al. (2021), Nguyen et al. (2021)
Gross domestic product (GDP)	Annual real GDP growth rate	Comparison of the difference between this year's GDP (t) and the previous year's GDP (t-1) with the GDP of the previous year (t-1)	Hazaea et al. (2021), Nguyen et al. (2021)

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