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The impact of banking digital transformation on financial inclusion in Vietnam: Empirical evidence from the digital ERA

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Abstract: In the context of digital transformation reshaping financial systems worldwide, this study examines the impact of banking digital transformation on financial inclusion in Vietnam during the period 2016-2025, with particular attention to the transmission mechanisms through eKYC adoption and SMEs' access to credit. A multi-method empirical framework is employed, combining Data Envelopment Analysis (DEA) to construct the Digital Banking Efficiency Index (DBEI), System Generalized Method of Moments (System-GMM) to estimate the dynamic effects of digital transformation on financial inclusion, and Partial Least Squares Structural Equation Modeling (PLS-SEM) to test mediating relationships. The findings show that banking digital transformation has a positive and statistically significant effect on financial inclusion. Banks with higher digital transformation efficiency tend to expand financial service accessibility, improve SMEs' credit access, and enhance digital customer onboarding. The results further confirm that eKYC serves as a partial mediator in the relationship between digital transformation and financial inclusion. This study concludes that banking digital transformation is not merely a process of technological modernization but a key driver of inclusive financial development in Vietnam. The findings offer practical implications for strengthening digital infrastructure, promoting eKYC, improving data governance, and developing digital credit solutions for SMEs.

Keywords: *Digital banking, eKYC, SMEs, Financial inclusion, Vietnam.*

1. Introduction

1.1. Research Background

During the first two decades of the twenty-first century, the rapid advancement of digital technologies has fundamentally transformed the global financial system. Under the traditional banking model, access to financial services largely depended on the availability of physical branch networks, geographical proximity, and customers' ability to be physically present at service locations. In an increasingly digitalized environment, however, these barriers have gradually been replaced by technology-driven platforms capable of delivering financial services in real time, on a broad scale, and at significantly lower costs.

The emergence of Artificial Intelligence (AI), Big Data analytics, Cloud Computing, Blockchain technology, Digital Identity systems, and digital banking platforms has profoundly reshaped the provision and consumption of financial services. Technology is no longer merely a supporting tool; rather, it has become a core component of the modern financial ecosystem.

Alongside the digital transformation process, financial inclusion has emerged as a major development objective within the international community. The United Nations, the World Bank, the International Monetary Fund (IMF), and numerous multilateral development organizations regard

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expanded access to formal financial services as a critical prerequisite for poverty reduction, inequality mitigation, and the enhancement of economic resilience against external shocks.

According to Klapper et al. [1], the proportion of adults worldwide holding an account with a financial institution or a mobile money service provider reached 79% in 2024, representing a substantial increase from 51% in 2011. This improvement has been driven primarily by low- and middle-income economies, highlighting the increasingly important role of digital transformation and digital finance in promoting financial inclusion and narrowing disparities in access to financial services across population groups.

Within this context, Vietnam has emerged as a particularly relevant case study. As a rapidly growing emerging economy with a young population, Vietnam has achieved significant progress in its national digital transformation agenda. The banking sector is widely recognized as one of the leading industries in terms of technology adoption and digital innovation.

By the end of 2024, approximately 87% of Vietnamese adults possessed a payment account, nearly triple the proportion recorded a decade earlier. Cashless payment transactions have expanded rapidly, while most commercial banks have implemented digital banking services, mobile payment solutions, and electronic Know-Your-Customer (eKYC) systems. These achievements demonstrate the considerable potential of digital transformation to advance financial inclusion.

Despite these positive developments, Vietnam continues to face substantial financial inclusion challenges. Disparities in access to financial services persist between urban and rural areas, as well as between economically advanced and less-developed regions. Small and medium-sized enterprises (SMEs), although accounting for more than 97% of all enterprises, continue to encounter significant barriers to obtaining formal credit. Furthermore, a considerable proportion of low-income individuals and workers in the informal sector remain insufficiently integrated into the formal financial system.

These issues give rise to an important research question: Does banking digital transformation genuinely promote financial inclusion, and if so, through which mechanisms does this effect operate?

1.2. Research Gaps

Despite the rapid growth of the literature on financial technology (FinTech) and digital finance in recent years, several important research gaps remain.

First, most existing studies assess the development of digital financial services using individual indicators, such as the volume of electronic transactions, the adoption rate of online banking, or the penetration of digital payment systems. While informative, these measures do not adequately capture the overall effectiveness of digital transformation within commercial banks.

Second, the majority of studies examining the relationship between digital transformation and financial inclusion rely on cross-sectional or static panel data approaches. However, this relationship is inherently dynamic and may be influenced by time-varying endogenous factors, making static analyses potentially insufficient to capture its full effects.

Third, existing research has yet to provide a comprehensive explanation of the transmission mechanisms through which banking digital transformation affects credit accessibility for small and medium-sized enterprises (SMEs), particularly within the context of emerging economies.

Fourth, most empirical evidence has been derived from developed economies or countries with relatively advanced financial systems. In contrast, in-depth studies focusing on Vietnam remain limited.

Therefore, investigating the case of Vietnam is relevant not only for domestic policymaking but also contributes valuable empirical evidence for other emerging economies pursuing digital transformation and financial inclusion strategies.

1.3. Research Objectives

This study pursues four main objectives.

First, it develops and quantifies a Digital Banking Efficiency Index (DBEI) for the Vietnamese commercial banking sector.

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Second, it evaluates the impact of banking digital transformation on the level of financial inclusion.

Third, it examines the transmission mechanisms through which digital transformation influences financial inclusion, particularly via enhanced access to financial services and improved credit accessibility for SMEs.

Fourth, it proposes policy implications aimed at promoting financial inclusion within the context of ongoing digital transformation.

2. Literature Review and Hypothesis Development

2.1. Financial Inclusion in the Context of Digital Transformation

Financial inclusion refers to the process of ensuring that individuals and businesses have access to and can effectively utilize formal financial products and services at affordable costs, with appropriate quality and adequate levels of security. According to Allen et al. [2], financial inclusion encompasses not only access to financial services but also the ability to use such services effectively to enhance economic and social welfare.

For several decades, research on financial development primarily focused on the role of the banking system in mobilizing savings, allocating capital, and promoting economic growth. However, this perspective often assumes that economic agents have equal access to formal financial institutions. In reality, a substantial proportion of the population in developing countries remains excluded from formal financial services due to barriers related to geography, income, educational attainment, transaction costs, and information asymmetries.

The rapid advancement of digital technologies has significantly transformed the approach to financial inclusion. Rather than relying on the costly expansion of physical branch networks, financial institutions can now reach customers through digital platforms, mobile devices, and electronic identification systems. Consequently, a new model of financial development has emerged, in which financial access increasingly depends on the quality of digital infrastructure rather than traditional geographical proximity.

According to Ozili [3], digital finance has become a key driver of financial inclusion in developing economies. Digital technologies reduce transaction costs, improve service delivery efficiency, and expand financial access to population segments that were previously excluded from the formal financial system. Within this context, banking digital transformation is widely regarded as a critical mechanism for achieving financial inclusion in the twenty-first century.

2.2. Banking Digital Transformation and Financial Inclusion: A Review of Empirical Evidence

2.2.1. The Positive Impact Perspective

The dominant stream of literature argues that digital transformation positively affects financial inclusion by reducing transaction costs and expanding access to financial services.

Sahay et al. [4] contend that digital financial technologies can narrow financial access gaps in developing countries by significantly lowering the cost of accessing banking services. Similarly, Khera et al. [5] in a study of emerging economies find that the level of digital financial development is positively associated with financial inclusion indicators.

Likewise, Banna et al. [6] demonstrate that digital finance contributes to sustainable economic growth by expanding financial access among low-income populations. The authors argue that digital technologies help overcome structural limitations of traditional banking systems, particularly in economies where financial infrastructure remains unevenly developed.

More recent studies further suggest that electronic payments and mobile banking serve as important gateways to financial inclusion. As individuals begin to adopt digital payment instruments, their access to higher-value financial services, such as savings, credit, and insurance, tends to improve substantially. Recent studies have provided further support for this positive perspective. Ha et al. [7], in a state-of-the-art systematic literature review of fintech and financial inclusion, show that recent research has increasingly emphasized three major themes: the emergence of new digital financial

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services, the transformation of financial markets, and the role of stakeholders in the fintech ecosystem. Their findings suggest that fintech and digital banking innovations have become central mechanisms through which financial institutions can broaden access, reduce service delivery costs, and reach underserved customer segments. Similarly, Edo [8] provides empirical evidence from emerging economies that digital transformation contributes positively to financial development by reducing information asymmetry and transaction costs, which is consistent with the financial intermediation perspective. In addition, Klapper et al. [1] highlight the growing importance of mobile connectivity and digital financial services in expanding account ownership, digital payments, savings, and borrowing opportunities. These recent findings reinforce the argument that banking digital transformation can serve as a key pathway for advancing financial inclusion in emerging economies such as Vietnam.

2.2.2. A Cautious Perspective: The Digital Divide and Risks of Financial Exclusion

Although most studies document positive effects of digital technologies on financial inclusion, some scholars argue that digitalization does not necessarily lead to inclusive financial outcomes.

Beck et al. [9] emphasize that financial access depends not only on the availability of financial services but also on users' capacity to utilize them effectively. In a digitalized environment, traditional financial barriers may be replaced by digital barriers.

Individuals with limited digital literacy, lower income levels, or those residing in areas with underdeveloped digital infrastructure may continue to face exclusion from the formal financial system. Ahamed and Mallick [10] further argue that while digital finance can broaden access to financial services, inadequate governance mechanisms may increase operational risks, cybersecurity vulnerabilities, and inequalities in access to information.

These findings suggest that the impact of digital transformation is not automatic but depends on the quality of digital infrastructure, the effectiveness of regulatory institutions, and the level of technological readiness among users.

2.2.3. Current Research Gaps

First, most existing studies employ single indicators such as the number of electronic transactions, Internet banking adoption rates, or mobile banking usage rates as proxies for banking digital transformation. Such measures fail to fully capture digital transformation effectiveness from the perspective of resource utilization and performance outcomes.

Second, research on financial inclusion has largely concentrated on the direct relationship between digital technologies and financial access, while the underlying transmission mechanisms remain insufficiently explored.

Third, there is a lack of studies that simultaneously integrate digital transformation efficiency, its impact on financial inclusion, and SMEs' access to credit within a unified analytical framework.

These research gaps are particularly evident in emerging economies such as Vietnam, where banking digital transformation is progressing rapidly while rigorous empirical evidence remains relatively limited.

2.3. Theoretical Foundations

2.3.1. Financial Intermediation Theory

According to Levine [11], the financial system performs five core functions: mobilizing savings, allocating capital, monitoring investments, managing risk, and facilitating economic exchange. These functions help reduce transaction costs and information asymmetries, thereby promoting economic growth.

In the context of digital transformation, technological advancements enable banks to perform their intermediation functions more efficiently and at lower cost. The application of Big Data analytics, Artificial Intelligence (AI), and customer behavior analysis significantly reduces information acquisition

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costs and enhances the quality of lending decisions. Consequently, banking digital transformation can be viewed as an upgrade of the financial intermediation function within the digital economy.

2.3.2. Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM), developed by Davis [12], posits that the adoption of a new technology is primarily determined by two factors: perceived usefulness and perceived ease of use.

Within the banking sector, customers can only benefit from digital financial services if they are willing to adopt and utilize the underlying technologies. Therefore, the effectiveness of digital transformation depends not only on banks' technological investments but also on end-users' willingness and ability to embrace digital innovations.

2.3.3. Digital Finance Theory

Ozili [3] argues that digital finance has the potential to simultaneously address three major barriers to financial inclusion: transaction costs, geographical constraints, and limitations in credit information.

Unlike traditional banking systems, digital financial platforms can provide services at low marginal costs, with high scalability and rapid processing capabilities. These characteristics facilitate the provision of financial services to customer segments that have historically been underserved by the formal financial system.

2.3.4. Financial Innovation Theory

Frame and White [13] contend that financial innovation is a critical driver of efficiency improvements within the financial system. Banking digital transformation represents a disruptive form of financial innovation, enabling the integration of digital technologies throughout the entire financial value chain.

From this perspective, the effectiveness of digital transformation is reflected not only in improvements in bank productivity and operational efficiency but also in its ability to expand financial access for previously underserved populations.

2.4. Hypothesis Development

- Banking Digital Transformation and Financial Inclusion

Digital transformation reduces transaction costs, broadens the scope of financial service provision, and enhances access to financial services. Existing empirical studies generally document a positive relationship between digital finance and financial inclusion.

Accordingly, the following hypothesis is proposed:

H_1: Banking digital transformation efficiency has a positive effect on the level of financial inclusion.

- Banking Digital Transformation and SMEs' Access to Credit

Small and medium-sized enterprises (SMEs) frequently face information-asymmetry problems and limited collateral availability. Digital technologies enable banks to utilize alternative data sources, automate credit-assessment processes, and reduce lending costs.

Therefore, the following hypothesis is proposed:

H_2: Banking digital transformation efficiency has a positive effect on SMEs' access to credit.

- The Mediating Role of eKYC

Electronic Know-Your-Customer (eKYC) systems substantially reduce entry barriers to the formal financial system by enabling remote customer verification and simplifying account-opening procedures.

Accordingly, the following hypothesis is proposed:

H_3: eKYC plays a mediating role in the relationship between banking digital transformation and financial inclusion.

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- Financial Inclusion and Bank Performance

As financial access expands, banks are likely to experience growth in their customer base, deposit mobilization, and fee-based service revenues.

Therefore, the following hypothesis is proposed:

H_4: Financial inclusion has a positive effect on bank performance.

- Proposed Research Model

Based on the foregoing hypotheses, this study proposes a theoretical framework in which the Digital Banking Efficiency Index (DBEI) exerts a direct influence on financial inclusion and SMEs' access to credit, while also affecting financial inclusion indirectly through the mediating role of eKYC. Financial inclusion, in turn, contributes to improvements in bank performance, thereby creating a positive feedback mechanism between banking digital transformation and inclusive financial development.

3. Research Methodology

3.1. Research Design

The primary objective of this study is to examine the impact of banking digital transformation on the level of financial inclusion in Vietnam while elucidating the underlying transmission mechanisms through financial service accessibility and SMEs' access to credit. Given that the research involves operational efficiency, dynamic causal relationships, and mediating effects, a multi-method approach is adopted to ensure the comprehensiveness and robustness of the findings.

The research framework is implemented through three sequential stages.

First, Data Envelopment Analysis (DEA) is employed to measure the digital transformation efficiency of commercial banks. The DEA results are subsequently aggregated to construct the Digital Banking Efficiency Index (DBEI).

Second, the DBEI is incorporated as the primary explanatory variable in a dynamic panel-data model estimated using the System Generalized Method of Moments (System-GMM) to assess the impact of banking digital transformation on financial inclusion.

Third, Partial Least Squares Structural Equation Modeling (PLS-SEM) is applied to examine both direct and indirect relationships and to test the mediating role of electronic Know-Your-Customer (eKYC) systems in the relationship between banking digital transformation and financial inclusion.

This research design integrates three complementary levels of analysis: (i) measuring digital transformation efficiency; (ii) assessing causal effects; and (iii) identifying transmission mechanisms. Such a multi-layered approach helps overcome the limitations of previous studies, which have generally focused on only one specific dimension of digital transformation.

3.2. Data

The study sample consists of 28 Vietnamese commercial banks observed over the period 2016-2025.

To enhance the objectivity and reliability of the analysis, data are collected from multiple sources, including:

- Annual reports of commercial banks;
- Banking sector digital transformation reports published by the State Bank of Vietnam;
- The International Monetary Fund's Financial Access Survey (FAS);
- The World Bank's World Development Indicators (WDI);
- The Global Findex Database;
- Reports published by NAPAS;
- Audited financial statements of commercial banks.

After removing observations with missing values and standardizing the study variables, the final dataset is organized as an unbalanced panel dataset.

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3.3. Construction of the Digital Banking Efficiency Index (DBEI)

3.3.1. Rationale for Index Construction

One of the most common limitations of the existing literature is the measurement of digital transformation using single indicators, such as the number of electronic transactions or the proportion of customers using digital banking services. However, digital transformation is a multifaceted process involving technological investments, operational restructuring, and the generation of new business outcomes. Accordingly, this study constructs the Digital Banking Efficiency Index (DBEI) based on the principle of evaluating the efficiency with which digital resources are transformed into measurable outputs.

The DBEI reflects a bank's ability to utilize technological resources effectively in generating tangible digitalization outcomes.

3.3.2. DEA Model Specification

This study employs an output-oriented Data Envelopment Analysis (DEA) model following the framework developed by Charnes et al. [14].

The DEA approach is selected for three main reasons.

First, DEA allows for the simultaneous consideration of multiple inputs and outputs.

Second, DEA does not require assumptions regarding the functional form of the production process.

Third, DEA has been widely applied in the banking literature to evaluate operational and managerial efficiency.

3.3.2.1. Input Variables

The input variables employed in the DEA model are presented as follows:

Table 1.
Input Variables Used in the DEA Model.

Symbol	Variable
ITCOST	Information Technology Investment Expenditure
DICOST	Digital Infrastructure Investment Expenditure
ITSTAFF	Number of Information Technology Personnel
OPCOST	Operating Expenditure for Digital Platforms

3.3.2.2. Output Variables

The output variables included in the DEA model are as follows:

Table 2.
Output Variables Used in the DEA Model.

Symbol	Variable
DTRANS	Volume of Digital Transactions
DUSER	Number of Digital Banking Customers
DREV	Revenue from Digital Services
DRATE	Ratio of Digital Transactions to Total Transactions

DEA efficiency scores range from 0 to 1.

A bank with an efficiency score equal to 1 is considered fully efficient and is located on the digital efficiency frontier.

3.4. Construction of the Financial Inclusion Index (FII)

3.4.1. Measurement Framework

Following the frameworks adopted by the International Monetary Fund (IMF) and the World Bank, financial inclusion is conceptualized as a multidimensional construct encompassing:

- Access to financial services;

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- Usage of financial services;
- Quality of financial services.

Accordingly, this study constructs a Financial Inclusion Index (FII) using the Min–Max normalization approach combined with Principal Component Analysis (PCA) for weight aggregation.

3.4.2. Components of the Financial Inclusion Index

- Financial Access Dimension
- Number of payment accounts per 1,000 adults;
- Number of ATMs per 100,000 adults;
- Number of payment acceptance points.
- Financial Usage Dimension
- Percentage of adults using banking services;
- Electronic payment adoption rate;
- Digital transaction ratio.
- Credit Inclusion Dimension
- Formal credit access rate;
- Percentage of enterprises with access to bank financing;
- Retail credit-to-GDP ratio.

The Financial Inclusion Index (FII) is normalized on a scale ranging from 0 to 1.
Higher values indicate a greater degree of financial inclusion.

3.5. Dynamic Panel Data Model: System-GMM

3.5.1. Rationale for Employing the System-GMM Estimator

Financial inclusion is inherently dynamic, as current levels are influenced by past outcomes. Furthermore, banking digital transformation and financial inclusion may exhibit a bidirectional relationship, potentially giving rise to endogeneity concerns.

To address these issues, this study employs the System Generalized Method of Moments (System-GMM) estimator developed by Blundell and Bond [15], which offers several advantages:

- Addressing endogeneity problems;
- Mitigating omitted-variable bias;
- Controlling for dynamic effects.

3.5.2. Model Specification

The baseline empirical model is specified as follows:

$$FII_{it} = \alpha FII_{i,t-1} + \beta_1 DBEI_{it} + \beta_2 SIZE_{it} + \beta_3 ROA_{it} + \beta_4 CAR_{it} + \beta_5 NPL_{it} + \beta_6 CIR_{it} + \varepsilon_{it}$$

Where:

- (FII_{it}): Financial Inclusion Index of bank *i* at time *t*;
- (FII_{i,t-1}): One-period lagged value of the Financial Inclusion Index;
- (DBEI_{it}): Digital Banking Efficiency Index;
- (SIZE_{it}): Bank size, measured as the natural logarithm of total assets;
- (ROA_{it}): Return on Assets;
- (CAR_{it}): Capital Adequacy Ratio;
- (NPL_{it}): Non-Performing Loan Ratio;
- (CIR_{it}): Cost-to-Income Ratio;
- (\alpha): Coefficient capturing the dynamic persistence of financial inclusion;
- (\beta_1, \beta_2, \ldots, \beta_6): Estimated coefficients;
- (\varepsilon_{it}): Random error term.

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3.5.3. Model Diagnostics

The validity and robustness of the System-GMM estimates are assessed using the following diagnostic tests:

- Hansen/Sargan test of overidentifying restrictions;
- Arellano–Bond AR (1) serial correlation test;
- Arellano–Bond AR (2) serial correlation test;
- Instrument proliferation diagnostics.

3.6. PLS-SEM Model

3.6.1. Rationale for Employing PLS-SEM

Partial Least Squares Structural Equation Modeling (PLS-SEM) is employed to evaluate complex relationships among multiple latent constructs and to examine mediating effects. This method is particularly appropriate for:

- Moderate sample sizes;
- Newly developed theoretical frameworks;
- Non-normally distributed data.

3.6.2. Model Structure

The proposed model consists of four latent constructs:

- Banking Digital Transformation (DBT);
- Electronic Know-Your-Customer (eKYC);
- Financial Inclusion (FI);
- SMEs' Credit Access (SMECA).

The following structural relationships are tested:

- DBT → FI
- DBT → SMECA
- DBT → eKYC
- eKYC → FI
- FI → Bank Performance

3.7. Measurement of Latent Constructs

- Banking Digital Transformation (DBT)

The latent construct of Banking Digital Transformation (DBT) is measured using the following indicators:

- Degree of service digitalization;
- Ratio of online transactions to total transactions;
- Level of technology investment;
- Proportion of digital banking customers.
- Electronic Know-Your-Customer(eKYC)

The eKYC construct is measured through:

- Percentage of customers opening accounts online;
- Customer verification processing time;
- Proportion of transactions conducted entirely through digital channels.
- Financial Inclusion (FI)

The Financial Inclusion (FI) construct comprises the following dimensions:

- Account ownership and access;
- Utilization of financial services;

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- Transaction frequency.

SMEs' Credit Access (SMECA)

The SMEs' Credit Access construct is measured using:

- Percentage of SMEs obtaining formal credit;
- Loan approval processing time;
- Cost of accessing financing.

3.8. Assessment of Reliability and Validity

Following Hair et al. [16], the measurement model is evaluated based on four groups of criteria.

- Internal Consistency Reliability
- Cronbach's Alpha > 0.70;
- Composite Reliability (CR) > 0.70.

- Convergent Validity
- Factor loadings > 0.70;
- Average Variance Extracted (AVE) > 0.50.

- Discriminant Validity
- Fornell–Larcker criterion;
- Heterotrait–Monotrait Ratio (HTMT < 0.85).

- Structural Model Assessment
- Path coefficients;
- Coefficient of determination (R^2);
- Predictive relevance (Q^2);
- Bootstrapping procedure with 5,000 resamples.

3.9. Data Analysis Procedure

The empirical analysis is conducted through six sequential steps.

Step 1: Data collection and standardization.

Step 2: Calculation of the Digital Banking Efficiency Index (DBEI) using Data Envelopment Analysis (DEA).

Step 3: Construction of the Financial Inclusion Index (FII).

Step 4: Estimation of the dynamic panel-data model using the System-GMM estimator.

Step 5: Examination of the mediating mechanisms through Partial Least Squares Structural Equation Modeling (PLS-SEM).

Step 6: Implementation of reliability tests, robustness checks, and sensitivity analyses.

This integrated methodological framework enables a comprehensive assessment of digital transformation efficiency, causal effects, and transmission mechanisms through which banking digital transformation influences financial inclusion in the Vietnamese context.

4. Empirical Results

4.1. Descriptive Statistics and Correlation Analysis

4.1.1. Descriptive Statistics of the Study Variables

Table 1 presents the descriptive statistics of the variables employed in the empirical analysis for a sample of 28 Vietnamese commercial banks over the period 2016–2025.

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Table 3.
Descriptive Statistics of the Study Variables.

Variable	Mean	Standard Deviation	Minimum	Maximum
FII	0.563	0.148	0.241	0.891
DBEI	0.674	0.171	0.223	1.000
SIZE	18.521	1.164	15.937	21.486
ROA	1.287	0.462	-0.352	3.118
CAR	10.814	2.746	7.891	18.227
NPL	1.924	1.137	0.421	6.842
CIR	38.731	9.115	21.446	67.325
eKYC	0.618	0.196	0.101	0.982
SMECA	0.547	0.162	0.213	0.914

The descriptive statistics indicate that the level of financial inclusion in Vietnam increased considerably during the study period. The Financial Inclusion Index (FII) recorded a mean value of 0.563, with a relatively high degree of dispersion, suggesting substantial heterogeneity among banks in their ability to expand access to financial services.

With respect to digital transformation, the Digital Banking Efficiency Index (DBEI) exhibited an average value of 0.674. This finding suggests that the digitalization process within the Vietnamese banking sector has achieved significant progress; however, a considerable gap remains between leading banks and their less advanced counterparts. Several large commercial banks operate at efficiency levels close to the DEA efficiency frontier, whereas many smaller banks are still at an early stage of digital transformation.

Notably, the eKYC variable displays a relatively high standard deviation, indicating uneven adoption and implementation of electronic customer identification systems across banks. This finding suggests that eKYC is increasingly emerging as a key differentiating factor in shaping digital competitiveness within the Vietnamese banking industry.

4.1.2. Correlation Matrix

Before estimating the regression models, Pearson correlation analysis is conducted to provide a preliminary assessment of the relationships among the study variables and to examine the potential presence of multicollinearity.

Table 4.
Pearson Correlation Matrix.

Variable	FII	DBEI	SIZE	ROA	CAR	NPL	CIR
FII	1.000						
DBEI	0.612***	1.000					
SIZE	0.437***	0.501***	1.000				
ROA	0.355***	0.394***	0.289***	1.000			
CAR	0.271**	0.184*	0.156	0.221**	1.000		
NPL	-0.298***	-0.212**	-0.179*	-0.356***	-0.182*	1.000	
CIR	-0.346***	-0.285***	-0.223**	-0.411***	-0.138	0.294***	1.000

Note: (* p<0.10; ** p<0.05; *** p<0.01).

The results indicate that the Digital Banking Efficiency Index (DBEI) is positively and moderately strongly correlated with the Financial Inclusion Index (FII) ($r = 0.612$, $p < 0.01$), providing preliminary empirical support for Hypothesis H1.

Furthermore, none of the pairwise correlation coefficients exceeds the threshold of 0.80. The Variance Inflation Factor (VIF) values range from 1.24 to 3.15, which are well below the threshold value of 10 commonly recommended in the econometric literature. These findings suggest that severe multicollinearity is not a concern in the study dataset.

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4.2. DEA Results: Digital Banking Transformation Efficiency

4.2.1. Digital Transformation Efficiency Across the Banking Sector

The DEA results indicate that the average level of digital transformation efficiency among Vietnamese commercial banks increased steadily throughout the study period.

Table 5.
DEA Efficiency Scores by Period.

Year	Average DEA Efficiency Score
2016	0.491
2017	0.524
2018	0.571
2019	0.612
2020	0.661
2021	0.712
2022	0.748
2023	0.792
2024	0.824
2025	0.851

The results indicate that the digital transformation efficiency of the banking system nearly doubled over the ten-year study period. This trend reflects the positive impact of the National Digital Transformation Strategy, the rapid expansion of electronic payment systems, and the widespread adoption of eKYC solutions following the COVID-19 pandemic.

Notably, the period from 2020 to 2023 witnessed the most substantial improvement in digital transformation efficiency, coinciding with banks' accelerated investments in technology to accommodate the surge in demand for online financial transactions.

4.2.2. Analysis by Bank Group

The DEA results reveal considerable heterogeneity across different groups of banks.

The leading group consists of banks that adopted digitalization strategies at an early stage and made substantial investments in technology, achieving average efficiency scores above 0.90.

In contrast, smaller banks and those with relatively low levels of technology investment recorded efficiency scores ranging from 0.45 to 0.60.

This disparity suggests that scale advantages and technological capabilities are increasingly becoming critical determinants of competitiveness in the modern banking industry.

More importantly, banks with higher DBEI scores also exhibit:

- Faster customer growth;
- Higher digital transaction ratios;
- Greater shares of fee-based service income;
- Higher levels of financial inclusion.

These findings suggest that digital transformation not only enhances operational efficiency but also contributes to expanding financial access.

4.3. System-GMM Estimation Results

4.3.1. Model Diagnostic Tests

Before interpreting the regression coefficients, a series of standard diagnostic tests is conducted to assess the validity and adequacy of the System-GMM model.

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Table 6.
Model Diagnostic Tests.

Test	Value
AR(1)	0.012
AR(2)	0.427
Hansen Test	0.356
Sargan Test	0.284

The diagnostic test results indicate that:

- The AR(1) test is statistically significant;
- The AR(2) test is not statistically significant;
- Both the Hansen and Sargan tests fail to reject the null hypothesis of instrument validity.

These findings suggest that the System-GMM specification is valid and that the estimates are reliable.

4.3.2. The Impact of Banking Digital Transformation on Financial Inclusion

Table 7.
System-GMM Regression Results.

Variable	Coefficient
FII(t-1)	0.482***
DBEI	0.267***
SIZE	0.091**
ROA	0.084**
CAR	0.051*
NPL	-0.074**
CIR	-0.116***

Note: The symbols *, **, and *** indicate that the estimated coefficients are statistically significant at the 10%, 5%, and 1% significance levels, respectively.

The results indicate that the coefficient of the Digital Banking Efficiency Index (DBEI) is 0.267 and statistically significant at the 1% level.

A one-unit increase in the DBEI is associated with a 0.267 increase in the Financial Inclusion Index, holding other factors constant.

The result provides empirical support for Hypothesis H1 and is consistent with the findings of Ozili [3], Sahay et al. [4], and Khera et al. [5].

From an economic perspective, this evidence suggests that digital technologies substantially reduce transaction costs, which have long been regarded as one of the most significant barriers to financial access in emerging economies.

Another noteworthy finding is that the coefficient of the lagged financial inclusion variable, FII(t−1), is 0.482 and highly statistically significant. This result reflects the persistence of the financial inclusion process: improvements in financial access achieved in the current period tend to generate spillover effects that continue into subsequent periods.

4.4. Robustness Checks

To ensure the stability and reliability of the empirical findings, three robustness tests are conducted.

First, an alternative measure of digital transformation efficiency is employed. Instead of using the composite DEA-based DBEI, the study replaces DBEI with the ratio of digital transactions to total transactions.

The results continue to indicate a positive and statistically significant effect at the 1% level.

Second, an alternative measure of financial inclusion is utilized. The original Financial Inclusion Index (FII) is replaced by the IMF Financial Access Survey (FAS) Index.

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The estimated coefficient of DBEI remains stable, ranging from 0.213 to 0.291.

Third, subgroup analyses are performed.

The sample is divided into two groups: (i) large banks and (ii) small banks.

The results reveal that the impact of digital transformation is stronger among smaller banks. This finding suggests that digital technology serves as a "gap-bridging" mechanism, enabling smaller banks to expand their service reach without requiring substantial investments in physical branch networks.

Overall, the findings remain highly consistent across alternative specifications, confirming the robustness of the study's empirical results.

4.5. PLS-SEM Results

4.5.1. Assessment of the Measurement Model

The results indicate that all measurement scales satisfy the recommended thresholds for reliability and convergent validity.

Table 8.
Measurement Model Reliability and Validity.

Latent Construct	Cronbach's Alpha	CR	AVE
DBT	0.903	0.927	0.719
eKYC	0.891	0.918	0.736
FI	0.914	0.935	0.783
SMECA	0.887	0.916	0.733

All values exceed the threshold levels recommended by Hair et al. [16], thereby confirming the reliability and validity of the measurement model.

4.5.2. Structural Model Results

Table 9.
Hypothesis Testing Results.

Relationship	Coefficient β	p-value
DBT → FI	0.412***	0.000
DBT → SMECA	0.361***	0.000
DBT → eKYC	0.687***	0.000
eKYC → FI	0.283***	0.001
FI → Bank Performance	0.247***	0.003

Note: The symbol *** indicates statistical significance at the 1% level.

The results indicate that all proposed hypotheses are supported. Among them, the strongest effect is observed in the relationship between banking digital transformation and eKYC ($\beta = 0.687$), suggesting that electronic customer identification has emerged as a core infrastructure component of the digital banking ecosystem.

4.6. Testing the Mediating Role of eKYC

To evaluate Hypothesis H3, the study employs the bootstrapping procedure with 5,000 resamples. The results reveal that:

- Direct effect (DBT → FI): $\beta = 0.412$;
- Indirect effect (DBT → eKYC → FI): $\beta = 0.194$;
- Total effect: $\beta = 0.606$.

The Variance Accounted For (VAF) reaches 32.0%.

According to the criteria proposed by Hair et al. [16], eKYC serves as a partial mediator in the relationship between banking digital transformation and financial inclusion.

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This finding carries important theoretical implications. It suggests that the effectiveness of digital transformation stems not only from technological investments per se but also from the ability to translate technological capabilities into mechanisms that reduce barriers to entry into the formal financial system. In the Vietnamese context, eKYC represents the critical link connecting digital infrastructure with the objective of expanding financial access for individuals and businesses.

4.7. Synthesis of Empirical Findings

The combined evidence from the DEA, System-GMM, and PLS-SEM analyses presents a consistent and coherent picture: banking digital transformation is not merely a process of technological modernization but has become a fundamental driver of financial inclusion in Vietnam.

First, the DEA results demonstrate that banks with higher levels of digitalization achieve superior operational efficiency and generate greater value from a given level of technology investment.

Second, the System-GMM estimates confirm that digital transformation exerts a positive, persistent, and statistically significant effect on financial inclusion.

Third, the PLS-SEM results elucidate the underlying transmission mechanism, highlighting the role of eKYC as a critical bridge between digital transformation and the expansion of financial access.

Overall, the empirical evidence consistently suggests that digital transformation is contributing to narrowing financial access gaps, expanding opportunities for individuals and businesses to access banking services, and establishing an important foundation for inclusive economic growth in the digital era.

These findings further indicate that, in emerging economies, the future competitive advantage of the financial system will no longer be determined primarily by the size of physical branch networks. Instead, it will increasingly depend on data quality, digital capabilities, and the connectivity of the broader digital financial ecosystem.

5. Discussion of Findings

The empirical results obtained from the DEA, System-GMM, and PLS-SEM analyses provide consistent evidence regarding the role of digital transformation in promoting financial inclusion in Vietnam. These findings not only support the proposed research hypotheses but also deepen our understanding of the mechanisms through which financial inclusion operates within the context of the digital economy in emerging markets.

First, the results indicate that banking digital transformation exerts a positive and statistically significant effect on financial inclusion. This finding is consistent with the argument advanced by Levine [11] concerning the intermediary role of the financial system in reducing transaction costs and improving the efficiency of resource allocation. However, in the digital era, the intermediary function of financial institutions is no longer confined to traditional deposit-taking and lending activities. Instead, it has expanded to encompass the ability to connect customers through technology-enabled platforms. This suggests that digital technology has evolved into an endogenous component of the modern financial system rather than merely serving as a supporting tool.

The System-GMM results demonstrate that improvements in the Digital Banking Efficiency Index are associated with corresponding increases in the level of financial inclusion. This finding reflects an important development: digitalization is gradually reducing traditional barriers that have historically constrained access to financial services. For decades, geographic distance has been regarded as a major obstacle preventing populations in remote and underserved areas from accessing formal banking services. However, the proliferation of digital banking, electronic payments, and online transaction platforms has enabled financial services to transcend physical constraints. In other words, the smartphone is increasingly replacing the bank branch as the primary point of financial access.

Another noteworthy finding is that the impact of digital transformation extends beyond the breadth of financial inclusion to encompass the depth of financial service usage. The results indicate that banks with higher levels of digitalization not only attract new customers but also increase the frequency with

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which existing customers use financial services. This finding is consistent with the Technology Acceptance Model proposed by Davis [12], which posits that perceived usefulness and perceived ease of use are key determinants of technology adoption. When banking services are delivered through user-friendly, convenient, and low-cost digital interfaces, customers are more likely to engage with them regularly, thereby enhancing their integration into the formal financial system.

The DEA analysis provides an additional perspective on digital transformation efficiency. The findings reveal that banks with higher digital efficiency scores also achieve higher levels of financial inclusion. This suggests that not all technology investments generate equivalent outcomes. The effectiveness of digital transformation depends largely on a bank's ability to convert technological resources into tangible value for customers. Banks that effectively leverage data, design superior user experiences, and offer integrated digital services tend to exert a stronger impact on financial inclusion.

One of the study's key contributions lies in elucidating the mediating role of eKYC. The PLS-SEM results indicate that eKYC accounts for a substantial portion of the effect of digital transformation on financial inclusion. This finding suggests that the benefits of digital transformation derive not only from technological investments but also from the capacity to reduce barriers to entry into the formal financial system. Under the traditional banking model, customers face numerous transaction costs, including travel expenses, waiting times, and administrative procedures. eKYC substantially reduces these costs, thereby expanding access to financial services for population segments that have historically been underserved.

From the perspective of SMEs, the study finds that digital transformation significantly improves access to credit. This result is particularly important for Vietnam, where SMEs account for more than 97% of all operating enterprises yet frequently encounter difficulties in obtaining bank financing. Digital technologies enable financial institutions to utilize alternative data sources, such as electronic transaction records, digital invoices, and payment histories, to assess credit risk. Consequently, firms lacking substantial collateral or lengthy credit histories can still be considered for financing.

Another important finding is the existence of a mutually reinforcing relationship between financial inclusion and bank performance. As the customer base expands, banks are able to increase deposit mobilization, diversify revenue streams, and improve operational performance. In turn, stronger financial performance generates additional resources for technological investment and innovation. This mechanism creates a virtuous cycle in which digital transformation, financial inclusion, and banking performance reinforce one another.

From a theoretical perspective, the findings contribute to the advancement of financial inclusion theory in the digital age. While earlier studies primarily emphasized the importance of branch network density or the number of financial institutions, the present results suggest that digital infrastructure and data capabilities are emerging as critical determinants of financial inclusion. This implies that theoretical models of financial development should be revised to incorporate digital technology as a central explanatory variable rather than treating it merely as an exogenous factor.

Taken together, the empirical evidence suggests that digital transformation is generating a structural shift in Vietnam's financial system. It represents not merely a process of technological modernization but also a fundamental reconfiguration of how financial services are accessed, utilized, and delivered throughout the economy.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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The authors used AI-based tools only for language refinement and reference checking. The research design, analysis, findings, and conclusions remain entirely the responsibility of the authors.

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