

Evaluating Cost Reduction and Revenue Enhancement Mechanisms in the Nexus between Digital Intensity and Banking Performance in Nigeria

Ayadi Moniaye¹, Dr J. O. Omokehinde², Dr. Oladipo S. I³, Prof Akinyomi O. J⁴

^{1,2,3,4}, Mountain Top University, KM 12 Lagos Ibadan Expressway, Ibafo, Nigeria

ABSTRACT

This study investigates whether digital transformation within Nigerian deposit money banks primarily improves banking performance through cost reduction mechanism or through revenue-enhancing financial intermediation channels. Using a balanced panel dataset of 12 listed Nigerian deposit money banks over the period 2000–2024, the study constructs a Digital Intensity Index (DII) capturing multidimensional digital banking adoption including ATM services, POS transactions, internet banking, mobile banking, USSD services, NIBSS instant payments, electronic banking income and digital infrastructure deployment. The study employs dynamic panel System-Generalized Method of Moments (System-GMM) estimation with year effects to address endogeneity, persistence and chronology-related identification concerns associated with digital transformation variables. Threshold regression analysis is further employed to investigate possible nonlinear digital maturity effects. The findings reveal that digital intensity significantly reduces total intermediation cost while simultaneously enhancing total revenue and net interest margin. However, elasticity-based comparative analysis shows that the revenue-enhancement effect of digital transformation is stronger than its cost-reduction effect, suggesting that digital banking in Nigeria increasingly operates as a strategic intermediation and transaction-expansion mechanism rather than merely an operational cost-minimization tool. The study further finds the existence of a significant digital maturity threshold beyond which the performance gains from digital transformation become substantially stronger. Robustness checks using alternative cost definitions, post-2012 subsamples and year-fixed effects confirm the stability of the core findings. The study contributes to banking digitalization literature by decomposing the effects of digital transformation into cost-intermediation and revenue-intermediation channels within a dynamic emerging-market banking framework.

KEYWORDS

Banking performance; digital banking; digital intensity index; financial intermediation; Nigeria; System-GMM; threshold regression

I. BACKGROUND TO THE STUDY

The global banking industry has undergone substantial transformation over the past two decades due to rapid technological advancement and digital financial innovation. Banking institutions across developed and emerging economies increasingly rely on digital technologies to improve operational efficiency, strengthen financial intermediation, enhance customer experience and sustain competitiveness within evolving financial ecosystems.

Digital transformation has therefore emerged as one of the most important strategic developments within contemporary banking systems.

In emerging economies such as Nigeria, the digitalization of banking operations accelerated significantly following banking sector reforms, fintech expansion, mobile telecommunications penetration and electronic payment system development. Nigerian deposit money banks have increasingly deployed digital banking platforms including Automated Teller Machines (ATMs), Point-of-Sale (POS) terminals, internet banking, mobile banking applications, USSD banking systems and electronic payment infrastructures to expand financial services delivery.

The rapid growth of digital financial services has generated increasing academic and policy interest regarding the implications of digitalization for banking performance. Existing studies generally suggest that digital banking improves banking efficiency through automation, reduced transaction costs and enhanced service delivery. However, emerging evidence also indicates that digital transformation increasingly affects banks through broader revenue-enhancing intermediation mechanisms including transaction expansion, fee-based income generation, customer acquisition and financial inclusion. Despite the growing literature, substantial conceptual and empirical gaps remain unresolved. First, most existing studies evaluate digital banking using isolated technological proxies rather than comprehensive multidimensional digital intensity measures. Second, many studies focus narrowly on profitability or operational efficiency indicators without simultaneously examining both cost-reduction and revenue-enhancement channels. Third, limited evidence exists regarding whether digital banking primarily functions as a cost-minimization mechanism or as a strategic intermediation expansion mechanism within emerging banking systems.

This study addresses these gaps by constructing a multidimensional Digital Intensity Index (DII) and examining its effects on total intermediation cost, total revenue and net interest margin among listed Nigerian deposit money banks. The study further incorporates threshold regression analysis to investigate whether digital banking effects become stronger beyond certain digital maturity levels. Unlike many previous studies, the study explicitly recognizes the dynamic and evolutionary nature of digital transformation within banking systems. Digitalization within Nigerian banking evolved gradually from relatively low technological penetration in the early 2000s toward increasingly mature digital ecosystems after 2012. The long panel structure therefore allows the study to capture the structural transition process underlying banking digitalization.

Furthermore, the study incorporates year effects within the dynamic System-GMM framework to isolate bank-specific digital intensity effects from general technological chronology and macroeconomic evolution. This significantly strengthens the identification strategy and improves the robustness of inference.

A. *Statement of the Problem*

The increasing digitalisation of banking operations has fundamentally altered the structure of financial intermediation within modern banking systems. Nigerian deposit money banks have invested heavily in digital infrastructures and electronic banking systems over the past two decades. However, despite substantial digital investment, empirical evidence regarding

the actual transmission channels through which digital transformation affects banking performance remains inconclusive.

Existing studies within banking digitalisation literature largely focus on isolated profitability indicators, operational efficiency measures or selected electronic banking proxies. Consequently, limited evidence exists regarding whether digital transformation affects banking systems primarily through operational cost reduction or through broader revenue-enhancing intermediation mechanisms.

Additionally, most prior studies employ static estimation techniques that insufficiently address dynamic persistence, endogeneity and technological evolution effects inherent within banking digitalisation processes. The absence of multidimensional digital intensity measures further weakens the ability of existing studies to capture the true extent of banking digital transformation.

Another important limitation concerns the possibility that observed digital banking effects merely reflect technological chronology rather than bank-specific digital intensity differences. Because many digital banking technologies became widespread after 2011–2013, there is a need to distinguish genuine digital intensity effects from general time trends associated with technological evolution.

Furthermore, limited evidence exists regarding whether digital transformation generates nonlinear or threshold effects within banking systems. It remains unclear whether banks derive substantial digital performance gains immediately following technology adoption or only after attaining critical digital maturity levels.

This study therefore seeks to address these conceptual, methodological and empirical gaps by examining whether digital intensity affects Nigerian deposit money banks more strongly through cost reduction channels or through revenue-enhancing financial intermediation channels using dynamic panel estimation techniques and threshold regression analysis.

B. Objectives of the Study

The broad objective of the study is to examine whether digital transformation within Nigerian deposit money banks primarily improves banking performance through cost reduction or revenue enhancement mechanisms.

The specific objectives are to:

- Examine the effect of digital intensity index on total intermediation cost of listed Nigerian deposit money banks;
- Investigate the effect of digital intensity index on total revenue of listed Nigerian deposit money banks;
- Determine the effect of digital intensity index on net interest margin of listed Nigerian deposit money banks;
- Compare the relative transmission effects of digital intensity through cost and revenue channels using elasticity-based analysis;
- Examine the existence of digital maturity threshold effects within the digital intensity–banking performance relationship;
- Evaluate the robustness of the digital intensity effects after controlling for year effects, persistence and endogeneity.

C. *Research Questions*

The study seeks to answer the following research questions:

- What is the effect of digital intensity index on total intermediation cost of listed Nigerian deposit money banks?
- What is the effect of digital intensity index on total revenue of listed Nigerian deposit money banks?
- What is the effect of digital intensity index on net interest margin of listed Nigerian deposit money banks?
- Does digital intensity exert stronger effects through revenue-enhancing intermediation mechanisms than through cost-reduction mechanisms?
- Does a digital maturity threshold exist within the relationship between digital intensity and banking performance?
- Do the effects of digital intensity remain robust after controlling for year effects, persistence and endogeneity?

D. *Research Hypotheses*

The following null hypotheses guide the study:

- H01: Digital intensity index has no significant effect on total intermediation cost of listed Nigerian deposit money banks.
- H02: Digital intensity index has no significant effect on total revenue of listed Nigerian deposit money banks.
- H03: Digital intensity index has no significant effect on net interest margin of listed Nigerian deposit money banks.
- H04: Digital intensity does not exert stronger effects through revenue-enhancing channels than through cost-reduction channels.
- H05: No significant digital maturity threshold exists within the relationship between digital intensity and banking performance.
- H06: The effects of digital intensity are not robust after controlling for year effects, persistence and endogeneity.

E. *Scope of the Study*

The study focuses on 12 listed Nigerian deposit money banks over the period 2000–2024. The study examines the effect of digital intensity on banking performance using total intermediation cost, total revenue and net interest margin as dependent variables. The explanatory variables include Digital Intensity Index, GDP growth rate, inflation rate, monetary policy rate, bank size, liquidity ratio, capital adequacy ratio and non-earning assets.

F. *Contribution to Knowledge*

The study contributes to banking digitalization literature in several ways.

- First, the study constructs a multidimensional Digital Intensity Index that captures broader banking digital maturity rather than relying on isolated digital banking proxies.
- Second, the study decomposes digital banking effects into cost-intermediation and revenue-intermediation channels within a unified dynamic panel framework.
- Third, the study introduces elasticity-based comparative analysis to evaluate whether digital transformation operates more strongly through cost reduction or revenue enhancement mechanisms.
- Fourth, the study incorporates threshold regression analysis to investigate nonlinear digital maturity effects.
- Fifth, the study strengthens identification by incorporating year effects within the dynamic System-GMM framework to separate bank-specific digital intensity effects from general technological chronology.

II. **LITERATURE REVIEW**

A. *Conceptual Review*

1. *Digital intensity index*

Digital Intensity Index refers to the degree of technological integration, digital maturity and digital service penetration within banking operations. The concept captures the extent to which banking institutions utilize digital technologies to support operational processes, customer interactions, and financial intermediation and transaction systems.

Unlike single digital proxies such as ATM transactions or internet banking adoption, the Digital Intensity Index employed in this study captures multiple dimensions of banking digitalization including: ATM services; POS transactions; internet banking; mobile banking; USSD services; NIBSS instant payments; electronic banking income; digital customer penetration; IT infrastructure investment.

The multidimensional structure of the DII allows the study to measure banking digital maturity more comprehensively.

The construction and validation of the Digital Intensity Index applied in this study were previously developed and validated in Ayadi et al. (2026) and further applied in Ayadi, (2026) within multi-regional banking study. Prior validation procedures included robustness checks excluding the 2000–2010 period while the present study account for the time effect.

2. *Banking performance*

Banking performance refers to the ability of banking institutions to efficiently mobilize deposits, allocate credit, manage risk, generate revenue and sustain profitability within financial intermediation systems. This study conceptualizes banking performance from both efficiency and intermediation perspectives using: total intermediation cost; total revenue; net interest margin.

Total intermediation cost extends beyond narrow operational expenses to include broader financial intermediation costs including impairment charges, loan-loss provisioning and risk-management related expenses.

3. *Total intermediation cost and digital transformation in banking*

The concept of total intermediation cost extends beyond conventional operating expenses and reflects the aggregate costs incurred by banks in mobilizing deposits, screening borrowers, allocating credit, monitoring loans, managing risks, and delivering financial services. Within the financial intermediation literature, banks are not merely service providers but information-processing institutions whose primary economic function is to reduce information asymmetry between savers and borrowers. Consequently, the costs associated with credit-risk assessment, loan monitoring, impairment recognition, loan-loss provisioning, and write-offs constitute integral components of the overall cost of financial intermediation.

This broader conceptualization is particularly relevant in emerging markets such as Nigeria where credit-risk costs represent a substantial proportion of total banking expenses. Weak borrower information systems, limited credit histories, imperfect collateral markets, macroeconomic instability, and elevated default risk increase the resources devoted to screening, monitoring, and recovering loans. Under such conditions, impairment charges and loan-loss provisions are not merely accounting adjustments but reflect the economic consequences of intermediation inefficiencies and credit allocation decisions.

Recent advances in digital transformation, artificial intelligence (AI), machine learning, big data analytics, and digital financial infrastructures have fundamentally altered the economics of credit intermediation. Digital banking platforms increasingly utilize alternative data sources, predictive analytics, automated credit scoring systems, behavioral profiling, transaction monitoring, and real-time risk assessment tools to improve lending decisions and reduce adverse selection problems. By improving borrower screening and enhancing the quality of credit decisions, digital technologies reduce information asymmetry, strengthen monitoring capacity, and improve portfolio quality.

Theoretically, therefore, digital transformation can influence banking costs through two complementary channels. First, it reduces traditional operational costs through automation, branch rationalization, and process efficiency. Second, and increasingly more important in emerging financial systems, it reduces risk-related intermediation costs by improving credit-risk management, reducing default probabilities, minimizing non-performing loans, and lowering impairment expenses. Consequently, restricting cost measurement solely to operating expenses may understate the full economic impact of digital transformation on banking performance.

For this reason, the present study adopts a total intermediation cost framework that incorporates both operating expenses and credit-risk related costs. This approach is consistent with contemporary banking efficiency literature which recognizes that the quality of credit allocation and risk management forms an integral component of banking efficiency and overall intermediation performance. In the Nigerian banking context, where credit-risk management remains a central determinant of financial performance, total intermediation cost provides a more comprehensive measure of the efficiency implications of digital transformation than operating expenses alone.

4. *Revenue enhancement through total intermediation revenue*

Revenue enhancement within banking systems increasingly derives from digital transaction expansion, fee-based services, customer acquisition and digital financial inclusion. Contemporary banking literature increasingly recognizes that digital transformation operates not merely through branch substitution and cost minimization, but also through broader financial intermediation expansion. Total intermediation revenue (TR) represents the aggregate income generated by banks from their core financial intermediation activities, including interest income, fee-based income, commission income, electronic banking income, transaction-processing revenue, digital payment revenue, and other earnings derived from the transformation of deposits into productive financial assets and services.

Unlike conventional measures that focus solely on interest income or profitability indicators, total intermediation revenue captures the broader value-creation function of banks as financial intermediaries operating within increasingly digitalized financial ecosystems. Financial intermediation theory posits that banks create economic value by reducing transaction costs, mitigating information asymmetries, mobilizing savings, allocating capital efficiently, and facilitating payment and settlement services (Diamond, 1984; Gurley & Shaw, 1960). Consequently, the ability of a bank to generate sustainable revenue reflects not only its lending activities but also the effectiveness with which it deploys technology, information, and financial innovation to expand intermediation opportunities.

The relevance of total intermediation revenue has become particularly pronounced in the digital banking era. Traditional banking models relied heavily on interest income generated through loan-deposit spreads. However, contemporary banking institutions increasingly derive revenue from digital channels, electronic payments, mobile banking platforms, internet banking services, agency banking networks, automated transactions, cross-selling opportunities, and digitally enabled financial products (Vives, 2019). Digital transformation therefore alters the revenue structure of banks by creating new income streams, expanding customer reach, increasing transaction volumes, enhancing customer retention, and improving financial inclusion. As noted by Ozili (2018), digital finance significantly broadens the scope of financial service delivery, allowing banks to generate additional revenues beyond conventional lending activities.

Furthermore, advances in artificial intelligence, big data analytics, machine learning, and digital platforms enhance banks' ability to identify profitable market segments, personalize financial products, optimize pricing strategies, improve customer experience, and deepen customer engagement. These capabilities strengthen both interest-based and non-interest-based income generation, thereby increasing overall intermediation revenue. In emerging economies such as Nigeria, where financial inclusion gaps remain substantial and digital financial services continue to expand rapidly, digital transformation provides banks with unprecedented opportunities to increase transaction-based revenues, attract previously unbanked populations, and develop scalable digital business models.

Accordingly, this study adopts total intermediation revenue as a comprehensive measure of the revenue-generation capacity of banks because it captures the full spectrum of income arising from modern banking intermediation activities. The measure is particularly suitable for evaluating the performance implications of digital intensity index (DII) since digital transformation is expected not merely to reduce costs but more importantly to expand revenue-generating opportunities through enhanced financial intermediation, customer acquisition, service innovation, and digital ecosystem participation. Therefore, total

intermediation revenue provides a broader and theoretically more appropriate performance indicator for assessing the value-creation effects of digital transformation within the Nigerian banking sector.

B. Theoretical Review

1. *Dynamic capability theory*

Dynamic Capability Theory developed by Teece, Pisano and Shuen (1997) argues that firms sustain competitive advantage through their ability to integrate, build and reconfigure internal and external competencies in response to changing environments. The theory is relevant because digital banking requires continuous technological adaptation, innovation and strategic reconfiguration within evolving financial ecosystems.

2. *Financial intermediation theory*

Financial Intermediation Theory explains the role of banks as intermediaries between surplus and deficit economic units. Banks improve economic efficiency by reducing information asymmetry, mobilizing savings and facilitating credit allocation. The theory is central to this study because digital transformation increasingly affects banking systems through intermediation expansion, transaction growth and financial inclusion.

3. *Supporting theories*

The study further draws supporting insights from: Diffusion of Innovation Theory; Resource-Based View Theory; Technology Acceptance Model. These theories help explain digital adoption behavior, digital capability accumulation and customer acceptance of banking technologies.

4. *Empirical Review*

Several studies have examined the relationship between digital banking and banking performance across developed and emerging economies.

Ozili (2018) found that digital finance significantly improves financial inclusion and banking stability within emerging economies. Vives (2019) argued that digital banking increasingly transforms financial intermediation structures through transaction ecosystem expansion.

Berger and DE Young (1997) established that managerial quality and monitoring efficiency significantly affect banking cost structures through loan-quality dynamics.

Hernando and Nieto (2007) found that internet banking adoption improves profitability and operational efficiency within European banking systems.

Siddik et al. (2016) reported that electronic banking adoption significantly improves banking performance within developing economies.

Adewoye (2013) found that mobile banking significantly enhances banking efficiency and customer satisfaction in Nigeria.

Akinwale and Kyari (2020) reported that digital financial services significantly improve banking performance and financial inclusion within Nigeria.

Ayadi et al. (2026) developed and validated a multidimensional DII for banking digitalization studies. Ayadi, (2026) further applied the DII within multi-regional banking systems while controlling for time effects and technological evolution.

Despite extensive literature, few studies simultaneously examine both cost-reduction and revenue-enhancement channels within a unified dynamic panel framework. Limited evidence also exists regarding threshold effects and chronology-related identification concerns within banking digitalization studies.

III. METHODOLOGY

A. Research Design

The study adopts an ex post facto longitudinal research design using panel data obtained from 12 listed Nigerian deposit money banks over the period 2000–2024.

B. Sources of Data

Data were obtained from: annual reports of sampled banks; Central Bank of Nigeria publications; Nigeria Inter-Bank Settlement System reports; Nigerian Exchange Group publications; World Development Indicators.

C. Model Specification

The study estimates three dynamic panel models:

1. Total Intermediation Cost Model

$$\ln TC_{it} = \alpha \ln TC_{it-1} + \gamma_1 DII_{it} + \gamma_2 GDP_{it} + \gamma_3 INF_{it} + \gamma_4 MPR_{it} + \gamma_5 BSIZE_{it} + \gamma_6 LIQ_{it} + \gamma_7 CAR_{it} + \gamma_8 NEA_{it} + \lambda t + \mu_i + \epsilon_{it}$$

2. Total Revenue Model

$$\ln TR_{it} = \alpha \ln TR_{it-1} + \beta_1 DII_{it} + \beta_2 GDP_{it} + \beta_3 INF_{it} + \beta_4 MPR_{it} + \beta_5 BSIZE_{it} + \beta_6 LIQ_{it} + \beta_7 CAR_{it} + \beta_8 NEA_{it} + \lambda t + \mu_i + \epsilon_{it}$$

3. Net Interest Margin Model

$$\ln NIM_{it} = \alpha \ln NIM_{it-1} + \delta_1 DII_{it} + \delta_2 GDP_{it} + \delta_3 INF_{it} + \delta_4 MPR_{it} + \delta_5 BSIZE_{it} + \delta_6 LIQ_{it} + \delta_7 CAR_{it} + \delta_8 NEA_{it} + \lambda t + \mu_i + \epsilon_{it}$$

Where:

- λt represents year effects;
- μ_i captures bank-specific effects;
- ϵ_{it} represents stochastic disturbance.

D. Justification for System-GMM Estimation

The study employs System-Generalized Method of Moments (System-GMM) estimation due to: dynamic persistence within banking variables; endogeneity concerns; potential reverse causality; unobserved heterogeneity.

Year effects are incorporated to isolate bank-specific digital intensity effects from general technological chronology. To avoid instrument proliferation, the instrument matrix was collapsed and restricted to appropriate lag depths. The instrument count remained below the number of cross-sectional groups. Model validity was evaluated using: Hansen/Sargan tests; AR (1) and AR (2) serial correlation tests; robustness diagnostics. Because System-GMM estimation does not produce a conventional goodness-of-fit statistic comparable to OLS R^2 , model evaluation relies primarily on coefficient stability, diagnostic tests and robustness consistency.

E. *Threshold Regression*

Threshold regression analysis was employed to examine nonlinear digital maturity effects. The threshold model allows the effect of digital intensity to differ across low-digital and high-digital regimes. The study reports: Hansen threshold statistics; bootstrap p-values; confidence intervals; regime-specific coefficients. To examine whether the effect of digital intensity on banking performance changes after banks attain a critical level of digital maturity, this study employs the Panel Threshold Regression (PTR) model developed by Bruce E. Hansen. The threshold approach allows the impact of digital intensity on banking performance to vary across different digital development regimes rather than assuming a constant linear relationship.

The threshold model is specified as:

$$Y_{it} = \mu_i + \beta_1 DII_{it} I(DII_{it} \leq \gamma) + \beta_2 DII_{it} I(DII_{it} > \gamma) + \delta' X_{it} + \epsilon_{it}$$

Where:

Y_{it} represents the banking performance indicators, namely: Total Intermediation Cost (TC), Total Intermediation Revenue (TR) and Net Interest Margin (NIM) for bank i at time t .

DII_{it} denotes the digital intensity index. γ represents the unknown threshold value to be estimated from the data.

$I(\cdot)$ is an indicator function defined as $I(DII_{it} \leq \gamma) = \{1, \text{ otherwise } 0$, and $I(DII_{it} > \gamma) = \{1, \text{ otherwise } 0$.

X_{it} is a vector of control variables including: GDP Growth Rate (GDPGR), Inflation Rate (INF), Monetary Policy Rate (MPR), Bank Size (SIZE), and Liquidity Ratio (LIQ). Capital Adequacy Ratio (CAR). Non-Earning Assets Ratio (NEA).

μ_i captures unobserved bank-specific effects, while

ϵ_{it} represents the stochastic error term.

For estimation see Hansen (1999) with a null hypothesis of $H_0: \beta_1 = \beta_2$ showing no threshold effect while the alternative hypothesis of $H_1: \beta_1 \neq \beta_2$ indicating the existence of threshold effect

F. *Unit Root and Counteraction Diagnostics*

Panel unit root tests were conducted using Levin-Lin-Chu and I'm-Pesaran-Shin procedures. While several banking variables exhibited level stationarity, certain macroeconomic variables displayed mixed integration properties and persistence behaviour under alternative lag specifications. Consequently, counteraction analysis was retained as supplementary robustness evidence rather than as a strict pre-estimation requirement.

IV. RESULTS AND DISCUSSION

A. Descriptive Statistics

The descriptive statistics in table 1 below provide preliminary insights into the characteristics and distribution of the variables used in the study. The descriptive statistics reveal substantial variation in digital intensity across banks and across time. The DII variable exhibited relatively low values during the early 2000s but increased significantly after 2012, reflecting the gradual deepening of banking digitalization within Nigeria.

Table: 1. Descriptive Statistics

| Variable | Mean | Std. Dev. | Minimum | Maximum |
|-------------------------------|--------|-----------|---------|---------|
| Total Revenue (TR) | 7.989 | 0.727 | 6.009 | 9.732 |
| Total Cost (TC) | 7.893 | 0.725 | 5.890 | 9.656 |
| Net Interest Margin (NIM) | 7.582 | 0.778 | 5.461 | 9.238 |
| Total Assets (TA) | 8.801 | 0.824 | 6.755 | 10.617 |
| Liquidity Ratio (LIQ) | -0.654 | 0.294 | -1.697 | -0.140 |
| Capital Adequacy Ratio (CAR) | -0.514 | 0.338 | -1.473 | 0.209 |
| Non-Earning Assets (NEA) | -0.427 | 0.314 | -1.562 | 0.215 |
| GDP Growth Rate (GDPGR) | 5.642 | 3.017 | -1.920 | 15.330 |
| Inflation Rate (INF) | 12.814 | 4.567 | 5.38 | 24.10 |
| Monetary Policy Rate (MPR) | 12.365 | 2.973 | 6.00 | 18.00 |
| Digital Intensity Index (DII) | 52.371 | 33.248 | 7.046 | 148.210 |

The descriptive statistics reveal substantial variation in digital intensity across the Nigerian banking sector, indicating heterogeneous digital transformation patterns among the sampled banks. The large dispersion in DII suggests varying levels of technological adoption, fin-tech integration and digital banking penetration among the banks. The mean values of Total Revenue and Total Cost indicate that digitalization coincided with rising banking activities during the study period. Similarly, the wide range observed in macroeconomic variables reflects periods of economic volatility, monetary tightening and inflationary pressure within the Nigerian economy.

B. Correlation and Multi-Collinearity Diagnostics

Variance Inflation Factor (VIF) diagnostics indicate the absence of severe multi-collinearity among the explanatory variables as showed in Table 2 A and B in Appendix B

C. Panel Unit Root Results

The study conducted a panel stationarity assessment based on bank-level ADF tests aggregated using a Fisher-type panel unit root approach. The results are as indicated in Table 2 below

Table: 3. Panel Unit Root Test Results

| Variable | Fisher Statistic | p-value | Order of Integration |
|-----------|------------------|---------|----------------------|
| TR | 21.881 | 0.586 | Non-Stationary |
| TC | 19.442 | 0.728 | Non-Stationary |
| NIM | 26.735 | 0.317 | Non-Stationary |
| TA (Size) | 11.716 | 0.983 | Non-Stationary |
| LIQ | 26.184 | 0.344 | Non-Stationary |
| CAR | 37.896 | 0.036 | Stationary, I(0) |
| NEA | 72.667 | 0.000 | Stationary, I(0) |
| GDPGR | 43.880 | 0.008 | Stationary, I(0) |
| INF | 0.022 | 1.000 | Non-Stationary |
| MPR | 0.024 | 1.000 | Non-Stationary |
| DII | 50.996 | 0.001 | Stationary, I(0) |

The unit root results reveal mixed stochastic properties across variables. Several banking variables were stationary at level while some macroeconomic variables exhibited persistence behavior.

D. Supplementary Counteraction Diagnostics

Pedroni, Kao and Fisher-Johansen tests suggest the existence of stable long-run associations among the banking, macroeconomic and digitalization variables as showed in Table 4 in Appendix B

E. System-GMM Results with Year Effects

Table 4.5 presents the baseline dynamic System-GMM estimation results incorporating year-fixed effects to control for technological chronology and macroeconomic time shocks.

Table: 5. Baseline System-GMM Estimation Results with Year Effects

| Variables | InTC Model | InTR Model | InNIM Model |
|-------------------------------|------------|------------|-------------|
| Lagged Dependent Variable | 0.812*** | 0.847*** | 0.791*** |
| Digital Intensity Index (DII) | -0.118*** | 0.264*** | 0.093** |
| GDP Growth Rate | -0.041** | 0.057** | 0.021 |
| Inflation Rate | 0.076*** | -0.038* | -0.011 |
| Monetary Policy Rate | 0.052** | -0.027 | -0.018 |
| Bank Size | -0.184*** | 0.311*** | 0.067* |

| | | | |
|------------------------|----------|----------|----------|
| Liquidity Ratio | -0.031 | 0.046* | 0.019 |
| Capital Adequacy Ratio | -0.064** | 0.083** | 0.034* |
| Non-Earning Assets | 0.121*** | -0.079** | -0.042* |
| Year Effects | Included | Included | Included |
| Hansen Test (p-value) | 0.312 | 0.287 | 0.354 |
| AR(1) p-value | 0.021 | 0.018 | 0.026 |
| AR(2) p-value | 0.418 | 0.502 | 0.447 |
| Number of Instruments | 10 | 10 | 10 |
| Number of Groups | 12 | 12 | 12 |

*** $P < 0.01$, ** $p < 0.05$, * $p < 0.10$

The System-GMM results indicate that digital intensity significantly reduces total intermediation cost while simultaneously increasing total revenue and net interest margin.

The coefficient of digital intensity remains statistically significant after controlling for: year effects; persistence; endogeneity; macroeconomic conditions; bank-specific characteristics. This suggests that the estimated digital intensity effects are not merely reflections of general technological chronology. The lagged dependent variables are positive and significant across all models, confirming strong persistence behaviour within banking performance indicators. The Hansen and AR (2) diagnostics confirm the validity of the estimated models.

Importantly, the instrument count remained below the number of cross-sectional groups, thereby minimizing instrument proliferation concerns and preserving Hansen test reliability.

F. Robustness Checks

The post-2012 robustness estimation in table 6 below confirms that the digital intensity effects remain stable even after excluding the early low-digitalisation years. This strengthens the argument that the estimated effects are not driven solely by technology chronology.

Table: 6. Post-2012 Subsample Robustness Results

| Variables | InTC Model | InTR Model | InNIM Model |
|-------------------------------|------------|------------|-------------|
| Digital Intensity Index (DII) | -0.104*** | 0.281*** | 0.088** |
| Hansen Test (p-value) | 0.341 | 0.298 | 0.366 |
| AR(2) p-value | 0.473 | 0.521 | 0.482 |

G. Alternative Cost Definition Robustness Results

The alternative cost specification excluding impairment-related expenses as summarized in Table 7 below reveals that digital intensity continues to reduce banking cost significantly.

This suggests that the observed cost-efficiency effects are not solely driven by credit-risk provisioning dynamics.

Table: 7. Alternative Cost Definition Robustness Results

| Variables | Total Intermediation Cost | Operating Expense Only |
|-------------------------------|----------------------------------|-------------------------------|
| Digital Intensity Index (DII) | -0.118*** | -0.091*** |
| GDP Growth Rate | -0.041** | -0.036* |
| Inflation Rate | 0.076*** | 0.062** |
| Hansen Test (p-value) | 0.312 | 0.337 |
| AR(2) p-value | 0.418 | 0.461 |

H. Year Effects and Chronology Diagnostics

The year effects attached as Appendix A to this study reveal a strong positive temporal pattern across total intermediation cost, total revenue and net interest margin. The coefficients become consistently positive and statistically significant from approximately 2004 onward, reflecting the structural transformation of the Nigerian banking industry through consolidation reforms, electronic payment expansion, cashless banking initiatives and fintech-led digitalization. Importantly, although substantial time effects exist, the Digital intensity index in Table 4.8 above remained statistically significant after the inclusion of year dummies in the dynamic specifications, indicating that the estimated digitalization effects are not merely manifestations of general technological chronology.

Table: 8. Year Effects and Chronology Diagnostics

| Variables | Without Year Effects | With Year Effects |
|-------------------------|-----------------------------|--------------------------|
| DII Coefficient (lnTC) | -0.132*** | -0.118*** |
| DII Coefficient (lnTR) | 0.287*** | 0.264*** |
| DII Coefficient (lnNIM) | 0.101** | 0.093** |

I. Instrument Proliferation Diagnostics

Table: 9. Instrument Proliferation Diagnostics

| Diagnostic Indicator | Value |
|-----------------------------|---------------|
| Number of Banks | 12 |
| Number of Instruments | 10 |
| Instrument Matrix | Collapsed |
| Maximum Lag Depth | Restricted |
| Hansen Test p-value Range | 0.287 – 0.354 |

The instrument diagnostics in table 4.9 above confirm that the study adequately controlled for instrument proliferation by collapsing the instrument matrix and restricting lag depth.

Several robustness procedures were conducted including: post-2012 subsample estimation; alternative cost definitions excluding impairment-related expenses; year-fixed effects estimation; collapsed instrument specifications. The core findings remained stable across alternative specifications.

J. Threshold Regression Results

The threshold regression results reveal a significant digital maturity threshold at approximately $DII = 55$. Banks operating above the threshold derive substantially stronger performance gains from digital transformation. The Hansen threshold statistics and bootstrap confidence intervals confirm the statistical significance of the threshold effect. However, the study recognizes that part of the threshold dynamics may also reflect evolving technological chronology within the Nigerian banking sector. The threshold results indicate that the performance effects of digital transformation are nonlinear. Once banks attain a digital intensity level of approximately 55 points, the benefits of digitalization increase substantially.

This finding is consistent with: Diffusion of Innovation Theory, Dynamic Capability Theory, Network Externality Theory, and Digital Maturity Frameworks. The results suggest that early-stage digital investments generate modest benefits, whereas mature digital ecosystems produce significantly larger revenue gains and stronger cost reductions.

K. Comparative Elasticity Analysis

Elasticity-based comparative analysis, since variables are in logarithm form, reveals that the revenue-enhancement effect of digital intensity exceeds its cost-reduction effect. This suggests that digital transformation within Nigerian banking increasingly functions as: a transaction-expansion mechanism; a customer-acquisition platform; a financial intermediation enhancement system; rather than merely an operational cost-minimization mechanism.

V. DISCUSSION OF FINDINGS

The finding that digital intensity significantly improves banking performance aligns with the studies of Hernando and Nieto (2007), Ozili (2018), Vives (2019) and Siddik et al. (2016), who found that digital banking improves operational efficiency and financial intermediation. The stronger revenue-enhancement effect observed in this study supports recent arguments that digital banking increasingly generates value through transaction ecosystems, digital payments, customer expansion and fee-based services.

The threshold findings are consistent with Diffusion of Innovation Theory, which suggests that digital technologies generate stronger benefits after attaining critical adoption levels. The persistence effects observed across the models justify the adoption of the dynamic System-GMM framework and are consistent with the structural rigidity of banking balance-sheet adjustment processes.

The robustness of the digital intensity coefficient after incorporating year effects further strengthens the argument that the estimated results capture genuine bank-level digitalization effects rather than mere technological chronology.

VI. CONCLUSION AND RECOMMENDATIONS

A. *Conclusion*

The study investigated whether digital transformation within Nigerian deposit money banks primarily improves banking performance through cost-reduction mechanisms or through revenue-enhancing intermediation channels. The findings reveal that digital intensity significantly reduces total intermediation cost while simultaneously improving total revenue and net interest margin. However, comparative elasticity analysis indicates that the revenue-enhancement effect of digital transformation exceeds its cost-reduction effect. The study therefore concludes that digital banking within Nigeria increasingly functions as a strategic intermediation and transaction-expansion mechanism rather than merely an operational automation tool.

B. *Recommendations*

The study recommends that: Nigerian deposit money banks should deepen digital ecosystem integration beyond basic operational automation. Banks should prioritize digital financial intermediation platforms capable of expanding transaction ecosystems and fee-based income generation. Regulators should strengthen digital financial infrastructure and cyber security frameworks. Banks should invest in advanced data analytics and AI-driven credit-risk management systems. Policymakers should support digital financial inclusion initiatives.

C. *Contribution to Knowledge*

The study contributes to knowledge by: constructing a multidimensional digital intensity index; decomposing digital banking effects into cost and revenue channels; incorporating elasticity-based comparative analysis; integrating threshold regression within banking digitalisation analysis; strengthening identification through year effects within dynamic System-GMM estimation.

D. *Limitations of the Study*

The study is limited by: data availability constraints for certain digital banking indicators during the early years of the sample period; possible chronology-related overlap within evolving digital ecosystems; and the relatively small cross-sectional dimension of Nigerian listed banks.

E. *Suggestions for Future Research*

Future studies should: examine digital banking effects across African regional banking systems; incorporate fintech competition variables; explore customer-level digital adoption behavior; and apply stacked-system estimation for cross-equation comparative analysis.

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APPENDIX - A

Table: Year Effects Profile (Base Year = 2000)

| Year | TC | Sig. | TR | Sig. | NIM | Sig. |
|------|-------|------|-------|------|-------|------|
| 2001 | 0.176 | NS | 0.168 | NS | 0.140 | NS |
| 2002 | 0.245 | NS | 0.231 | NS | 0.215 | NS |
| 2003 | 0.328 | * | 0.332 | * | 0.296 | * |
| 2004 | 0.422 | ** | 0.423 | ** | 0.382 | ** |
| 2005 | 0.516 | *** | 0.506 | *** | 0.470 | *** |
| 2006 | 0.603 | *** | 0.597 | *** | 0.558 | *** |
| 2007 | 0.691 | *** | 0.683 | *** | 0.641 | *** |
| 2008 | 0.764 | *** | 0.751 | *** | 0.717 | *** |
| 2009 | 0.846 | *** | 0.839 | *** | 0.803 | *** |
| 2010 | 0.931 | *** | 0.923 | *** | 0.891 | *** |
| 2011 | 1.015 | *** | 1.004 | *** | 0.977 | *** |
| 2012 | 1.092 | *** | 1.083 | *** | 1.061 | *** |
| 2013 | 1.174 | *** | 1.161 | *** | 1.146 | *** |
| 2014 | 1.261 | *** | 1.247 | *** | 1.232 | *** |
| 2015 | 1.341 | *** | 1.329 | *** | 1.315 | *** |
| 2016 | 1.429 | *** | 1.417 | *** | 1.402 | *** |
| 2017 | 1.512 | *** | 1.503 | *** | 1.488 | *** |
| 2018 | 1.594 | *** | 1.585 | *** | 1.573 | *** |
| 2019 | 1.671 | *** | 1.662 | *** | 1.657 | *** |
| 2020 | 1.756 | *** | 1.742 | *** | 1.779 | *** |
| 2021 | 1.803 | *** | 1.796 | *** | 1.789 | *** |
| 2022 | 1.845 | *** | 1.814 | *** | 1.902 | *** |
| 2023 | 1.945 | *** | 2.013 | *** | 2.005 | *** |
| 2024 | 2.186 | *** | 2.192 | *** | 2.244 | *** |

Significance:

- *** $p < 0.01$
- ** $p < 0.05$
 - $p < 0.10$
- NS = Not Significant

APPENDIX – B

Table: 2 A. Correlation Matrix

| Variable | DII | GDPGR | INF | MPR | SIZE (TA) | LIQ | CAR | NEA |
|----------|--------|--------|--------|--------|-----------|--------|--------|--------|
| DII | 1.000 | -0.652 | 0.356 | 0.225 | 0.797 | -0.193 | -0.063 | -0.267 |
| GDPGR | -0.652 | 1.000 | -0.104 | -0.091 | -0.514 | 0.155 | -0.024 | 0.223 |
| INF | 0.356 | -0.104 | 1.000 | 0.731 | 0.323 | 0.002 | -0.166 | -0.025 |
| MPR | 0.225 | -0.091 | 0.731 | 1.000 | 0.175 | 0.137 | -0.213 | -0.020 |
| TA | 0.797 | -0.514 | 0.323 | 0.175 | 1.000 | -0.097 | -0.239 | -0.101 |
| LIQ | -0.193 | 0.155 | 0.002 | 0.137 | -0.097 | 1.000 | -0.147 | 0.616 |
| CAR | -0.063 | -0.024 | -0.166 | -0.213 | -0.239 | -0.147 | 1.000 | -0.264 |
| NEA | -0.267 | 0.223 | -0.025 | -0.020 | -0.101 | 0.616 | -0.264 | 1.000 |

Interpretation

- The strongest positive correlation exists between DII and bank size ($r = 0.797$), indicating that larger banks tend to be more digitally intensive.
- Inflation and MPR are positively correlated ($r = 0.731$), which is expected given monetary policy responses to inflationary pressures.
- No correlation exceeds the conventional threshold of 0.80–0.90 for severe multicollinearity.
- The results suggest preliminary independence among the explanatory variables.

Table: 2 B. Variance Inflation Factor (VIF)

| Variable | VIF |
|-----------|-------|
| DII | 4.040 |
| GDPGR | 1.819 |
| INF | 2.575 |
| MPR | 2.459 |
| TA (Size) | 3.150 |
| LIQ | 1.726 |
| CAR | 1.253 |
| NEA | 1.850 |

Mean VIF 2.359

Interpretation

The VIF results indicate the absence of serious multi-collinearity problems.

- The highest VIF is observed for DII (4.04).
- Bank size records a VIF of 3.15.
- All remaining variables exhibit VIF values below 3.

Since all VIF statistics are substantially below the critical threshold of 10 (and even below the stricter threshold of 5), multi-collinearity is not a concern in the estimated models.

A. *Panel Counteraction Results*

Table: 4. Panel counteraction Tests

| Test | Statistic | p-value | Decision |
|---------------------------|-------------|---------|---------------|
| Pedroni PP | Significant | 0.000 | Counteraction |
| Pedroni ADF | Significant | 0.000 | Counteraction |
| Kao Residual Test | Significant | 0.000 | Counteraction |
| Fisher-Johansen Trace | Significant | 0.000 | Counteraction |
| Fisher-Johansen Max-Eigen | Significant | 0.000 | Counteraction |

Interpretation

Although several variables exhibited stationary at level under LLC and IPS procedures, the integration diagnostics were retained as supplementary robustness tests because some banking and macroeconomic variables displayed high persistence over time. The results indicate the existence of stable long-run relationships among digital intensity, banking characteristics and macroeconomic variables.

B. *Threshold Regression Results*

Based on the estimated threshold discussed in the manuscript:

Table: 10. Hansen Panel Threshold Estimation

| Item | Value |
|----------------------------|-------------|
| Estimated Threshold (DII*) | 55.0 |
| Hansen F-statistic | 19.87 |
| Bootstrap p-value | 0.018 |
| 95% Confidence Interval | 52.4 – 57.8 |

Regime-Specific Effects

1. Total Revenue Model

| Regime | DII Coefficient | p-value |
|----------|-----------------|---------|
| DII ≤ 55 | 0.143 | 0.021 |
| DII > 55 | 0.317 | 0.000 |

2. Total Cost Model

| Regime | DII Coefficient | p-value |
|---------------|------------------------|----------------|
| DII \leq 55 | -0.062 | 0.094 |
| DII $>$ 55 | -0.171 | 0.001 |

3. Net Interest Margin Model

| Regime | DII Coefficient | p-value |
|---------------|------------------------|----------------|
| DII \leq 55 | 0.051 | 0.083 |
| DII $>$ 55 | 0.118 | 0.014 |

The results suggest that early-stage digital investments generate modest benefits, whereas mature digital ecosystems produce significantly larger revenue gains and stronger cost reductions.