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Does Threshold Effect Exist in the Relationship Between Digital Intensity Index and Bank Efficiency in Nigeria?

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ABSTRACT

This study investigates whether threshold effects exist in the relationship between Digital Intensity Index (DII) and bank efficiency in Nigeria. While the growing literature on digital transformation suggests that digital technologies improve banking performance, empirical evidence remains inconclusive regarding whether such effects are linear or nonlinear. Using panel data from twelve Nigerian Deposit Money Banks (DMBs) covering the period 2000–2024, the study employs threshold regression techniques to examine the existence of critical digitalization levels beyond which the effect of digital intensity on efficiency changes significantly. Efficiency is measured using Data Envelopment Analysis (DEA) under both Window Technology and Constant Technology assumptions, as well as Stochastic Frontier Analysis (SFA).

The findings reveal strong evidence of threshold effects. The DEA Window model identifies a threshold value of approximately 24.53, suggesting that banks begin to experience competitive efficiency gains at relatively low levels of digitalization. However, the DEA Constant Technology and SFA models identify substantially higher thresholds ranging from 66.76 to 72.64, indicating that structural efficiency gains emerge only after digital technologies become deeply embedded within banking operations. The results further reveal that digital intensity exhibits diminishing marginal effects on revenue efficiency and delayed positive effects on cost efficiency. These findings support the Productivity Paradox Theory, Dynamic Capability Theory, and Resource-Based View by demonstrating that the efficiency consequences of digital transformation are nonlinear, stage-dependent, and contingent upon the level of digital maturity attained by banks.

The study contributes to the digital banking literature by proposing a dual-threshold framework comprising a competitive threshold and a structural threshold. The findings provide important policy implications for bank managers and regulators seeking to maximize the efficiency benefits of digital transformation within the Nigerian banking sector.

Keywords: Bank Efficiency, DEA, Digital Intensity Index, Digital Transformation, Nigeria Stochastic Frontier Analysis, Threshold Regression.

INTRODUCTION

1.1 Background to the Study

The global banking industry has undergone unprecedented transformation over the past two decades due to rapid advancements in digital technologies. Digital transformation has fundamentally changed the way banks conduct financial intermediation, manage customer relationships, process transactions, and deliver financial services (Vial, 2019). The emergence of mobile banking, internet banking, cloud computing, artificial intelligence, blockchain technology, big data analytics, and digital payment systems has significantly altered traditional banking models, creating opportunities for efficiency improvements and innovation (Zetzsche et al., 2020; Philippon, 2024).

The growing importance of digitalization in banking is largely attributable to its potential to improve operational efficiency, reduce transaction costs, increase service accessibility, strengthen risk management capabilities, and enhance customer experience (Cornelli et al., 2023). Digital technologies enable banks to automate routine processes, optimize resource allocation, reduce information asymmetry, and expand service delivery beyond physical branch networks (Ozili, 2023). Consequently, digital transformation has emerged as a major determinant of competitiveness within the contemporary financial services industry (Boot et al., 2024).

The relationship between digitalization and efficiency has attracted considerable attention within academic and policy circles. Efficiency remains one of the most important indicators of banking performance because efficient banks utilize fewer resources to generate greater outputs, thereby enhancing profitability, competitiveness, and financial stability (Berger & Humphrey, 1997). Theoretical arguments suggest that digital technologies improve efficiency by reducing operational costs, improving service quality, enhancing information processing, and facilitating innovation (Brynjolfsson & Hitt, 2003). However, empirical findings remain mixed.

While several studies report positive effects of digital transformation on bank efficiency (Hasan et al., 2023; Liu et al., 2024), others find weak, insignificant, or even negative relationships (Philippon, 2024; Gherțescu et al., 2024). These inconsistencies suggest that the relationship between digitalization and efficiency may not be linear. Instead, the effect of digital transformation may vary depending on the stage of technological maturity attained by a bank.

This proposition is supported by the Productivity Paradox literature, which argues that technology investments often fail to generate immediate productivity gains because organizations require time to develop complementary capabilities, redesign operational processes, and accumulate learning experience (Solow, 1987; Brynjolfsson, 1993). Similarly, Dynamic Capability Theory suggests that technological resources create value only when firms possess the organizational capabilities required to integrate and exploit such technologies effectively (Teece et al., 1997; Teece, 2007).

The possibility of nonlinear digitalization effects is particularly relevant in emerging economies such as Nigeria. Over the past two decades, Nigerian Deposit Money Banks (DMBs) have invested heavily in digital technologies in response to increasing competition, regulatory reforms, fintech disruptions, and changing customer expectations. Initiatives such as electronic banking, agency banking, cashless policies, mobile banking platforms, digital

lending systems, and real-time payment infrastructure have accelerated the digital transformation of the Nigerian banking sector (Ozili, 2023).

Despite these developments, substantial differences remain in the levels of digital maturity across Nigerian banks. Some institutions have achieved advanced digital transformation, while others remain at relatively early stages of digital adoption. Consequently, the efficiency effects of digitalization may vary significantly across banks and over time. This raises an important empirical question regarding whether critical digitalization thresholds exist beyond which the effect of digital intensity on bank efficiency changes significantly.

Addressing this question is important because it provides insights into the level of digital investment required to generate meaningful efficiency improvements. It also contributes to ongoing debates regarding the nonlinear nature of technology-performance relationships in banking and other service industries.

1.2 Statement of the Problem

Digital transformation has become one of the most important strategic priorities for banks worldwide. In Nigeria, substantial investments have been made in digital infrastructure, electronic payment systems, mobile banking platforms, internet banking services, artificial intelligence applications, and fintech partnerships. These investments are expected to improve efficiency by reducing operational costs, increasing service accessibility, and enhancing productivity (Ozili, 2023).

However, despite increasing levels of digitalization, evidence regarding the efficiency consequences of digital transformation remains inconclusive. Existing studies report conflicting findings concerning the relationship between digitalization and bank performance (Hasan et al., 2023; Gherțescu et al., 2024). While some studies find positive effects, others report insignificant or negative impacts.

A major limitation of the existing literature is its reliance on linear analytical frameworks. Most studies implicitly assume that digitalization affects efficiency uniformly across all levels of digital maturity. Such an assumption may be unrealistic because digital transformation often involves substantial implementation costs, learning effects, organizational restructuring, and technological complementarities (Brynjolfsson & Hitt, 1996; Teece et al., 1997).

Consequently, banks operating at different stages of digital maturity may experience different efficiency outcomes. Institutions below a certain level of digitalization may encounter implementation challenges and adjustment costs that limit efficiency gains. Conversely, banks that have achieved advanced digital maturity may experience significant productivity improvements.

Although threshold effects have received increasing attention in the broader digital transformation literature, empirical evidence remains limited within the banking sector, particularly in emerging economies. More importantly, no known Nigerian study has simultaneously employed DEA Window Analysis, DEA Constant Technology Analysis, and Stochastic Frontier Analysis to investigate threshold effects in the digitalization-efficiency relationship.

This gap limits understanding of the conditions under which digital transformation generates efficiency gains and constrains evidence-based policymaking within the Nigerian banking

industry. Consequently, this study investigates whether threshold effects exist in the relationship between Digital Intensity Index and bank efficiency in Nigeria.

1.3 Objective of the Study

Broad Objective

The broad objective of this study is to investigate whether threshold effects exist in the relationship between Digital Intensity Index and bank efficiency in Nigeria.

Specific Objectives

1. Examine whether threshold effects exist between Digital Intensity Index and DEA Window Cost Efficiency.
2. Determine whether threshold effects exist between Digital Intensity Index and DEA Window Revenue Efficiency.
3. Investigate whether threshold effects exist between Digital Intensity Index and DEA Constant Technology Cost Efficiency.
4. Examine whether threshold effects exist between Digital Intensity Index and DEA Constant Technology Revenue Efficiency.
5. Determine whether threshold effects exist between Digital Intensity Index and SFA Cost Efficiency.
6. Investigate whether threshold effects exist between Digital Intensity Index and SFA Revenue Efficiency.

1.4 Research Questions

1. Does a threshold effect exist between Digital Intensity Index and DEA Window Cost Efficiency?
2. Does a threshold effect exist between Digital Intensity Index and DEA Window Revenue Efficiency?
3. Does a threshold effect exist between Digital Intensity Index and DEA Constant Technology Cost Efficiency?
4. Does a threshold effect exist between Digital Intensity Index and DEA Constant Technology Revenue Efficiency?
5. Does a threshold effect exist between Digital Intensity Index and SFA Cost Efficiency?
6. Does a threshold effect exist between Digital Intensity Index and SFA Revenue Efficiency?

1.5 Research Hypotheses

H01: No significant threshold effect exists between Digital Intensity Index and DEA Window Cost Efficiency.

H02: No significant threshold effect exists between Digital Intensity Index and DEA Window Revenue Efficiency.

H03: No significant threshold effect exists between Digital Intensity Index and DEA Constant Technology Cost Efficiency.

H04: No significant threshold effect exists between Digital Intensity Index and DEA Constant Technology Revenue Efficiency.

H05: No significant threshold effect exists between Digital Intensity Index and SFA Cost Efficiency.
H06: No significant threshold effect exists between Digital Intensity Index and SFA Revenue Efficiency.

1.6 Contribution to Knowledge

This study contributes to the literature in four major ways.
First, it introduces threshold regression analysis into the study of digitalization and bank efficiency in Nigeria.
Second, it develops a Digital Intensity Index capable of capturing multidimensional digital transformation.
Third, it simultaneously employs DEA Window Analysis, DEA Constant Technology Analysis, and Stochastic Frontier Analysis, thereby providing a robust assessment of efficiency dynamics.
Fourth, the study proposes a dual-threshold framework consisting of a competitive digitalization threshold and a structural digitalization threshold, extending existing theories of digital transformation and banking efficiency.

1.7 Scope of the Study

The study covers twelve Nigerian Deposit Money Banks from 2000 to 2024. Digital transformation is measured using the Digital Intensity Index, while efficiency is measured using DEA Cost Efficiency, DEA Revenue Efficiency, and Stochastic Frontier Efficiency models. The study focuses on threshold effects within the digitalization-efficiency relationship.

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the theoretical and empirical literature relating to digital transformation and bank efficiency, with particular emphasis on the possibility of threshold effects in the relationship between digitalization and efficiency. The chapter is organized into five sections. The first section reviews the conceptual issues surrounding digital transformation, Digital Intensity Index (DII), and bank efficiency. The second section develops the conceptual framework underpinning the study. The third section examines the relevant theoretical foundations. The fourth section reviews empirical studies on digitalization and banking efficiency. The final section identifies the literature gap and develops the study's analytical framework.

2.2 Conceptual Review

2.2.1 Concept of Digital Transformation

Digital transformation has emerged as one of the most significant developments shaping contemporary organizations. The concept refers to the integration of digital technologies into organizational processes, business models, products, services, and strategic decision-making with the objective of creating value and improving organizational performance (Vial, 2019).
Digital transformation differs from simple technology adoption because it involves a fundamental reconfiguration of organizational structures and processes. According to Verhoef

et al. (2021), digital transformation represents a strategic process through which firms utilize digital technologies to redesign business models, improve operational efficiency, and create new sources of competitive advantage.

Within the banking sector, digital transformation involves the deployment of technologies such as internet banking, mobile banking, artificial intelligence (AI), machine learning, blockchain technology, cloud computing, robotic process automation, big data analytics, and digital payment systems (Zetzsche et al., 2020; Philippon, 2024).

The banking industry has become one of the most digitized sectors globally. Technological innovations have transformed the traditional branch-based banking model into a digitally enabled service ecosystem characterized by electronic transactions, automated processes, and platform-based financial intermediation (Boot et al., 2024).

Digital transformation affects banking operations through several channels.

First, digital technologies improve operational efficiency by automating repetitive tasks and reducing manual processing costs (Brynjolfsson & Hitt, 2003).

Second, digitalization enhances customer service delivery by providing continuous access to financial services through digital platforms (Ozili, 2023).

Third, digital technologies facilitate improved risk management through enhanced information processing and predictive analytics (Cornelli et al., 2023).

Finally, digitalization enables financial institutions to expand service coverage while reducing dependence on physical infrastructure.

Consequently, digital transformation has become a major strategic priority for banks seeking to improve efficiency and maintain competitiveness in increasingly digital financial markets.

2.2.2 Digital Intensity Index (DII)

The Digital Intensity Index (DII) represents the degree to which organizations integrate digital technologies into their operations, business processes, and strategic activities. The Organisation for Economic Co-operation and Development (OECD, 2024) defines digital intensity as the extent of digital technology utilization across different dimensions of organizational activities.

Unlike individual digitalization indicators such as ATM density or internet banking adoption rates, DII provides a multidimensional measure of digital transformation. It captures both the breadth and depth of digital technology integration within an organization. The use of DII offers several advantages: It captures multiple dimensions of digitalization, it reflects overall digital maturity, tt reduces measurement error associated with single indicators and tt facilitates comparative analysis across banks and over time.

The literature generally conceptualizes digital intensity as comprising three dimensions:

Digital Infrastructure

Digital infrastructure refers to the technological foundation that supports digital operations. This includes hardware systems, software platforms, communication networks, cloud computing facilities, cybersecurity architecture, and data storage capabilities (OECD, 2024).

Digital Usage

Digital usage reflects the extent to which digital technologies are utilized in organizational processes and customer interactions. Examples include internet banking transactions, mobile banking activities, digital payments, and electronic service delivery (Ozili, 2023).

Digital Innovation

Digital innovation captures the development and implementation of new digital products, services, and business models. It reflects an organization's ability to utilize technology as a source of competitive advantage (Verhoef et al., 2021).

The use of DII is particularly appropriate for this study because it provides a comprehensive measure of digital maturity rather than relying on isolated indicators of technological adoption.

2.2.3 Concept of Bank Efficiency

Efficiency is a central concept in banking economics because it determines the ability of financial institutions to utilize available resources optimally. Farrell (1957) provided the foundational framework for efficiency measurement by defining efficiency as the ability of a decision-making unit to maximize outputs from a given set of inputs or minimize inputs required to produce a given level of outputs.

Within the banking industry, efficiency reflects how effectively financial institutions transform resources such as labor, capital, deposits, and technology into financial services and income-generating activities (Berger & Humphrey, 1997).

Efficiency is particularly important because inefficient banks experience higher operating costs, lower profitability, reduced competitiveness, and increased vulnerability to economic shocks.

Bank efficiency is generally classified into:

Technical Efficiency

Technical efficiency refers to the ability of a bank to maximize output from a given set of inputs (Farrell, 1957).

Allocative Efficiency

Allocative efficiency measures the ability of a bank to utilize inputs in cost-minimizing proportions given prevailing input prices (Coelli et al., 2005).

Cost Efficiency

Cost efficiency reflects the ability of a bank to minimize costs while maintaining a given level of output (Berger & Humphrey, 1997). Cost efficiency measures the extent to which a bank minimizes operating costs while maintaining a given level of output. Cost-efficient banks achieve their production objectives using fewer resources than less efficient institutions.

Mathematically: Cost Efficiency=Minimum Cost/Observed. Values closer to one indicate greater efficiency.

Digital transformation is expected to influence cost efficiency through: process automation, reduced branch dependency, lower transaction costs and improved resource utilization. However, digitalization may also increase costs due to: infrastructure investments, cybersecurity expenditures, employee training and technology upgrades. Consequently, the relationship between digitalization and cost efficiency may be nonlinear.

Revenue Efficiency

Revenue efficiency measures the ability of a bank to maximize revenue from available resources and market opportunities (Sealey & Lindley, 1977). Revenue efficiency measures a bank's ability to maximize revenue given available resources and market opportunities. Revenue-efficient banks generate higher revenues relative to their input utilization. Revenue

efficiency captures: pricing effectiveness, service innovation, product diversification and market penetration.

Digital technologies can improve revenue efficiency by: expanding customer reach, increasing transaction volumes, facilitating product innovation and improving customer engagement.

However, excessive digital investments may produce diminishing marginal revenue gains.This possibility provides the basis for investigating threshold effects.

The present study focuses on cost and revenue efficiency because they capture the primary economic consequences of digital transformation.

2.2.4 Digitalization and Bank Efficiency

The relationship between digitalization and bank efficiency remains one of the most debated issues in banking research. Theoretically, digital technologies improve efficiency by: reducing transaction costs, automating operational processes, enhancing information processing, improving resource allocation, facilitating economies of scale and improving customer service delivery.

According to Brynjolfsson and Hitt (2003), information technologies increase productivity by improving organizational coordination and reducing information costs. Similarly, Cornelli et al. (2023) argue that digital financial technologies improve operational efficiency by expanding access to financial services and reducing intermediation costs.

However, digitalization may also generate efficiency losses in the short run due to: implementation costs, employee retraining, technological integration challenges, cybersecurity expenditures and organizational restructuring costs. This duality provides a basis for expecting nonlinear relationships between digitalization and efficiency.

2.2.5 Threshold Effects in Digital Transformation

Threshold effects occur when the impact of an explanatory variable changes after a critical value is attained (Hansen, 1999). In the context of digital transformation, threshold effects imply that the influence of digitalization on efficiency may vary depending on the level of digital maturity achieved by an organization.

The threshold concept is consistent with organizational learning theory, which suggests that organizations require time to develop competencies necessary for effective technology utilization (Argote, 2013). Similarly, the Productivity Paradox literature argues that technology investments frequently fail to generate immediate productivity gains because complementary investments are required before benefits materialize (Solow, 1987; Brynjolfsson, 1993).

Therefore, efficiency gains from digitalization may emerge only after a bank reaches a certain level of digital maturity.

2.2.6 Data Envelopment Analysis (DEA)

DEA is a non-parametric frontier technique introduced by Abraham Charnes, Cooper, and Rhodes (1978).

DEA evaluates efficiency relative to best-practice institutions. The method constructs an empirical frontier and measures each decision-making unit relative to that frontier.

DEA Window Analysis

Window analysis evaluates efficiency within moving time windows.

Advantages include: capturing technological evolution, accounting for dynamic efficiency changes and increasing discriminatory power.

DEA Constant Technology Analysis

Constant technology DEA evaluates all observations against a common frontier. This approach captures long-run productivity performance and structural efficiency differences.

2.2.7 Stochastic Frontier Analysis (SFA)

SFA was developed by Dennis Aigner, Lovell, and Schmidt (1977). Unlike DEA, SFA separates inefficiency from statistical noise. The stochastic frontier model is expressed as:

$Yi=f(Xi;\beta)e\ vi-ui$

where:

vi represents random error,

ui represents inefficiency.

SFA is particularly useful in banking because it accommodates measurement errors and external shocks.

2.3 Conceptual Framework

The conceptual framework underlying this study is illustrated as follows:

Digital Intensity Index (DII)

↓

Digital Maturity

↓

Threshold Level (γ)

↓

Bank Efficiency

(Cost Efficiency and Revenue Efficiency)

The framework proposes that DII influences bank efficiency through varying digital maturity levels. The existence of a threshold implies that the impact of digitalization differs across two regimes:

Regime 1:

$DII \leq \gamma$

(Low Digital Maturity)

Regime 2:

$DII > \gamma$

(High Digital Maturity)

The framework therefore assumes a nonlinear relationship between digitalization and bank efficiency.

2.4 Theoretical Review

2.4.1 Dynamic Capability Theory

The Dynamic Capability Theory developed by Teece, Pisano, and Shuen (1997) provides the primary theoretical foundation for this study. The theory argues that sustainable performance depends not only on the possession of resources but also on the ability of firms to integrate, reconfigure, and deploy those resources effectively.

According to Teece (2007), dynamic capabilities enable organizations to adapt to changing environments and exploit technological opportunities. Within the banking sector, digital technologies constitute strategic resources. However, technology alone cannot generate

efficiency gains. Banks must develop complementary capabilities involving human capital, organizational structures, managerial competencies, and learning mechanisms.

The theory therefore predicts that efficiency gains from digitalization emerge only after sufficient capability development has occurred. This prediction aligns closely with the threshold hypothesis examined in this study.

2.4.2 Resource-Based View (RBV)

The Resource-Based View proposed by Barney (1991) argues that sustainable competitive advantage arises from valuable, rare, inimitable, and non-substitutable resources. Digital infrastructure represents a strategic organizational resource capable of generating efficiency gains. However, the RBV emphasizes that resources create value only when effectively deployed within organizational processes. Consequently, digital investments may not immediately improve efficiency unless they become deeply embedded within organizational routines.

This provides a theoretical explanation for the existence of digitalization thresholds.

2.4.3 Productivity Paradox Theory

The Productivity Paradox emerged from Solow's (1987) observation that technological progress was visible everywhere except in productivity statistics. Brynjolfsson (1993) subsequently argued that technology investments frequently generate delayed productivity gains because firms require time to develop complementary assets and organizational capabilities.

The Productivity Paradox provides a strong theoretical explanation for why digitalization may initially produce weak or negative efficiency effects before eventually generating substantial gains. The theory therefore supports the possibility of threshold effects in the digitalization-efficiency relationship.

2.4.4 Diffusion of Innovation Theory

Rogers (2003) proposed that innovations diffuse gradually through organizations over time. The theory identifies several stages of innovation adoption including awareness, persuasion, adoption, implementation, and confirmation. Because digital transformation is a cumulative process, banks operating at different stages of digital maturity are likely to experience different efficiency outcomes.

This theoretical perspective further supports the threshold hypothesis.

2.5 Empirical Review

Empirical evidence regarding the relationship between digitalization and bank efficiency remains mixed. Ahamed and Mallick (2019) found that technology adoption improves bank performance, although the magnitude of the effect varies across institutions. Cornelli et al. (2023) reported that digital financial innovations contribute significantly to financial intermediation efficiency.

Ozili (2023) found that digital finance positively influences banking sector development and performance within emerging economies. Hasan, Mollah, and Saba (2023) reported that digital transformation improves banking efficiency, particularly among institutions that have achieved advanced technological maturity. Similarly, Liu et al. (2024) documented significant efficiency gains associated with digital technology diffusion within Pakistan's banking industry.

However, several studies report nonlinear effects. Philippon (2024) argues that digital transformation often generates substantial implementation costs before productivity benefits emerge. Boot et al. (2024) found evidence of diminishing marginal returns to digitalization among financial institutions. Gherțescu et al. (2024) reported that digital strategies improve efficiency only after organizations attain sufficient digital maturity.

The literature therefore increasingly suggests the possibility of threshold effects. Despite this growing evidence, studies examining threshold effects remain limited, particularly within African banking systems.

More importantly, no known study has simultaneously employed DEA Window Analysis, DEA Constant Technology Analysis, and Stochastic Frontier Analysis to investigate digitalization thresholds within the Nigerian banking industry.

2.6 Literature Gap

The review reveals four major gaps.

First, most studies assume a linear relationship between digitalization and efficiency despite increasing theoretical evidence supporting nonlinear effects. Second, empirical studies investigating threshold effects remain scarce, particularly within developing economies. Third, Nigerian studies have focused primarily on electronic banking adoption and financial innovation without explicitly examining digital maturity thresholds. Fourth, existing studies rely on single efficiency measures, thereby limiting robustness.

This study addresses these gaps by employing DEA Window Analysis, DEA Constant Technology Analysis, and Stochastic Frontier Analysis within a threshold regression framework to investigate whether digital intensity exhibits threshold effects in the Nigerian banking sector.

2.7 Summary of Literature Review

The literature suggests that digital transformation has the potential to improve banking efficiency through cost reduction, operational automation, and enhanced service delivery. However, theoretical perspectives and emerging empirical evidence indicate that such effects may not be linear. Instead, digitalization may generate different efficiency outcomes depending on the level of digital maturity attained by banks. Dynamic Capability Theory, Resource-Based View, Productivity Paradox Theory, and Diffusion of Innovation Theory collectively support the existence of threshold effects. The identified gaps provide the justification for investigating threshold effects in the relationship between Digital Intensity Index and bank efficiency in Nigeria.

Dynamic Capability Theory serves as the lead theory because it explains how banks transform digital resources into efficiency gains through learning, adaptation, and capability development.

METHODOLOGY

3.1 Introduction

This chapter presents the methodology adopted for examining the existence of threshold effects in the relationship between Digital Intensity Index (DII) and bank efficiency in Nigeria. The chapter describes the research design, population of the study, sample selection procedure, sources of data, variable measurement, efficiency estimation techniques, threshold estimation procedure, model specification, estimation techniques, and diagnostic procedures.

The study adopts a quantitative research design and utilizes panel data obtained from selected Nigerian Deposit Money Banks (DMBs) over the period 2000–2024. The analysis is implemented in multiple stages. First, bank efficiency scores are estimated using Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). Second, a Digital Intensity Index is constructed to measure the degree of digital transformation among banks. Third, Hansen's (1999) panel threshold regression approach is employed to determine whether critical levels of digital intensity exist beyond which the relationship between digitalization and bank efficiency changes significantly.

3.2 Research Design

The study adopts an ex post facto research design. The design is appropriate because the variables examined are historical in nature and beyond the direct control of the researcher.

The ex post facto approach has been widely used in banking efficiency studies because it allows researchers to investigate relationships among variables using already existing financial and operational information (Berger & Humphrey, 1997).

The study also employs a longitudinal panel design because observations are obtained across both cross-sectional units (banks) and time periods. The panel structure permits the investigation of dynamic efficiency patterns while controlling for unobserved heterogeneity among banks.

3.3 Population of the Study

The population comprises all Deposit Money Banks (DMBs) operating in Nigeria during the study period. The Nigerian banking sector provides an appropriate context for investigating digital transformation because it has experienced substantial technological development over the past two decades, including the introduction of electronic banking platforms, mobile banking systems, internet banking services, agency banking, real-time payment systems, and fintech collaborations.

3.4 Sample Selection and Coverage

The study employs purposive sampling. Only banks with continuous and reliable financial information over the study period were included.

The final sample consists of twelve Deposit Money Banks:

1. Access Holdings Plc
2. Fidelity Bank Plc
3. First HoldCo Plc
4. FCMB Group Plc
5. Guaranty Trust Holding Company Plc
6. Stanbic IBTC Holdings Plc
7. United Bank for Africa Plc
8. Wema Bank Plc
9. Zenith Bank Plc
10. Ecobank Transnational Incorporated
11. Sterling Financial Holdings Plc
12. Union Bank of Nigeria Plc

The sample period spans 2000–2024.

This period captures major phases of banking sector digitalization, including consolidation reforms, cashless policy implementation, fintech expansion, and recent digital banking developments.

3.5 Sources of Data

The study relies exclusively on secondary data.

Data were obtained from:

- Annual reports and accounts of sampled banks.
- Exchange Group (NGX) filings.
- Central Bank of Nigeria (CBN) Statistical Bulletins.
- Nigeria Inter-Bank Settlement System (NIBSS) reports.
- Banks' sustainability and digital transformation reports.

The data cover financial, operational, and digitalization indicators required for efficiency estimation and DII construction.

3.6 Measurement of Variables

3.6.1 Dependent Variable: Bank Efficiency

Bank efficiency is measured using both non-parametric and parametric approaches.

Data Envelopment Analysis (DEA)

DEA evaluates the relative efficiency of banks by comparing observed input-output combinations against a best-practice frontier (Charnes et al., 1978).

The study estimates:

- Cost Efficiency (VRS)
- Revenue Efficiency (VRS)

under:

- Window Technology
- Constant Technology

The Variable Returns to Scale (VRS) assumption is adopted because Nigerian banks operate under heterogeneous scales of operation.

Stochastic Frontier Analysis (SFA)

To ensure robustness, efficiency scores are also estimated using Stochastic Frontier Analysis. Following Aigner et al. (1977) and Battese and Coelli (1995), SFA decomposes deviations from the frontier into:

$$\gamma_{it} = v_{it} + u_{it} \quad \text{-----} \quad \{1\}$$

where:

v_{it} represents random error and

u_{it} represents inefficiency.

The resulting efficiency scores include:

- Cost Efficiency (SFA)
- Revenue Efficiency (SFA)

3.6.2 Independent Variable

Digital Intensity Index (DII)

Digital Intensity Index represents the degree of digital transformation achieved by a bank.

Following OECD (2024) guidelines and prior digital transformation studies, DII is constructed using indicators reflecting: Digital infrastructure, digital usage and digital innovation. The indicators are standardized and aggregated into a composite index ranging from 0 to 100. Higher values indicate greater digital maturity.

3.7 Estimation of Efficiency Scores

3.7.1 DEA Model Specification

The DEA model follows the Variable Returns to Scale framework proposed by Banker, Charnes, and Cooper (1984).

The output-oriented VRS model is specified as:

max θ

subject to:

$Y\sum \quad yi/\sum xi \quad = \quad 0$

where:

θ denotes efficiency score,

X represents input matrix,

Y represents output matrix,

and

μ represents intensity variables.

Window analysis is subsequently employed to account for time-varying efficiency changes.

3.7.2 Stochastic Frontier Model

The stochastic frontier production function is specified as:

$Y_{it}=f \quad (X_{it} \quad + \quad \beta exp(v_{it} \quad - \quad u_{it}) \quad -------\{2\}$

where:

Y_{it} represents bank output,

X_{it} denotes input vector,

v_{it} represents statistical noise,

and

u_{it} captures inefficiency.

Technical efficiency is estimated as:

$TE_{it}=e^{\{-uit\}--------}\{3\}$

3.8 Threshold Regression Framework

The primary objective of the study is to determine whether digitalization exhibits threshold effects in influencing bank efficiency.

To achieve this objective, Hansen's (1999) panel threshold regression model is employed.

The threshold model is specified as:

$EFF_{it} = \mu_i + \beta_1 DII_{it}\, I(DII \leq \gamma) + \beta_2 DII_{it}\, I(DII > \gamma) + \varepsilon_{it}$ -------{4}

EFF_{it} represents bank efficiency,

DII_{it} denotes Digital Intensity Index,

γ. represents the unknown threshold parameter,

I(.) is the indicator function,

and

u_i captures bank-specific fixed effects.

The threshold value is estimated endogenously from the data.

3.9 Estimation Procedure

The empirical analysis follows five sequential steps.

Step 1

Estimate cost and revenue efficiency scores using DEA Window Analysis.

Step 2

Estimate cost and revenue efficiency scores using DEA Constant Technology Analysis.

Step 3

Estimate cost and revenue efficiency scores using SFA.

Step 4

Construct the Digital Intensity Index.

Step 5

Estimate threshold regression models separately for:

- DEA Window Cost Efficiency
- DEA Window Revenue Efficiency
- DEA Constant Cost Efficiency
- DEA Constant Revenue Efficiency
- SFA Cost Efficiency
- SFA Revenue Efficiency

3.10 Threshold Significance Testing

Following Hansen (1999), the significance of threshold effects is evaluated using bootstrap procedures.

The null hypothesis is:

$H0: \beta 1 = \beta 2$

against:

$H1: \beta 1 \neq \beta 2$

A statistically significant difference between the two coefficients indicates the presence of threshold effects.

The bootstrap likelihood ratio statistic is employed to determine significance.

3.11 Reliability and Robustness Checks

To ensure robustness of findings, efficiency is estimated using both DEA and SFA approaches. The use of: DEA Window Technology, DEA Constant Technology, and Stochastic Frontier Analysis provides methodological triangulation and minimizes model-specific biases.

Consistency of threshold estimates across different efficiency measures strengthens the reliability of the findings.

3.12 A Priori Expectation

Digital transformation is expected to improve bank efficiency after a critical level of digital maturity has been attained.

Consequently: $\beta > 1$ is expected for efficiency-enhancing effects.

The expectation is consistent with Dynamic Capability Theory (Teece et al., 1997), Resource-Based View (Barney, 1991), and Productivity Paradox Theory (Brynjolfsson, 1993).

3.13 Ethical Considerations

The study utilizes publicly available secondary data obtained from audited financial statements and official regulatory publications. Consequently, no human subjects were involved, and no ethical concerns relating to confidentiality or informed consent arise.

DATA PRESENTATION, ANALYSIS AND DISCUSSION OF FINDINGS

4.1 Introduction

This chapter presents and discusses the empirical findings of the study. The results from threshold regression to be used here are summarized in Appendix A to this study. The primary objective is to determine whether threshold effects exist in the relationship between Digital Intensity Index (DII) and bank efficiency among Nigerian Deposit Money Banks (DMBs). The chapter presents threshold regression results based on three efficiency measurement approaches: Data Envelopment Analysis (DEA) Window Technology, DEA Constant Technology, and Stochastic Frontier Analysis (SFA).

The chapter is organized according to the study objectives and hypotheses. The estimated threshold values are first presented, followed by detailed interpretation and discussion of the regression coefficients. The findings are then evaluated within the context of Dynamic Capability Theory (Teece et al., 1997), Resource-Based View (Barney, 1991), Productivity Paradox Theory (Brynjolfsson, 1993; Solow, 1987), and existing empirical literature.

4.2 Threshold Regression Results in Appendix A based on DEA Window Technology Efficiency Scores

DEA Window Analysis evaluates efficiency relative to contemporaneous best-practice frontiers. Consequently, it captures short-run competitive positioning and adaptive efficiency rather than long-run structural productivity changes (Coelli et al., 2005).

The threshold estimation procedure identified a common digitalization threshold of approximately 24.53 for both cost and revenue efficiency.

The implication is that banks operating below this level of digital intensity belong to a low digital maturity regime, while banks operating above this level belong to a higher digital maturity regime.

4.2.1 Threshold Effect between DII and Window Cost Efficiency

Test of Hypothesis One

H01: No significant threshold effect exists between Digital Intensity Index and DEA Window Cost Efficiency.

Result Summary

Threshold Value:

$$\gamma = 24.53$$

Below Threshold:

$\beta_1 = 0.000565$ $(p < 0.01)$

Above Threshold:

B_2 = 0.000011 (p > 0.10)

Decision

The null hypothesis is rejected.

Discussion of Findings

The result demonstrates the existence of a significant threshold effect in the relationship between digital intensity and cost efficiency under the DEA Window framework.

Below the threshold value of 24.53, digital intensity exerts a positive and statistically significant influence on cost efficiency. This finding suggests that during the early stages of digital transformation, investments in digital technologies generate substantial efficiency improvements. The result is consistent with the argument that basic digitalization initiatives such as electronic banking, mobile banking, online transaction platforms, and automated customer services reduce operating costs and improve resource utilization.

The finding supports the Resource-Based View (Barney, 1991), which posits that strategic technological resources create performance advantages when effectively deployed. At low levels of digital maturity, banks are able to exploit relatively inexpensive digital innovations to generate immediate operational improvements.

However, the effect becomes statistically insignificant after the threshold is crossed. This indicates that additional digital investments beyond moderate levels of digital maturity no longer generate proportional cost-efficiency gains.

This phenomenon may reflect diminishing marginal returns to digital investments. Once basic operational processes have been digitized, further improvements require increasingly sophisticated technologies whose benefits may be more difficult to realize. Similar findings have been reported by Boot et al. (2024), who observed that digitalization exhibits declining marginal efficiency effects as institutions become more technologically advanced.

The result also aligns with Dynamic Capability Theory. While digital resources initially improve performance, sustained efficiency gains require organizational learning, managerial adaptation, and capability development (Teece et al., 1997).

4.2.2 Threshold Effect between DII and Window Revenue Efficiency in Appendix A

Test of Hypothesis Two

H02: No significant threshold effect exists between Digital Intensity Index and DEA Window Revenue Efficiency.

Result Summary

Threshold Value:

γ= 24.53

Below Threshold:

β_1 = -0.000520 (p < 0.05)

Above Threshold:

B_2 = -0.000028 (p > 0.10)

Decision

The null hypothesis is rejected.

Discussion of Findings

The result reveals a negative and statistically significant relationship between digital intensity and revenue efficiency below the threshold.

This finding initially appears counterintuitive because digital technologies are generally expected to improve revenue generation. However, the result becomes understandable when viewed through the lens of the Productivity Paradox.

According to Solow (1987) and Brynjolfsson (1993), technology investments frequently generate substantial implementation costs before productivity gains emerge. During the early stages of digitalization, banks incur expenditures relating to infrastructure acquisition, software deployment, employee retraining, cybersecurity investments, and organizational restructuring. Consequently, revenue efficiency may initially decline because digital investment costs increase faster than revenue gains.

The disappearance of significance above the threshold suggests that banks gradually overcome these adjustment costs as digital maturity increases.

This finding supports Philippon's (2024) argument that technology adoption frequently produces delayed performance benefits.

4.3 Threshold Regression Results Based on DEA Constant Technology Efficiency Scores (see Appendix A for summary)

Unlike Window DEA, Constant Technology DEA evaluates all observations against a common frontier. Consequently, the model captures long-run productivity performance and structural efficiency differences rather than short-run competitive effects (Färe et al., 1994).

The estimated threshold values were approximately 72.64 for cost efficiency and 69.59 for revenue efficiency.

These thresholds are considerably larger than those obtained under Window DEA.

This suggests that while modest levels of digitalization generate competitive benefits, substantially higher levels of digital maturity are required before digitalization alters the production frontier itself.

4.3.1 Threshold Effect between DII and Constant Technology Cost Efficiency

Test of Hypothesis Three

H03: No significant threshold effect exists between Digital Intensity Index and DEA Constant Technology Cost Efficiency.

Discussion of Findings

The findings reveal that digital intensity exerts a negative effect on cost efficiency below and above the threshold, although the magnitude of the adverse effect declines significantly after the threshold is crossed.

This result in Appendix A suggests that digital transformation is characterized by substantial implementation costs.

At lower levels of digital maturity, investments in technology create cost pressures associated with infrastructure development, organizational restructuring, and capability acquisition.

However, the reduction in the magnitude of the negative coefficient above the threshold indicates that banks begin to recover these costs as digital maturity increases.

This finding strongly supports Dynamic Capability Theory.

The theory predicts that organizations require time to develop capabilities necessary to exploit technological resources effectively (Teece, 2007).

The threshold of approximately 72.64 therefore represents the point at which learning effects begin to offset implementation costs.

4.3.2 Threshold Effect between DII and Constant Technology Revenue Efficiency

Test of Hypothesis Four

H04: No significant threshold effect exists between Digital Intensity Index and DEA Constant Technology Revenue Efficiency.

Discussion of Findings

The findings indicate that digital intensity positively influences revenue efficiency below the threshold but becomes insignificant beyond the threshold.

This suggests that moderate levels of digitalization generate significant revenue opportunities through increased customer access, transaction volumes, and service innovation.

However, once banks attain advanced digital maturity, additional digital investments produce limited incremental revenue gains.

This finding is consistent with diminishing marginal returns theory and supports the arguments of Gherțescu et al. (2024), who found that digital transformation benefits eventually plateau after a certain level of technological development.

4.4 Threshold Regression Results Based on Stochastic Frontier Analysis (SFA)

SFA differs from DEA because it separates inefficiency from random noise and estimates efficiency relative to a stochastic production frontier (Aigner et al., 1977).

The threshold estimation procedure identified a common threshold value of approximately 66.76 for both cost and revenue efficiency.

The similarity between the SFA threshold and the Constant Technology DEA thresholds provides important evidence regarding the robustness of the findings.

4.4.1 Threshold Effect between DII and SFA Cost Efficiency

Test of Hypothesis Five

H05: No significant threshold effect exists between Digital Intensity Index and SFA Cost Efficiency.

Discussion of Findings

The findings reveal that digital intensity does not significantly affect cost efficiency below the threshold but becomes positive and statistically significant above the threshold.

This result provides perhaps the strongest evidence supporting the study's central argument.

The threshold of approximately 66.76 suggests that digital transformation begins to generate meaningful cost-efficiency improvements only after banks attain advanced levels of digital maturity.

This finding aligns closely with Dynamic Capability Theory and Organizational Learning Theory.

Digital technologies do not automatically improve efficiency. Rather, organizations must develop complementary capabilities that enable effective utilization of technological resources (Argote, 2013; Teece et al., 1997).

The threshold therefore represents a critical digital maturity level at which technological investments become fully integrated into organizational processes.

4.4.2 Threshold Effect between DII and SFA Revenue Efficiency

Test of Hypothesis Six

H06: No significant threshold effect exists between Digital Intensity Index and SFA Revenue Efficiency.

Discussion of Findings

The results indicate that digital intensity exerts no significant influence below the threshold but becomes significantly negative above the threshold.

The finding suggests that highly digitalized banks may experience diminishing marginal returns in revenue generation.

Although digitalization expands revenue opportunities, advanced digital ecosystems also require substantial maintenance expenditures, cybersecurity investments, platform upgrades, and technology management costs.

Consequently, revenue growth may not keep pace with the resources required to sustain advanced digital operations.

This finding supports the argument that digital transformation involves trade-offs between innovation and efficiency.

4.5 Comparative Discussion of Threshold Estimates

One of the most important findings of this study is the emergence of two distinct digitalization thresholds.

The first threshold, approximately 24.53, is identified by the DEA Window model.

The second threshold, ranging between 66.76 and 72.64, is identified by the DEA Constant Technology and SFA models.

The lower threshold reflects a competitive digitalization threshold at which banks begin to experience relative efficiency advantages over contemporaneous competitors.

The higher threshold represents a structural digitalization threshold at which digital technologies become sufficiently embedded to alter the production frontier itself.

This finding provides strong empirical support for the Productivity Paradox literature. Technology investments initially generate competitive benefits but require substantial capability development before producing long-term productivity gains (Brynjolfsson, 1993; Solow, 1987).

The existence of these dual thresholds constitutes a major contribution to the digital banking literature and suggests that digital transformation occurs in stages rather than through a single linear process.

4.6 Summary of Findings

The study finds strong evidence supporting the existence of threshold effects in the relationship between Digital Intensity Index and bank efficiency in Nigeria.

The results demonstrate that digital transformation does not affect efficiency uniformly across all levels of digital maturity. Instead, efficiency outcomes vary according to the stage of digital development attained by banks.

The findings support all major theoretical perspectives reviewed in Chapter Two and provide evidence for a nonlinear, stage-dependent relationship between digitalization and bank efficiency.

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the summary of the study, conclusions drawn from the findings, policy implications, contributions to knowledge, limitations of the study, and recommendations for

future research. The study investigated whether threshold effects exist in the relationship between Digital Intensity Index (DII) and bank efficiency in Nigeria. Specifically, the study sought to determine whether the impact of digitalization on efficiency changes after banks attain certain levels of digital maturity.

Using panel data obtained from Nigerian Deposit Money Banks (DMBs) covering the period 2000–2024, efficiency was measured using Data Envelopment Analysis (DEA) under Window Technology and Constant Technology assumptions as well as Stochastic Frontier Analysis (SFA). Hansen's (1999) threshold regression framework was employed to estimate critical digitalization thresholds.

The chapter synthesizes the findings and discusses their implications for theory, policy, and practice.

5.2 Summary of the Study

The banking industry has experienced profound transformation due to the rapid diffusion of digital technologies. Digital banking platforms, mobile banking systems, electronic payment channels, artificial intelligence applications, cloud computing, and fintech innovations have fundamentally altered the nature of financial intermediation (Vial, 2019; Philippon, 2024).

Despite extensive investments in digital transformation, the literature provides conflicting evidence regarding the relationship between digitalization and bank efficiency. While some studies suggest that digital technologies improve efficiency through automation and cost reduction (Hasan et al., 2023; Liu et al., 2024), others report weak, insignificant, or even adverse effects due to implementation costs, organizational restructuring, and technological complexity (Boot et al., 2024; Gherțescu et al., 2024).

A major limitation of existing studies is the assumption of linearity. Most previous studies implicitly assume that the effect of digitalization remains constant regardless of the level of digital maturity attained by a bank.

This study challenged this assumption by proposing that the relationship between digitalization and efficiency is nonlinear and threshold-dependent.

The study employed threshold regression analysis to investigate whether critical levels of digital maturity exist beyond which the impact of Digital Intensity Index changes significantly.

The findings revealed significant threshold effects across all efficiency measures.

For DEA Window Technology efficiency scores, a threshold of approximately 24.53 was identified.

For DEA Constant Technology efficiency scores, threshold values ranged between 69.59 and 72.64.

For SFA efficiency scores, the threshold value was approximately 66.76.

The results consistently indicate that digital transformation influences bank efficiency differently at different stages of digital maturity.

5.3 Summary of Major Findings

The study generated six major findings.

Finding One

The study found significant threshold effects between Digital Intensity Index and DEA Window Cost Efficiency.

Digitalization significantly improves cost efficiency below the threshold of 24.53 but loses significance beyond this point.

Finding Two

The study found significant threshold effects between Digital Intensity Index and DEA Window Revenue Efficiency.

Digitalization initially reduces revenue efficiency due to implementation and adjustment costs but becomes insignificant after the threshold is attained.

Finding Three

The study found significant threshold effects between Digital Intensity Index and DEA Constant Technology Cost Efficiency.

Although digitalization initially exerts a negative effect on cost efficiency, the magnitude of this adverse effect declines substantially after banks attain advanced digital maturity.

Finding Four

The study found significant threshold effects between Digital Intensity Index and DEA Constant Technology Revenue Efficiency.

Digitalization enhances revenue efficiency below the threshold but exhibits diminishing marginal benefits beyond the threshold.

Finding Five

The study found significant threshold effects between Digital Intensity Index and SFA Cost Efficiency.

Digitalization becomes positively associated with cost efficiency only after banks attain a digital intensity level of approximately 66.76.

Finding Six

The study found significant threshold effects between Digital Intensity Index and SFA Revenue Efficiency.

While digitalization does not significantly influence revenue efficiency at lower levels of digital maturity, excessive digitalization appears to reduce revenue efficiency beyond the threshold.

5.4 Conclusion

The central conclusion of this study is that the relationship between Digital Intensity Index and bank efficiency in Nigeria is fundamentally nonlinear.

The findings demonstrate that digital transformation does not affect efficiency uniformly across all levels of digital maturity. Rather, the efficiency consequences of digitalization depend critically on the stage of digital development attained by a bank.

The study provides strong evidence that digital transformation is characterized by threshold behaviour.

Perhaps the most important contribution of the study is the identification of two distinct categories of digitalization thresholds.

The first threshold, identified through DEA Window Analysis at approximately 24.53, represents what may be described as a Competitive Digitalization Threshold.

At this stage, banks begin to experience efficiency advantages relative to competitors through the adoption of basic digital technologies and operational automation.

The second threshold, identified through DEA Constant Technology and SFA models at approximately 66.76–72.64, represents a Structural Digitalization Threshold.

At this stage, digital technologies become deeply embedded within organizational processes and begin to alter the production frontier itself.

The existence of these two thresholds suggests that digital transformation is not a single event but rather a progressive developmental process involving multiple stages of technological maturity.

Consequently, banks should not expect immediate efficiency gains from digital investments. Instead, efficiency improvements emerge gradually as digital capabilities, organizational learning, and complementary resources accumulate over time.

5.5 Implications of the Findings

5.5.1 Theoretical Implications

The findings provide strong support for Dynamic Capability Theory (Teece et al., 1997; Teece, 2007).

The theory argues that technological resources alone do not create superior performance. Rather, organizations must develop complementary capabilities that enable effective utilization of such resources.

The identified thresholds provide empirical evidence supporting this theoretical proposition.

The findings also support the Resource-Based View (Barney, 1991), which emphasizes that resources create value only when they become effectively integrated into organizational processes.

Furthermore, the study provides strong evidence supporting the Productivity Paradox literature (Brynjolfsson, 1993; Solow, 1987).

The results suggest that digital technologies may initially generate adjustment costs before productivity gains emerge.

Thus, the study contributes to resolving the long-standing debate regarding the inconsistent relationship between technology investment and organizational performance.

5.5.2 Managerial Implications

The findings suggest that bank managers should view digital transformation as a long-term strategic process rather than a short-term efficiency initiative.

Management should recognize that substantial digital investments may initially generate implementation costs and temporary efficiency declines.

Consequently, performance evaluations should focus on long-term digital maturity rather than immediate financial outcomes.

Banks should also invest in complementary organizational capabilities such as employee training, digital governance systems, cybersecurity frameworks, and innovation management structures.

5.5.3 Regulatory Implications

The findings have important implications for financial regulators, particularly the Central Bank of Nigeria (CBN).

Regulatory policies should encourage sustained digital transformation rather than short-term technological adoption.

The CBN should continue supporting initiatives aimed at strengthening digital infrastructure, payment systems, cybersecurity resilience, and technological innovation within the banking sector.

In addition, supervisory frameworks should recognize that efficiency gains from digitalization may emerge gradually rather than immediately.

5.6 Contribution to Knowledge

This study contributes to knowledge in six major ways.

First Contribution

The study provides one of the first empirical investigations of threshold effects in the relationship between Digital Intensity Index and bank efficiency within the Nigerian banking sector.

Second Contribution

The study introduces the concept of Dual Digitalization Thresholds.

Specifically, the findings identify:

- Competitive Digitalization Threshold (approximately 24.53)
- Structural Digitalization Threshold (approximately 66.76–72.64)

This framework extends existing digital transformation theory.

Third Contribution

The study demonstrates that the relationship between digitalization and efficiency is nonlinear rather than linear.

Fourth Contribution

The study integrates DEA Window Analysis, DEA Constant Technology Analysis, and Stochastic Frontier Analysis within a unified threshold regression framework.

Fifth Contribution

The study provides empirical support for Dynamic Capability Theory within the context of banking digitalization.

Sixth Contribution

The study extends the Productivity Paradox literature by demonstrating that digital transformation benefits emerge only after critical levels of digital maturity are attained.

5.7 Policy Recommendations

Based on the findings, the following recommendations are proposed.

Recommendation One

Banks should adopt a long-term digital transformation strategy focused on capability development rather than short-term efficiency gains.

Recommendation Two

Bank management should prioritize investments in digital skills, employee training, and organizational learning mechanisms.

Recommendation Three

The Central Bank of Nigeria should continue promoting digital banking initiatives through supportive regulatory frameworks.

Recommendation Four

Digital performance metrics should incorporate measures of digital maturity rather than focusing exclusively on technology expenditure.

Recommendation Five

Banks should periodically assess their digital intensity levels to determine whether they have attained the critical thresholds necessary for sustained efficiency improvements.

5.8 Limitations of the Study

Despite its contributions, the study has certain limitations.

First, the study focuses exclusively on Nigerian Deposit Money Banks and may therefore limit generalization to other financial systems.

Second, the Digital Intensity Index was constructed using available indicators, which may not capture all dimensions of digital transformation.

Third, the threshold regression model focuses on single-threshold effects and does not explicitly examine multiple-threshold structures.

Fourth, the study concentrates on efficiency outcomes and does not examine profitability, stability, risk, or market valuation effects.

5.9 Suggestions for Future Research

Future studies should consider the following directions.

1. Examination of multiple-threshold digitalization models.
2. Comparative studies involving African and non-African banking systems.
3. Investigation of threshold effects on profitability and financial stability.
4. Analysis of nonlinear relationships between digitalization and risk-taking behaviour.
5. Application of dynamic threshold models incorporating macroeconomic factors.
6. Examination of fintech-mediated threshold effects within banking ecosystems.

5.10 Final Remark

The study concludes that digital transformation is not merely a technological phenomenon but a developmental process characterized by distinct stages of digital maturity. The evidence demonstrates that the efficiency consequences of digitalization are threshold-dependent and that meaningful efficiency gains emerge only after banks attain critical levels of digital capability. Consequently, understanding digitalization through a threshold perspective provides a more accurate explanation of banking efficiency dynamics than traditional linear approaches and offers a new framework for evaluating digital transformation within emerging financial systems.

Appendix A

RESULT PRESENTATION AND INTERPRETATION

4.1 Introduction

This chapter presents the empirical findings of the study on the existence of threshold effects in the relationship between Digital Intensity Index (DII) and bank efficiency in Nigeria. The analysis utilizes three efficiency measurement approaches:

1. DEA Window Technology Efficiency Scores.
2. DEA Constant Technology Efficiency Scores.
3. Stochastic Frontier Analysis (SFA) Efficiency Scores.

The threshold regression approach proposed by Bruce Hansen was employed to determine whether the effect of digital intensity differs across levels of digital maturity. The underlying proposition is that digitalization may not influence bank efficiency uniformly across all stages of technological development. Instead, the impact may change once a critical digitalization

threshold is attained. This proposition is consistent with Dynamic Capability Theory, Resource-Based View, and the Productivity Paradox literature.

4.2 Threshold Regression Results Using DEA Window Efficiency Scores

4.2.1 Cost Efficiency (Window Technology)

Estimated Threshold

γ=24.53

Threshold Regression Results

Variable	Coefficient	p-value
DII (Below Threshold)	0.000565	0.004
DII (Above Threshold)	0.000011	0.797

Decision on Hypothesis H01

Since the coefficients differ significantly across regimes, the null hypothesis is rejected.

Interpretation

The result indicates that digital intensity significantly improves cost efficiency when DII is below 24.53. However, beyond this threshold, additional increases in digital intensity no longer generate statistically significant improvements in cost efficiency.

This finding suggests that digitalization yields substantial efficiency gains during the early stages of technological adoption. Once banks attain moderate levels of digital maturity, the marginal contribution of additional digital investments becomes negligible.

The result supports the argument that digital transformation initially delivers efficiency gains through automation, process digitization, and improved operational coordination. However, after a certain point, the easily obtainable efficiency benefits are exhausted, resulting in diminishing marginal returns. This finding is consistent with studies emphasizing nonlinear digital transformation outcomes.

4.2.2 Revenue Efficiency (Window Technology)

Estimated Threshold

γ=24.53

Threshold Regression Results

Variable	Coefficient	p-value
DII (Below Threshold)	-0.000520	0.030
DII (Above Threshold)	-0.000028	0.598

Decision on Hypothesis H02

The null hypothesis is rejected.

Interpretation

Digital intensity significantly reduces revenue efficiency below the threshold but becomes insignificant beyond the threshold.

This result suggests that digital transformation initially imposes adjustment costs that outweigh revenue gains. During the early phases of digital adoption, banks incur substantial expenditures on technology acquisition, employee training, organizational restructuring, and system integration.

As digital maturity increases, these negative effects disappear, suggesting that banks gradually learn how to utilize digital technologies more effectively.

The result is highly consistent with the Productivity Paradox proposition that technology investments frequently precede productivity gains.

4.3 Threshold Regression Results Using DEA Constant Technology Efficiency Scores

4.3.1 Cost Efficiency

Estimated Threshold

$\gamma=72.64$

Results

Variable	Coefficient	p-value
DII (Below Threshold)	-0.000281	<0.001
DII (Above Threshold)	-0.000077	0.013

Decision on Hypothesis H03

The null hypothesis is rejected.

Interpretation

Digital intensity exerts a significant negative effect on cost efficiency in both regimes. However, the adverse effect becomes substantially weaker after the threshold is crossed.

This finding indicates that digitalization initially generates substantial implementation costs. Nevertheless, as banks attain advanced digital maturity, learning effects, process optimization, and economies of scale reduce the magnitude of efficiency losses.

The result suggests that digital transformation is characterized by a long learning curve and delayed benefits.

4.3.2 Revenue Efficiency

Estimated Threshold

$\gamma=69.59$

Results

Variable	Coefficient	p-value
DII (Below Threshold)	0.000310	<0.001
DII (Above Threshold)	0.000028	0.495

Decision on Hypothesis H04

The null hypothesis is rejected.

Interpretation

Digital intensity significantly improves revenue efficiency below the threshold. However, beyond the threshold, the effect becomes statistically insignificant.

This result suggests that digital transformation initially creates opportunities for revenue expansion through customer acquisition, transaction growth, and service innovation. Once banks attain advanced digital maturity, the incremental benefits of additional digital investments become limited.

The finding is consistent with the theory of diminishing marginal returns to technology investments.

4.4 Threshold Regression Results Using SFA Efficiency Scores

4.4.1 Cost Efficiency

Estimated Threshold

γ=66.76

Results

Variable	Coefficient	p-value
DII (Below Threshold)	-0.000028	0.553
DII (Above Threshold)	0.000088	0.003

Decision on Hypothesis H05

The null hypothesis is rejected.

Interpretation

Digital intensity has no significant effect below the threshold. However, above the threshold, the effect becomes positive and statistically significant.

This finding suggests that digital transformation generates meaningful cost-efficiency improvements only after banks attain advanced levels of digital maturity.

The result supports Dynamic Capability Theory, which argues that technology produces performance gains only after organizations develop complementary capabilities and routines.

4.4.2 Revenue Efficiency

Estimated Threshold

γ=66.76

Results

Variable	Coefficient	p-value
DII (Below Threshold)	0.000023	0.638
DII (Above Threshold)	-0.000095	0.003

Decision on Hypothesis H06

The null hypothesis is rejected.

Interpretation

Digital intensity exerts no significant influence below the threshold but significantly reduces revenue efficiency above the threshold.

This suggests that excessive digitalization may generate diminishing marginal revenue gains due to increasing complexity, maintenance costs, cybersecurity expenditures, and technology management challenges.

4.5 Summary of Findings

Efficiency Measure	Threshold
DEA Window Cost Efficiency	24.53
DEA Window Revenue Efficiency	24.53
DEA Constant Cost Efficiency	72.64
DEA Constant Revenue Efficiency	69.59
SFA Cost Efficiency	66.76
SFA Revenue Efficiency	66.76

The results reveal two broad threshold categories:
Competitive Threshold
$\gamma \approx 24$
captured by Window DEA.
Structural Threshold
$\gamma \approx 67-73$
captured by Constant DEA and SFA.
This distinction constitutes a major contribution of the study.

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38. Because your thesis relies heavily on DEA, Window Analysis, SFA, and threshold estimation, I strongly recommend adding the following seminal references:
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