

Article

Revolutionizing Banking: Neobanks' Digital Transformation for Enhanced Efficiency

Riris Shanti ^{1,*}, Hermanto Siregar ², Nimmi Zulbainarni ¹ and Tony ³

¹ School of Business, IPB University, Bogor 16151, Indonesia; nimmizu@apps.ipb.ac.id

² Department of Economics, Faculty of Economics and Management, IPB University, Bogor 16680, Indonesia; hsiregar@apps.ipb.ac.id

³ Indonesia Financial Services Authority, Jakarta 10350, Indonesia; tony@ojk.go.id

* Correspondence: riris.shanti17@gmail.com or ririsshanti@apps.ipb.ac.id

Abstract: Changes in customer behaviors after the COVID-19 pandemic have encouraged the transformation of banking systems. Neobanks have emerged as an innovation and entered the banking system to compete with traditional banks by offering new customer experiences. Neobanks transform traditional banking products and services which are delivered through physical interactions into those delivered via digital channels. This paper analyzes traditional banks that have transformed into neobanks, specifically their efficiency after digital transformation. Efficiency was measured using Stochastic Frontier Analysis (SFA), as it is highly accurate in estimating efficiency scores. This study also used a Pooled Mean Group (PMG) estimation of the Panel ARDL (Autoregressive Distributed Lag), as this approach is useful for analyzing the relationship between variables in panel data, to investigate digital transformation as a determinant of neobanks' efficiency and examine the existence of short-term and long-term relationships between digital transformation and efficiency. We found that the efficiency of neobanks increases after digital transformation. Furthermore, it can be concluded that digital transformation is a determinant of efficiency and that there is long-term relationship between digital transformation and efficiency. In the short term, digital transformation has a significant negative correlation with efficiency, but in the long term, it has a significant positive relationship; this is because the cost of digital transformation initially decreases the profit efficiency, but afterwards, it increases the efficiency.

Keywords: digital business; digital transformation; neobank; efficiency



Citation: Shanti, Riris, Hermanto Siregar, Nimmi Zulbainarni, and Tony. 2024. Revolutionizing Banking: Neobanks' Digital Transformation for Enhanced Efficiency. *Journal of Risk and Financial Management* 17: 188. <https://doi.org/10.3390/jrfm17050188>

Academic Editor: Pierluigi Murro

Received: 30 March 2024

Revised: 20 April 2024

Accepted: 24 April 2024

Published: 1 May 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The massive development of digital technology and the COVID-19 pandemic has caused societies to enter into a digital era, and digital transformation has become a common reality in every sector, including manufacturing, transportation, healthcare, education, and agriculture, as well as economy and finance. To respond to this digitalization phenomenon, in 2020, Indonesia developed the Digital Indonesia Roadmap, with the long-term aim of supporting digital transformation in four strategic sectors, namely digital infrastructure, digital government, digital economy, and digital community (Ministry of Communication and Informatics 2021).

The development of a digital economy requires the digitalization of banking, as banks are one of the financial system elements that accelerate digital finance activities. According to the Indonesia Financial Services Authority (FSA)/Otoritas Jasa Keuangan (OJK 2021a), there are three key factors supporting digitalization in the Indonesia banking sector: digital opportunities, digital behavior, and digital transactions. Digital opportunities involve the demographic potency of the Indonesian population, which is dominated by the tech-savvy millennial generation; digital economy and financial potency; internet penetration; and the increasing number of potential customers in trading activities. Digital behavior includes

the ownership and usage of smartphones and mobile apps. Digital transactions indicate the increasing prevalence of online trading (*e-commerce*), digital banking transactions, and electronic money transactions and the declining prevalence of bank branch offices (OJK 2021b).

The recent changing customer behaviors align with the transformation of banking, as stated by King (2018), who mentioned that digital transformation in banking began with changes in traditional bank office activities, described as phase 1.0; then developed into phase 2.0, during which people started to use ATM technology; then continued with phase 3.0, which was supported by smartphone mobile banking innovation; and is currently in phase 4.0, with further digital transformation and the emergence of digital banks with digital-based products or services. Digital banks or neobanks or challenger banks focus only on digital banking products and services and deliver these via digital channels (BaFin 2021). Neobanks are a new type of bank that have entered the banking system to compete with traditional banks by offering new digital experiences for customers. Neobanks usually only have a limited number of branch offices or even no branches, as their target audience is digital customers who visit banks rarely (Delgado 2021).

This study comprehensively explores the digital transformation of traditional banks into neobanks and its implication on their efficiency. The findings from this study address the limitations in the existing research, as most of the current discussions are about efficiency in traditional banks and determinants of efficiency but not digital transformation. Our focus on neobanks is one of the novelties of this study, as well as our analyses of digital transformation as a determinant of neobanks' efficiency and the short-term and long-term relationships between digital transformation and efficiency.

Neobanks' digital transformation and its long-term impact on efficiency are the focus of this study. This study demonstrates its novelty by focusing on three analyses: Firstly, efficiency is analyzed by implementing SFA to measure the Alternative Profit Efficiency with a translog approach. Secondly, we investigate whether digital transformation is a determinant of banks' efficiency. Thirdly, this study analyzes digital transformation's long-term impacts on neobanks' efficiency.

Initially, digital transformation was defined as an organizational change or new investment towards a business model with digital infrastructure to scale up digital interactions with customers in every single aspect of their daily life (Bell 2011). Digital transformation has also been defined as an erudite and literate change (Bharadwaj et al. 2013) or a strategic performance change (Rogers 2016). Fitzgerald (2013) defined digital transformation as "the use of new technology such as social media, mobile devices, and analytics tools to support significant business model improvement for example customer experience development and innovation for operational simplification".

On the one hand, the concept of efficiency for a firm, according to Farrell (1957) and Porcelli (2009), consists of two components, namely Allocative (or Price) Efficiency and Technical Efficiency. Allocative or Price Efficiency refers to a firm's capacity to incorporate input factors and output factors at optimum levels based on market prices, valued according to the objectives of a production unit, for example, assessing realized costs with the optimal costs or comparing realized earnings with the optimal returns. On the other hand, Technical Efficiency measures efficiency by assessing the realized number of outputs in relation to the optimum number of outputs in the form of a ratio, assuming that the number of inputs used is fixed, or by evaluating the minimum number of realized inputs while assuming a fixed number of outputs. In measuring a financial institution's efficiency, Berger and Mester (1997) stated the three concepts of economic efficiency: Cost Efficiency, Standard Profit Efficiency, and Alternative Profit Efficiency. This research explores the Alternative Profit Efficiency approach to measure neobanks' efficiency.

The results of our analysis were obtained differently to those of previous studies, as we used two methods to find complete results for two different objectives. The first method was Stochastic Frontier Analysis (SFA), which was used to analyze the efficiency of banks, and the second method was Panel of ARDL, which was applied to analyze the short-term

and long-term relationship (Agovino et al. 2022) between digital transformation and banks' efficiency and facilitate a discussion on digital transformation as a determinant of neobanks' efficiency. The data used in this study focused on Indonesia's neobanks, making this study different from the existing literature.

Previous studies on banks' efficiency and its determinants have used all kinds of variables and methodologies. Barth et al. (2013) mentioned that regulation on capital is positively associated with determining the efficiency of banks. On the methodology side, Sharma (2018) and Firdaus and Hosen (2014) analyzed banking sector efficiency by using Data Envelopment Analysis (DEA), while Alber et al. (2019) discussed the concept, drivers, and measurement of banks' efficiency. Generally, most researchers have used traditional banks (not neobanks) as their research objects (Ikhwan and Riani 2022), whereas they classified traditional banks according to their size in terms of total assets (large banks and small banks), ownership (state-owned banks and private banks), and performance across specific periods (before crises and after crises).

The structure of this paper is as follows: Following the Introduction, a literature review of the theoretical analysis for generating hypotheses is presented in Section 2, the methodology of the research and research hypotheses statements are described in Section 3, and the results of the study are described in Section 4. A discussion of the results is provided in Section 5, followed by the conclusions that can be derived from them in Section 6, and recommendations for the future, as well as the limitations of this study, are discussed in Section 7.

2. Literature Review

2.1. Digital Transformation and The Emergence of Neobanks

According to Westerman (2017), digital transformation involves the development and improvement of business models, activities, processes, and capabilities to achieve benefits from digital technologies which have strategic effects on the public. Digital transformation can lead to excellent achievements by governing internal and external organizational elements comprehensively (Ismail et al. 2018). Digital transformation is indicated by the frequent usage of digital technology in achieving performance enhancement and improvement, also holding great significance for organizations in the industry sector (Dahlstrom et al. 2017). Digital innovation and information technology are frequently used in the manufacturing sector (Shehadeh et al. 2023), as evidenced by the adoption of Mobile Information Technology for service innovation capabilities (SICs) and service innovation performance (SIP), as noted by Liu et al. (2022).

In banking, digitalization is defined as the usage of digital technology to make banking transactions easier (Bhutani and Paliwal 2015) and reduce operating costs; thus, digitalization also requires financial contexture transformation (Yoo et al. 2010). The main objectives of digitalization are to increase consumer satisfaction and to identify the profiles of potential customers to target in the future (Valenduc and Vendramin 2017). Digitalization in banking encourages the presence of digital banks or direct/branchless neobanks, which deliver their financial services to customers mainly via digital channels, for example, mobile apps (International Monetary Fund 2022). Neobanks are a new type of bank that have entered the banking system to compete with the traditional banks by offering a new digital experience for customers.

Neobanks have some pros and cons, as research on neobanks has found several potential risks associated with their growth. First, there is a greater potential credit risk trend based on loans due to the underpricing credit risk, as neobanks are not covered with suitable provisions; second, there is a greater potential risk in terms of portfolio security; and third, there is inadequate liquidity risk management (International Monetary Fund 2022). In contrast, Pierrri and Timmer (2022) stated that IT adoption promotes banks' resiliency, as it can help better risk management for debtor screening.

A study by Banerjee et al. (2022) that involved using the Chow Test and pooled regression found that the adoption of neobanking as a form of digital transformation in the

United Arab Emirates (UAE) has impacted the financial performance of banks, as indicated by specific bank factors such as NPL, ROE, NIM, and cost efficiency. The International Monetary Fund (IMF)'s study on the development of neobanks in 18 economies around the globe, including Asia, Europe, America, and Russia, stated that neobanks have grown and assumed systemic importance in each country's market. Neobanks in emerging markets tend to perform better than those in advanced economies, even though neobanks shows greater operational expenses and are less cost-efficient than traditional banks due to the higher customer acquisition costs and IT security costs (International Monetary Fund 2022).

Digitalization is one of the resources of banks that can be used to increase profitability and to differentiate their position in the market, also changing banks' core businesses by reducing costs, increasing quality, and helping banks to develop new financial products. While previous researchers have stated that the relationship between bank performance and electronic banking services is positive, Dehnert (2020) analyzed 83 providers of financial services, including ones related to electronic banking, fintech, and big tech, and found a systematic connection between the dimension of digital transformation and the efficiency of these financial service providers, which was identified based on the digital configurations of each company, which represent a company's digital evolution.

2.2. Digital Transformation and Innovation

Digital transformation is not just the simple implementation of information and communication technology; rather, in the wider interpretation of the concept, digital transformation is commonly understood as compulsory for the expertise and capabilities needed for optimum operation (Kane et al. 2019). Over time, as digital tools and techniques have evolved, digital transformation's definition has become more distinctive. Warner and Wager (2019) define digital transformation as a response to novel technologies with digital attributes, such as cloud computing, artificial intelligence, Internet of Things (IoT), and blockchain, that can be explored to make major changes to a business' operational model, provide customers a high-value experience, simplify the business' operation, and/or create a new business model. The existing research on the relationship between digital transformation and neobank's efficiency is limited, and most of it pertains to theoretical and conceptual analyses. Researchers have stated that digital transformation can immediately increase banks' efficiency and, eventually, increase banks' profitability and financial capital.

Digital transformation is commonly associated with innovation, specifically technological innovation. According to Ang (2010), enterprises' level of technological innovation will increase if improvements in terms of financial capital, as the endogenous variable, are obtained. The banking sector has received a huge amount of capital support for their digital innovation, which will increase the impact of innovation on their financial performance. Jusufi (2023) also found that innovation in marketing and processes will generate a moderate positive linear relationship with financial performance, while organizational innovation and product innovation have weak but positive linear relationships with financial performance.

2.3. Concept and Measurement of Efficiency

Another focus in this study is efficiency. Berger and Mester (1997) differentiated the concept of efficiency into: Cost Efficiency, Standard Profit Efficiency, and Alternative Profit Efficiency. Cost efficiency assesses efficiency based on the cost of generating a similar output with the same inputs as the current situation compared to the benchmark cost. This involves comparing the costs of one bank to the best-performing bank, in terms of operating costs, who can generate similar products using similar technology. In Standard Profit Efficiency, the efficiency of the bank is measured by the maximum possible profit that can be achieved with a certain price of input and output. Standard Profit Efficiency assesses a bank's efficiency by evaluating the capability of a bank to obtain profit at maximum level with a particular level of output price, and this capability is compared to the most profitable bank in the sample. In this situation, the input-output factors' prices are defined by the

market and generally associated with perfect market competition, which means that no banks can define the input or output prices, and thus, banks evaluate their position just by taking the total price into account. Lastly, Alternative Profit Efficiency measures efficiency by comparing the projections of actual profits to the best-practicing bank's maximum profit projections as a reference. Alternative Profit Efficiency is commonly interpreted as a condition of imperfect market competition, with the assumption being that each bank has market power in terms of setting the output price. Meanwhile, each bank does not have the power to determine the input price. This study adopts the Alternative Profit Efficiency method to measure the efficiency of neobanks, as this approach provides a solution for controlling for unmeasured differences in output quality, such as higher service quality with higher charges for the customer, and differences in the number of total assets among the banks.

According to [Bauer et al. \(1998\)](#), the measurement of financial institutions' performance mostly focuses on x-efficiency or frontier efficiency, which assesses the deviation from "best practice" or from the efficient frontier. Financial institutions' frontier efficiency is calculated by comparing the performance of a financial institution to the projection of the "best" financial institution, in terms of performance, in the same industry and market environment. Frontier efficiency is the general standard of the financial performance ratios from financial reports such as Return on Asset (ROA) or Cost/Revenue Ratio reports, which are commonly used by regulators, financial institution managers, and consultants in the financial sector in evaluating the performance of financial institutions. The more efficient a bank is, the more its profitability will increase.

Frontier efficiency is divided into two categories, namely the parametric approach and non-parametric approach. The parametric approach is more detailed compared to the non-parametric approach as it assumes a specific function which connects the input and output, and it assumes a particular probability distribution for the error component of the function. On the other hand, those two conditions are not required in the non-parametric approach. Basically, both approaches are based on the concept of estimating the level of efficiency, which is carried out by using the frontier curve as the reference. The banks on the frontier curve are categorized as efficient banks, while the banks outside of the frontier are indicated as inefficient banks. The parametric approach measures efficiency by using stochastic econometrics and attempts to incorporate noise and inefficiency analysis, while the non-parametric approach attempts to omit the effect of inefficiency. The Parametric econometric approach consists of three types of approaches: (1) the Stochastic Frontier Approach (SFA); (2) the Thick Frontier Approach (TFA); and (3) the Distribution-free Approach (DFA).

This study uses the Stochastic Frontier Approach (SFA) to measure the efficiency levels of seven neobanks. This approach can estimate panel data and differentiates stochastic inefficiencies and shocks caused by error terms more accurately in estimating the score of efficiency. The SFA has a better statistical control than the other generally used efficiency-measuring approaches, such as Data Envelope Analysis (DEA) ([Asmare and Begashaw 2018](#); [Huang and Wang 2002](#); [Sari and Saraswati 2017](#)). In investigating the efficiency scores, this study employs a cost function model described by [Coelli and Battese \(1995\)](#), which uses a translog profit function for each observation by utilizing three kinds of inputs and outputs.

When estimating bank efficiency by using parametric or non-parametric methods, [Matthews and Thompson \(2008\)](#) suggest using the intermediation approach because financial institutions intermediate, transform, and transfer financial assets in the financial system. The input factors include interest expenses on deposits, labor costs, and operational costs, while output is measured by using interest income, operational income, and loans ([Hadad et al. 2003](#)).

Profit efficiency refers to one of banks' core business objectives. In recent years, banks' management systems have undergone digital transformation to achieve this efficiency because banks and financial services providers are in a technology-intensive business sector.

Banks utilize digital technology as the input to produce the financial product and services. Another input is high-quality talent with relevant knowledge reserves and advanced levels of technical skill in the field of digital technology. Digital technology and tech talents, in relation to human capital, are the elements of technological innovation (Schworer 2012; Amity and Khandelwal 2009), which also become part of digital transformation. In conclusion, digital transformation is an important thing that supports efficiency. The first hypothesis in this paper is as follows: Digital transformation will enhance neobank efficiency.

2.4. Determinants of Efficiency

In testing digital transformation as the determinant of neobanks' efficiency, this study uses a quantitative research method to examine the influence of independent variables, namely digital transformation, capital adequacy, liquidity, net interest margins, and economic growth, on the response variable of profit efficiency. The variable of digital transformation in this study uses the proxy of operational cost for digital transformation features such as IT infrastructure investment; the cost of outsourcing digital services; labor expenses, including tech talent (Bharadwaj et al. 2013); and the cost of marketing and promotion for digital bank branding. Investment in IT encourages bank efficiency, but there is a time lag from carrying out digital transformation up to achieving efficiency (Kriebel and Debener 2021). Therefore, this study applies Panel ARDL to investigate digital transformation as a determinant of bank efficiency and the short-term and long-term relationship between digital transformation and neobanks' efficiency. According to Peng and Zhou (2017), technological innovation investment is impacting factors based on digital transformation; therefore, this paper takes IT investment and IT costs as proxies for digital transformation as an independent variable.

In the banking industry, capital adequacy, which is indicated by the Capital Adequacy Ratio (CAR), has also been identified as a determinant of efficiency (Widiarti et al. 2015). All neobanks in Indonesia have high CARs above the minimum regulatory requirement (8%), as they have been strongly supported by their shareholders in their digital transformation. This high-level capital represents strong resilience in absorbing risks. Therefore, banks should maintain their minimum level of equity as the reserve to support the main roles in mitigating operational and financial risks, i.e., the primary financing for operating the bank before obtaining other sources of financing to assure the depositors that the bank has sufficient equity to generate products and provide financial assistance, as well as sufficient infrastructure, and the source of development, to ensure continuous long-term growth (Rose and Hudgins 2010).

Another variable used in this study is the liquidity of the bank, which is proxied by the Loan Deposit Ratio (LDR). The liquidity of a bank is adequate if the bank has sufficient cash or other liquid assets that make it able to escalate the fast financing from other financial assets while also covering their obligations and financial commitments on schedule. Bank liquidity is also indicated by the adequacy of funds to cover the instantaneous flow of money (Rose and Hudgins 2010). According to a study by Sidhu et al. (2023), as bank liquidity increases, bank efficiency improves. But after achieving its maximum level, the efficiency goes down.

This study also uses net interest margin (NIM) as the proxy for the market power of a bank. In an imperfect competitive market, banks have market control and set the price of their products and services without diminishing the demand (Sulaeman et al. 2019). Net interest margin measures the deviation between the interest income from loans and other interest-bearing products and the interest expenses for deposits relative to the total number of interest-earning assets. For the banking sector, price is represented by interest rates, both on the funding side (customer deposits) and financing side (loan product). Market power also describes the competitiveness of a bank, which also affects banks' efficiency (Case et al. 2012). Another study states that efficiency in production process will reduce output cost per unit; thus, the output can be disposed at competitive prices in the market (Gaspersz 2011). Based on the theoretical concept of digital transformation

and its implication on bank efficiency, as well as the time lag of the impact, the following hypotheses are proposed: Digital transformation increases neobanks' efficiency, digital transformation is one of the determinants of neobanks' efficiency, and there is a U-shape long-term relationship between digital transformation and banks' efficiency.

3. Methodology

This study employs all the financial data of seven neobanks; these data were taken from the website of the Financial Services Authority-OJK (OJK 2024) at www.ojk.go.id, accessed on 31 January 2024, and the websites of the banks, consisting of data from balance sheets and profit and loss accounts from 2016 to 2023. The hypotheses of this study and the methodologies used to address these hypotheses are as follows:

Hypothesis 1. *Digital transformation enhances the efficiency of the neobanks.*

To measure efficiency, Stochastic Frontier Analysis (SFA) is used as it can estimate panel data and it can calculate the scores of efficiencies precisely and differentiate the stochastic inefficiencies and shocks from errors. SFA has a better statistical control than other approaches for measuring efficiency, such as Data Envelope Analysis (DEA), as it is more accurate in estimating the score of efficiency inefficiency (Asmare and Begashaw 2018). As a parametric method, SFA has substantial benefits in efficiency analysis because it can distinguish the random noise (Huang and Wang 2002).

Hypothesis 2. *Digital transformation is one of the determinants of neobanks' efficiency.*

Hypothesis 3. *There is a U-shape short-term and long-term relationship between digital transformation and neobanks' efficiency.*

To investigate these two hypotheses, Panel ARDL is used as a methodology to estimate which independent variables have positive or negative and significant or insignificant relationships with the dependent variable of efficiency.

3.1. Stochastic Frontier Analysis

3.1.1. Translog Profit Function

This study first analyzes the efficiency of the banks by applying SFA to measure the level of efficiency. The SFA method requires a parametric model construction for efficient frontier, which shows a relationship between input factor and output factor. Recent studies on efficiency measurement have used a stochastic model function to show production frontier, in which the error term consists of two components. Aigner et al. (1977) proposed the following stochastic model:

$$q_i = f(\beta x) + u_i + v_i \quad (1)$$

where q is the maximum output that can be produced using input factors x_i by firm i ; β represents the unknown parameters to be estimated; u_i is the independent error component of non-positive disturbance, which reflects any deviation as the impact of factors under the control of the firm's management in the example of technical and economic inefficiency; and v_i is the symmetric error component, that is, the effect of favorable and non-favorable outside environment events such as events related to topography, climate, errors of observation/measurement, luck, or technology performance (Aigner et al. 1977). In SFA, the measurement of inefficiency follows the production process, which can be translated into the production of a frontier function. In general, there are three production functions commonly used in efficiency studies, namely the Cobb–Douglas production

function, translog production function, and transcendental production function. In this study, the SFA method is used with the translog profit function, which is as follows:

$$\ln q_i = \beta_0 + \sum_j \beta_j \ln x_j + 1/2 \sum_j \sum_k \beta_{jk} \ln x_j \ln x_k \tag{2}$$

where $\beta_{jk} = \beta_{kj}$, and the function is homogenous if $\sum_k \beta_{jk} = 0$ for all j .

3.1.2. Production Function in Analyzing Efficiency

In the production function, there are two approaches for analyzing the efficiency. The first is an output-oriented production process which states that inefficiency exists when a greater quantity of output can be produced using the given quantity of input, obtained by simply adding the u_i term into the above equation; thus, the equation is as follows:

$$\ln q_i = \beta_0 + \sum_j \beta_j \ln x_j + 1/2 \sum_j \sum_k \beta_{jk} \ln x_j \ln x_k + u_i \tag{3}$$

The second one is an input-oriented production process which states that production is technically inefficient if the observed output quantity can be generated with a lower input quantity. The equation is derived from the equation above by simply adding the u_i term to $\ln x_j$ term as follows:

$$\ln q_i = \beta_0 + \sum_j \beta_j (\ln x_j + u_i) + 1/2 \sum_j \sum_k \beta_{jk} (\ln x_j + u_i) (\ln x_k + u_i) \tag{4}$$

SFA follows the general approach that an input has a similar function of derivative log cost in comparison with the corresponding log input price. The general situation is applied by normalizing the total cost of output and all costs of input with the labor price. The cost function is employed to estimate efficiency scores of each observation by using Stochastic Frontier Analysis. This study adopts a model described by [Kabir and Worthington \(2017\)](#) which estimates marginal cost using the translog cost function, which consists of prices of output Q_{it} (loans) and three prices of input W_{hit} ($h =$ deposits, capital, and labor) for the next variable of cost replaced with variable of profit. This study uses the SFA method with the intermediation approach and defines the input variables as the Price of Deposits (w_{1it}), Price of Labor (w_{2it}), and Price of Capital (w_{3it}), while Loans act as an output variable (Q_{1it}); the control variables are Equity (E_{1it}) and Trend (T_{2it}). The equation for the profit efficiency model is as follows:

$$\begin{aligned} \ln((\pi) + |(\pi_{\min}) + 1|)_{it} / W_{3it} = & \beta_0 + \beta_1 \ln Q_{it} + \sum_{h=1}^2 \beta_h \ln(W_{hit} / W_{3it}) + \\ & \frac{1}{2} \beta_{QQ} (\ln Q_{it})^2 + \frac{1}{2} \beta_{12} \ln(W_{1it} / W_{3it}) \ln(W_{2it} / W_{3it}) + \sum_{h=1}^2 \beta_{Qh} \ln Q_{it} \ln(W_{hit} / W_{3it}) + \\ & \beta_E \ln E_{it} + \frac{1}{2} \beta_{EE} (\ln E_{it})^2 + \sum_{h=1}^2 \beta_{Eh} \ln E_{it} \ln(W_{hit} / W_{3it}) + \beta_{EQ} \ln E_{it} \ln Q_{it} + \beta_T T + \\ & \frac{1}{2} \beta_{TT} T^2 + \sum_{h=1}^2 \beta_{Th} T \ln(W_{hit} / W_{3it}) + \beta_{TQ} T \ln Q_{it} + \varepsilon_{it} \end{aligned} \tag{5}$$

where:

- π = Profit.
- w_{1it} = Price of Deposits (interest expense/deposits).
- w_{2it} = Price of Capital (other operational expenses/fixed assets).
- w_{3it} = Price of Labor (labor expenses/total assets).
- Q_{it} = Loans.
- E_{it} = Equity.
- T_{it} = Trend.
- v = Error term.
- u = Inefficiency term.

The gap from the profit frontier can be determined as an error (v_{it}) after the estimation process, and the error might be distinguishable between a random error (v_{it}) and inefficiency term (u_{it}). These two variables compete to be autonomous of one another and act as objectives of the elements that cause profit inefficiency. The inefficiency terms can be

calculated to be cost efficiency scores by using the estimation model used by [Coelli and Battese \(1995\)](#), which is shown in the equation below:

$$EFF_{it} = -\exp(u_{it}) \tag{6}$$

where EFF_{it} = score of efficiency for banks i in period t ; u_{it} = inefficiency score of banks i for period t . The profit efficiency has a range from 0 to 1, which means that the higher the score, the higher the profit efficiency of the bank. The efficiency score might be interpreted inversely as the bank's inefficiency score. The efficiency score is then used as a response variable for the regression model to obtain the key factors of bank efficiency in Indonesia.

3.2. Panel Autoregressive Distributed Lag (ARDL)

To further examine whether digital transformation has an important moderating role on the efficiency of the bank and whether it has a short-term and/or long-term relationship with efficiency, the Panel ARDL model is constructed with the following equation:

$$Eff_{i,t} = \sum_{j=1}^p \lambda_{ij} Eff_{i,t-j} + \sum_{j=0}^q \gamma_{ij} X_{i,t-j} + \omega_i + \varepsilon_{i,t} \tag{7}$$

where:

- $Eff_{i,t}$ = profit efficiency;
- $X_{i,t-j}$ = vector ($k \times 1$) of explanatory variable (digital transformation, CAR, LDR, NIM, and economic growth are independent variables);
- ω_i = fixed effect of a specific bank;
- ε_{it} = error term;
- λ_{ij} = coefficient of previous lag-dependent variable ($t - j$);
- γ_{ij} = coefficient vector on current and previous lag of explanatory variable.

The model of Panel ARDL in the equation below can serve as an alternative for representing error correction (EC):

$$\Delta Eff_{i,t} = \theta_i (Eff_{i,t-1} - \beta'_i X_{i,t-1}) + \sum_{j=1}^{p-1} \tilde{\lambda}_{ij} \Delta Eff_{i,t-j} + \sum_{j=0}^{q-1} \tilde{\gamma}'_{ij} \Delta X_{i,t-j} + \omega_i + \varepsilon_{i,t} \tag{8}$$

where:

- Δ = first difference;
- $Eff_{i,t-1} - \beta'_i X_{i,t-1}$ = long-term relationship cointegration among variables;
- β'_i = cointegration vector;
- θ_i = coefficient of error correction (EC) in measuring the speed of adjustment on long-term equilibrium, which measures the long-term effect/contribution of the explanatory variable on the short-term dynamic of the dependent variable of bank efficiency (eff);
- $\tilde{\lambda}_{ij} \Delta Eff_{i,t-j}$ and $\tilde{\gamma}'_{ij} \Delta X_{i,t-j}$ = estimation of additional short-term effect on $Eff_{i,t}$.

This study uses the Panel ARDL method, as it can appropriately ascertain the correlation between digital transformation and the efficiency of the bank and simultaneously determine their short-term and long-term relationship with the existence of nonlinearity and without non-stationarity problems among the variables. The Panel ARDL assessment analyzes time-series and cross-section dimensions as it boosts the number of observations and its variation. Furthermore, the estimation panel reduces the disturbance from the estimation of individual time series and increases the reliable inference.

The steps in this empirical approach initially begin with identifying the order of data cointegration in the regression ARDL model, as it is integrated at level $I(0)$ or integrated at first difference $I(1)$, while variables of $I(2)$ must be omitted from the data set. The IPS ([Im et al. 2003](#)) and LLC ([Levin et al. 2002](#)) tests are used to investigate the unit root in the panel series group regardless of whether the variables are non-stationary. Also, the ADF (Augmented Dickey–Fuller) test, in conjunction with the Fisher and PP (Phillips–Peron) test and Fisher test alone, is used as a foundational framework to test the null hypothesis of the non-existence of cointegration among all the independent variables with the alternative

hypothesis of cointegration existence. The latter, the Akaike Information Criterion (AIC) test, is used to complete the order of vector autoregression, which shows the total number of lags that will be applied. Then, the regression of Panel ARDL is measured by using a Pooled Mean Group (PMG) estimation, which shows the results regarding the short-term and long-term correlations of the dependent variable and the regressors.

4. Results

Based on the financial data of the seven neobanks in Table 1, the majority of the banks have low efficiency, as described by the high operating expense to operational income ratios. Profitability, which is indicated by ROA and ROE, is also at a low level, even being negative for some banks. The CAR of neobanks in Indonesia in December 2023 was at the range of 27.86–118.21%, while LDR shows a variety of liquidity levels from 51.72 to 150.77%, which indicates that some banks have levels of loan exposure greater than the deposits they have collected, while other banks disburse the loan only about half of the deposits.

Table 1. Financial performance of neobanks as of December 2023.

No.	Bank	CAR	NPL	ROA	ROE	NIM	OC/OI	LDR
1	Bank A	27.86	3.73	−2.99	−17.56	18.39	112.27	77.73
2	Bank B	43.84	4.40	1.05	4.03	3.91	90.51	84.21
3	Bank C	71.48	1.10	0.18	1.16	5.36	97.66	51.72
4	Bank D	38.73	1.94	1.20	5.62	18.75	95.30	67.72
5	Bank E	61.77	0.84	0.49	1.02	9.45	95.83	107.77
6	Bank F	79.53	0.08	4.76	6.70	9.01	59.87	150.77
7	Bank G	118.21	0.00	−3.89	−4.86	4.83	157.59	87.93

Source: Financial reports on each bank's website. Abbreviations: CAR: Capital Adequacy Ratio; NPL: Non-Performing Loan; ROA: Return on Asset; ROE: Return on Equity; NIM: net interest margin; OC/OI: Operational Cost to Operational Income; LDR: Loan to Deposit Ratio.

4.1. Profit Efficiency and SFA Results Analysis

The results of the SFA show that the profit efficiency of all neobanks in this study increased after they carried out digital transformation. The digital transformation and executives' technical background, as well as their innovation consciousness, improved banks' efficiency, as stated by [Zhu and Jin \(2023b\)](#) based on their study on A-share listed banks in China from 2011 to 2021. Another study by [Shehadeh et al. \(2023\)](#) also found a significant effect of digital transformation on Islamic banks' efficiency and competitive advantage in Jordan. Table 2 details the profit efficiency of each neobank in Indonesia during 2016–2023. The annual profit efficiency of each bank is the quarterly average of efficiency in every year. Based on the results, the efficiency of all neobanks increased after digital transformation compared with the efficiency before digital transformation, although the efficiency went down for cases when the digital transformation process was initiated in 2019–2021. Bank B was previously the biggest neobank in terms of total assets, and it is affiliated with a state-owned bank; thus, the digital transformation process for this bank is more complex than for the other banks, which are more agile and can resolve the digital transformation process faster to improve their efficiency sooner.

Table 2 presents the profit efficiency trend of the seven neobanks in Indonesia before and after initiating the digital transformation. All of them showed the lowest point of efficiency at the time of the digital transformation process. The banks' profit efficiency values show that, even though the profit efficiencies decreased when they began to implement digital transformation, afterward, the profit efficiency of digital business banks increased. The deterioration of the banks' efficiency is aligned with the large amount of investment required in digital transformation, including, for example, investment in digital

infrastructure, investment in changing the management and culture, investment in tech talent, and promotional expenses for the marketing and branding of a new business model.

Table 2. Profit efficiency of neobanks from 2016 to 2023.

Bank	2016	2017	2018	2019	2020	2021	2022	2023
Bank A	0.524	0.460	0.389	0.325	0.330	0.184	0.405	0.572
Bank B	0.607	0.526	0.454	0.387	0.237	0.290	0.430	0.401
Bank C	0.481	0.404	0.394	0.319	0.349	0.303	0.310	0.386
Bank D	0.461	0.267	0.186	0.142	0.329	0.407	0.524	0.587
Bank E	0.473	0.366	0.323	0.239	0.177	0.256	0.406	0.527
Bank F	0.528	0.464	0.363	0.245	0.241	0.321	0.412	0.517
Bank G	0.505	0.356	0.246	0.180	0.229	0.127	0.218	0.391

Source: Data were sourced from the banks’ financial reports.

This finding supports the work of [Kriebel and Debener \(2021\)](#), who found that IT investment increases banks’ efficiency, but there is time lag to achieving targeted efficiency. The decrease in banks’ efficiency aligns with the high cost of digital transformation, which covers huge investment in IT infrastructure, digital–tech talent expenses, organizational/management change expenses, and promotional expenses for the marketing and branding of a new business model. This finding is also relevant to the work of [Zhu and Jin \(2023a\)](#), who found that the efficiency and operational capabilities of Chinese commercial banks has improved because of digital transformation.

4.2. Digital Transformation and Determinant of Efficiency

The next stage in this study is to investigate whether digital transformation is a determinant of neobanks’ efficiency and to analyze the relationship between digital transformation and efficiency in the short run and in the long run.

4.2.1. Multicollinearity Test

First, the test starts with descriptive statistics. All variables used for Panel ARDL are shown in the descriptive statistics in [Table 3](#), which presents the variables at natural level. Next is the multicollinearity analysis, which focused on identifying the existence of strong correlations between the independent variables in the regression model, as such correlations can complicate or distort the interpretation of regression coefficients. In this context, examining the correlation matrix between the variables of digital transformation (DT), capital adequacy (CAR), liquidity (LDR), interest margin (NIM), and economic growth (GDP) allowed for the initial identification the of relationships between variables in a linear model. As described in [Table 4](#), the variables’ correlation ranges from -0.317 (between capital adequacy and interest margin) to 0.408 (between digital transformation and net interest margin), indicating that there is no strong relationship or high correlation, which is usually indicated by a correlation value close to 1 or -1 . Hence, it can be concluded that there was no striking evidence of multicollinearity problems in this study.

Table 3. Descriptive statistics.

Variables	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
Eff	0.369	0.379	0.653	7.05×10^{-12}	0.134	223
DT	8.58×10^{10}	4.68×10^{10}	7.15×10^{11}	-1.03×10^{10}	1.11×10^{11}	224
LDR	4560.734	90.955	429,824.900	0.000	41,104.100	224
NIM	5.053	4.636	19.570	-12.229	4.535	224
GDP	4.047	5.030	7.080	-5.320	2.773	224
Ln DT	24.574	24.571	27.296	22.534	1.100	223

Table 4. Multicollinearity test result.

	DT	CAR	LDR	NIM	GDP
DT	1				
CAR	−0.091	1			
LDR	−0.127	0.071	1		
NIM	0.408	−0.317	−0.157	1	
GDP	0.074	−0.243	0.040	0.169	1

Source: Data were sourced from the banks’ financial reports.

4.2.2. Unit Root Test

Secondly, the results of the LLC test and the IPS test, which were implemented into this study to investigate whether the variables’ unit roots were applicable to the same root or applicable to no root, respectively, are described in Table 5. This unit root test is conducted to avoid the pseudo-regression phenomenon in analyses involving empirical models by testing each variable’s stationarity, because panel data consist of both cross-sectional data and time-series data. The LLC test presumes the equal parameters are tested across all panels. In the meantime, the IPS test is less opposed as it allows the parameters to vary across panels, and the data are obtained as the means of the ADF statistic. The unit root test describes the stationarity at the levels of some variables and other variables that are at first-difference stationarity, regardless of whether the test is using a constant with or without trend. The results of the unit root test shows that aside from LDR and GDP, which are stationary at this level, the other variables (DT, CAR, NIM, and GDP) are stationary at the first difference. The unit root test determines the I(0) and I(1) integration existence among the variables. The assessment identified the presence of a long-running equilibrium in stable relationship between variables; thus, the Panel of ARDL was chosen for this analysis.

Table 5. Results of stationarity test.

	Level	LLC	IPS	
		Δ (first diff)	Level	Δ (first diff)
EFF	0.3652	0.0000 ***	0.1919	0.0000 ***
DT	0.9463	0.0000 ***	0.9959	0.0000 ***
CAR	0.3029	0.0000 ***	0.3632	0.0000 ***
LDR	0.0537 *	0.0000 ***	0.0248 **	0.0000 ***
NIM	0.9768	0.0006 ***	0.9203	0.0000 ***
GDP	0.5908	0.0000 ***	0.0179 **	0.0000 ***

Notes: ***, **, and * stationarity at the 1%, 5%, and 10% levels, respectively.

Thirdly, after the stationarity test, the Akaike Information Criterion (AIC) model test is conducted to define the vector autoregression (VAR) order, which shows the number of lags to be applied. Table 6 describes the AIC optimum lags, which is automatically selected based on which choose the smallest value of AIC as the optimum lags ARDL (2, 2, 2, 2, 2, 2, 2).

Table 6. Results of optimum lag.

LogL	AIC *	BIC	HQ	Specification
449.791	−3.318	−1.372	−2.530	ARDL(2, 2, 2, 2, 2, 2, 2)
411.914	−3.009	−1.179	−2.268	ARDL(1, 2, 2, 2, 2, 2, 2)
358.512	−2.895	−1.757	−2.435	ARDL(1, 1, 1, 1, 1, 1, 1)
364.944	−2.889	−1.636	−2.382	ARDL(2, 1, 1, 1, 1, 1, 1)

Notes: * is the model to chosen define the optimum lags.

4.2.3. Cointegration Test

The results of another test conducted in this study (the test of cointegration) are reported in Table 7. After all variables across all panels become stationary at first difference, the next step is to conduct a cointegration test for efficiency, as the dependent variable, and the independent variables by applying the Pedroni (1999) Cointegration Test. This cointegration test was used to check the hypothesis regarding whether there is no existence of cointegration for all five variables of digital transformation (DT), CAR, LDR, NIM, and economic growth (GDP). The results indicate that no cointegration as the null hypothesis is rejected, which indicates that the dependent variables and the explanatory variables are in a long-term relationship. The analysis suggests a reliable short- and long-term estimate, which means that digital transformation and other explanatory variables are statistically significant and have a positive relationship with profit efficiency in the long run.

Table 7. Results of cointegration test.

Cointegration Test		Statistic	Prob
Kao Residual Cointegration Test	ADF	−4.210759	0.0000 ***
Pedroni Cointegration Test	Panel v-Statistic	−0.651922	0.7428
	Panel rho-Statistic	−1.071797	0.1419
	Panel PP-Statistic	−8.431710	0.0000 ***
	Panel ADF-Statistic	−2.823261	0.0024 ***

Notes: *** means cointegrated at a 1% significance level.

The final stage involved using Pooled Mean Group (PMG) to estimate the Panel ARDL regression by incorporating the optimum lag, which had been selected based on the AIC lag selection criteria. Table 8 presents the short-term and the long-term ARDL Panel regression results of digital transformation and other explanatory variables of the full panel of sample banks from 2016 to 2023.

Table 8. Results of ARDL estimation (short-run and long-run).

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Long-Run Equation				
DT ²	0.1251	0.0246	5.0794	0.0000 ***
DT	−6.0158	1.1783	−5.1055	0.0000 ***
CAR	0.0006	0.0002	3.6362	0.0004 ***
LDR	0.0017	0.0007	2.3284	0.0219 **
NIM	0.0094	0.0093	1.0098	0.3150
GDP	0.0643	0.0232	2.7789	0.0065 ***
Short-Run Equation				
COINTEQ01	−0.2063	0.0669	−3.0852	0.0026 ***
D(EFF(−1))	−0.1812	0.2434	−0.7443	0.4584
D(DT ²)	−0.0423	0.0531	−0.7961	0.4279
D(DT(−1) ²)	−0.0004	0.0633	−0.0065	0.9949
D(DT)	2.2109	2.6681	0.8287	0.4093
D(DT(−1))	0.0809	3.0369	0.0266	0.9788
D(CAR)	0.0008	0.0017	0.4676	0.6411
D(CAR(−1))	0.0013	0.0030	0.4349	0.6646
D(LDR)	0.0020	0.0011	1.8353	0.0694 *
D(LDR(−1))	0.0015	0.0020	0.7452	0.4579
D(NIM)	0.0417	0.0199	2.0927	0.0389 **
D(NIM(−1))	−0.0132	0.0252	−0.5257	0.6002
D(GDP)	0.0051	0.0153	0.3353	0.7381
D(GDP(−1))	−0.0015	0.0041	−0.3716	0.7109
COVID	0.0130	0.0223	0.5822	0.5617
C	14.8409	4.8164	3.0813	0.0027 ***

Note: *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively.

Table 8 shows that there is a relationship between the variables in the short run and long run, as the result of the Panel ARDL regression with Cointeq (1) for the Error Correction Term coefficient ($ECT_t - 1$) is -0.206 , which implies that efficiency adjusts towards its long-run equilibrium by about 20.6% in each period. This means that any deviation from the long-run equilibrium of efficiency will adjust towards it with a speed of adjustment of around 5 times that of the quarterly period data (around 15 months). The high significant and negative value of the ECT coefficient also provides strong evidence of a stable level of long-run relationship between the regressors and the dependent variable. In the short run, only LDR and NIM, as independent variables, have a significant positive relationship with the efficiency, as a higher LDR and NIM implies that the bank is capable of managing liquidity and interest margins efficiently. Digital transformation (DT) has an insignificant negative impact on bank efficiency because of the huge investment required for the digital transformation.

In the long run, digital transformation (DT) with a quadratic function has a U-shape relationship with profit efficiency at the 1% significance level. Other variables, namely CAR, LDR, and GDP, have a significant positive relationship with banks' profit efficiency at the 1% (CAR, GDP) and 5% (LDR) significance levels, while NIM does not have a significant relationship, as a higher NIM contributes to profitability. Hence, it can be concluded that DT can boost bank efficiency after a certain period of implementation, as discussed by Qehaja-Keka et al. (2023) and Yang et al. (2018).

4.2.4. Impulse Response Function (IRF)

This study empirically analyzes the impact of digital transformation on neobanks' efficiency. The empirical results are shown in terms of the Impulse Response Function in Figure 1, which shows that the impacts of digital transformation, as an independent variable, on neobanks' efficiency, split into dependent variables, are consistent, with there being a negative coefficient of digital transformation in the short run and positive coefficient of digital transformation in the long run. Figure 1 confirms the speed of adjustment described in the ECT in the above analysis, whereas the long-run equilibrium remained stable starting at the point fifth period.

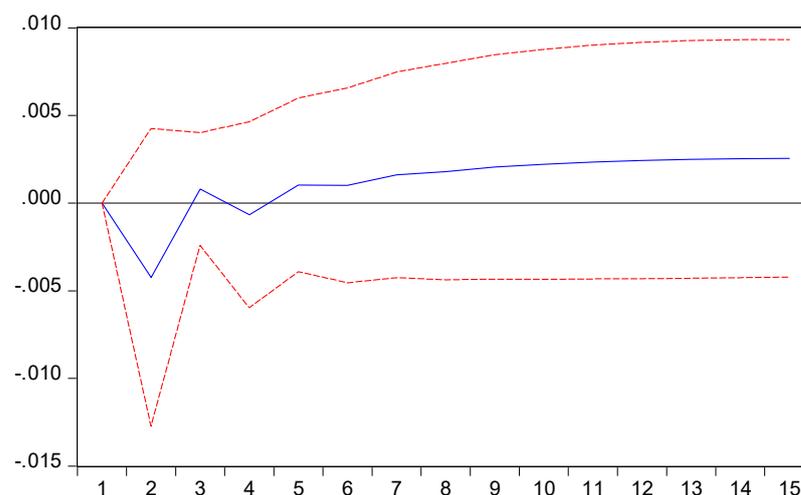


Figure 1. Response of efficiency to digital transformation.

4.2.5. CUSUM Test of Heterogeneity

Even after the cointegration has been tested, testing the stability of the estimated coefficients is required to obtain reliable results (Bahmani-Oskooee and Chomsisengphet 2002). Therefore, testing the stability of long-term parameters is important. This study used Pesaran et al. (1999)'s suggestion by adopting the cumulative sum of recursive residuals (CUSUM) and used Brown et al. (1975)'s suggestion of using the cumulative sum of

recursive residuals squared (CUSUM squared) to test the proposed residuals of the ECMs to test for parameter constancy.

We assumed that when the statistics plot lies inside the 5% significance critical bounds, the estimated coefficients are stable. These tests are commonly interpreted via graphical visualization, which allow for the evaluation of stability over time. Figure 2a,b shows a cumulative sums plot with 5% critical lines. The stability of the parameters is indicated by movement inside the critical lines. Based on the figures, it can be summarized that out of the imperceptible instability in 2020–2021, the CUSUM squared (Figure 2) results suggest that the residuals' variance can be defined as quite stable within the 5% significance lines.

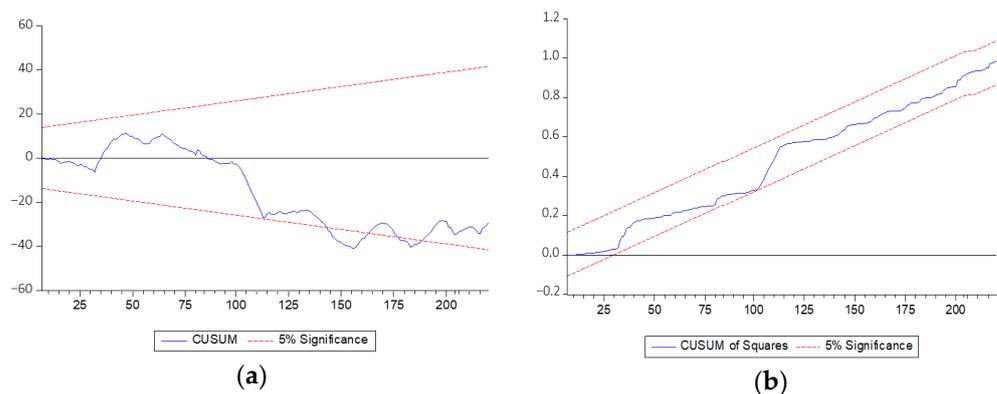


Figure 2. (a) CUSUM; (b) CUSUM square.

5. Discussion

Based on the results of the methodologies used in this study, all the hypotheses that were described in Section 3 are accepted. The first hypothesis that digital transformation enhances efficiency, described based on SFA efficiency score, is accepted because the banks showed higher scores after digital transformation. The second hypothesis, which was about digital transformation being one of the determinants neobanks' efficiency, is also accepted as digital transformation shows a significant relationship with efficiency, according to the Panel ARDL results. The third hypothesis, which proposed a U-shape short-term and long-term relationship between digital transformation and efficiency, is also accepted, as the estimation based on Panel ARDL shows a negative significant relationship at the beginning of the transformation process and then a positive significant relationship afterward.

Digital transformation has impacts on the efficiency of the neobanks, having both a negative impact at the beginning of the transformation process, then a directly positive impact, then a negative impact for a certain period, and then back to a positive impact afterward. As stated by [Sadigh et al. \(2021\)](#), digital transformation is an organization's collective action in adopting disruptive digital technology to achieve its goal and significantly change its performance and efficiency. One of the reasons for banks to explore digital transformation is to reduce operational costs; another reason is to differentiate themselves from competitors ([Indriasari et al. 2019](#)). This profit efficiency study supports a previous study by [Kriebel and Debener \(2021\)](#), who found that IT investment will affect banking efficiency in the long run and that there is time lag of up to 5 years from the beginning of digital transformation up to the achievement of efficiency.

This study supports previous studies about digital transformation's impact on banks' efficiency and shows that digital transformation is one of the determinants of banks' efficiency. Digital transformation has a direct continuous impact on operational performance rather than financial performance because the expected efficiency in operational activities and innovation environments for operating performance are easier to see. Digital technology is the *enabling factor* in transforming banks into a different kind of bank, not only in terms of time and cost efficiency but also in terms of providing customers with high-quality services with security guarantees that are efficient and conducive to easier personal

relationships (Filotto et al. 2020). Another study by Al-Busaidi and Al-Muharrami (2020) also discussed the significant finding of the impact of information and communication technology (ICT) investment on non-financial performance indicators, such as customers, internal processes, and learning models, and financial performance indicators.

According to this research, factors which become determinants of bank efficiency include DT, CAR, LDR, and GDP. The CAR is the proxy for capital. Having greater capital will support a bigger digital transformation and support bank efficiency. Another independent variable of the bank-specific factors is the LDR as the proxy of liquidity. This variable significantly and positively impacts banks' efficiency, as a higher LDR means higher interest income, which has an impact on bank efficiency. The LDR indicates banks' capability of managing their liquidity portfolio efficiently. A higher LDR means that the bank can manage their loans and obtain higher profits. On the macroeconomic level, higher GDP or economic growth encourages more financial transactions in the economy through the financial system, including digital banks as one of the financial system's elements. In contrast, the NIM, as the proxy of net interest income, does not significantly affect the efficiency, as the NIM will directly impact on competitiveness and profitability.

The impact of the time required for digital transformation on efficiency is described by U-shape short-term and long-term relationships. This estimation is based on the Panel ARDL results, which show a negative significant relationship at the beginning of the transformation process and then a positive significant after the transformation process. Each management team has their own strategy for achieving efficiency, as well as the goals of their digital transformation. The magnitude and acceleration of the impact on bank efficiency depends on the digital transformation strategy developed by the bank. As stated by Hadi and Hmood (2020), digital transformation combines information technology and the work of the banks to address future challenges in business. A bigger digital transformation requires a more expansive technological revolution and higher costs for IT investment. Krasonikolakis et al. (2020) found that digitalization in banking could serve as a platform for technological revolution due to the mass usage of technology and digital service innovations in the sector, helping to change banking products and services exponentially and replace conventional banking practices.

In implementing a digital transformation, some banks' efficiency has significant movement, both decreasing and increasing. Other banks have a smooth, gradual process in terms of managing the investment costs, which, consequently, helps in achieving the efficiency target. A problem arises if a bank believes that digital transformation is just about workflows and systems rather than customer experience (Indriasari et al. 2019). In the last few years, companies around the globe have started to transform and improve their competitive advantage, even though not all companies have been able to realize the business value of digital transformation due to the high costs and long time required to reach expected performance targets, including in efficiency (McKinsey 2020). In McKinsey's survey, 92% of the company executives stated that their business model will no longer survive in the era of digitalization if they do not transform their business.

6. Conclusions

Based on the above findings and discussions, it can be summarized that digital transformation increases neobanks' efficiency. Furthermore, it can be concluded that digital transformation is one of the determinants of neobanks' efficiency. In terms of the time required for digital transformation to impact the efficiency of neobanks, the results show that there is a short-run and long-run relationship between digital transformation and efficiency, and the indicative time for the digital transformation impact is around 15 months. This study confirms the findings of the previous studies featured in the literature review by finding that digital transformation reduces operational costs and upscales customer satisfaction. It also supports the previous findings that digital transformation has positive implications on neobanks' performance in terms of cost efficiency, NPL, ROE, and the NIM. This finding also reinforces those of an earlier study which noted the systematic relationship

between digital transformation and banks' efficiency, represented by the digital evolution of banks.

Digital transformation enhances neobanks' efficiency, as indicated by the increases in the efficiency scores. Based on our measurement of efficiency, carried out using the SFA approach, the overall neobanks' efficiency improved in the long term, aligning with the development of their digital capability to deliver relevant products and services to customer efficiently. The profit efficiency trend shows that efficiency deteriorates in the short term during the digital transformation process due to the huge costs required in digital transformation, which involves IT infrastructure investment, changing management and culture, investment in tech talent, and promotional expense for the marketing and branding of a new neobank.

Regarding the determinants of neobank's efficiency, through our analysis on all the variables used in this study, we can conclude that digital transformation, capital, liquidity, and economic growth are significant determinants of profit efficiency. Digital transformation has an important role in achieving neobanks' efficiency. Having greater capital supports digital transformation for bank efficiency, and sufficient liquidity management positively impacts banks' efficiency. Economic growth also significantly affects banks' efficiency by encouraging more financial transactions. On the other side, the net interest margin insignificantly impacts efficiency because a higher net interest margin will impact competitiveness and profitability.

This study also confirms the "U"-shape relationship between digital transformation and banks' efficiency, as described by non-linear functions. In the short term, digital transformation has a negative effect on the profit efficiency of banks due to the costs of digital transformation. Afterwards, in the long term, digital transformation has a positive implication on the profit efficiency of banks, which means that, in the beginning, digital transformation causes the deterioration of banks' efficiency because of digital transformation-related expenses, but subsequently, banks' efficiency will increase.

Each neobank has its own process in achieving efficiency as one of the goals of digital transformation. The magnitude of digital transformation's impact on banks' efficiency depends on the digital transformation strategy developed by the banks because the transformation combines the information technology and strategy of the bank. A bigger digital transformation means greater investment or higher costs for digital transformation and, consequently, leads to a longer time before the bank achieves efficiency, specifically if the bank does not have a sufficient strategy for facilitating digital transformation.

7. Recommendations and Limitations

Digital transformation is associated with digital technological innovation. This research has verified that digital transformation can increase the efficiency of neobanks. The analyses in this study, which analyzed digital transformation's effects on efficiency, confirmed that digital transformation will be advantageous for neobanks' operational performance and enhancing neobanks' efficiency.

Improving banks' efficiency by implementing digital transformation will also potentially encourage micro lending, as this lending is critical for supporting the growth of microscale enterprises (Farida et al. 2015). For Indonesia, as an archipelago emerging country dominated by Micro-, Small-, and Medium-sized Enterprises (MSMEs) in the business sector, banks' efficiency will promote MSMEs' activities and the prosperity of people with low-level income, specifically providing financial support for MSMEs' digital transformation and inclusive growth (Fauzi et al. 2023). The support of neobanks is part of interventions aiming to boost the digital transformation of MSMEs, particularly in terms of the financing aspects.

Customer engagement is a substantial element of banking service-oriented transformation. The relationship between consumers and bankers will create valuable information for innovation. Hence, neobanks need to transform their innovation strategies and focus more on customer experience. Specifically, neobanks are suggested to evaluate information

from consumers, meaning the consumers could serve as innovation partners to establish and improve the process of generating banking product and services.

Other aspects to focus on include capturing valuable insights provided by customers, scaling up information acquisition capabilities, and appointing relevant officers to comprehensively collect important information from consumers to provide relevant innovations for improving consumer satisfaction. Large-scale peripheral interconnections are essential to banking activities. In the digital transformation process, neobanks should focus on establishing collaboration instead of competing with bigger and smaller banks and other financial services providers, governments, and universities.

Moreover, digital business banks should ensure long-term and harmonious synergy with colleagues and determine the technology and capabilities needed to obtain corresponding benefits based on other banks with advanced levels of digital technology usage. In contrast, with ambiguity in the external surroundings, establishing collaborations with related banks will enable neobanks to distribute risks, decrease losses, and improve their capability to manage risks and adapt responses while still maintaining prudential approach towards data protection and risk management pertaining to cyber security, helping to bolster coordination and correspondence between colleagues, establish the production and propagation of innovative capabilities, and increase the impact of digital technology innovation.

Digital technology input in traditional banking products and services has little influence in improving the output of banks, while the high-end input of digital technology, knowledge, and tech talent can bring about enormously beneficial financial services, which become catalysts for achieving efficiency. Overall, the banking industry should prioritize the quality and efficiency of their traditional services and focus on the digital transformation process and expenses. More attention should be afforded to the inputs, such as digital infrastructure investment and investment in tech talent, for the best results regarding digital transformation elements, which lead to profit efficiency for banks.

The number of Indonesian neobanks is still limited compared with the hundreds of traditional banks in Indonesia. Some traditional banks build their digital banking services via separate lines of business. Scholars studying related topics state that the business strategy of digital transformation is not fully adopted by most banks because of the limited information regarding the adoption of digital transformation and the money required for digital transformation investment. Hence, it is important to empower studies on promoting digital transformation to enhance banks' efficiency.

As all studies do, this study had some limitations. The object of this study was limited to the seven neobanks in Indonesia; future research might benefit from studying additional newcomer neobanks. The determinants of neobanks' efficiency were limited to the five tested independent variables, namely digital transformation, capital adequacy, liquidity, the net interest margin, and economic growth, while there are many other factors that can influence banks' profit efficiency, including both bank-specific factors and macroeconomic factors. Furthermore, future research could use other recent statistical tools and be conducted with the optimum strategy regarding implementing digital transformation to accelerate the achievement of efficiency goals.

Author Contributions: Conceptualization, R.S.; methodology, R.S.; software, R.S.; validation, R.S., H.S., N.Z., and T.; formal analysis, R.S.; investigation, R.S.; resources, R.S.; data curation, R.S., H.S., N.Z., and T.; writing—original draft preparation, R.S.; writing—review and editing, R.S., H.S., N.Z., and T.; visualization, R.S.; supervision, H.S., N.Z., and T.; project administration, R.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: The views expressed in this paper are the authors' and do not represent any institutional views.

Conflicts of Interest: The authors declare no conflicts of interest.

References

- Agovino, Massimiliano, Silvana Bartoletti, and Antonia Garofalo. 2022. A long-term analysis of efficiency in the Italian banking system from 1861 to 2010. *Structural Change and Economic Dynamics* 61: 227–41. [CrossRef]
- Aigner, Dennis, Charles Albert Knox Lovell, and Peter Schmidt. 1977. Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics* 6: 21–37. [CrossRef]
- Alber, Nader, Mayssa Elmofty, Israa Kishk, and Reda Sami. 2019. Banking Efficiency: Concepts, Drivers, Measures, Literature and Conceptual Model. SSRN. pp. 1–24. Available online: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3310982 (accessed on 2 March 2024).
- Al-Busaidi, Kamla Ali, and Saeed Al-Muharrami. 2020. Beyond profitability: ICT Investment and financial institutions performance measures in a developing economy. *Journal of Enterprise Information Management* 34: 900–21. [CrossRef]
- Amiti, Mary, and Amit K. Khandelwal. 2009. Import Competition and Quality Upgrading. *The Review of Economics and Statistics* 95: 476–90. Available online: <https://www.nber.org/papers/w15503> (accessed on 4 March 2024). [CrossRef]
- Ang, James B. 2010. A survey of recent development in the literature of finance and growth. *Journal of Economic Surveys* 22: 536–76. [CrossRef]
- Asmare, Erkie, and Andualem Begashaw. 2018. Review on parametric and nonparametric methods of efficiency analysis. *Biostatistics and Bioinformatics* 2: 1–7. [CrossRef]
- BaFin. 2021. BaFin Federal Financial Supervisory Authority. Digital Banking, Neobanks and Direct Banks. Available online: https://www.bafin.de/EN/Aufsicht/FinTech/Geschaeftsmodelle/NeoBanks/NeoBanks_node_en.html (accessed on 2 March 2024).
- Bahmani-Oskooee, Mohsen, and S. Chomsisengphet. 2002. Stability of M2 demand functions in industrial countries. *Applied Economics* 34: 2075–83. Available online: https://libkey.io/10.1080/00036840210128744?utm_source=ideas (accessed on 2 March 2024).
- Banerjee, Rachna, Sudipa Majumdar, and Maryam Albastaki. 2022. Ideal self-congruence: Neobanking by traditional banks and the impact on market share—A case of UAE banks. *International Journal of Professional Business Review* 7: 1–21. [CrossRef]
- Barth, James, Chen Lin, Yue Ma, Jesus Seade, and Frank M. Song. 2013. Do bank regulation, supervision and monitoring enhance or impede bank efficiency? *Journal of Banking & Finance* 37: 2879–92. [CrossRef]
- Bauer, Paul W., Allen N. Berger, Gary D. Ferrier, and David B. Humphrey. 1998. Consistency conditions for regulatory analysis of financial institutions: A comparison of frontier efficiency methods. *Journal of Economics and Business* 50: 85–114. Available online: [http://www.sciencedirect.com/science/article/pii/S0148-6195\(97\)00072-6](http://www.sciencedirect.com/science/article/pii/S0148-6195(97)00072-6) (accessed on 1 March 2024).
- Bell, R. 2011. *Digital Transformation*. IBM Global Business Services. Somers: IBM Institute for Business Value.
- Berger, Allen N., and Loretta J. Mester. 1997. Inside the Black Box: What explains differences in the efficiencies of financial institutions? *Journal of Banking and Finance* 21: 895–947. [CrossRef]
- Bharadwaj, Anandhi, Omar A. El Sawy, Paul A. Pavlou, and N. Venkatraman. 2013. Digital business strategy: To ward a next generation insight. *MIS Quarterly* 37: 471–82. [CrossRef]
- Bhutani, Sumeet, and Yashi Paliwal. 2015. Digitalization: A step towards sustainable development. *International Journal of Sustainable Development* 8: 11–24.
- Brown, Robert L., James Durbin, and James M. Evans. 1975. Techniques for testing the constancy of regression relationships over time. *Journal of the Royal Statistical Society* 37: 149–92. [CrossRef]
- Case, Karl E., Ray C. Fair, and Sharon M. Oster. 2012. *Case & Fair Principles of Economics*, 10th ed. Boston: Pearson Education.
- Coelli, Timothy James, and George E. Battese. 1995. A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics* 20: 325–332. [CrossRef]
- Dahlstrom, Peter, Driek Desmet, and Marc Singer. 2017. *The Seven Decision That Matter in a Digital Transformation: A CEO's Guide to Reinvention*. New York: McKinsey Digital.
- Dehnert, Maik. 2020. Sustaining the current or pursuing the new: Incumbent digital transformation strategies in the financial service industry. *Business Research* 13: 1071–13. [CrossRef]
- Delgado, Maria. 2021. *Digital Transition in the Banking Business. Lessons after COVID-19*. Basel: Bank for International Settlements.
- Farida, Farida, Hermanto Siregar, Nunung Nuryartono, and Eka K. P. Intan. 2015. Micro enterprises' access to people business credit program in Indonesia: Credit rationed or non-credit rationed? *International Journal of Economic Perspectives* 9: 57–70.
- Farrell, M. J. 1957. The Measurement of productive efficiency. *Journal of the Royal Statistical Society* 120: 253–90. [CrossRef]
- Fauzi, Firman, Hermanto Siregar, Baba Barus, and Galuh Syahbana Indraprahasta. 2023. Digital transformation for SMEs development based at four levels of analysis—A Literature review. *ABAC Journal* 43: 276–302. [CrossRef]
- Filotto, Umberto, Massimmo Caratelli, and Fabrizio Fornezza. 2020. Shaping the digital transformation of the retail banking industry. Empirical evidence from Italy. *European Management Journal* 39: 366–75. [CrossRef] [PubMed]
- Firdaus, Muhammad Faza, and Muhamad Nadratuzzaman Hosen. 2014. The Efficiency of Sharia Commercial Bank Using Two-Stage Data Envelopment Analysis Approach. *Bulletin of Monetary Economics and Banking* 16: 167–88. [CrossRef]

- Fitzgerald, Michael. 2013. Embracing Digital Technology: A New Strategic Imperative. *MIT Sloan Review*, October 7.
- Gasparsz, Vincent. 2011. *Total Quality Management for Business Practitioner and Industry*. Jakarta: Gramedia.
- Hadad, Muliaman D., Wimboh Santoso, Eugenia Mardanugraha, and Ilyas Daniel. 2003. Parametric Approach for Banking Efficiency. *Bulletin of Monetary Economics and Banking*.
- Hadi, Anmar Muzaffar, and Salam Jassim Hmood. 2020. Analysis of the role of digital transformation strategies in achieving the edge of financial competition. *International Journal of Innovation, Creativity, and Change* 10: 19–40.
- Huang, Tai-Hsin, and Mei-Hui Wang. 2002. Comparison of economic efficiency estimation methods: Parametric and non-parametric techniques. *Manchester School* 70: 682–709. [CrossRef]
- Ikhwan, Ihsanul, and Ririn Riani. 2022. The efficiency level of Indonesian banks in the COVID-19 pandemic era and its determinant. *Islamic Economic and Finance Journal* 8: 221–35. [CrossRef]
- Im, Kyung So, M. Hashem Pesaran, and Yongcheol Shin. 2003. Testing for unit roots in heterogeneous panels. *Journal of Econometrics* 115: 53–74. [CrossRef]
- Indriasari, Elisa, Ford Lumban Gaol, and Tokuro Matsuo. 2019. Digital banking transformation: Application of artificial intelligence and big data analytics for leveraging customer experience in the Indonesia banking sector. Paper presented at 8th International Congress on Advances Applied Informatic, Toyama, Japan, July 7–11.
- International Monetary Fund. 2022. The Rapid Growth of Fintech: Vulnerabilities and Challenges for Financial Stability. Global Financial Stability Report: Shockwaves from The War in Ukraine Test the Financial System's Resilience. Chapter 3. Global Financial Stability Report, April 2022: Shockwaves from the War in Ukraine Test the Financial System's Resilience. Available online: <https://www.imf.org> (accessed on 5 March 2024).
- Ismail, Mariam H., Mohamed Khater, and Mohamed Zaki. 2018. Digital business transformation and strategy: What do we know so far? Working Paper. *Cambridge Service Alliance* 10: 1–35.
- Jusufi, Arben. 2023. Relationship between innovation and financial performance in the global environment of exporting companies. *Journal of Liberty and International Affairs* 9: 74–88. [CrossRef]
- Kabir, Md Nurul, and Andrew C. Worthington. 2017. The 'competition-stability/fragility' nexus: A comparative analysis of Islamic and conventional banks. *International Review of Financial Analysis* 50: 111–28. [CrossRef]
- Kane, Gerald C., Anh Nguyen Philips, Jonathan Copulsky, and Andrus Garth. 2019. How Digital Leadership Is (n't) Different. *MIT Sloan Management* 60: 34–39.
- King, Brett. 2018. *Bank 4.0: Banking Everywhere, Never at a Bank*. Singapore: Marshall Cavendish International Asia Pte Ltd.
- Krasonikolakis, Ioannis, Michalis Tsarbopoulous, and Teck-Yong Eng. 2020. Are incumbent banks bygones in the face of digital transformation. *Journal of General Management* 46: 60–69. [CrossRef]
- Kriebel, Johannes, and Jorn Debener. 2021. The Effect of Digital Transformation on Bank Performance. SSRN. Available online: <https://ssrn.com/abstract=3461594> (accessed on 5 March 2024).
- Levin, Andrew, Chien-Fu Lin, and Chia-Shang James Chu. 2002. Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics* 108: 1–24. [CrossRef]
- Liu, Caihong, Hannah Ji, and Jonah Ji. 2022. Mobile information technology's impacts on service innovation performance manufacturing enterprises. *Technological Forecasting and Social Change* 184: 121996. [CrossRef]
- Matthews, Kent, and John Thompson. 2008. *The Economics of Banking*, 32nd ed. London: John Wiley & Sons.
- McKinsey. 2020. *How Six Companies Are Using Technology and Data to Transform Themselves*. Chicago: McKinsey & Company.
- Ministry of Communication and Informatics. 2021. *Indonesia Digital Roadmap 2021–2024*. Jakarta: Kementerian Komunikasi dan Informatika.
- [OJK] Otoritas Jasa Keuangan/Indonesian Financial Service Authority. 2021a. Material presented on OJK Virtual Innovation Day 2021. Available online: <https://ojk.go.id> (accessed on 5 March 2024).
- [OJK] Otoritas Jasa Keuangan/Indonesian Financial Service Authority. 2021b. Blue Print of Banking Digital Transformation. Cetak Biru Transformasi Digital Perbankan (Short Version). Available online: <https://ojk.go.id> (accessed on 5 March 2024).
- [OJK] Otoritas Jasa Keuangan/Indonesian Financial Service Authority. 2024. Indonesia Banking Statistics. Website OJK. Available online: <https://ojk.go.id> (accessed on 5 March 2024).
- Pedroni, Peter. 1999. Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics* 61: 653–70. [CrossRef]
- Peng, S., and C. Zhou. 2017. Can enterprise internationalization enhance enterprise innovation capability—Test based on panel data of Chinese listed companies. *Research on Science and Technology Management* 37: 6–13.
- Pesaran, M. Hashem, Yongcheol Shin, and Ron P. Smith. 1999. Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association* 94: 621–34. [CrossRef]
- Pierrri, Nicola, and Yannick Timmer. 2022. The importance of technology in banking during a crisis. *Journal of Monetary Economics* 128: 88–104. [CrossRef]
- Porcelli, Francesco. 2009. *Measurement of Technical Efficiency. A Brief Survey on Parametric and Non-Parametric Techniques*. Coventry: University of Warwick, pp. 1–27.
- Qehaja-Keka, Vese, Skender Ahmeti, and Muhamet Aliu. 2023. Bank profitability determinants: Evidence from Kosovo and Albania. *Journal of Liberty and International Affairs* 9: 297–311. [CrossRef]

- Rogers, David L. 2016. *The Digital Transformation Playbook: Rethink Your Business for the Digital Age*. Columbia Business School Publishing. Columbia University. Available online: <http://cup.columbia.edu/book/the-digital-transformation-playbook/9780231175449>. (accessed on 6 March 2024).
- Rose, Peter S., and Sylvia C. Hudgins. 2010. *Bank Management and Financial Services*, 8th ed. International Edition. New York: McGraw-Hill.
- Sadigh, Ali Naimi, Tayebeh Asgari, and Mohammad Rabiei. 2021. Digital transformation in the value chain disruption of banking services. *Journal of the Knowledge Economy* 13: 1212–42. [CrossRef]
- Sari, Putri Zanufa, and Erwin Saraswati. 2017. The determinant of banking efficiency in Indonesia (DEA Approach). *Journal of Accounting and Business Education* 1: 208–29. [CrossRef]
- Schworer, Tillman. 2012. Offshoring, domestic outsourcing and productivity: Evidence for a number of European countries. *Review of World Economics* 149: 131–49. [CrossRef]
- Sharma, Dipasha. 2018. Stock market performance and efficiency of banks in a developing economy: Evidence from the Indian banking sector. *Sage Journals* 7: 178–93. [CrossRef]
- Shehadeh, Maha, Ahmad Almohtaseb, Jehad Aldehayyat, and Ibrahim A. Abu-ALSondos. 2023. Digital transformation and competitive advantage in the service sector: A moderated-mediation model. *Sustainability* 15: 2077. [CrossRef]
- Sidhu, Anureet Virk, Rebecca Abraham, Venkata Mrudula Bhimavarapu, Jagjeevan Kanoujiya, and Shailesh Rastogi. 2023. Impact of liquidity on the efficiency of banks in India using panel data analysis. *Risk and Financial Management* 16: 390. [CrossRef]
- Sulaeman, Heti Suryani Fitri, Sri Mulyantini Moelyono, and Jubaedah Nawir. 2019. Determinant of banking efficiency for commercial banks in Indonesia. *Contemporary Economics* 13: 205–18. [CrossRef]
- Valenduc, Gerard, and Patricia Vendramin. 2017. Digitalisation, between disruption and evolution. *Transfer* 23: 121–34. [CrossRef]
- Warner, Karl S. R., and Maximilian Wager. 2019. Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal. *Business. Long Range Planning* 52: 326–49. [CrossRef]
- Westerman, George. 2017. Your Company Doesn't Need a Digital Strategy. MIT Sloan Management Review. *Magazine*, October 25.
- Widiarti, Astoeti Wahjoe, Hermanto Siregar, and Trias Andati. 2015. The Determinants of Bank's Efficiency in Indonesia. *Bulletin of Monetary Economy Monetary and Banking* 18: 129–56. [CrossRef]
- Yang, Shaohua, Zeyun Li, Yaxin Ma, and Xingxing Chen. 2018. Does electronic banking really improve bank performance? Evidence in China. *International Journal of Economic and Finance* 10: 82–94. [CrossRef]
- Yoo, Youngjin, Ola Henfridsson, and Kalle Lyytinen. 2010. The new organizing logic of digital innovation: An agenda for information systems research. *Information Systems Research* 21: 724–35. [CrossRef]
- Zhu, Yongjie, and Shanyue Jin. 2023a. COVID-19, digital transformation of banks, and operational capabilities of commercial banks. *Sustainability* 15: 8783. [CrossRef]
- Zhu, Yongjie, and Shanyue Jin. 2023b. How does the digital transformation of banks improve efficiency and environmental, social, and governance performance? *Systems* 11: 328. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.