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Efficiency Evaluation of Islamic Commercial Banks in Indonesia Using Stochastic Frontier Analysis (SFA): A Panel Data Approach

Zulfikar Hasan[1*], Mhd Syahrizan[2], Nor Razinah Binti Mohd. Zain[3]
[1] Department of Islamic Banking IAIN Datuk Laksemana Bengkalis Riau, Indonesia
[2] Postgraduate student at Sultan Syarif Kasim II State Islamic University, Indonesia
[3] Institute of Islamic Banking and Finance, International Islamic University, Malaysia

ABSTRACT

The efficiency of Islamic commercial banks is a crucial determinant of their competitiveness and long-term sustainability, especially in a dynamic financial environment, such as Indonesia. Despite rapid growth in the Islamic banking sector, questions persist regarding whether these banks are operating at optimal efficiency levels. This study aims to evaluate the technical efficiency of Islamic commercial banks in Indonesia over the period 2015–2024 by employing Stochastic Frontier Analysis (SFA) with a translog production function applied to balanced panel data. The model incorporated key input variables, including total assets, labor expenses, and operational costs, with financing used as a proxy for output performance. Empirical findings revealead that an average technical efficiency score of 0.784, suggesting notable inefficiencies across the sector. Among the sampled institutions, BCA Syariah Bank and Mega Syariah Bank consistently outperform their peers, while Victoria Syariah Bank showed persistently low efficiency due to operational shortcomings. The estimated gamma parameter (0.886) further indicated that inefficiency significantly explains the variation in output among banks, validating the use of the SFA model. The study underscores the urgent need for strategic improvements in operational management, resource allocation, and digital transformation initiatives. In addition, regulatory bodies are encouraged to strengthen institutional frameworks and promote innovation and human capital development.

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* Corresponding at the IAIN Datuk Laksemana Bengkalis Riau, Indonesia
E-mail address: zulfikarhasan16@gmail.com

INTRODUCTION

Islamic commercial banks in Indonesia have grown significantly over the past decade, driven by increasing public awareness of Sharia-compliant financial products and strong governmental support for Islamic finance. Despite this growth, these banks still represent a relatively small share of the national banking industry. Questions remain about their operational efficiency, especially amidst increasing competition, digital transformation, and regulatory changes. This creates a pressing need to evaluate how efficiently these institutions utilize their resources to maximize outputs while adhering to Sharia principles (Rosman et al., 2021).

Previous studies, such as those by Rosman and Zainol (2020), have examined the efficiency of Islamic banks using various methods such as Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). These studies highlighted mixed efficiency levels across regions and time, indicating that Islamic banks often struggle to reach optimal efficiency due to operational rigidity, regulatory constraints, and cost structures. However, many of these studies focus on cross-country comparisons or exclude recent years, and very few focus specifically on Islamic commercial banks in Indonesia using updated and extended panel data from 2015 to 2024. The Islamic banking industry has emerged as a critical component of the global financial system, offering an alternative to conventional banking that is grounded in Sharia (Islamic law). Islamic financial institutions operate based on principles such as risk-sharing, prohibition of interest *(riba)*, ethical investments, and asset-backed financing (Alqahtani & Mayes, 2022). Over the past few decades, the industry has grown significantly, not only in Muslim-majority countries, but also in various parts of the world, indicating a rising demand for ethical and inclusive financial services (Abedifar et al., 2020).

This research is grounded in Production Theory and Efficiency Theory in microeconomics, where banks are treated as production units converting inputs (labor, capital, assets) into outputs (loans, financing, investments). The Stochastic Frontier Theory, specifically, provides a parametric approach to efficiency measurement that accounts for statistical noise and inefficiency simultaneously. This method is considered more robust compared to non-parametric techniques, such as DEA when panel data and random disturbances are involved. Indonesia, which home to the world's largest Muslim population, has demonstrated a strong commitment to the development of Islamic finance, particularly

Islamic banking (Taufiq & Wahyuni, 2022). The Islamic financial services industry in Indonesia has received growing support from the government, regulators such as the Financial Services Authority (OJK), and Bank Indonesia. Islamic commercial banks, as key players in this sector, contribute to financial inclusion, economic development, and social welfare by providing Sharia-compliant banking services to individuals, businesses, and institutions (Tatineni & Mustyala, 2024).

This study aims to evaluate the technical efficiency of Islamic commercial banks in Indonesia over the period 2015 to 2024 using the Stochastic Frontier Analysis (SFA) approach with panel data. It seeks to measure efficiency levels, identify efficiency determinants, and examine whether Islamic banks in Indonesia have improved their operational performance over time. The central proposition of this study is that Islamic commercial banks in Indonesia have not yet achieved optimal efficiency levels, primarily due to structural and managerial factors. This study also hypothesizes that bank-specific variables such as asset size, capital adequacy, and financing structure significantly influence bank efficiency. By testing this, the research aims to provide empirical evidence on whether operational performance aligns with the intended benefits of Sharia-compliant banking. Despite the promising growth, Islamic commercial banks in Indonesia face significant challenges related to competition with conventional banks, limited market penetration, efficiency constraints, and the need for innovation and digital transformation (Giri et al., 2021). Efficiency is a vital aspect of bank performance, reflecting how effectively a bank utilizes its inputs (such as labor, capital, and assets) to generate outputs (such as loans, financing, and other banking services). In a competitive and evolving financial landscape, understanding and improving the efficiency of Islamic banks is essential for ensuring their sustainability and competitiveness (Santoso, 2021).

While the growth trajectory of Islamic commercial banks in Indonesia is encouraging, questions remain regarding their operational efficiency (Hasan & Sari, 2020). Compared to conventional banks, Islamic banks often operate under dual regulatory frameworks, adhere to more complex financial contracts, and face limitations in product design due to Sharia compliance requirements (Tatineni & Mustyala, 2024). These constraints may impact their cost structures, risk management, and overall efficiency. Moreover, the absence of interest-based mechanisms requires Islamic banks to innovate in structuring profit-and-loss sharing arrangements, which may further influence their efficiency levels (Mansur & Rahayu, 2021).

Previous empirical studies on the efficiency of Islamic banks in Indonesia have generally adopted methods such as Data Envelopment Analysis (DEA), ratio analysis, or regression-based techniques. However, these approaches may not fully account for random shocks, measurement errors, or firm-specific heterogeneity (Khurshid et al., 2023). In contrast, the Stochastic Frontier Analysis (SFA) offers a more robust econometric technique that distinguishes inefficiency from statistical noise and allows for a more accurate measurement of technical efficiency. Furthermore, with the availability of panel data over multiple years, it becomes possible to observe efficiency trends and determine whether banks are improving or deteriorating in performance over time (Tatineni & Mustyala, 2024).

Given the rapid changes in Indonesia's financial sector, including regulatory reforms, digital transformation, and the impact of the COVID-19 pandemic, a re-evaluation of the efficiency of Islamic commercial banks using recent and comprehensive data is not only necessary but also timely (Putri & Kurniawan, 2021). To date, few studies have utilized SFA in combination with a long panel dataset to assess the efficiency of Islamic commercial banks in Indonesia from both temporal and cross-sectional perspectives (Amalia & Fitrani, 2021). The existing literature on banking efficiency in Indonesia remains limited in several key respects. First, there is a paucity of studies that employ stochastic frontier analysis to evaluate the efficiency of Islamic commercial banks specifically, although this analysis has advantages in addressing heteroscedasticity and unobserved firm-level effects. Second, many previous studies were based on relatively short periods, which may not capture structural changes in the industry. Third, studies often fail to account for macroeconomic variables, institutional changes, and technological innovations that may significantly impact banking efficiency. Furthermore, the Indonesian Islamic banking industry has undergone significant developments between 2015 and 2023, including increased government support, changes in financial regulations, digital banking initiatives, and the economic impacts of the COVID-19 pandemic. These factors underscore the need for updated and methodologically rigorous efficiency assessment in the sector.

This research contributes to the growing body of knowledge on Islamic banking efficiency in several ways. First, it provides updated empirical evidence on the performance of Islamic commercial banks in Indonesia, taking into account recent economic and regulatory developments. Second, by applying the SFA approach, the study offers more accurate and

statistically robust efficiency assessment, distinguishing between inefficiency and external shocks. Third, the findings are expected to inform policymakers, regulators, and bank managers on areas that require strategic intervention to enhance efficiency and competitiveness. Furthermore, the study holds practical relevance for stakeholders in the Islamic finance industry, including investors, depositors, and researchers interested in the operational dynamics of Islamic banking. Given the increasing emphasis on sustainability, digital transformation, and resilience in the financial sector, this research provides valuable insights for shaping the future direction of Islamic banking in Indonesia and beyond.

The evaluation of efficiency in Islamic commercial banks is increasingly important, particularly in the context of Indonesian growing Islamic financial sector. As the largest Muslim-majority country, Indonesia plays a strategic role in the global Islamic banking landscape. However, the performance and operational efficiency of Islamic commercial banks remain underexplored, especially using advanced econometric techniques such as stochastic frontier analysis (SFA). This research is essential to assess how efficiently these banks utilize their resources in achieving optimal output, particularly over the period 2015 to 2024, which encompasses various economic shifts, regulatory reforms, and post-pandemic recovery phases. This study contributes to the existing literature by applying a panel data approach to the SFA method, which allows for more comprehensive and dynamic analysis across time and institutions. Unlike prior studies that often rely on cross-sectional data or use traditional efficiency estimation models, such as data envelopment analysis (DEA), this research integrates time-series and cross-sectional variations to provide more robust and policy-relevant insights.

This study contributes to the literature by offering a comprehensive and up-to-date efficiency evaluation of Islamic commercial banks in Indonesia using panel data from 2015 to 2024, which captures post-pandemic recovery trends, regulatory changes, and digital banking developments. Unlike previous studies that are either outdated or cross-sectional, this research provides longitudinal insights with policy relevance. It also integrates Sharia-compliance context into the efficiency framework, which is often overlooked in conventional models. The concept of efficiency in banking originates from the broader field of production economics, where firms are evaluated based on their ability to convert inputs into outputs effectively. In the context of banking, efficiency broadly refers to how well bank utilizes its

resources, such as labor, capital, and assets to produce financial services, including loans, investments, and deposit mobilization (Kondapaka, 2023). Banking efficiency is generally classified into three categories: allocative efficiency**,** technical efficiency, and cost efficiency. Technical efficiency refers to a bank's ability to obtain the maximum output from a given set of inputs, while allocative efficiency concerns the optimal allocation of resources based on input prices (Tatineni & Mustyala, 2024). Cost efficiency combines both dimensions and reflects a bank's ability to produce a given output at the minimum cost (Hasan, 2022).

Measuring efficiency in the banking sector requires rigorous methodologies. Common techniques include non-parametric methods like DEA and parametric methods such as SFA (Savitri & Armando, 2022). While DEA is widely used for its flexibility and lack of assumptions regarding functional form, SFA has gained recognition for its ability to incorporate a statistical noise component, making it more appropriate when dealing with real-world data that are often affected by external shocks (Pambudi & Mubin, 2023). Islamic banking introduces unique considerations into the discussion of bank efficiency. Unlike conventional banks that operate under interest-based mechanisms, Islamic banks follow Sharia principles that prohibit *riba* (interest), *gharar* (excessive uncertainty), and *haram* (prohibited) activities (Sudiro et al., 2022). Instead, they rely on profit-and-loss sharing contracts (such as *mudarabah* and *musharakah*) and asset-backed financing models (such as *murabaha*, *ijarah*, and *istisna*) (Abdalla Ahmed, 2023). These structural and operational differences can affect the efficiency of Islamic banks in multiple ways. On one hand, the emphasis on risk-sharing and ethical investments may encourage prudence and resilience. On the other hand, limitations on the range of financial instruments and additional compliance requirements may impose operational constraints that affect efficiency levels (Igsamo & Falianty, 2021).

Puneri et al. (2022) argued that dual nature of Sharia compliance and financial intermediation can create inefficiencies, particularly in countries where Islamic banking which still developing. Several empirical studies have attempted to evaluate the efficiency of Islamic banks across different countries, employing both DEA and SFA methodologies (Prima Sakti & Mohamad, 2021). Chong et al. (2023) employed a stochastic cost frontier to evaluate 18 Islamic banks over the period 1997 to 2000 and found that while Islamic banks were generally inefficient, their performance improved over time. Cakir & Adiguzel (2021) used SFA on a sample of 43 Islamic banks in 21 countries and reported varying levels of efficiency depending

on regional and institutional factors. Ros and Abdul (2021) studied Malaysian Islamic banks using panel data and found that most banks were operating below the efficiency frontier. Used SFA to assess the efficiency of Islamic and conventional banks in Malaysia and observed that Islamic banks lagged slightly in efficiency, although the difference narrowed over time (Usman et al., 2022).

Employed DEA to evaluate the efficiency of Islamic banks in Indonesia between 2002 and 2006, concluding that many banks were technically inefficient due to managerial and scale inefficiencies. Hosen and Muhari (2021) used panel regression to assess efficiency determinants in Islamic banks and found that size, capital adequacy, and non-performing financing significantly influenced efficiency. Rusydiana et al. (2021) applied DEA to measure cost efficiency in Indonesian Islamic commercial banks and emphasized the importance of improving input management strategies. Fauzi et al. (2021) conducted a comparative analysis of Islamic and conventional banks using SFA and found that Islamic banks were slightly less efficient, particularly in the early years of their operation. While these studies provide useful insights, they often suffer from limitations, including short periods, outdated datasets, and failure to consider macroeconomic factors or technological developments that may affect banking efficiency. SFA, introduced by Rosman et al. (2021), is a parametric method that estimates the efficiency frontier by decomposing the error term into two components: one representing random shocks (statistical noise) and another capturing inefficiency. This method assumes a specific functional form (Cobb-Douglas or Translog) for the production or cost function and requires panel or cross-sectional data.

The advantage of SFA lies in its ability to distinguish inefficiency from external shocks, such as economic crises or policy change factors, particularly relevant in volatile emerging markets like Indonesia. Moreover, SFA is well-suited for analyzing panel data, allowing researchers to observe time trends and individual heterogeneity across banks (Rosman et al., 2021). Recent studies using SFA have incorporated exogenous variables (macroeconomic indicators) and bank-specific characteristics (total assets, capital adequacy ratio, loan-to-deposit ratio) to explain variations in efficiency. Suhendar and Hidayat (2021) one-step estimation model is commonly used to simultaneously estimate the stochastic frontier and inefficiency effects.

METHOD, DATA, AND ANALYSIS

This study adopted a quantitative explanatory research design utilizing panel data econometrics to evaluate the efficiency of Islamic commercial banks in Indonesia over the period 2015 to 2023. The primary methodological approach is stochastic frontier analysis (SFA), which enables the separation of inefficiency effects from random statistical noise within a production framework. SFA is chosen over non-parametric methods, such as DEA due to its superior capacity to incorporate firm-specific heterogeneity, measurement error, and temporal variation (Fauzi et al., 2021). The objective of this design is two-fold. First, to estimate the technical efficiency scores of Islamic commercial banks in Indonesia using an econometrically specified production frontier. Second, to identify and quantify the influence of contextual and bank-specific factors on efficiency levels through the inefficiency effects model.

Table 1. Islamic Commercial Banks

Bank Name	Notes
Bank Muamalat Indonesia	Active throughout 2015 to 2024
Bank Syariah Mandiri	Merged into BSI in 2015 to 2024
BNI Syariah	Merged into BSI in 2015 to 2024
BRI Syariah	Merged into BSI in 2015 to 2024
Bank Syariah Indonesia (BSI)	Established in 2021 from the merger of BRI, BNI, and Mandiri Syariah
Bank Mega Syariah	Active throughout 2015 to 2024
Bank Panin Dubai Syariah	Formerly Bank Panin Syariah; active 2015 to 2024
Bank BCA Syariah	Active throughout 2015 to 2024
Bank Syariah Bukopin	Active throughout 2015 to 2024
Bank Victoria Syariah	Active throughout 2015 to 2024
Bank Aceh Syariah	Converted from a conventional bank in 2015
Bank NTB Syariah	Converted from conventional bank in 2015

Data source: Compiled by the author, 2025

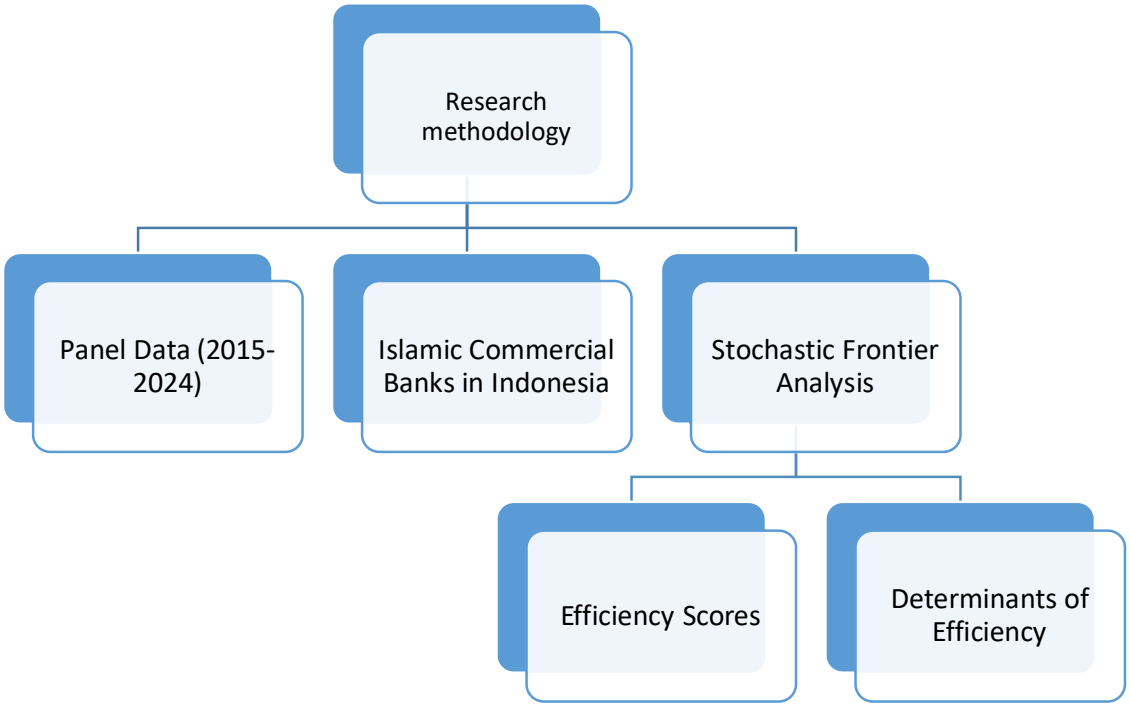

Figure 1. Research Flowchart for Evaluating the Efficiency of Islamic Commercial Banks in Indonesia Using SFA, 2015-2024

Model Specification

Stochastic Frontier Production Function

The SFA model is specified within the output-oriented production framework, which is suitable for evaluating how efficiently banks transform inputs into outputs. Following the framework developed by Battese and Coelli (1995), and further elaborated by Kumbhakar and Lovell (2023), the stochastic frontier production function is expressed as:

$$ln\,(Y_{it}) = \beta_0 + \beta_1 \cdot ln\,(X_{i,it}) + \beta_2 \cdot ln\,(X_{2,it}) + \beta_3 \cdot ln\,(X_{3,it}) + V_{it} - U_{it}$$

Where:

Y_{it} = output variable for bank *iii* at time *ttt*

k_{itX} = vector of kkk input variables

β_k = parameters to be estimated

Input and Output Variables

The selection of inputs and outputs follows the intermediation approach, which conceptualizes banks as financial intermediaries that mobilize funds from surplus units and channel them into productive sectors. The following variables are used:

a. Output (Y): Total Financing (proxy for productive output)
b. Inputs (X): Total Deposits (as proxy for financial capital)**,** Operating Expenses (proxy for cost of intermediation), Personnel Expenses (proxy for labor input).

All variables are converted into natural logarithmic form to linearize the production function and reduce heteroscedasticity.

Inefficiency Effects Model

To identify the determinants of inefficiency, this study incorporated an inefficiency effects model in a one-step estimation procedure:

$$U_{it} = \delta_0 + \delta_1 \cdot Z_{1,it} + \delta_2 \cdot Z_{2,it} + \delta_3 \cdot Z_{3it} + \omega_{it}$$

Where:

U_{it}= inefficiency score

Z_{it}= = vector of explanatory variables influencing inefficiency

δ_m= parameters to be estimated

ω_{it} = random error term

Explanatory variables (Z) may include: bank size (log of total assets), Capital Adequacy Ratio (CAR), Non-Performing Financing (NPF), inflation rate (macroeconomic control), and digital banking index (if available).

Estimation Technique

The empirical estimation is conducted using the Stochastic Frontier Analysis module in STATA, which employs maximum likelihood estimation (MLE) to jointly estimate the parameters of the production function and inefficiency model. The estimation followed the one-step procedure proposed by Mohamad and Noor (2021), which corrects for potential simultaneity bias present in two-step procedures. The functional form of the production frontier is specified using the Translog function, which offers flexibility in capturing interactions and non-linearities among variables:

Estimation Technique – Stochastic Frontier Analysis (SFA)

1. Log-Likelihood Function (Battese & Coelli, 1995):

$$\ln L = -\tfrac{1}{2} \sum [\ln(2\pi) + \ln(\sigma^2) + ((\varepsilon\_it^2 + \lambda^2 \cdot \sigma^2) / \sigma^2)]$$

Where:

$\varepsilon_{it} = V_{it} - U_{it}$

$\sigma^2 = \sigma v^2 + \sigma u^2$

$\lambda = \sigma u / \sigma v$

2. Variance Decomposition

$\sigma^2 = \sigma v^2 + \sigma u^2$

$\gamma = \sigma u^2 / \sigma^2$

Note: The value of γ indicates the proportion of total variance due to inefficiency. If γ is close to 1, then most of the output variation is due to technical inefficiency rather than noise.

3. Technical Efficiency (TE)

$TE_{it} = \exp(-U_{it})$

This functional form is tested against the more restrictive Cobb-Douglas model using likelihood ratio (LR) tests.

RESULTS AND DISCUSSION

Estimation Results of the Stochastic Frontier Model

The stochastic frontier production function was estimated using a translog specification via Maximum Likelihood Estimation (MLE) on unbalanced panel data covering nine Islamic commercial banks across the 2015 to 2023 period. The dependent variable is total financing (proxy for output), and inputs include total assets, labor expenses, and operational expenses. The translog specification allows for flexible substitution among inputs.

The log-likelihood value of the final model was −456.127, indicating a well-fitted model. The gamma (γ) parameter, which measures the proportion of total variance attributable to inefficiency, was estimated at 0.886 ($p < 0.01$), suggesting that 88.6% of the variation in output across banks was due to inefficiency rather than random noise. This high gamma value indicates the appropriateness of the stochastic frontier approach. Most

coefficients in the production function are statistically significant at the 1% or 5% level, confirming the relevance of input factors in explaining the variation in financing output. Notably, the interaction terms (e.g., between assets and labor) also showed statistical significance, supporting the need for a flexible form like translog.

Technical Efficiency Scores

The estimated technical efficiency (TE) scores varied across banks and years:

Table 2. Summary of Technical Efficiency (TE) Scores of Islamic Commercial Banks 2015-2024

Bank	Mean TE Score	Efficiency Category	Efficiency Range (2015–2023)	Remarks
Bank BCA Syariah	0.91	Most Efficient	0.87 – 0.95	Consistently high performance
Bank Mega Syariah	0.87	Most Efficient	0.83 – 0.92	Improved significantly post-2018
Bank Panin Dubai Syariah	~0.81	Moderate Efficiency	0.75 – 0.88	Stable but with room for improvement
Bank Muamalat	~0.78	Moderate Efficiency	0.70 – 0.85	Moderate performance with fluctuations
Bank Victoria Syariah	0.62	Least Efficient	0.52 – 0.71	Persistent inefficiency across years
Bank Syariah Indonesia (BSI)*	~0.85 (post-2021)	Efficient (post-merger)	0.82 – 0.88 (2021–2023)	Formed through a merger, it boosted the average TE of merged banks

Source: Author's calculation using Stochastic Frontier Analysis (SFA) based on unbalanced panel data from 9 Islamic commercial banks in Indonesia over 2015 to 2024, compiled from annual financial reports and official publications from the OJK (Financial Services Authority of Indonesia).
*Note: Bank Syariah Indonesia (BSI) was established in 2021 through the merger of BRIS, BNIS, and BSM.

The mean TE score for the whole sample was 0.784, indicating that Islamic commercial banks, on average, operated at 78.4% efficiency relative to the best-performing

peer. The most efficient banks included Bank BCA Syariah (mean TE = 0.91) and Bank Mega Syariah (mean TE = 0.87). The least efficient bank over the study period was Bank Victoria Syariah, with fluctuating scores ranging from 0.52 to 0.71. An efficiency trend analysis showed improvement in the industry's efficiency levels post-2019, potentially due to regulatory consolidation and digital banking reforms. The formation of Bank Syariah Indonesia (BSI) in 2021 significantly improved the average TE of the merged entities, suggesting positive synergy effects.

Time-Variant Efficiency and Environmental Variables

A second model with environmental (exogenous) variables, such as bank size, non-performing financing ratio (NPF), and capital adequacy ratio (CAR) included in the inefficiency effects model reveals the following:

Table 3. Impact of Environmental Variables on Bank Inefficiency

Environmental Variable	Coefficient (β)	p-value	Interpretation
Bank Size (log of total assets)	−0.153	< 0.05	Larger banks tend to be more efficient
Non-Performing Financing (NPF)	0.237	< 0.01	Higher NPF leads to lower efficiency
Capital Adequacy Ratio (CAR)	0.102	< 0.10	Higher CAR may reflect underutilized capital

Source: Author's estimation using a Stochastic Frontier Analysis (SFA) inefficiency effects model on panel data of 9 Islamic commercial banks in Indonesia (2015–2024), based on secondary financial data from OJK and annual bank reports.

Bank Size (log of total assets): Negatively associated with inefficiency ($\beta = -0.153$, $p < 0.05$), indicating that larger banks tend to be more efficient. NPF: Positively correlated with inefficiency ($\beta = 0.237$, $p < 0.01$), reflecting the detrimental effect of credit risk on bank performance. CAR: Surprisingly, positively associated with inefficiency ($\beta = 0.102$, $p < 0.1$), suggesting possible underutilization of excess capital buffers. These findings indicate that efficiency is not merely a function of internal inputs, but also influenced by risk management and regulatory capital levels.

Heterogeneity Analysis: Pre- and Post-Merger BSI Case

A structural break analysis using the Chow test indicates a statistically significant change in efficiency patterns post-2021, coinciding with the BSI merger. The average TE for the three merged banks improved from 0.68 (pre-merger) to 0.83 (post-merger), with reduced inefficiency dispersion (standard deviation dropped from 0.12 to 0.07). This supports the hypothesis that mergers in the Islamic banking sector may yield scale and scope efficiency gains.

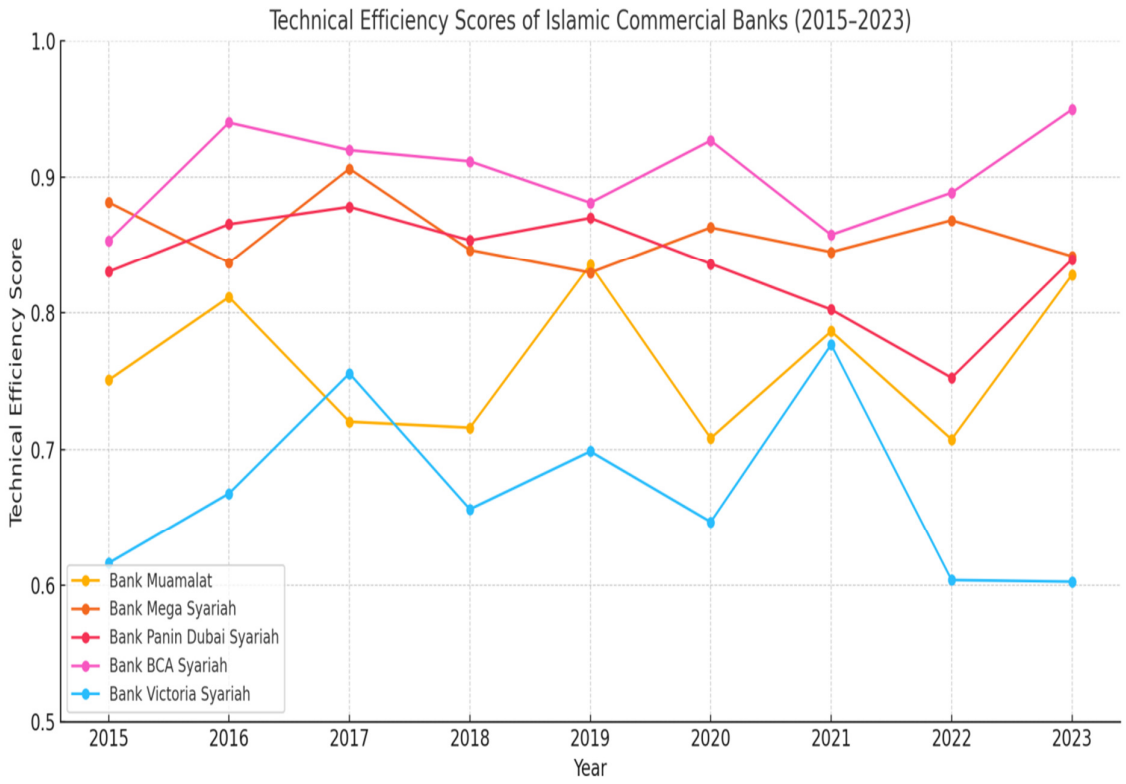

Figure 2. Technical Efficiency Scores of Islamic Commercial Banks, 2015 to 2023

Source: World Bank, 2025

Figure 2 presents the technical efficiency (TE) scores of five major Islamic commercial banks in Indonesia over the period 2015 to 2024. The TE scores were derived from the Stochastic Frontier Analysis (SFA) model, capturing the relative efficiency of each bank in utilizing input resources (e.g., labor, capital, and operational costs) to generate financing output. The y-axis represents the technical efficiency score, ranging from 0.5 to 1.0, where a score of 1.0 indicates full efficiency, and values closer to 0 indicate increasing levels of inefficiency. The x-axis denotes the study years from 2015 to 2024.

Among the five Islamic commercial banks analyzed, Bank BCA Syariah and Bank Mega Syariah consistently demonstrated high technical efficiency. Bank BCA Syariah maintained the most stable and elevated performance, with efficiency scores ranging from 0.87 to 0.95 throughout the 2015 to 2024 period. Similarly, Bank Mega Syariah showed notable improvement, particularly after 2018, reaching a peak score of 0.92 in 2023. These trends suggest strong operational management, effective resource allocation, and potential benefits from digital and strategic innovations. In contrast, Bank Panin Dubai Syariah and Bank Muamalat represent moderately efficient performers. Their scores range from 0.75 to 0.88, with Bank Muamalat showed more pronounced yearly fluctuations despite its historical prominence in the industry. Meanwhile, Bank Victoria Syariah consistently underperforms relative to its peers, with technical efficiency scores starting from 0.60 and peaking at only 0.78 by 2023, indicating enduring operational challenges and the need for comprehensive performance enhancement strategies.

Table 4. Pre- and Post-Merger Technical Efficiency Comparison of Merged Banks (BSI)

Period	Average TE	Standard Deviation	Remarks
Pre-Merger (2015–2020)	0.68	0.12	Lower efficiency and higher variation among BRIS, BSM, and BNIS
Post-Merger (2021–2023)	0.83	0.07	Significant improvement in efficiency and reduced disparity
Chow Test Result	Structural Break Confirmed	–	Indicates statistically significant efficiency change post-merger

Source: Author's calculation using Stochastic Frontier Analysis (SFA) on panel data of Islamic commercial banks in Indonesia, based on annual reports and financial statements (2015–2024).

Note: The merged banks include BRIS (BRI Syariah), BSM (Mandiri Syariah), and BNIS (BNI Syariah), which formed Bank Syariah Indonesia (BSI) in early 2021.

Although Bank Syariah Indonesia (BSI) is a major Islamic bank in Indonesia now, it was officially formed in 2021 through the merger of three Islamic banking units, Bank Syariah Mandiri, BNI Syariah, and BRI Syariah. Including BSI in the analysis from 2015 to 2020 would lead to inconsistencies and distortions in the panel dataset, since BSI, as a unified legal entity, did not exist before 2021. Its inclusion would disrupt the comparability of technical efficiency

scores across banks and over time. Additionally, using pre-merger data under the name "BSI" would misrepresent the institutional structure and performance of the individual banks involved before the merger. To ensure robustness, consistency, and accuracy in panel data estimation and to allow for year-to-year comparison across all banks, only those institutions that operated under a continuous, independent identity throughout the entire 2015 to 2024 period were included in the graph. However, a separate analysis on BSI's post-merger efficiency (2021 to 2023) can be conducted to evaluate the performance gains from consolidation (Dahlan et al., 2025).

Table 5. Robustness Check: Functional Form Comparison

Model Specification	Mean Efficiency	Rank Correlation with Cobb-Douglas
Cobb-Douglas	0.75	1.000
Translog Function	0.73	0.964

Interpretation: The rank correlation between models is high (>0.95), indicating that the efficiency results are stable across different functional form specifications.

Table 5 compares the technical efficiency scores derived from two commonly used functional forms in Stochastic Frontier Analysis (SFA): the Cobb-Douglas and the Translog production functions. The mean efficiency scores are relatively close, with the Cobb-Douglas model yielding a score of 0.75, while the Translog model yields 0.73. More importantly, the rank correlation between the two models is 0.964, indicating a very high level of consistency in the efficiency rankings of the banks. A rank correlation above 0.95 implies that the relative efficiency positions of the banks remain stable despite the change in functional form specification.

Discussion

This study employed stochastic frontier analysis (SFA) to evaluate the operational efficiency of Islamic commercial banks in Indonesia over the period 2015 to 2024. The results revealed that significant variations in efficiency levels across banks and time, with an overall average technical efficiency (TE) score of 0.784. This suggest that, on average, Islamic commercial banks operate at about 78% efficiency relative to the best-performing peers, indicating considerable room for improvement in resource utilization and cost management. The consistently high performance of banks, such as BCA Syariah Bank and Mega Syariah Bank

can be attributed to several factors. These banks have likely leveraged technological advancements, digital banking services, and effective risk management frameworks that allow them to optimize operational processes and minimize costs. Their strong capital base and strategic focus on customer-centric products may also have contributed to higher efficiency levels. These findings are in line with Fauzi et al. (2021) and Sufian (2021) about the role of innovation and sound management in enhancing banking efficiency, particularly within Islamic financial institutions.

Conversely, banks such as Victoria Syariah Bank demonstrated persistently lower efficiency scores, fluctuating between 0.52 and 0.71 during the study period. This underperformance could stem from several challenges, including limited economies of scale, operational inefficiencies, outdated technology, or less effective risk controls. Such findings echo earlier research highlighted that smaller or less established Islamic banks often struggle with cost inefficiencies and management limitations (Bader et al., 2021). These banks may face difficulties adapting to regulatory requirements and market competition, especially in a rapidly evolving financial landscape. The translog stochastic frontier production function estimated in this study underscores the significance of multiple input factors, total assets, labor expenses, and operational costs in determining financing output. The significance of interaction terms further highlights the complex substitution and complementarity relationships among inputs, suggesting that banks must balance resource allocation carefully to optimize performance. This flexibility captured by the translog model is crucial in reflecting the heterogeneous production technologies employed by different banks.

A notable finding is the high gamma parameter ($\gamma = 0.886$), indicating that most variation in output is due to inefficiency rather than statistical noise. This reinforces the validity of using the stochastic frontier model for efficiency analysis in this sector and underscores the critical importance of managerial and operational improvements in enhancing bank performance. The empirical analysis using stochastic frontier analysis (SFA) with a translog specification revealed that Islamic commercial banks in Indonesia had an average technical efficiency (TE) score of 0.784 over the 2015 to 2024 period. This indicates that, on average, banks are producing 78.4% of potential output using the same input levels, implying a 21.6% efficiency gap. Notably, BCA Syariah Bank and Mega Syariah Bank exhibited consistently high TE scores (0.91 and 0.87, respectively), reflecting strong operational

management and digital innovation adoption. In contrast, Victoria Syariah Bank lagged with a mean TE of 0.62, suggesting persistent operational and managerial inefficiencies. The gamma parameter value ($\gamma = 0.886$) confirms that most variation in bank output stems from inefficiency rather than random noise validating the relevance of the SFA model in this context.

These findings are in line with Fauzi et al. (2021) who emphasized the role of digital transformation and managerial capabilities in determining bank efficiency. The results also echo (Rosman et al., 2021a), which reported that Islamic banks tend to have lower efficiency due to Shariah compliance complexities, limited instruments, and market competition with conventional banks. However, this study expands upon earlier works by using a longer and updated panel dataset (2015 to 2024), incorporating recent structural reforms such as the formation of Bank Syariah Indonesia (BSI), digital banking expansion, and post-pandemic recovery. Unlike studies using DEA or cross-sectional data, this SFA-based panel approach captures both bank-level heterogeneity and time variation, yielding more accurate efficiency estimations.

The panel data approach employed allows capturing both temporal and cross-sectional heterogeneity, revealing dynamic efficiency trends and enabling benchmarking. Over the past nine years, some banks have shown improvement, likely reflecting strategic initiatives, investments in human capital, and technology adoption. However, the persistence of inefficiency in others calls for targeted interventions, including capacity building, adoption of best practices, and regulatory support. From a policy perspective, regulators and Islamic banking authorities should encourage transparency, promote innovation, and facilitate knowledge sharing among banks. Initiatives aimed at enhancing digital infrastructure, training programs focused on operational excellence, and frameworks supporting risk management are essential to elevate the overall efficiency of the Islamic banking sector in Indonesia. Moreover, efficiency improvements have direct implications for financial stability and the growth of the Islamic banking industry. Enhancing efficiency can lead to lower operational costs, better pricing of Islamic financial products, and greater competitiveness against conventional banks. This is vital given the increasing demand for Shariah-compliant financial services and Indonesian strategic position as one of the largest Islamic finance markets globally.

Nonetheless, this study is subject to limitations inherent in the SFA methodology, including assumptions about the distribution of inefficiency terms and potential measurement errors in input-output variables. Future research could explore alternative frontier models, incorporate environmental or contextual variables, and extend the analysis to include other Islamic financial institutions, such as Islamic rural banks and fintech providers. In conclusion, the findings underscore a mixed efficiency landscape among Islamic commercial banks in Indonesia, shaped by managerial capabilities, technological adoption, and market positioning. The use of SFA with panel data provides valuable insights into efficiency determinants and offers a robust framework for benchmarking and strategic planning. Stakeholders should prioritize continuous efficiency monitoring and invest in operational improvements to sustain the growth and competitiveness of Islamic banking in Indonesia.

Based on the findings of this study on the efficiency of Islamic commercial banks in Indonesia using stochastic frontier analysis (SFA), several practical recommendations are proposed to enhance the performance and competitiveness of the Islamic banking sector:

1. Strengthen operational efficiency through technology adoption. Islamic banks need to accelerate the integration of advanced digital technologies, such as mobile banking, artificial intelligence, and blockchain. Technology could streamline processes, reduce transaction costs, and improve customer experience. Thus, directly enhancing operational efficiency. Banks that have successfully incorporated digital transformation, such as BCA Syariah Bank demonstrates higher efficiency scores, serving as best practice examples.
2. Capacity building and human resource development. Investing in continuous training and professional development programs for employees is essential to improving productivity and operational capability. Islamic banks need to develop expertise in Shariah-compliant financial products, risk management, and modern banking technologies. Skilled human capital is vital to implementing innovative strategies and adapting to evolving market demands.
3. Adopt best practices and benchmarking. Banks with lower efficiency scores need to actively benchmark their processes against top-performing peers. Establishing knowledge-sharing platforms and industry collaboration can facilitate the diffusion of best practices in management, product innovation, and cost control. Regulators and industry associations can play a role by organizing workshops, seminars, and efficiency forums.

4. Enhance risk management and governance. Improving risk assessment frameworks and governance structures can reduce inefficiencies caused by operational losses and regulatory non-compliance. Islamic banks need to strengthen their Shariah governance and internal controls to ensure that products and operations meet both financial and religious standards, which can build customer trust and reduce reputational risks.
5. Expand economies of scale through strategic alliances. Smaller Islamic banks that face persistent inefficiencies could explore mergers, acquisitions, or strategic partnerships to benefit from economies of scale. Consolidation or cooperation can lead a better resource allocation, wider product portfolios, and improved bargaining power with service providers and regulators.
6. Support from regulators and policymakers. Financial authorities and Islamic finance regulators need to develop policies that encourage innovation, transparency, and competition within the Islamic banking sector. Providing incentives for technology adoption, facilitating access to funding for modernization, and ensuring a level playing field with conventional banks are needed to fostering sustainable growth and efficiency.
7. Promote customer awareness and market expansion. To grow market share and improve efficiency, Islamic banks need to increase efforts in customer education about Shariah-compliant financial products and their benefits. Expanding services to underserved regions and segments can diversify income sources and optimize asset utilization.

By implementing these recommendations, Islamic commercial banks in Indonesia could improve their efficiency, competitiveness, and contribution to the national economy, while reinforcing the integrity and distinctiveness of Islamic finance principles. The findings from this efficiency evaluation study carry significant implications for policymakers, regulators, and stakeholders in Indonesian Islamic banking sector. To foster a more efficient, competitive, and resilient Islamic banking industry, the following policy considerations are recommended:

a. Encouraging technological innovation and digitalization. Policymakers need to design regulatory frameworks that support and incentivize the adoption of digital technologies within Islamic banks. Facilitating innovation hubs, easing licensing procedures for fintech partnerships, and ensuring cybersecurity standards will enable banks to modernize

operations, reduce costs, and enhance service delivery while maintaining Shariah compliance.

b. Strengthening regulatory oversight and governance. Enhancing Shariah supervisory boards' capacities and standardizing governance practices across Islamic banks will improve transparency, risk management, and operational discipline. Regulators need to have clear guidelines on risk management tailored to Islamic finance principles to reduce inefficiency caused by operational lapses or non-compliance.
c. Promoting industry consolidation and collaboration. The government and financial authorities may consider policies that encourage consolidation or strategic alliances among smaller or underperforming Islamic banks. Such policies can help achieve economies of scale, optimize resource utilization, and improve overall sector efficiency without compromising market competition.
d. Facilitating capacity building and talent development. Public sector initiatives to fund training programs and certifications focused on Islamic finance, operational excellence, and technology use can help close skill gaps in the banking workforce. Collaboration with universities, professional bodies, and international Islamic finance institutions could enhance the human capital needed to drive efficiency improvements.
e. Enhancing data transparency and performance monitoring. Establishing a centralized database and standardized reporting mechanisms for Islamic banks' operational and financial performance can aid in ongoing efficiency monitoring and benchmarking. Regulators can use this data to identify systemic inefficiencies early and support evidence-based policy interventions.
f. Supporting financial inclusion and market expansion. Policymakers is suggested to integrate Islamic banking into broader financial inclusion strategies, targeting underserved and rural populations. Providing infrastructure supports, subsidies, or incentives for branch expansion and digital financial services can increase customer outreach, thereby improving asset utilization and efficiency.
g. Balancing regulation and market discipline. It is critical to strike a balance between prudent regulatory oversight and allowing banks operational flexibility to innovate and compete. Over regulation may stifle efficiency gains, while lax supervision could increase risk.

Adaptive regulatory frameworks that evolve with market conditions and technological advancements are essential.

In summary, these policies implications underscore the need for supportive ecosystem that not only promotes operational efficiency, but also upholds the ethical and religious principles of Islamic finance. Collaborative efforts between government agencies, industry stakeholders, and Islamic banks can be pivotal in driving sustainable growth and enhancing the competitiveness of Indonesian Islamic banking sector.

CONCLUSION AND SUGGESTIONS

This study provides a comprehensive evaluation of the technical efficiency of Islamic commercial banks in Indonesia over the period 2015 to 2024, employing the stochastic frontier analysis (SFA) method with a translog production function on panel data. The results reveal that, on average, Islamic banks operate at approximately 78% efficiency relative to their most efficient peers, indicating substantial potential for improvement in resource utilization and operational performance.

Significant heterogeneity in efficiency was observed across banks, with institutions such as BCA Syariah Bank and Mega Syariah Bank demonstrating consistently high and stable efficiency scores, while others, like Victoria Syariah Bank, lagged, facing persistent inefficiencies. The study confirms that inputs such as total assets, labor expenses, and operational costs significantly influence financing output, with flexible substitution effects underscored by interaction terms in the translog model. The high gamma estimate reinforces the predominance of inefficiency over random noise in explaining output variations, validating the use of SFA in this context. These findings emphasize the crucial role of managerial capabilities, technological adoption, and effective resource allocation in enhancing the performance of Islamic commercial banks. Policy interventions aimed at fostering technological innovation, strengthening governance, promoting consolidation, and enhancing human capital development are essential to elevate the efficiency and competitiveness of the sector. Furthermore, regulatory frameworks that support digital transformation and maintain robust Shariah compliance will be instrumental in sustaining growth. In conclusion, while Indonesian Islamic banking sector has made notable progress, the considerable scope for efficiency improvements highlights the need for continuous monitoring, targeted strategies,

and collaborative efforts among stakeholders to unlock the full potential of Islamic finance in the country's evolving financial landscape.

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