JEKOBS Vol. 5, No. 3, 2026, pp: 149-160

Jurnal Ekonomi dan Bisnis

http://publikasi.dinus.ac.id/index.php/JEKOBS

Long-Term Dynamics of Operational Efficiency in Indonesia's Islamic Banking Sector: Digital Transformation, Business Scale, and Financing Quality within an ARDL Framework

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Article Information

Article history:

Accepted: July 2026

Approved: August 2026

Published: September 2026

Keywords:
BOPO
Islamic banking
ARDL
digital transformation
NPF

Abstract

This study analyzes the determinants of operational efficiency in Indonesian Islamic banking, measured by the Operational Expense to Operational Income ratio (BOPO), encompassing digital transformation (JKFISIK), bank size (ASET), financing quality (NPF), external digital ecosystem (NIL), inflation (INF), and BI Rate (BIRATE). The study employs the Autoregressive Distributed Lag (ARDL) approach using monthly aggregate data from Islamic Commercial Banks and Islamic Business Units spanning January 2014 to December 2024, yielding 114 observations after adjustment. Phillips-Perron unit root tests confirm a mixed I(0) and I(1) integration order with no I(2) variables, validating the ARDL framework. The F-Bounds test produces an F-statistic of 360.50, confirming long-run cointegration. NPF emerges as the dominant determinant with a significant positive effect on BOPO, while ASET exhibits a significant positive effect contrary to the economies of scale hypothesis. JKFISIK, NIL, INF, and BIRATE are statistically insignificant. The Error Correction Term coefficient of -0.9833 indicates a 98.33 percent monthly adjustment speed toward long-run equilibrium. Parameter stability is confirmed through CUSUM tests. These findings underscore that financing quality management is the primary lever for improving operational efficiency in Indonesian Islamic banking.

Penelitian ini menganalisis faktor-faktor penentu efisiensi operasional di perbankan syariah Indonesia, yang diukur melalui rasio Biaya Operasional terhadap Pendapatan Operasional (BOPO), meliputi transformasi digital (JKFISIK), ukuran bank (ASET), kualitas pembiayaan (NPF), ekosistem digital eksternal (NIL), inflasi (INF), dan Suku Bunga BI (BIRATE). Penelitian ini menggunakan pendekatan Autoregressive Distributed Lag (ARDL) dengan data agregat bulanan dari Bank Komersial Syariah dan Unit Bisnis Syariah selama periode Januari 2014 hingga Desember 2024, yang menghasilkan 114 pengamatan setelah penyesuaian. Uji akar unit Phillips-Perron mengonfirmasi urutan integrasi campuran I(0) dan I(1) tanpa variabel I(2), sehingga memvalidasi kerangka kerja ARDL. Uji F-Bounds menghasilkan statistik F sebesar 360,50, yang mengonfirmasi adanya kointegrasi jangka panjang. NPF muncul sebagai penentu dominan dengan efek positif yang signifikan terhadap BOPO, sementara ASET menunjukkan efek positif yang signifikan yang bertentangan dengan hipotesis skala ekonomi. JKFISIK, NIL, INF, dan BIRATE secara statistik tidak signifikan. Koefisien Istilah Koreksi Kesalahan sebesar -0,9833 menunjukkan kecepatan penyesuaian bulanan sebesar 98,33 persen menuju keseimbangan jangka panjang. Stabilitas parameter dikonfirmasi melalui uji CUSUM. Temuan ini menegaskan bahwa pengelolaan kualitas pembiayaan merupakan pendorong utama untuk meningkatkan efisiensi operasional di perbankan syariah Indonesia.

DOI identifier: https://10.33633/jekobs.v5i3.16339

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ISSN
2964-8866 (online)

PENDAHULUAN

Indonesia, as the country with the world's largest Muslim population, has a strong demographic foundation for the development of the Islamic banking industry. In line with this potential, the national Islamic banking sector has recorded consistent growth. According to data from the Financial Services Authority (OJK), total Islamic banking assets as of December 2024 reached Rp980.30 trillion, representing a year-on-year growth of 9.88 percent, with its market share increasing to 7.72 percent of the total national banking industry (OJK, 2025). This achievement is part of the long-term efforts outlined in the Roadmap for the Development and Strengthening of Indonesian Islamic Banking 2023–2027 (RP3SI), which explicitly targets the acceleration of economies of scale while strengthening the differentiation of the Islamic business model (OJK, 2023).

However, behind this growth, the challenge of operational efficiency remains a fundamental issue. Operational efficiency in Islamic banking is commonly measured using the Operating Expense to Operating Income (BOPO) ratio, where a lower value reflects more efficient performance. Hijriyani and Setiawan (2017) demonstrated that the OIR has a significant negative impact on the profitability of Islamic commercial banks in Indonesia, indicating that operational inefficiencies directly erode financial performance. Historically, the OIR in Islamic banking has tended to be higher than in conventional banking, due in part to relatively small business scale, Sharia compliance costs, and infrastructure investment burdens during the expansion phase (Muttaqin et al., 2020; Wulandari & Ryandono, 2020). This situation underscores the urgency of systematically identifying the determinants of the BOPO ratio, as also emphasized by Fathurrahman and Rahmadani (2024) who found that the NPF significantly influences the BOPO ratio of Indonesian Islamic commercial banks during the 2017–2022 period.

The advancement of digital transformation is opening up new dimensions in the discourse on banking efficiency. The reduction in the number of physical branches, as one manifestation of the adoption of digital services, reflects what is known as the digital substitution effect—the replacement of physical infrastructure with digital channels, which theoretically reduces operational overhead costs. At the same time, the continuously rising value of national mobile banking transactions creates competitive pressure from the external digital ecosystem, driving Islamic banks to adapt and enhance their efficiency. On the other hand, internal factors such as business scale and financing quality, as well as macroeconomic variables like inflation and interest rates, have also been identified as key determinants of the BOPO in various studies (Sa'diyah & Nasrulloh, 2025; Saleh, 2021; Supriatin et al., 2019; Wahyudi, 2020).

The predominance of static panel data approaches in existing studies introduces a methodological limitation that is particularly consequential for aggregate Islamic banking data. Panel models, whether fixed or random effects, are designed to exploit cross-sectional variation across individual bank entities. When the unit of analysis is the national aggregate of BUS and UUS, as in this study, cross-sectional variation is eliminated by construction, and the relevant dimension of variation becomes purely temporal. Static panel estimators applied to aggregate time-series data risk obscuring the dynamic transmission mechanisms through which shocks to NPF, asset growth, or digital variables propagate into BOPO over successive months. The monthly frequency of the data compounds this issue: short-run responses and long-run adjustments operate across different time horizons and should be estimated distinctly rather than collapsed into a single average coefficient. These considerations make an ARDL time-series framework not merely an alternative but a methodologically superior choice for this specific research context, as it explicitly models both the speed of short-run adjustment and the magnitude of long-run equilibrium effects within a single coherent specification.

Although the literature on the determinants of Islamic banking efficiency continues to grow, most existing studies employ a panel data approach with static estimations that cannot simultaneously accommodate the dynamics of short-term and long-term relationships. Time-series-based studies that specifically utilize digital transformation proxies relevant to the Islamic context within the Autoregressive Distributed Lag (ARDL) framework remain very limited.

Given this background, this study aims to analyze the impact of business scale, financing quality, and the external digital ecosystem—as measured by the value of national mobile banking transactions, the inflation rate, and interest rates—on the aggregate operational efficiency (BOPO) of Indonesia's Islamic banking sector,

Literature Review

Efficiency and the BOPO in Islamic Banking.

The BOPO is the most consistently used proxy for operational efficiency in studies of Indonesian Islamic banking. This ratio measures how much a bank must spend to generate one unit of operating income; the lower the value, the more efficient the bank's operations. Setiawan et al. (2020) in their systematic review confirm that BOPO remains a relevant and consistent performance measurement indicator for Islamic banking in the empirical literature. Supriatin et al. (2019) identified that the efficiency of Islamic commercial banks is influenced multidimensionally by both internal and external factors, including capital adequacy, asset quality, and business scale. Wulandari and Ryandono (2020) in their empirical study covering the 2012–2018 period, found that the determinants of Islamic banking efficiency are dynamic and cannot be explained by a single variable. Furthermore, Iman and Umiyati (2022) confirmed that BOPO consistently contributes to the profitability of Islamic banks in Indonesia, making it an appropriate dependent variable in efficiency analysis.

Digital transformation in banking refers to the process of a fundamental shift in the operational model from physical infrastructure to digital technology-based services. In the context of Indonesian Islamic banking, the number of physical branches is used as a proxy for digital transformation through the mechanism of the digital substitution effect: a decrease in the number of branches reflects the increasing adoption of digital channels as a substitute for conventional infrastructure. Theoretically, this substitution reduces overhead costs such as rent, utilities, and personnel costs associated with physical branches, which constitute a significant component of a bank's operational expenses. Muttaqin et al. (2020) highlight that the efficiency of conventional Islamic banks is also influenced by their ability to adapt to changes in the operational ecosystem, while Wulandari and Ryandono (2020) indicate that variables reflecting a bank's operational capacity and structure have a significant impact on efficiency. Thus, a positive relationship between the number of physical branches and BOPO is anticipated: the more physical branches a bank has, the higher the overhead costs, and the higher the BOPO.

Business Scale and Economies of Scale

The theory of economies of scale states that the larger a bank's scale of operations, the lower its average cost per unit of output, as fixed costs are spread across a broader asset base. Total assets are used as a proxy for business scale in this study. Several empirical studies support a negative relationship between bank size and BOPO. Larger banks tend to be more efficient because they can allocate fixed costs more proportionally to their revenue (Hijriyani & Setiawan, 2017; Muttaqin et al., 2020). This argument also forms the basis for the Islamic banking consolidation policy promoted by the OJK through the 2023–2027 RP3SI, including the establishment of Bank Syariah Indonesia (BSI) in 2021 (OJK, 2023).

Loan Quality and Credit Risk

Non-Performing Financing (NPF) measures the proportion of non-performing financing relative to total financing at Islamic banks. A high NPF has direct implications for the BOPO through an increase in the provisioning expense for the Allowance for the Write-off of Earning Assets (PPAP), which is a component of operating expenses. The higher the NPF, the greater the PPAP provision that must be set aside, and the higher the BOPO ratio (Fitri & Sriyana, 2023; Wahyudi, 2020). Fathurrahman and Rahmadani (2024) empirically confirm that NPF has a significant effect on the BOPO of Indonesian Islamic commercial banks.

External Digital Ecosystem

The value of national mobile banking transactions reflects the overall development of the digital banking ecosystem. Although this data covers the entire national banking sector, this variable serves as a proxy for the external digital competitive pressures faced by Islamic banks. The increasing volume of digital transactions is driving Islamic banks to optimize their digital services and reduce operational costs to remain competitive against conventional banks and fintech firms (Sa'diyah & Nasrulloh, 2025). Theoretically, the more mature the digital ecosystem, the greater the pressure to adapt, which in turn drives operational efficiency.

Macroeconomic Variables: Inflation and the BI Rate

Inflation affects the BOPO through a cost-push mechanism: general price increases raise the costs of operational inputs such as wages, rent, and utilities, which ultimately increase operating expenses relative to revenue (Saleh, 2021; Wahyudi, 2020). A positive impact of inflation on the BOPO is therefore anticipated. Meanwhile, interest rates operate through a more complex mechanism. On the one hand, an increase in interest rates has the potential to boost the returns on sharia instruments such as the Bank Indonesia Sharia Certificate (SBIS), which adds to the operational income component. On the other hand, an increase in interest rates also

drives up the cost of funds raised by banks. The net effect depends on the sensitivity of the sharia bank's balance sheet structure to the benchmark interest rate (Sa'diyah & Nasrulloh, 2025).

Conceptual Framework Diagram

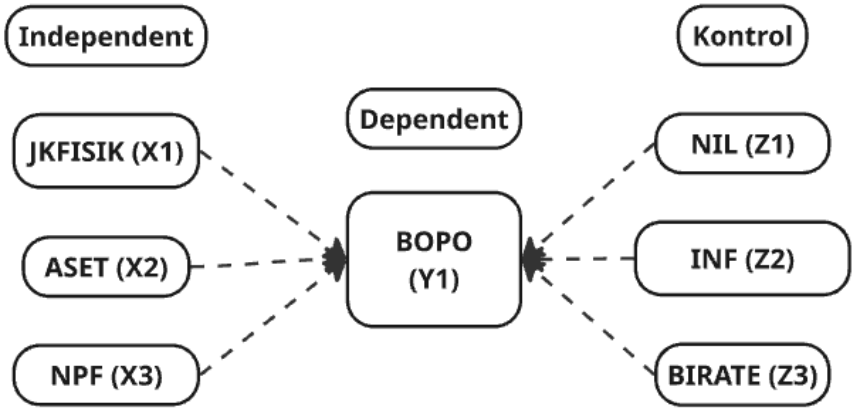

Figure 1. Conceptual Framework of Research
Source: Authors' conceptualization (2026)

METHODS

This study employs a quantitative approach based on monthly time-series secondary data, with the aggregate units of analysis being Sharia Commercial Banks (BUS) and Sharia Business Units (UUS) throughout Indonesia. The observation period is from January 2014 to December 2024, yielding 132 observations. Of the 132 raw observations, the effective estimation sample is reduced to 114 observations spanning June 2014 to July 2024 after lag adjustments. The reduction at the start of the sample (January to May 2014, five months) results from the first-differencing transformation, which consumes one observation, combined with the four-lag specification of the ARDL(4,0,0,0,0,0,0) model, which requires four additional initial observations as conditioning values. Observations beyond July 2024 were excluded due to data availability constraints at the time of estimation, as the most recent complete monthly releases for certain variables had not yet covered the full period through December 2024. The data were obtained from four verifiable official sources. The operational definitions and measurements of all research variables are presented in Table 1.

Table 1. Operational Definition and Measurement of Research Variables

Position	Symbol	Variable	Measurement	Source
Dependent	BOPO	Operational efficiency	Ratio of operational expenses to operational income of BUS+UUS (%)	OJK SPS
Independent	JKFISIK	Digital transformation	Number of physical offices of BUS+UUS (KP+KC+KCP+KK) (units)	OJK SPS
Independent	ASET	Business scale	Natural logarithm of total assets of BUS+UUS (IDR Billion)	OJK SPS
Independent	NPF	Financing quality	Ratio of non-performing financing to total financing of BUS+UUS (%)	OJK SPS
Control	NIL	External digital ecosystem	Natural logarithm of national mobile banking transaction value (IDR Billion)	BI SPIP
Control	INF	Inflation	General CPI inflation rate, year-on-year (%)	BPS
Control	BIRATE	Monetary policy	BI 7-Day Reverse Repo Rate (%)	BI SEKI

Source: OJK (2025), Bank Indonesia (2024), BPS (2024), processed by authors

The long-term model estimated in this study is:

Equation (1)

$$BOPO_t = \beta_0 + \beta_1 JKFISIK_t + \beta_2 ASET_t + \beta_3 NPF_t + \beta_4 NIL_t + \beta_5 INF_t + \beta_6 BIRATE_t + \mu_t$$

where β_1 is expected to carry a positive sign (H1), β_2 a negative sign (H2), β_3 a positive sign (H3), β_4 a negative sign (H4), β_5 a positive sign (H5), and the sign of β_6 is theoretically ambiguous (H6).

To estimate Equation (1) within the ARDL framework, the Unrestricted Error Correction Model (UECM) formulated by Pesaran et al. (2001) is employed:

Equation (2)

$$\begin{aligned}\Delta BOPO_t = \alpha_0 &+ \sum_{i=1}^{p} \alpha_{1i}\, \Delta BOPO_{t-i} + \sum_{i=0}^{q_1} \alpha_{2i}\, \Delta JKFISIK_{t-i} + \sum_{i=0}^{q_2} \alpha_{3i}\, \Delta ASET_{t-i} + \sum_{i=0}^{q_3} \alpha_{4i}\, \Delta NPF_{t-i} \\ &+ \sum_{i=0}^{q_4} \alpha_{5i}\, \Delta NIL_{t-i} + \sum_{i=0}^{q_5} \alpha_{6i}\, \Delta INF_{t-i} + \sum_{i=0}^{q_6} \alpha_{7i}\, \Delta BIRATE_{t-i} + \delta_1 BOPO_{t-1} + \delta_2 JKFISIK_{t-1} \\ &+ \delta_3 ASET_{t-1} + \delta_4 NPF_{t-1} + \delta_5 NIL_{t-1} + \delta_6 INF_{t-1} + \delta_7 BIRATE_{t-1} + \varepsilon_t\end{aligned}$$

Should the existence of a long-run relationship be confirmed, the short-run adjustment dynamics are estimated through the Error Correction Model (ECM):

Equation (3)

$$\begin{aligned}\Delta BOPO_t = \alpha_0 &+ \sum_{i=1}^{p} \gamma_i\, \Delta BOPO_{t-i} + \beta_1 \Delta JKFISIK_t + \beta_2 \Delta ASET_t + \beta_3 \Delta NPF_t + \beta_4 \Delta NIL_t + \beta_5 INF_t \\ &+ \beta_6 \Delta BIRATE_t + \varphi ECT_{t-1} + \varepsilon_t\end{aligned}$$

where ECT*t-1* denotes the one-period lagged residual from Equation (1), and φ is the speed of adjustment coefficient, which must be negative and statistically significant to confirm the cointegrating relationship.

The analysis procedure was conducted sequentially in four stages.

a) The first stage involved testing for stationarity using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests for all variables (Dickey & Fuller, 1979; Phillips & Perron, 1988). This stage is a prerequisite to ensure that no variables are integrated of order two (I(2)), as the presence of I(2) variables would invalidate the ARDL bounds test procedure.

b) The second stage involves determining the optimal lag length using the Akaike Information Criterion (AIC) with a maximum limit of four lags, in accordance with general recommendations for monthly frequency data.

c) The third step is the cointegration bounds test, which compares the F-statistic value against the lower critical limit for I(0) and the upper critical limit for I(1). H_0 (no cointegration) is rejected if the F-statistic exceeds the upper limit of I(1), while the result is inconclusive if the F-statistic falls between the two limits.

d) The fourth stage is the estimation of long-run coefficients and the ECM, accompanied by a series of diagnostic tests including tests for autocorrelation and heteroscedasticity, as well as a test for parameter stability using the Cumulative Sum of Recursive Residuals (CUSUM). All estimations were performed using EViews software.

Based on the theoretical framework and literature review outlined above, the research hypotheses are formulated as follows.

H1: JKFISIK has a positive effect on BOPO, as a greater number of physical branches reflects higher overhead costs.

H2: ASET have a negative effect on BOPO through the mechanism of economies of scale.

H3: NPF has a positive effect on BOPO because it increases the PPAP reserve burden as a component of operating costs.

H4: NIL has a negative effect on BOPO because competitive pressures in the digital ecosystem drive efficiency adaptations.
H5: INF has a positive effect on BOPO through the cost-push mechanism on operational input costs.
H6: BIRATE has an ambiguous effect on BOPO because the net effect depends on the sensitivity of the Islamic bank's balance sheet structure to the benchmark interest rate.

RESULTS AND DISCUSSION

Results

Stationarity Test Results

A Phillips-Perron (PP) stationarity test was conducted on all variables in two stages: a test at the level and a test on the first difference. The complete results are presented in Table 2.

Table 2. Phillips-Perron Unit Root Test Results

Variable	Level (Prob.)	First Difference (Prob.)	Conclusion
BOPO	0.9344	0.0000	I(1)
JKFISIK	0.1762	0.0000	I(1)
NPF	0.8938	0.0000	I(1)
ASET	1.0000	0.0000	I(1)
NIL	1.0000	0.0000	I(1)
INF	0.0000	0.0001	I(0)
BIRATE	0.4112	0.0000	I(1)

Source: EViews output, processed by authors

The test results show that six variables (BOPO, JKFISIK, NPF, ASET, NIL, BIRATE) are non-stationary at the original level but stationary at the first difference, and thus have an I(1) status. One variable, INF, is stationary at the original level with a probability of 0.0000, and thus has an I(0) status. With a combination of I(0) and I(1) variables and no I(2) variables, the requirements for using ARDL are met (Pesaran et al., 2001). The I(1) variables are included in the model in first-difference form, while INF is included in level form according to its status.

Selection of Optimal Lags and Diagnostic Tests

Based on selection using the Akaike Information Criterion (AIC), the selected ARDL model is ARDL(4,0,0,0,0,0,0), which consists of four lags for the dependent variable and zero additional lags for all regressors. Estimation was conducted for the period from June 2014 to July 2024 with 114 observations after lag adjustment.

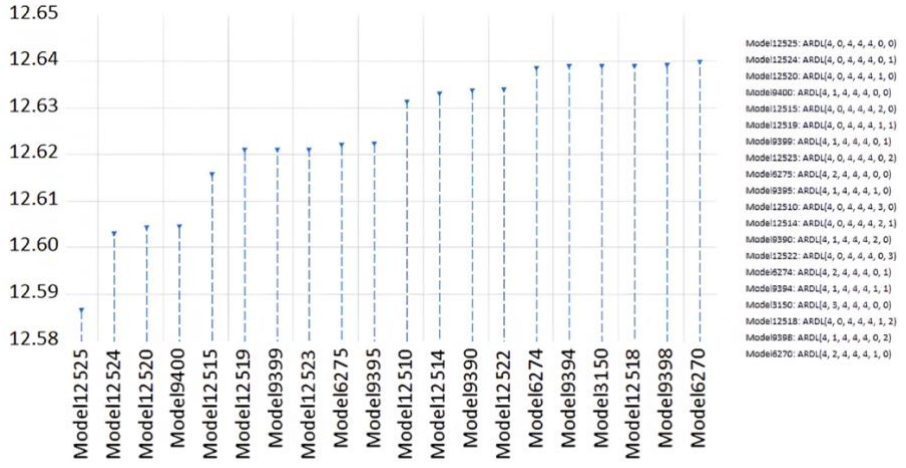

Figure 2. ARDL Lag Length Selection Based on Akaike Information Criterion
Source: EViews output, processed by authors

Diagnoctic Test

After determining the optimal lag, two diagnostic tests were conducted to verify the BLUE (Best Linear Unbiased Estimator) model, as presented in Table 3.

Table 3. Model Diagnostic Test Results

Test	Statistic	Prob.	Conclusion
Breusch-Godfrey LM Test (serial correlation, 2 lags)	F = 0.9787	0.3790	No serial correlation
Breusch-Pagan-Godfrey Test (heteroscedasticity)	F = 1.2290	0.2815	Homoscedastic

Source: EViews output, processed by authors

Both diagnostic tests yielded probability values above 0.05, so neither the null hypothesis of homoscedasticity nor the null hypothesis of no autocorrelation could be rejected. The model is free from both serial autocorrelation and heteroscedasticity, which means that the OLS estimates are BLUE (Best Linear Unbiased Estimators).

Cointegration Test: Bounds Test

The results of the F-bound test show an F-statistic of 360.4966 with k = 6 independent variables. This value substantially exceeds the upper critical limit for I(1) at all significance levels, both asymptotic and finite-sample. The complete results are presented in Table 4.

Table 4. F-Bounds Cointegration Test Results

Significance Level	Lower Bound I(0)	Upper Bound I(1)
10% (n=1000)	1.99	2.94
5% (n=1000)	2.27	3.28
1% (n=1000)	2.88	3.99
10% (n=80)	2.088	3.103
5% (n=80)	2.431	3.518
1% (n=80)	3.173	4.485
F-statistic	360.4966	

Source: EViews output, processed by authors

With an F-statistic of 360.4966, which exceeds the upper critical value for I(1) at all significance levels, H_0 (the absence of a long-run relationship) is decisively rejected. There is a significant long-run dynamic relationship among the variables in the model.

Best ARDL Estimate and Goodness of Fit

Based on the AIC selection, the best ARDL model selected is ARDL(4,0,0,0,0,0,0) with the dependent variable D(BOPO) and seven explanatory variables. The complete estimation results are presented in Table 5.

Table 5. Best ARDL Model Estimation Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
D(BOPO(-1))	0.016148	0.020645	0.782182	0.4359
D(BOPO(-2))	0.022607	0.020877	1.082855	0.2814
D(BOPO(-3))	-0.021589	0.024456	-0.882773	0.3794
D(BOPO(-4))	-0.000510	0.020633	-0.024720	0.9803
D(JKFISIK)	-0.130127	0.428098	-0.303966	0.7618
D(NPF)	1061.834	22.44172	47.31519	0.0000
D(ASET)	0.005693	0.001625	3.503519	0.0007
D(NIL)	0.000187	0.000320	0.586139	0.5591
INF	20.37897	44.14094	0.461680	0.6453
D(BIRATE)	-59.19522	81.89630	-0.722807	0.4714
C	-42.01139	22.11449	-1.899722	0.0603

Source: EViews output, processed by authors

The best ARDL estimates in Table 5 reflect the short-run dynamics between changes in BOPO and changes in all explanatory variables. The four lags of the dependent variable, namely D(BOPO(-1)) through D(BOPO(-4)), are all statistically insignificant with respective probabilities of 0.4359, 0.2814, 0.3794, and 0.9803. This indicates that changes in BOPO in the previous period have no significant effect on changes in BOPO in the current period after controlling for all explanatory variables, so there is no significant autoregressive persistence in the D(BOPO) series in this model.

Among the explanatory variables, only two are statistically significant in the short term. First, D(NPF) has a coefficient of 1,061.834 and is highly significant at the 1% level (t = 47.315, Prob. = 0.0000). This means that every increase in the change in NPF during the current period directly and strongly drives an increase in BOPO in the same month. The mechanism operates through the immediate and non-deferrable obligation to form PPAP when the quality of financing deteriorates. Second, D(ASET) has a positive coefficient of 0.005693 and is significant at α = 1% (t = 3.504, Prob. = 0.0007), indicating that short-term asset growth actually increases the BOPO, consistent with the interpretation that capacity expansion entails operational costs that precede the realization of economies of scale.

The other four variables are not significant in the short term. D(JKFISIK) is not significant (Prob. = 0.7618), confirming that changes in the number of physical branches do not immediately affect the BOPO in the same month. D(NIL) is also insignificant (Prob. = 0.5591), indicating that the growth in the volume of national mobile banking transactions does not directly and immediately affect the operating costs of Islamic banks. Similarly, INF (Prob. = 0.6453) and D(BIRATE) (Prob. = 0.4714) are both insignificant, suggesting that macroeconomic pressures are not directly transmitted into changes in the BOPO within a one-month period. The constant has a value of -42.011 and is borderline significant at α = 10% (Prob. = 0.0603), indicating a moderate tendency for the average BOPO to decrease when all explanatory factors are controlled for.

Table 6. goodness of fit

Model Statistic	Value
R-squared	0.9565
Adjusted R-squared	0.9523
S.E. of Regression	170.9397
F-statistic	226.7464
Prob(F-statistic)	0.0000
Akaike Info Criterion	13.2120
Schwarz Criterion	13.4760
Durbin-Watson Statistic	1.6723

Source: EViews output, processed by authors

The selected ARDL model demonstrates an excellent goodness of fit. An R-squared value of 0.9565 indicates that 95.65 percent of the variation in D(BOPO) is explained collectively by all the explanatory variables in the model. After adjusting for degrees of freedom, the adjusted R-squared remains high at 0.9523, indicating that the high R-squared is not merely an artifact of the number of variables included. The F-test yields an F-statistic of 226.7464 with a Prob. of 0.0000, meaning that all explanatory variables simultaneously have a significant effect on the dependent variable. The Durbin-Watson value of 1.6723 is slightly below the ideal value of 2.00; however, definitive confirmation of the absence of serial autocorrelation still relies on the results of the Breusch-Godfrey LM test reported in Table 3, given that the DW test is unreliable in models with lagged dependent variables. The AIC value of 13.2120 served as the basis for selecting this model as the best specification compared to other lag alternatives.

Long-Term Estimate

The coefficients of the long-run equation derived from the Levels Equation are presented in Table 7. Of the seven estimated parameters, two independent variables showed a statistically significant effect: D(NPF) at α = 1% and D(ASET) at α = 1%. The other four variables were not significant at either the 5% or 10% significance levels.

Table 7. Long-Run Estimation Results (Levels Equation)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(JKFISIK)	-0.1323	0.4357	-0.3037	0.7619
D(NPF)	1079.8198	54.8184	19.6981	0.0000
D(ASET)	0.0058	0.0017	3.4134	0.0009
D(NIL)	0.0002	0.0003	0.5915	0.5555
INF	20.7242	44.9421	0.4611	0.6457
D(BIRATE)	-60.1979	83.4734	-0.7212	0.4724
C	-42.7230	22.8464	-1.8700	0.0643

Source: EViews output, processed by authors

Estimation of the Error Correction Model (ECM)

The results of the ECM estimation, which capture short-term adjustment dynamics, are in Table 8.

Table 8. Error Correction Model (ECM) Estimation Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(BOPO(-1),2)	-0.0005	0.0219	-0.0232	0.9815
D(BOPO(-2),2)	0.0221	0.0220	1.0044	0.3175
D(BOPO(-3),2)	0.0005	0.0177	0.0288	0.9771
CointEq(-1)*	-0.9833	0.0177	-55.4975	0.0000

Source: EViews output, processed by authors

The Error Correction Term coefficient (CointEq(-1)) is -0.9833 and is significant at the 1% level (Prob. = 0.0000). The negative sign confirms a valid error correction mechanism: any deviation from long-term equilibrium will be corrected by 98.33% within one period (one month). This very high adjustment speed indicates that the Islamic banking system has a correction mechanism that is highly responsive to short-term shocks, consistent with the characteristics of high-frequency monthly data.

Parameter Stability Test (CUSUM)

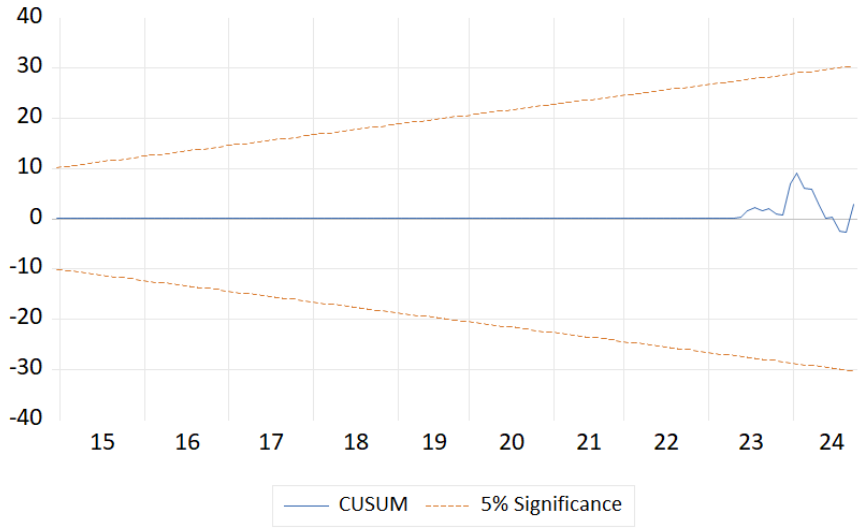

Figure 3. CUSUM Test for Parameter Stability (2014-2024)
Source: EViews output, processed by authors

The CUSUM test results show that the Cumulative Sum of Recursive Residuals plot (blue line) remains within the 5% critical limit (dashed line) throughout the entire estimation period. There is slight fluctuation at the end of the period (2023–2024), coinciding with the post-pandemic normalization phase and adjustments to the monetary policy interest rate; however, the CUSUM plot does not exceed the critical limit. Thus, the null hypothesis (H_0) of parameter stability is not rejected, and it is concluded that the model parameters are stable throughout the 2014–2024 observation period.

Discussion

Effect of Digital Transformation (JKFISIK) on BOPO

The variable D(JKFISIK) has a coefficient of -0.1323 with Prob. = 0.7619, indicating statistical insignificance. H1, which predicted a positive effect of the number of physical offices on BOPO, is rejected. This finding suggests that in a dynamic first-difference model, changes in the number of physical offices of Islamic banking do not significantly affect changes in BOPO. Several factors may explain this result. First, the reduction in physical offices during the observation period does not fully reflect genuine digital transformation; a substantial portion of the decline in JKFISIK in 2021 was attributable to structural network consolidation following the BSI merger, rather than digital substitution. Second, cost savings from office reduction may have been offset by increased spending on digital infrastructure investment, resulting in an insignificant net effect on operational expenses in the short run. This finding aligns with the argument that cost benefits from digital transformation are latent and require a longer period to materialize in BOPO, as identified in the review by Muttaqin et al. (2020)

Effect of Business Scale (ASET) on BOPO

The variable D(ASET) exhibits a positive coefficient of 0.0058 and is significant at $\alpha = 1\%$ (Prob. = 0.0009). H2, which predicted a negative effect through economies of scale, is rejected due to the opposing direction of the result. This finding reveals that in the dynamic dimension, asset growth is positively correlated with an increase in BOPO. This outcome can be interpreted through the mechanism of investment-led cost expansion: periods of rapid asset growth in Islamic banking are typically accompanied by operational capacity expansion, including the addition of human resources, technological infrastructure, and new service systems, all of which increase operational expenses in the short run before scale efficiencies are realized. Hijriyani and Setiawan (2017) noted that the relationship between bank size and operational efficiency in Islamic banking is non-linear and dependent on the phase of the growth cycle, while Wulandari and Ryandono (2020) identified that asset expansion does not automatically yield efficiency gains without adequate operational governance.

A more structural explanation for this anomaly lies in the distinctive cost architecture of Islamic banking technology in Indonesia. Unlike conventional banks, Islamic banks are required to support multiple sharia-compliant contract types simultaneously, including *murabahah*, *musyarakah*, *mudharabah*, and *ijarah*, each of which carries distinct accounting treatment, profit-sharing calculation logic, and regulatory reporting requirements. This demands either purpose-built Islamic core banking systems or heavily customized adaptations of conventional platforms, both of which carry substantially higher procurement, implementation, and maintenance costs. During periods of asset expansion, these technology costs are front-loaded and cannot be deferred, creating an immediate drag on operational efficiency before revenue growth materializes.

Furthermore, Islamic banks in Indonesia face additional compliance-related cost burdens during expansion that have no direct equivalent in conventional banking. Every new product launched requires endorsement from the *Dewan Pengawas Syariah* (DPS), and the human capital requirements for Islamic finance operations, including sharia-literate relationship managers, compliance officers, and product development specialists, command premium compensation relative to conventional banking roles. When asset growth is rapid, these fixed-to-quasi-fixed costs scale faster than the revenue base, producing the positive ASET-BOPO relationship observed in this study. This finding is consistent with the lifecycle cost hypothesis, wherein short-run expansion inefficiency is a necessary precondition for long-run scale economies, provided that governance quality and digital infrastructure investment keep pace with balance sheet growth.

Effect of Financing Quality (NPF) on BOPO

The variable D(NPF) has a coefficient of 1079.8198 and is significant at $\alpha = 1\%$ (Prob. = 0.0000), with a positive direction consistent with the hypothesis. H3 is accepted. D(NPF) is the variable with the strongest and most dominant influence in the model. Mechanically, an increase in NPF obliges Islamic banks to set aside larger loan loss provisions (Penyisihan Penghapusan Aktiva Produktif/PPAP), which directly increases the operational expense component and drives BOPO upward. This finding is consistent with and reinforces previous studies. Fitri and Sriyana (2023) found that NPF is the primary determinant of operational performance in Islamic banking, while Fathurrahman and Rahmadani (2024) confirms the significant impact of NPF on the BOPO of Indonesian Islamic commercial banks during the 2017–2022 period. Wahyudi (2020) also noted that NPF consistently explains variations in BOPO even under extreme pressure conditions such as the Covid-19 pandemic. These

findings affirm that financing quality management is a critical determinant of operational efficiency in Islamic banking.

Effect of the External Digital Ecosystem (NIL) on BOPO

The variable D(NIL) has a coefficient of 0.0002 with Prob. = 0.5555, indicating statistical insignificance. H4 is rejected. Growth in national mobile banking transaction values does not significantly affect changes in the BOPO of Islamic banking. This result can be explained by the nature of the NIL variable, which encompasses all national banking institutions rather than Islamic banking exclusively, so that the competitive pressure it captures is diffuse and does not specifically drive efficiency responses within Islamic banks. Furthermore, adaptation to digital ecosystem pressures likely occurs through long-term strategic investments that are not immediately reflected in monthly BOPO movements, consistent with the argument by Sa'diyah and Nasrulloh (2025) that banking responses to the digital ecosystem are gradual in nature.

Effect of Inflation (INF) on BOPO

INF has a coefficient of 20.7242 with Prob. = 0.6457, indicating statistical insignificance. H5 is rejected. Although theoretically inflation should increase operational input costs, Indonesia's inflation rate during 2014–2024 remained relatively controlled and fluctuated within a moderate range. More importantly, the adjustment of operational costs to inflationary pressure generally occurs gradually and is not immediately reflected in monthly BOPO changes. Wahyudi (2020) and Saleh (2021) found that the effect of inflation on Islamic banking financial performance is more pronounced in the profitability dimension (ROA) than in direct operational cost efficiency (BOPO).

Effect of BI Rate (BIRATE) on BOPO

D(BIRATE) has a coefficient of -60.1979 with Prob. = 0.4724, indicating statistical insignificance. H6, which was theoretically ambiguous, is not confirmed. This insignificant finding is consistent with the fundamental characteristics of Islamic banking, which operates on the basis of profit and loss sharing and margin-based contracts rather than direct interest rates. The transmission of BI Rate changes to the BOPO of Islamic banks operates indirectly and with a longer time lag compared to conventional banks, as identified by Sa'diyah and Nasrulloh (2025) in their study of macroeconomic variables on the profitability of Indonesian Islamic banking.

CONCLUSIONS AND RECOMMENDATIONS

This study analyzes the determinants of aggregate operational efficiency (BOPO) in the Indonesian Islamic banking sector for the period from January 2014 to December 2024 using the ARDL approach. The results of the cointegration test confirm the existence of a long-run dynamic relationship among the variables (F = 360.50). Of the six variables tested, NPF proved to be the dominant determinant with a positive and significant effect on BOPO, confirming that non-performing financing is the primary source of operational inefficiency. ASET had a significant positive effect, contrary to expectations of economies of scale, indicating that short-term asset expansion imposes cost burdens that precede the realization of efficiency. Meanwhile, JKFISIK, NIL, INF, and BIRATE were not found to be significant. The ECM coefficient of -0.9833 confirms a very rapid correction mechanism, and parameter stability was confirmed throughout the observation period.

Recommendations

For the management of Islamic commercial banks and regulators, controlling the quality of financing (NPF) must be a top priority in operational efficiency strategies, given its direct and significant impact on the BOPO ratio. Asset expansion must also be balanced with the early strengthening of operational cost management so that the benefits of economies of scale can be realized. For OJK, the dominant role of NPF in driving BOPO, with a coefficient of 1,079.82, carries a direct implication for the revision of the Roadmap Pengembangan dan Penguatan Perbankan Syariah Indonesia 2023-2027 (RP3SI). Rather than prioritizing branch reduction metrics as a proxy for digital progress, OJK should consider embedding NPF-linked efficiency incentives into its supervisory framework. Concretely, this could take the form of capital relief mechanisms for Islamic banks that demonstrate measurable adoption of AI-based credit scoring systems (*AI credit scoring*) for financing monitoring, as preventive NPF management through early warning systems addresses the cost driver at its source rather than its symptom. Digital transformation targets should additionally be anchored to BOPO improvement benchmarks, ensuring that

investment in technology produces verifiable efficiency gains rather than merely restructuring physical infrastructure.

For future research, it is recommended to use level variables in the standard ARDL specification, include dummy variables to control for the structural break resulting from the BSI merger in 2021, and explore more specific proxies for digital transformation, such as the proportion of digital transactions relative to total Islamic banking transactions. An individual Islamic bank panel data approach is also recommended to distinguish efficiency dynamics across institutions.

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