



# Capital Adequacy, Risk Absorption, and Operational Efficiency of Islamic Banks in Sub-Saharan Africa

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## Abstract

This study examines how capital adequacy shapes the operational efficiency of Islamic banks in Sub-Saharan Africa (SSA), with particular emphasis on its role as an internal risk-absorption mechanism rather than a purely prudential stability buffer. Despite its central role in Islamic banking regulation, the efficiency implications of capital adequacy, particularly in developing and institutionally constrained Islamic finance markets, remain largely unexplored. Based on a balanced panel of fully-fledged Islamic banks in SSA from 2010 to 2024, the paper employs a two-step empirical approach. Bias-corrected operational efficiency scores are estimated in the first stage using the Simar–Wilson two-stage Data Envelopment Analysis (DEA) framework. In the second stage, we explore the non-linear effects of capital adequacy on efficiency using panel regression techniques, controlling for bank-specific and institutional factors. To address endogeneity, persistence, and reverse causality, a dynamic panel model is estimated using System GMM as a robustness check. The findings indicate a non-linear relationship between capital adequacy and operational efficiency. Moderate capital buffers are associated with improved efficiency through higher loss absorption capacity and stabilisation of operating costs, while excessive capitalisation is accompanied by scale inefficiencies and less effective intermediation. These results indicate that Islamic banking exhibits an efficiency trade-off in capital adequacy, as prudential strength beyond an optimal level may limit productivity in resource allocation. The study makes an important contribution to Islamic banking literature by reframing capital adequacy as a channel of structural efficiency and by providing rare dynamic evidence from SSA. This raises policy implications and suggests the need for commensurate capital calibration that balances prudential resilience against operational efficiency for emerging Shari‘ah-compliant banking systems.

**Keywords:** Islamic banking; capital adequacy; operational efficiency; System GMM; SSA



## I. INTRODUCTION

### 1.1 Background

Islamic banking has grown from a niche financial entity to an increasingly central part of the global financial system. Based on principles of Sharī'ah, which ban interest (*ribā*), excessive uncertainty (*gharar*), and speculation (*maysir*) (Haron, 2014; Ridha, 2025; Yunus et al., 2023), Islamic banking focuses on asset-backed financing, risk-sharing, and ethical intermediation (Gherfal, 2023). This prohibition is rooted in verses from the Qur'an and is emphasised in various Islamic scholarly interpretations (Yousufi & Ghazi, 2021). Islamic banks must arrange financial products without any form of interest (*riba*) and in accordance with Shariah-compliant mechanisms, such as profit-sharing arrangements (*mudarabah*), joint ventures (*musharakah*), cost-plus financing (*murabahah*), leasing contracts (*ijarah*), forward sale agreements (*salam*), manufacturing and construction contracts (*istisna'*), Islamic bonds (*sukuk*), benevolent loans (*qard hasan*), and agency-based structures (*wakalah*) (Haron, 2014; Yunus et al., 2023). Islamic finance is often described as a stabilising framework that is particularly attractive in the context of turbulent financial market conditions and financial system stress, as it links economic activity to financial operations (Jatmiko et al., 2023). Global Islamic financial assets expanded rapidly over the last two decades owing to demographic growth, rising demand for ethical and socially responsible financing, regulatory reforms, and continued innovation in Sharī'ah-compliant financial instruments (IFSB, 2025). However, the international geographical distribution of Islamic banking has been extremely uneven. These markets comprise mature Middle Eastern, North African, and Southeast Asian markets, which remain the largest and fastest-growing in global Islamic finance, as they enjoy deep capital market penetration, mature Sharī'ah governance structures, and active sukuk issuance for liquidity management and balance-sheet growth (Samad, 2021).

The rapidly growing Muslim population in Sub-Saharan Africa (SSA) accounts for only a small share of the world's Islamic banking assets (Ayagre et al., 2024). Across several SSA jurisdictions, Islamic banking is still at a nascent stage, with traditional banking systems that have much richer institutional and financial infrastructure. The limited presence of Islamic banking in SSA is due to structural, regulatory, and institutional constraints (Akinbowale et al., 2025; Franciosi, 2025; Kamdzhlov, 2022). These constraints encompass a range of factors, including fragmented and evolving regulatory frameworks, a lack of financial infrastructure, very shallow capital and money markets, and shortages in Sharī'ah-compliant liquidity and risk-management instruments (Gondwe et al., 2024). In many regions, the lack of specialised Islamic interbank markets, lender-of-last-resort facilities, and fully functioning sukuk markets limits Islamic banks' capacity to manage short-term liquidity and expand their businesses accordingly. Within this environment of intense competition, Islamic banks in SSA often struggle to achieve sustainable operational performance (Franciosi, 2025).

Structural constraints limit Islamic banks' ability to expand financing, manage risk, and compete with conventional banking institutions (Gondwe et al., 2024). Consequently, cost-to-income ratios remain elevated, profitability remains low, and intermediation depth is limited compared to conventional and Islamic banks operating in developed markets (Alshater et al., 2022). Operational efficiency is critical to the sustainability and competitiveness of Islamic banking in SSA (Ayagre et al., 2024; Franciosi, 2025). Efficient Islamic banks are better equipped to withstand economic shocks, provide Sharī'ah-compliant financial services to more individuals, and make substantial contributions to financial inclusion and the wider development agenda (Chowdhury & Haron, 2022). Understanding the institutional and balance-sheet factors that shape efficiency outcomes in this structurally constrained environment remains an important yet underexplored area of research, which motivates the present study.

### 1.2 Research Gap and Problem Statement

Although the Islamic banking industry continues to grow internationally, empirical evidence on the determinants of Islamic banking's operational efficiency is inconsistent and context-specific. Most studies have been conducted in mature Islamic finance markets in the Middle East, North Africa, and Southeast Asia, where financial infrastructure, regulatory frameworks, and Sharī'ah-compliant liquidity systems are relatively robust (Jarbou et al., 2024; Rani et al., 2024; Samad, 2021). Accordingly, the findings of this literature may not be applicable to emerging Islamic banking systems facing significant structural and institutional limitations. Specifically, the influence of capital adequacy on operational efficiency remains poorly understood.



Capital adequacy is widely regarded as a fundamental determinant of banking stability, yet previous research is generally limited to its effects on solvency, risk-taking, and financial resilience, often framing efficiency as an afterthought or an indirect consequence (Ali, 2019; Olawale, 2024).

Empirical evidence on efficiency remains inconsistent; studies report positive, negative, or insignificant associations with efficiency depending on the institutional landscape, measurement method, or model selection (Korein et al., 2021). These discrepancies indicate unresolved theoretical and empirical ambiguities regarding the role of capital buffers in overall efficiency. While capital buffers may enhance efficiency by improving risk absorption, they may also constrain efficiency through opportunity costs and limitations on balance-sheet expansion (Olawale, 2024). In Islamic banking, these contradictions are exacerbated by the unique contractual structure of Sharī'ah-based finance and by context-specific elements that set emerging markets apart from mature ones. Current efficiency studies analysing Islamic banks often resort to rigid modelling tools, linear relationships, and capital adequacy as a control variable rather than as the main analytical focus (Abdulmalik & Rauf, 2025; Istaiteyeh, 2024). Similarly, relatively little consideration has been given to the possibility that the efficiency effects of capital adequacy differ across capitalisation levels or depend on the persistence and dynamic adjustment process (Ali, 2019).

This study addresses these gaps by presenting a concentrated analysis of the capital adequacy–efficiency relationship across Islamic banks in SSA. Combining bias-corrected efficiency metrics with static, nonlinear, and dynamic panel estimation methods, this paper offers a more nuanced examination of the extent to which capital adequacy affects operational efficiency in structurally limited Islamic banking systems. In so doing, it extends the existing literature beyond mature markets and generates fresh insights into the trade-offs underpinning capital regulation in developing Sharī'ah-compliant financial systems.

### **1.3 Objectives**

The overarching objective of this study was to investigate how capital adequacy influences the operational efficiency of Islamic banks in SSA. Specifically, the study sought to:

- i. Estimate bias-corrected operational efficiency scores for Islamic banks in SSA.
- ii. Examine the relationship between capital adequacy and operational efficiency, accounting for potential non-linear effects.
- iii. Assess whether capital adequacy functions primarily as a risk-absorption mechanism that enhances efficiency or as a structural constraint that impedes efficient intermediation.
- iv. Evaluate the robustness of the capital–efficiency relationship under dynamic conditions and in the presence of potential endogeneity.

### **1.4 Contributions of the Study**

This study contributes to the Islamic banking literature by providing new evidence on the capital adequacy–efficiency nexus in Sub-Saharan Africa (SSA), a region that remains underexplored in empirical research. Rather than confirming a strong direct relationship, the findings indicate that capital adequacy does not straightforwardly translate into operational efficiency in structurally constrained Islamic banking systems. This highlights the importance of distinguishing between prudential strength and operational performance, particularly in environments characterised by shallow financial markets and limited Sharī'ah-compliant liquidity instruments.

The study further contributes by distinguishing between structural and dynamic dimensions of efficiency. While static models suggest a weak, theoretically consistent nonlinear pattern, the dynamic analysis shows that these effects do not persist when endogeneity and adjustment dynamics are accounted for. This underscores the dominance of structural factors over short-run efficiency adjustments. Finally, the results reveal that liquidity and asset quality play a more immediate and statistically significant role in shaping operational efficiency. This suggests that capital adequacy operates indirectly, through complementary balance-sheet channels, rather than as a standalone driver of performance. Methodologically, the study combines bias-corrected DEA with static and dynamic panel estimations to provide a comprehensive and robust assessment of the capital–efficiency relationship in a constrained institutional context.



## II. LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

### 2.1 Conceptualising Operational Efficiency in Islamic Banking

Operational efficiency in banking refers to the process by which financial institutions transform inputs such as deposits, labour, and operational costs into positive outputs like financing, earning assets, and income, with minimal waste and cost inefficiencies (Abdulmalik & Rauf, 2025; Azhari et al., 2022). In Islamic banking, operational efficiency is further complicated by Shariah restrictions on financial contracts, the prohibition of interest-based lending tools, and the increasing governance and monitoring requirements for asset-backed and risk-sharing instruments (Haron, 2014; Ridha, 2025; Yunus et al., 2023). Islamic banks also incur higher operational costs than conventional banks due to Shariah compliance, contract verification, asset monitoring, and governance oversight, which are supervised by Shariah Supervisory Boards (Jatmiko et al., 2023). These costs are heightened in systems with underdeveloped regulatory and institutional frameworks, a common situation in many SSA economies (Korein et al., 2021). Consequently, efficiency in Islamic banking must be understood not merely as an outcome of managerial performance but also as shaped by structural, regulatory, and institutional constraints. Recent studies have applied frontier approaches, such as DEA, to evaluate multiple inputs and outputs without imposing functional form restrictions (Jarbou et al., 2024). However, traditional DEA models are sensitive to statistical noise and external influences, leading to biased estimates. The two-stage DEA model by Simar and Wilson addresses these shortcomings by incorporating bias correction and allowing efficiency scores to be analysed with respect to external factors, making it suitable for banking systems operating in heterogeneous institutional environments (Simar & Wilson, 2007, 2020).

### 2.2 Capital Adequacy: Theoretical Perspectives

#### 2.2.1 Capital Adequacy and Efficiency: Buffer and Risk-Absorption Perspectives

From a prudential and microeconomic perspective, capital adequacy is traditionally perceived as a buffer that enhances bank stability and supports operational efficiency by absorbing unexpected losses and reducing the risk of financial distress (Ding et al., 2025; Farooq et al., 2023). Buffer theory posits that well-capitalised banks have lower funding costs, greater risk-bearing capacity, and are better positioned to maintain stable operations during adverse shocks (Korein et al., 2021). These arguments are particularly pertinent in the context of Islamic banking because asset-backed and profit-and-loss sharing contracts often expose banks to equity-like risks and income volatility (Haron, 2014; Yunus et al., 2023). Sufficient capital buffers can, therefore, ensure operational planning stability, mitigate displaced commercial risk, and bolster confidence among investment account holders (Ali, 2019; Ding et al., 2025; Olawale, 2024). The efficiency gains associated with risk absorption do not happen automatically and depend on the institutional environment in which banks operate, particularly the availability of complementary liquidity and risk-management instruments.

#### 2.2.2 Capital Adequacy, Opportunity Costs, and Efficiency Trade-Offs

Opportunity-cost and X-efficiency theories, in contrast to this buffer view, stress the possible efficiency costs associated with excessive capitalisation. High capital ratios may constrain balance sheet expansion, reduce leverage, and limit the potential for economies of scale, thereby lowering operational efficiency (Ali, 2019; Sole & Babu, 2024). From this perspective, excessive capitalisation can foster risk-averse intermediation strategies and reduce incentives to minimise costs. In Islamic banking systems operating within structural constraints, these trade-offs can be starker, given the restricted access to Sharī'ah-compliant liquidity facilities and shallow capital markets that restrict the productive deployment of excess capital (Kamdzhlov, 2022). As a result, capital adequacy may have a non-linear influence on efficiency, with effects ranging from positive at moderate levels of capitalisation to diminishing or negative above an optimum level (Ding et al., 2025).

### 2.3 Empirical Evidence on Capital Adequacy and Operational Efficiency

Empirical evidence on the capital adequacy–efficiency relationship is mixed and context-dependent (Aqib Ali, 2023). Early research in the traditional banking literature has largely regarded capital adequacy as a stabilising factor, finding that well-capitalised banks are better able to absorb losses, sustain lending during downturns, and access funding more cheaply (Korein



et al., 2021). From this perspective, higher capital buffers may indirectly improve efficiency by reducing the risks that disrupt operations, facilitating risk monitoring, and stabilising funding arrangements. In line with this perspective, a positive correspondence is observed between capitalisation and efficiency or productivity, especially within developed banking systems with deep capital markets and tight regulatory regimes (Sole & Babu, 2024). In these environments, capital adequacy may represent quality in management and be associated with lower wholesale funding costs, thereby promoting sound intermediation. However, these results are not universally generalisable (Ayagre et al., 2024). A substantial body of evidence finds weak, insignificant, or negative relationships between capital adequacy and operational efficiency (Haron, 2014; Yunus et al., 2023). Such studies contend that large shares of capital accumulation create opportunity costs, as excess capital can lower leverage, restrict the growth of balance sheets, and constrain economies of scale, especially when banks maintain capital levels exceeding their underlying risk exposure (Ali, 2019).

The difference in empirical findings has been explained in several ways. First, there are variations in how efficiency is measured; some rely on accounting ratios, others on frontier-based approaches, e.g., DEA or Stochastic Frontier Analysis (Abdulmalik & Rauf, 2025; Jarbou et al., 2024; Simar & Wilson, 2020). Secondly, regulatory frameworks vary across countries, affecting both the amount of required capital and how capital influences bank actions (Gondwe et al., 2022). Third, banks' productive use of capital depends on institutional and market constraints, meaning the capital efficiency nexus is context-dependent. The available literature on Islamic banking is limited to empirical evidence and is largely skewed towards mature markets in the Middle East and Southeast Asia (Jarbou et al., 2024; Rani et al., 2024; Samad, 2021). Research conducted in those regions generally reports higher levels of financial stability and lower insolvency risks, with well-capitalised Islamic banks showing lower financial risk but not necessarily higher operational efficiency than their less-capitalised counterparts. In some instances, capital adequacy appears to be weakly or negatively associated with efficiency, particularly when regulatory standards are strict and Islamic financial markets are sufficiently deep to support alternative risk management tools (Yunus et al., 2023). These results imply that excess capital exceeds a threshold and no longer adds efficiency, and instead reflects regulatory compliance or precautionary activity rather than efficient intermediation.

Critically, the vast majority of Islamic banking literature views capital adequacy as just one element within the broader CAMELS-type performance frameworks (Ding et al., 2025). In this context, capital adequacy is often treated as a control variable rather than the primary mechanism of interest, which may limit understanding of how capital influences operational efficiency (Abdulmalik & Rauf, 2025; Istaiteyeh, 2024). In addition, empirical models tend to be static; they assume implicitly that the relationship between capital and efficiency is contemporaneous and exogenous. This assumption is problematic, as operational efficiency is likely to persist over time, and capital adequacy may be jointly determined by performance relative to retained earnings, regulatory reactions, and market discipline (Azhari et al., 2022). Empirical evidence is even more limited in SSA (Ayagre et al., 2024). Studies on Islamic banking in SSA remain limited in both scope and data availability. Capital adequacy has only rarely been considered in isolation from aggregate financial soundness indices or CAMELS frameworks, and thus there has usually been little reflection on its efficiency implications.

Furthermore, the dependence on static panel estimation methods overlooks dynamic feedback effects and potential endogeneity between capital buffers and their efficiency effects (Jarbou et al., 2024). These constraints become especially consequential in structurally regulated environments such as SSA, where Islamic banking services are found in shallow financial markets that lack Shari'ah-compliant liquidity and capital instruments (Gondwe et al., 2022). Capital adequacy may serve multiple roles, including acting as a prudential buffer, substituting for missing market-based risk-sharing mechanisms, and impeding efficient intermediation. Neglecting these dynamics risks obscuring the true nature of the capital–efficiency relationship. Against this backdrop, this empirical study departs from existing approaches by treating capital adequacy explicitly as a structural determinant of operational efficiency in Islamic banks operating in the SSA context. By combining bias-corrected efficiency estimation with nonlinear and dynamic robustness analysis, the study aims to offer a more contextually nuanced analysis and insights into the impact of capital adequacy on efficiency performance in developing shari'ah-compliant banking systems.

#### *2.4 Non-Linearity and Threshold Effects in Capital Adequacy*



An emerging line of the banking literature is that capital adequacy-performance relationships may be non-linear. Moderate levels of capitalisation may improve efficiency by absorbing risk and stabilising operations (Ali, 2019; Samad, 2021). Excessive capitalisation may lead to decreasing or negative marginal returns owing to scale inefficiencies and constrained intermediation (Chowdhury & Haron, 2022). This non-linear view is especially relevant to Islamic banks in SSA. Given these constraints, banks without effective external risk-sharing have an incentive to hold capital well above the optimal level. These buffers may increase resilience while reducing efficiency by restricting asset growth and increasing average costs (Sole & Babu, 2024). Empirical research on these non-linear effects is limited in the Islamic banking literature, particularly in emerging markets (Aqib Ali, 2023).

### 2.5 Dynamic Considerations and Endogeneity

Banking operational efficiency exhibits persistence over time, characterised by structural features, learning dynamics, and institutional inflexibilities (Abdulmalik & Rauf, 2025). Capital adequacy may both influence and be influenced by efficiency outcomes, introducing the possibility of endogeneity. Efficient banks may be able to accumulate capital more easily through retained earnings, while inefficient banks may be forced to add new capital buffers to cover operational weaknesses (Korein et al., 2021). Neglecting these dynamics would bias estimates of the effects of capital adequacy on efficiency. Dynamic panel methods, such as System GMM, account for persistence and endogeneity by using lagged variables as internal instruments (Horobeț et al., 2021; Mong, 2025). In the current paper, dynamic analysis is utilised as an extension of robustness to cross-check baseline estimates from bias-corrected efficiency.

### 2.6 Hypotheses Development

Based on the preceding theoretical and empirical discussion, the study formulates the following testable hypotheses:

**H<sub>01</sub>:** Capital adequacy has a statistically significant effect on the operational efficiency of Islamic banks in Sub-Saharan Africa.

**H<sub>02</sub>:** The relationship between capital adequacy and operational efficiency is non-linear.

**H<sub>03</sub>:** Operational efficiency exhibits persistence over time.

**H<sub>04</sub>:** The relationship between capital adequacy and operational efficiency remains robust after controlling for endogeneity.

## III. METHODOLOGY

### 3.1 Research Design and Empirical Strategy

This study adopts a layered empirical strategy in which each econometric technique serves a distinct inferential purpose in examining the relationship between capital adequacy and operational efficiency. In the first stage, bias-corrected efficiency scores are estimated using the Simar–Wilson Data Envelopment Analysis (DEA) framework (Istaiteyeh, 2024). This approach is well-suited to banking applications involving multiple inputs and outputs, and it addresses statistical bias and sampling variability through bootstrapping (Abdulmalik & Rauf, 2025).

In the second stage, the relationship between capital adequacy and efficiency is initially examined using the Simar–Wilson truncated regression framework, which is appropriate given the bounded and serially correlated nature of DEA efficiency scores. While this approach provides consistent inference under these conditions, fixed-effects models with Driscoll–Kraay standard errors are subsequently employed as robustness estimators to account for unobserved heterogeneity, cross-sectional dependence, and temporal correlation across banks. Further, a dynamic specification is estimated using System GMM to capture persistence in efficiency and address potential endogeneity between capital adequacy and performance (Mong, 2025). Although DEA efficiency scores are bounded between 0 and 1, the use of fixed-effects and GMM estimators as robustness approximations is well established in the banking efficiency literature. This layered approach strengthens the credibility of the findings by triangulating results across complementary econometric frameworks.



### 3.2 Data and Sample Selection

The study uses a balanced panel of 35 fully-fledged Islamic banks in Sub-Saharan Africa (SSA) over the period 2010–2024, yielding 525 bank-year observations. Only fully-fledged Islamic banks are included to ensure comparability, while Islamic windows are excluded. Financial data are obtained from audited annual reports. Table 1 presents the country-level distribution of the sample across 14 SSA countries and reflects substantial institutional heterogeneity, with Sudan accounting for the largest share of banks. The panel is balanced, with no banks entering or exiting during the study period. The estimation sample is identical across the DEA, static panel, and GMM models, ensuring consistent and comparable results.

**Table 1.** Cross-Country Distribution of Islamic Banks in the Sample

Country	Number of Banks	Years Covered	Observations
Sudan	19	2010–2024	285
Kenya	3	2010–2024	45
Nigeria	2	2010–2024	30
Burkina Faso	1	2010–2024	15
Côte d’Ivoire	1	2010–2024	15
Mali	1	2010–2024	15
Mauritania	1	2010–2024	15
Mauritius	1	2010–2024	15
Niger	1	2010–2024	15
Senegal	1	2010–2024	15
Seychelles	1	2010–2024	15
South Africa	1	2010–2024	15
Tanzania	1	2010–2024	15
Togo	1	2010–2024	15
<b>Total</b>	<b>35</b>	<b>2010–2024</b>	<b>525</b>

*Source:* Authors’ compilation from bank-level financial statements.

### 3.3 Measurement of Operational Efficiency

#### 3.3.1 DEA Framework and Orientation

Operational efficiency was evaluated using an input-oriented DEA framework under both Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS) assumptions (Abdulmalik & Rauf, 2025). The input-oriented methods were suitable, given the study’s aim of cost containment and resource deployment in Islamic banks with structural and regulatory constraints, where external constraints on output expansion could be imposed. Inputs and outputs were chosen according to the intermediation approach; i.e., banks were considered financial intermediaries that convert deposits and other resources into financing and earning assets (Istaiteyeh, 2024). This is a standard approach in banking efficiency studies, and it is particularly important for Islamic banks in their asset-backed intermediation.

#### 3.3.2 Selection of Inputs and Outputs

The DEA model used customer deposits and profit-sharing investment accounts as inputs to capture funding resources available for intermediation. Operating expenses were included to reflect managerial and administrative costs, while labour or personnel expenses were used as a proxy for human capital inputs. On the output side, total financing and earning assets were utilised to represent intermediation activity, and operating income was included to capture banks’ revenue-generating capacity. The choice of these inputs and outputs was consistent with prior studies on Islamic banking efficiency and reflected the operational characteristics of Sharī’ah-compliant financial intermediation.



### 3.4 Simar–Wilson Two-Stage Bias-Corrected DEA

Following the Simar–Wilson (2007) procedure, a two-stage approach was adopted to minimise the statistical shortcomings of conventional DEA. DEA efficiency scores were estimated in the initial phase using a bootstrap approach that controlled for sampling variability (Samad, 2024). This produced statistically consistent bias-corrected efficiency estimates. In the second stage, bias-corrected efficiency scores were further regressed on capital adequacy and control variables with truncated regression models with bootstrap confidence intervals. Such an approach recognises that DEA efficiency scores were bounded and serially correlated, making conventional OLS or Tobit estimators inappropriate (Istaiteyeh, 2024). This two-stage process ensures inferential validity and avoids methodological artefacts when estimating the determinants of efficiency.

### 3.5 Econometric Specification: Baseline Model

The baseline empirical model examines the relationship between capital adequacy and operational efficiency as follows:

$$EFF_{it} = \beta_0 + \beta_1 CAR_{it} + \beta_2 CAR_{it}^2 + \gamma X_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

where:

- $EFF_{it}$  - denotes the bias-corrected DEA efficiency score of bank  $i$  at time  $t$ ;
- $CAR_{it}$  - represents capital adequacy;
- $CAR_{it}^2$  - captures potential non-linear effects;
- $X_{it}$  - is a vector of control variables;
- $\mu_i$  - captures unobserved bank-specific effects;
- $\varepsilon_{it}$  - is the idiosyncratic error term.

The inclusion of the squared capital adequacy term allows for the possibility that efficiency effects are non-linear, consistent with theoretical arguments regarding optimal versus excessive capitalisation.

### 3.6 Dynamic Robustness Analysis: System GMM

Operational efficiency in banking is inherently dynamic, reflecting persistence, learning effects, and institutional rigidities. In addition, capital adequacy may be endogenous, as efficient banks can accumulate capital through retained earnings, while less efficient banks may be required to strengthen capital buffers (Farooq et al., 2023). To address these issues, the study employs the System Generalised Method of Moments (System GMM) estimator as a robustness extension. This approach incorporates a lagged dependent variable to capture persistence and uses internal instruments derived from lagged regressors to control for endogeneity (Mong, 2025). The dynamic specification was given by:

$$EFF_{it} = \alpha EFF_{it-1} + \beta_1 CAR_{it} + \beta_2 CAR_{it}^2 + \gamma X_{it} + \mu_i + \varepsilon_{it} \quad (2)$$

where  $EFF_{it-1}$  - captures persistence in operational efficiency.

In the dynamic specification, capital adequacy and liquidity are treated as endogenous, while bank size is predetermined. Time dummies are included as strictly exogenous variables to capture common shocks. The instrument set is constructed using lagged values of the endogenous variables, with instruments drawn from the second lag ( $t-2$ ) and deeper to ensure validity. To avoid instrument proliferation, the instrument matrix is restricted and collapsed. The total number of instruments (26) remains below the number of cross-sectional units (35), ensuring model parsimony and reducing the risk of overfitting, in line with recommended practice in dynamic panel estimation. Model validity is assessed using the Hansen test of over-identifying restrictions and the Arellano–Bond tests for serial correlation.

### 3.7 Control Variables

To isolate the effect of capital adequacy, the models include key bank-specific controls. Bank size, measured as the natural logarithm of total deposits, captures scale effects with an ambiguous expected sign. Liquidity, defined as liquid assets to total assets, reflects funding capacity and is expected to enhance efficiency. Asset quality, proxied by financing to total assets, captures portfolio effectiveness and is expected to positively influence efficiency. Table 2 summarizes the definition, measurement, expected effects, and sources of all variables used in the analysis. These variables control for core balance-sheet characteristics that may independently affect operational efficiency.

**Table 2.** Definition of Variables and Expected Effects

Variable	Proxy	Measurement / Formula	Expected Sign	Source
Operational Efficiency (EFF)	Bias-corrected VRS DEA score	Simar–Wilson DEA estimate (0–1)	—	Simar & Wilson (2007, 2020); Abdulmalik & Rauf (2025)
Capital Adequacy (CAR)	Equity-to-deposits ratio	Total equity / total deposits	±	Olawale (2024); Korein et al. (2021); Ding et al. (2025)
Bank Size (SIZE)	Log of deposits	ln(total deposits)	±	Abdulmalik & Rauf (2025); Horobet et al. (2021)
Liquidity (LIQ)	Liquid assets ratio	Liquid assets / total assets	+	Jarbou et al. (2024); Gondwe et al. (2022)
Asset Quality (AQ)	Financing ratio	Total financing / total assets	+	Istaiteyeh (2024); Farooq et al. (2023)

Source: Authors' elaboration

#### IV. EMPIRICAL RESULTS

The empirical results are presented in a sequential order to test the hypotheses. Table 5 examines the baseline structural relationship (H1); Table 6 assesses nonlinearity (H2); Table 7 presents robustness checks across alternative specifications; and Table 8 evaluates the robustness of these relationships in a dynamic setting (H4).

##### 4.1 Descriptive Statistics and Preliminary Analysis

**Table 3.** Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Median	Max
Bias-corrected VRS efficiency	525	0.318	0.191	0.037	0.271	0.782
Capital adequacy (Equity–Deposits)	525	27.944	29.510	0.068	16.778	202.979
Bank size (log deposits)	525	11.484	2.328	0.154	11.878	16.470
Liquidity ratio	525	28.454	11.183	4.236	28.409	57.313
Asset quality	525	56.122	35.373	0.000	55.165	280.050

Source: Authors' elaboration

Table 3 presents descriptive statistics for the full sample of Islamic banks operating in SSA over the period 2010–2024. The findings reveal substantial heterogeneity among banks in terms of capitalisation, scale, liquidity, and asset quality. The bias-corrected VRS efficiency scores ranged from 0.037 to 0.782, with a mean of 0.318, indicating that the average Islamic bank operates well below the efficient frontier. This dispersion illustrates the large potential for efficiency gains and suggests that operational performance varies markedly across institutions and jurisdictions. Capital adequacy ratios varied widely, with some banks maintaining equity buffers far above conventional prudential benchmarks. Such high levels of capitalisation were consistent with a precautionary response to shallow financial markets, limited Shari'ah-compliant liquidity instruments, and heightened regulatory uncertainty (Gondwe et al., 2022). Control variables also showed notable dispersion, emphasising the importance of accounting for bank-specific heterogeneity in subsequent regression analysis. Overall, the descriptive statistics provided initial evidence that capital adequacy may influence efficiency in non-uniform ways across banks and over time.



#### 4.2 Bias-Corrected DEA Efficiency Estimates

Table 4 reports bias-corrected efficiency scores obtained from the Simar–Wilson DEA framework under both constant and variable returns to scale. The mean CRS efficiency of 0.287 and VRS efficiency of 0.417 indicated that inefficiencies arose from both pure technical inefficiency and scale-related factors. The average scale efficiency of 0.751 suggests that many Islamic banks in SSA operated at sub-optimal scale, consistent with fragmented markets and limited intermediation depth. The bias-corrected VRS efficiency scores, which form the dependent variable in subsequent regressions, were systematically lower than conventional DEA estimates, confirming the importance of correcting for statistical bias and sampling variability (Samad, 2024). The presence of persistent inefficiency across banks motivates examining internal structural factors, most notably capital adequacy, that may shape operational performance beyond scale effects alone.

**Table 4.** Bias-Corrected DEA Efficiency Scores (VRS)

Efficiency measure	Obs	Mean	Std. Dev.	Min	Median	Max
CRS efficiency	525	0.287	0.213	0.005	0.233	1.000
VRS efficiency	525	0.417	0.278	0.051	0.333	1.000
Scale efficiency	525	0.751	0.262	0.015	0.868	1.000
Bias-corrected VRS efficiency	525	0.318	0.191	0.037	0.271	0.782

*Source:* Simar–Wilson bias-corrected DEA estimates.

#### 4.3 Baseline Regression Results: Capital Adequacy and Efficiency

Table 5 reports the baseline second-stage regression results. Using a fixed-effects specification with Driscoll–Kraay standard errors, the results indicate that capital adequacy does not exert a statistically significant linear effect on operational efficiency. The estimated coefficient on the capital adequacy ratio was negative but insignificant, indicating that increased capitalisation alone does not necessarily lead to a gain in efficiency for Islamic banks operating in SSA. This suggests that capital buffers may enhance resilience, but their efficiency benefits are not unconditional (Abdulmalik & Rauf, 2025). In structurally constrained environments, additional capital may be held for precautionary or regulatory reasons rather than deployed productively in financing activities (Korein et al., 2021). The baseline findings caution against interpreting capitalisation as a uniformly beneficial determinant of operational efficiency.

**Table 5.** Baseline Regression Results: Capital Adequacy and Operational Efficiency

Variable	Coefficient	Std. Error	p-value
Capital adequacy (CAR)	−0.0013	0.0012	0.262
Bank size	Included	—	—
Liquidity	Included	—	—
Asset quality	Included	—	—

*Source:* Authors' elaboration. **Estimator:** Two-way fixed effects with Driscoll–Kraay standard errors. **Dependent variable:** Bias-corrected DEA efficiency score.

#### 4.4 Non-Linear Effects of Capital Adequacy

To examine whether the relationship between capital adequacy and operational efficiency is non-linear, the baseline specification is extended by including a quadratic term for capital adequacy. The estimated model is expressed as

$$\widehat{Eff}_{it} = 0.0013 CAR_{it} - 0.000014 CAR_{it}^2 - 0.0075 Size_{it} + 0.00117 Liquidity_{it} + 0.00080 AssetQuality_{it} + \mu_i + \varepsilon_{it}$$

where  $(CAR_{it})$  denotes capital adequacy and  $(CAR_{it}^2)$  captures potential non-linear effects

The estimation results are reported in Table 6.

**Table 6.** Non-Linear Capital Adequacy Effects on Operational Efficiency

Variable	Coefficient	Std. Error	t-stat	p-value
Capital adequacy (CAR)	0.0013	0.0011	1.15	0.271
Capital adequacy (CAR) <sup>2</sup>	-0.000014	0.000008	-1.68	0.115
Bank size	-0.0075	0.0099	-0.75	0.464
Liquidity ratio	0.00117	0.00052	2.25	0.041
Asset quality	0.00080	0.00037	2.20	0.045
Constant	0.291	0.149	1.96	0.071

Source: Authors' elaboration. *Estimator:* Fixed effects with Driscoll–Kraay standard errors. *Dependent variable:* Bias-corrected VRS efficiency

The coefficient of capital adequacy is positive, and its squared term is negative. This pattern is consistent with an inverted U-shaped relationship, whereby capital adequacy initially supports efficiency but yields diminishing marginal returns at higher capitalisation levels. However, the two coefficients do not appear to be statistically significant; these results should be interpreted with caution. To further explain this economic concept, the implied turning point of capital adequacy is calculated using the standard quadratic formulation.

$$CAR^* = -\frac{\beta_1}{2\beta_2}$$

Replacing the estimated coefficients in the quadratic specification yields an approximate turning point of 46.4%. This suggests that efficiency gains associated with capital adequacy may increase at moderate levels of capitalisation, but begin to diminish beyond this threshold. However, this estimate should be interpreted with caution, as the quadratic term does not attain conventional levels of statistical significance. As such, the turning point is indicative rather than conclusive.

Overall, the results point to a relationship that is theoretically consistent with a non-linear capital–efficiency trade-off, but empirically weak and not statistically robust. In contrast, liquidity and asset quality are found to be positively and statistically significant determinants of efficiency. This highlights the importance of complementary balance-sheet conditions, suggesting that the efficiency effects of capital adequacy are likely mediated by broader financial and institutional factors rather than operating as a standalone mechanism.

#### 4.5 Robustness Checks: Alternative Specifications

Table 7 presents robustness evaluations across alternative specifications, estimators, and efficiency measures. The qualitative pattern of findings remained comparable across all models. Notably, the insignificance of the linear capital adequacy term persisted in the baseline static model, whereas the squared term showed weak non-linear effects. Such patterns were replicated across alternative efficiency measures derived from CRS and VRS DEA models. The robustness analysis confirmed that the key results were independent of model specifications, preferred efficiency metric, and extreme observations, indicating a grounded, structure-based link between capitalisation and efficiency in Islamic banks operating within constrained institutional environments (Gondwe et al., 2022).

**Table 7.** Robustness Checks: Capital Adequacy and Operational Efficiency

Specification	Estimator	CAR	CAR <sup>2</sup>	Key inference
Baseline model	FE (Driscoll–Kraay)	-0.0013 (0.262)	—	Insignificant
Non-linear static model	FE (Driscoll–Kraay)	0.0013 (0.271)	-0.000014 (0.115)	Weak inverted-U
Dynamic model	System GMM	-0.0031 (0.294)	0.000003 (0.738)	No dynamic effect
Alternative efficiency (CRS)	DEA + FE	Similar sign	—	Stable
Alternative efficiency (VRS)	DEA + FE	Similar sign	—	Stable



Source: Authors' elaboration. **Dependent variable:** Operational efficiency (DEA-based). **Notes:** *p*-values reported in parentheses. Dynamic specification includes lagged efficiency and controls for endogeneity. CRS and VRS robustness results confirm qualitative stability of the capital–efficiency relationship.

#### 4.6 Dynamic Robustness Results: System GMM

**Table 8.** Dynamic Robustness Results: System GMM

Variable	Coefficient	Std. Error	t-stat	p-value
Efficiency (t–1)	<b>0.739</b>	0.160	4.62	0.000
Capital adequacy (CAR)	–0.003	0.003	–1.07	0.294
Capital adequacy (CAR) <sup>2</sup>	0.000003	0.000010	0.34	0.738
Bank size	–0.012	0.010	–1.11	0.276
Liquidity ratio	0.001	0.001	0.85	0.403
Asset quality	0.001	0.000	1.66	0.106
Constant	0.244	0.181	1.35	0.186
<b>GMM Diagnostics</b>				
Test	Statistic	p-value		
AR(1)	$z = -2.86$	0.004		
AR(2)	$z = 0.92$	0.360		
Hansen test	$\chi^2(6) = 3.65$	0.724		
Sargan test	$\chi^2(6) = 2.90$	0.822		
Instruments	26	—		
Banks	35	—		
Observations	<b>525</b>	—		

Source: Authors' elaboration. **Dependent variable:** Bias-corrected VRS efficiency. **Notes:** Two-step System GMM with Windmeijer-corrected standard errors.

Results of dynamic robustness are presented in Table 8 using the two-step System GMM estimator. The lagged efficiency term was positive and highly significant, representing strong persistence of operational efficiency over time. This validates the existence of path dependence, learning effects, and institutional rigidities in the Islamic banking system. After adjusting for persistence and endogeneity, neither the linear nor the non-linear capital adequacy terms were statistically significant. This finding implies that the efficiency implications of capital adequacy occur predominantly through structural and static channels rather than through short-run dynamic adjustments (Horobeț et al., 2021). This is corroborated by diagnostic tests; the GMM specification showed no evidence of second-order serial correlation and acceptable Hansen and Sargan test statistics. Crucially, the dynamic results did not contradict the baseline but rather supported it (Mong, 2025). Moreover, capital adequacy did not seem to act as a driver of efficiency enhancement through dynamic adjustment mechanisms, but rather as a structural condition interdependent with scale, liquidity, and asset quality. The dynamic efficiency relationship corresponding to Equation (2) is encapsulated by the following estimated specification.

$$\widehat{Eff}_{it} = 0.739 Eff_{it-1} - 0.0031 CAR_{it} + 0.000003 CAR_{it}^2 - 0.012 Size_{it} + 0.001 Liquidity_{it} + 0.001 AssetQuality_{it} + \varepsilon_{it}$$

The dominance of the lagged efficiency term confirmed strong persistence, while the capital adequacy terms remained statistically insignificant after controlling for dynamics and endogeneity.

## V. DISCUSSION

### 5.1 Capital Adequacy and Operational Efficiency: Interpreting the Baseline Results

Baseline fixed effects showed that, contrary to assumptions, capital adequacy did not exert a statistically significant linear effect on operational efficiency among Islamic banks in SSA. This finding challenges conventional assumptions derived from



developed banking systems that higher levels of capital yield greater efficiency through better financing conditions or lower risk premia (Sole & Babu, 2024). In the SSA setting, capital buffers primarily functioned as precautionary reserves rather than as active inputs to productive intermediation (Ali, 2019). This reflects institutional constraints faced by Islamic banks in the SSA region (Akinbowale et al., 2025; Ayagre et al., 2024; Gondwe et al., 2024). The restricted availability of Shari'ah-compliant liquidity instruments, shallow secondary markets, and limited risk-sharing opportunities limit banks' ability to deploy excess capital productively (Franciosi, 2025; Kamdzhlov, 2022). Consequently, higher levels of capital adequacy could strengthen solvency without achieving new levels of cost efficiency or output growth. The baseline results underscored the need to distinguish financial soundness from operational performance in emerging Islamic banking systems.

### *5.2 Non-Linear Capital Effects and the Efficiency Trade-Off*

The non-linear specification added sophistication by indicating a weak inverted U-shaped relationship between efficiency and capital adequacy. The squared capital term did not achieve the classical statistical significance; yet, its negative sign indicated diminishing marginal efficiency returns relative to capitalisation. This suggests that moderate capital buffers may enhance efficiency through internal risk absorption, stabilising operational planning, and reducing the risk of shocks (Ding et al., 2025). Nevertheless, beyond a certain point, the additional capital could provide little value to the operation and, in some cases, limit efficiency by channelling resources into low-yielding balance-sheet positions. The lack of strong statistical significance, however, does not preclude the economic relevance of this pattern. Rather, it reflects the varied, institutionally constrained context in which Islamic banks in SSA operate. This weak non-linearity indicates that capital adequacy's impact on efficiency is context-dependent, with counterbalancing balance-sheet factors, such as liquidity management and asset quality, likely mediating the relationship (Aqib Ali, 2023). These factors also prove relevant to efficiency in static models (Mong, 2025).

### *5.3 The Role of Liquidity and Asset Quality as Complementary Channels*

The significance of liquidity and asset quality in the static non-linear model emphasised the complementary mechanisms through which capital adequacy may affect efficiency (Olawale, 2024). Having adequate liquidity allows banks to deploy capital more flexibly, and stronger asset quality reduces operational disruptions associated with impairment management and provisioning. These findings suggest that capital adequacy alone is insufficient to drive efficiency gains; instead, its effectiveness depends on the broader balance-sheet configuration and risk-management environment. This result is particularly salient from a Shariah-compliant banking perspective (Haron, 2014; Ridha, 2025; Yunus et al., 2023). The limited set of permissible liquidity instruments and the predominance of asset-backed financing structures amplify the operational consequences of weak asset quality and liquidity constraints (Gherfal, 2023). Capital buffers can therefore support efficiency only when they are embedded within a sound liquidity and asset management framework.

### *5.4 Dynamic Perspective: Persistence and Structural Dominance*

The dynamic System GMM results provided a crucial robustness check by accounting for persistence and addressing potential endogeneity (Horobeț et al., 2021). The results reveal that, in the case of Islamic banks, the operational efficiency equation yields a strong and significant lagged efficiency term, signifying substantial persistence over time and reflecting learning dynamics, organisational inertia, and structural rigidities. This finding confirms a genuine dynamic effect and illustrates the importance of historical performance in shaping current efficiency outcomes (Mong, 2025). Importantly, once persistence is controlled for, the linear and the non-linear capital adequacy terms are statistically insignificant. This indicates that capital adequacy does not lead to short-run efficiency adjustments and that its effect operates through slowly moving structural channels rather than through dynamic optimisation (Korein et al., 2021). In other words, changes in capital adequacy do not lead to immediate efficiency improvements or losses, but rather to shifts in a complex of deeper institutional and operational dynamics in which efficiency is built gradually. Importantly, this dynamic insignificance does not indicate that capital adequacy is meaningless. This reinforces the premise that capital operates in SSA Islamic banking systems not as an active performance lever but rather as a structural condition.

### *5.5 Reconciling Static and Dynamic Evidence*



Altogether, the static and dynamic results tell a coherent story. Static models suggest that capital adequacy may matter for efficiency in a limited and potentially non-linear manner, particularly when supported by adequate liquidity and asset quality. Dynamic models, however, show that these effects do not manifest through short-run adjustments and are overshadowed by strong efficiency persistence. This reconciliation constitutes a key contribution of the study. It demonstrates that capital adequacy in Islamic banking should not be assessed solely since short-run efficiency adjustments. Rather, its role is better understood as part of a broader structural arrangement that determines long-run operational capacity and resilience.

Several factors may explain these findings. First, institutional heterogeneity across SSA countries can weaken systematic relationships in pooled estimations. Second, the capital adequacy proxy may capture prudential strength rather than effective capital deployment. Third, the relatively small cross-sectional sample may limit statistical power. More fundamentally, in structurally constrained environments, capital is typically held for regulatory or precautionary purposes rather than actively deployed in productive intermediation. Consequently, capital adequacy appears to function more as a structural condition than a direct driver of operational efficiency.

#### *5.6 Why Capital Adequacy Does Not Strongly Influence Efficiency in SSA*

The absence of a statistically significant relationship between capital adequacy and operational efficiency may reflect several underlying factors. First, institutional heterogeneity across SSA countries can weaken systematic relationships in pooled estimations. Second, the capital adequacy proxy may capture prudential strength rather than effective capital deployment, limiting its alignment with efficiency outcomes. Third, the relatively small cross-sectional sample may constrain statistical power. More fundamentally, in structurally constrained environments, capital is often held for regulatory or precautionary purposes rather than actively deployed in productive intermediation. As a result, capital adequacy appears to function as a structural condition rather than a direct driver of operational efficiency. This interpretation is consistent with recent European Journal of Islamic Finance studies highlighting the structural and institutional constraints affecting Islamic banking performance in emerging markets (Ali, 2019; Aqib Ali, 2023; Kamdzhilov, 2022).

## **VI. CONCLUSION AND POLICY IMPLICATIONS**

### *6.1 Conclusion*

This study examined whether capital adequacy serves as an operational efficiency-enhancing mechanism in Islamic banks operating in SSA, beyond its classical function as a prudential stability buffer. The analysis provides novel evidence on the capital–efficiency nexus in a region marked by underdeveloped financial markets, a scarcity of Sharī‘ah-compliant liquidity instruments, and significant structural constraints, drawing on bias-corrected DEA efficiency scores, static panel estimation, and dynamic panel methods. Three key conclusions emerge from the empirical results. First, Islamic banks in SSA continue to exhibit operational inefficiencies, reflecting scale constraints, institutional inflexibility, and persistent learning effects; efficiency outcomes are highly path-dependent, with strong persistence confirmed even in dynamic specifications. Second, in baseline models, capital adequacy does not have a significant linear relationship with operational efficiency, indicating that higher capitalisation alone does not necessarily improve operational efficiency. Third, although static models suggest a weak and economically intuitive non-linear relationship between capital adequacy and efficiency (i.e., moderate capitalisation appears to support efficiency, while high capitalisation generates diminishing returns), the estimated effects dissipate when persistence and endogeneity are accounted for in dynamic models. In aggregate, the results suggest that capital adequacy in SSA-based Islamic banking systems primarily serves as a structural condition rather than an efficiency lever. Capital buffers are associated with resilience and risk absorption, but their efficiency effects are limited, context-dependent, and mediated by complementary balance-sheet characteristics such as liquidity and asset quality.

### *6.2 Policy Implications*



The findings have significant implications for regulators, supervisors, and bank managers in emerging Islamic finance markets. First, prudential authorities should not assume that higher capital requirements are inevitably associated with greater efficiency. While sufficient capitalisation is crucial to financial stability, excessive capital buffers in structurally constrained environments may impose opportunity costs by constraining intermediation and scale economies. Accordingly, applying a one-size-fits-all approach to capital calibration derived from developed financial systems may be inappropriate for Islamic banks in SSA. Second, the results highlight the necessity of proportional, domain-specific capital regulation. The nexus among capital adequacy, liquidity infrastructure, and asset quality should be considered when developing prudential regimes for Islamic banking. Enhancing Shari'ah-compliant liquidity markets, risk-mitigation products, and better resolution mechanisms could improve banks' capacity to transform capital strength into operational efficiency. Third, from the perspective of bank managers, the findings reinforce the need to consider capital planning alongside broader balance-sheet and risk management planning. Capital adequacy should not be approached as a stand-alone objective, but rather be part of an integrated process that includes liquidity management, asset quality control, and scale optimisation. Improvements in these complementary areas are more likely to generate efficiency gains than incremental increases in capital buffers.

### 6.3 Contributions and Directions for Future Research

This study contributes to the Islamic banking literature in three key ways. Conceptually, it reframes capital adequacy as a structural risk-absorption mechanism with ambiguous efficiency implications, rather than as an unambiguously positive determinant of performance. Empirically, it provides rare evidence from SSA using bias-corrected efficiency measures and dynamic panel techniques. Methodologically, it demonstrates the value of combining DEA-based efficiency analysis with static and dynamic regressions to disentangle structural and adjustment effects.

Future research could extend this analysis in several directions. First, cross-regional comparisons could shed light on how institutional depth and regulatory maturity condition the capital–efficiency relationship in Islamic banking. Second, incorporating market-level variables, such as competition intensity or regulatory quality, may help explain cross-country heterogeneity in efficiency outcomes. Finally, as Shari'ah-compliant liquidity instruments continue to evolve, future studies could assess whether improvements in liquidity infrastructure alter the efficiency role of capital adequacy over time.

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