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Abstract

This research evaluated the extent to which commercial banks' compliance with capital adequacy guideline levels positively or negatively impacts technical efficiency in Kenya. The research employed a quantitative approach using ten years' data for all licensed commercial banks in Kenya. Data Envelopment Analysis (DEA) was used to determine the measures for efficiency, and the two-limit Tobit model and Maximum Likelihood Estimation (MLE) were used to determine the efficiency measure effects. The results showed that there was a positive and statistically significant relationship between commercial banks' capital adequacy and technical efficiency. It showed that commercial banks with higher and better levels of capital had improved levels of efficiency. The study recommends that commercial banks maintain high levels of prudential compliance, as greater adherence to capital adequacy guidelines is positively associated with higher technical efficiency. The paper also recommends that regulators and policymakers consider bank size when designing and implementing prudential guidelines. It was further recommended that researchers examine this relationship across other financial institutions, including microfinance and cooperative banks, and over longer time periods to capture evolving regulatory and operational dynamics

Keywords: *Capital Adequacy, Technical efficiency, Bank size, Commercial banks*

1.0 Introduction

Stability in the banking sector provided a growth environment for the economy, specifically for the developing economies, which were vulnerable to macroeconomic extremes (Korneev *et al.,* 2023). Following occurrences of financial crises, Central Bank of Kenya (CBK) prudential guidelines received utmost priority for the purpose of ensuring the sustainability of individual financial entities (Wanjiru, 2025). The requirement of capital adequacy was the most important tool for maintaining the solvability of the banking sector (Kirimi *et al.,* 2023). In the context of the Basel Accords, the capital adequacy requirement sought to ensure that a minimum capital base against unforeseen losses is reserved by the banks to avoid the chances of institutional failure (Bayar *et al.,* 2021).

Some emerging economies, like Kenya, localized these international principles by establishing a prerequisite level of capital requirements under the auspices of the CBK (Waweru *et al.,* 2021). The CBK has always underscored the significance of capital adequacy in addressing prudent measures aimed at bolstering risk management and guarding depositors (Muiruri, 2024). However, despite these measures in place, the empirical research on capital adequacy in connection with the technical efficiency of the Kenyan banking sector had not comprehensively scrutinized this consideration. This is particularly important in consideration of the fact that commercial banks operating in Kenya face specific risk profiles in respect to volatility associated with credit risk exposure (Duho, 2020).

Technical efficiency, whereby a bank's ability to maximize output using available inputs is reflected, signifies an important area in terms of bank performance and compliance with regulatory requirements (Waweru *et al.,* 2021). Banks that are more technically efficient are able to manage resources, reduce costs, and are more resilient in the event of financial downturns, thereby supplementing the mitigative role of capital adequacy. On the other hand, inefficiencies negate efforts made by banks towards meeting capital requirements, since banks that manage their resources poorly are unable to harness efficiency in bank performance arising from regulatory requirements (Nyaga, 2022). Therefore, the interaction between capital adequacy and technical efficiency is critical, particularly where bank size moderates the interaction in banking institutions. Large banks are known to enjoy economies of scale, diversity, and strong internal mechanisms for managing risk, such that banks are in a position to meet their capital requirements while also remaining efficient in their operations. Small banks, on the other hand, may find it difficult to meet their capital requirements without compromising their activities or taking higher risks (Andersen & Juelsrud, 2024).

The Kenyan banking sector is more significant in the context of economic development due to its role in the mobilization of funds, credit allocation, or payment services (Wanjagi *et al.,* 2024). However, the sector is still more vulnerable to potential inefficiency in operations, hence the criticality of effective capital regulation for the mitigation of potential risks in the sector (Margono *et al.,* 2020). Although successive changes in CBK capital requirements, the question of whether the results have or have not contributed towards enhancing the technical efficiency of banks of assorted sizes still lacks empirical acceptance (Ikape *et al.,* 2023).

1.1 Statement of the Problem

A stable and efficient financial sector is essential for economic development, especially in developing countries like Kenya (Sukmana *et al.,* 2020). Despite the measures initiated by the Central Bank of Kenya (CBK) through prudential guidelines that ensure capital adequacy, there is limited empirical evidence regarding the extent to which non-compliance or compliance with capital adequacy ratios affects the technical efficiency of commercial banks (Otieno & Kiptoo, 2024). The existing literature was largely dominated by financial stability or solvency with little examination of the financial performance of banks impacted by capital guideline compliance.

In practice, banks demonstrated varying levels of compliance, where some underperformed relative to the minimum threshold set, while others adhered to set standards, with others overperforming (Gatu *et al.,* 2023). This variation is most likely to influence technical efficiency but has still not been delved into by existing literature regarding the Kenyan setting. Therefore, despite the implementation of the CBK prudential guidelines, the impact of the compliance levels of the capital adequacy requirement on the technical efficiency of commercial banks and the moderating variable of the size of the bank is not clear. This is a problem to the regulator who wishes to improve the efficiency of the industry.

1.2 Research Objectives

i. To examine the influence of level of compliance with capital adequacy guidelines on technical efficiency of commercial banks in Kenya
ii. To evaluate the moderating influence of bank size on the relationship between level of compliance with capital adequacy guidelines and technical efficiency of commercial banks in Kenya

2.0 Literature Review

The Risk Absorption Theory was developed by Berger *et al.,* (1995) and it serves as a model to explain that the fundamental role of bank capital is to serve as a shock-absorbing mechanism against unforeseen losses. Sufficient capital increases the capacity of a bank to absorb financial shocks, stay afloat, and protect depositor funds, especially when a bank is experiencing economic hardship. The theoretical framework is the basis of global capital regulation standards, including Basel II and Basel III, which require minimum capital ratios using risk-weighted assets of a bank (Ogunmola *et al.,* 2022). The Risk Absorption Theory in the current study offers a conceptual explanation to the factors used in assessing the impact of the capital adequacy regulation on technical efficiency of commercial banks in Kenya. It confirms the hypothesis that stronger capital positioning makes banks more resilient and operationally efficient because they are better able to absorb internal and external shocks (Sitienei *et al.,* 2023).

Mishkin (2006) has popularized the Too-Big-to-Fail (TBTF) Theory, which claims that big financial institutions are systemic risks by virtue of their size, complexity and interconnectedness in the economy. Since their collapse can cause instability in the rest of the financial system, they are more likely to get government or regulatory assistance when they are in distress such as bailouts or special treatment by supervisors (Mishkin, 2006). In Kenya, the capacity of a firm to abide by capital rules, control risks, and tap capital markets depends greatly on the bank size (Lei & Yuan, 2021). Thus, TBTF Theory can be considered very topical in this study since it helps to justify the

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introduction of bank size as a moderating factor in the association between capital adequacy and technical efficiency.

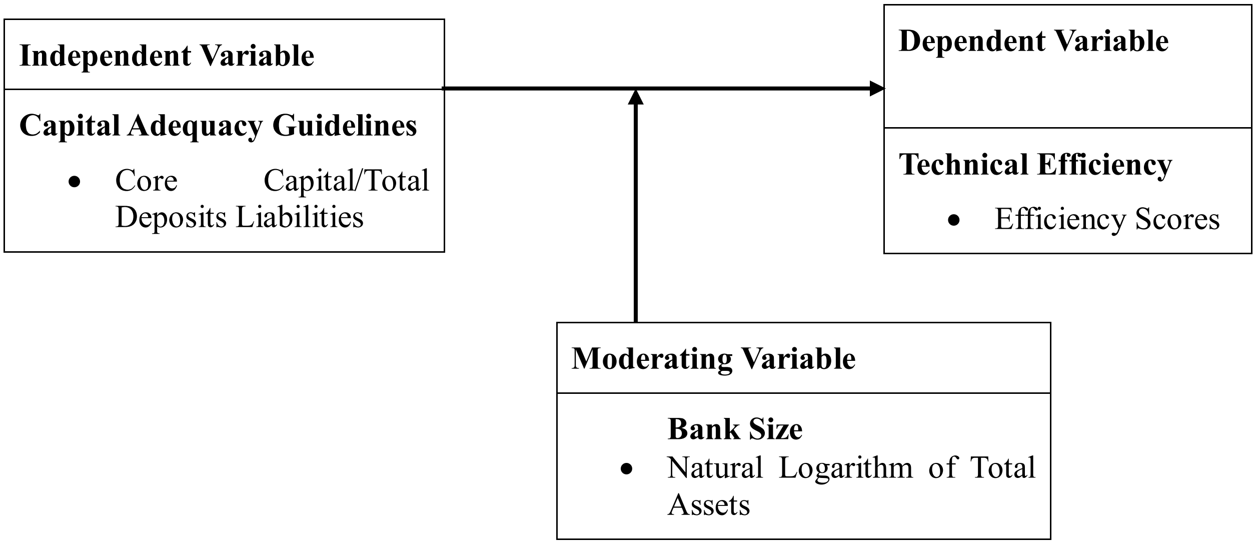

Figure 1: Conceptual Framework

2.1 Empirical Review

Berger and Bouwman (2013) developed a seminal study in the United States and Europe, which was conducted between 2000 and 2010. Their main goal was to determine the impact of capital on the performance of a bank, especially in times of financial crisis. They evaluated the performance of a large sample of more than 1,000 commercial banks by using dynamic panel regression models and profitability and survival measures. The researchers concluded that capital positively influences performance and survival in times of financial crisis more strongly than in good times. Capital adequacy increased resilience more in larger banks, suggesting that capital adequacy is particularly important in systemically important banks. The authors found that capital is essential to financial stability and that the size of the Bank is a magnifier of the outputs of capital in the alleviation of systemic shocks, supporting both the Risk Absorption and Too-Big-to-Fail theories.

Obadire *et al. (*2022) explored the relationship between capital adequacy and the performance of banks by using data on 24 commercial banks in the 2010 -2018 period in South Africa. It was aimed at testing whether Basel capital frameworks could lead to better bank resilience. The study has used Generalized Method of Moments (GMM) estimation, and discovered that there was a significant positive correlation between Tier 1 capital ratios with financial soundness measures, such as return on assets and Z-scores. These findings were in line with the Risk Absorption Theory and indicated that capital adequacy is a legitimate predictor of stability. The paper however pointed to a size effect by showing that large banks were doing better than smaller ones.

Boamah *et al.* (2023) narrowed that debate by examining the moderating effect of bank size on the relationship between capital regulation and performance by 37 commercial banks in Kenya in the 2013-2022 sample. They found using interaction term models in a panel regression framework that although capital adequacy had an overall positive impact on bank performance, the relationship was much stronger among large banks. Small banks could not compete with large banks because they had limited capacity to lend and could not compete on capital requirements. The research was able to conclude that regulatory framework must consider institutional size in order to prevent unintended outcomes like market concentration or diminished access to finance.

3.0 Methodology

In this research, a quantitative, explanatory research design is implemented to investigate the impact of capital adequacy regulation on technical efficiency of commercial banks in Kenya and evaluate the moderating role of bank size. The research relied on secondary panel data extracted from 37 licensed commercial banks in Kenya. Data was sourced from the Central Bank of Kenya (CBK) and Bank Supervision Annual Reports, covering 2013 to 2022.

3.1 DEA (First stage Analysis)

To determine the efficiency of the commercial banks in Kenya, the study used Data Envelopment Analysis (DEA) which is a common non-parametric technique, proposed by Charnes *et al.* (1978). The bootstrap method was employed to boost the accuracy and reliability of the DEA efficiency scores because it takes into account the impact of sampling and data noise (Shrestha, 2025). To calculate technical efficiency this study adopted the efficiency perspective based on the DEA model.

Following the notation of Cook and Seiford (2009), consider a set of nDMUs: with each DMU_j (j= 1, ..., n) using x_{ij} $(j = 1, \ldots, m)$ and generating *s* outputs y_{rj} $(r = 1, \ldots, s)$,

the efficiency score of a DMU (e_0^*) can be computed as

$$e_0^* = \text{Max}\left\{\theta = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{r=1}^{m} v_i x_{i0}}\right\}$$

Subject to

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{r=1}^{m} v_i x_{ij}} \leq 1; j = 1,2, \ldots, n$$

Where;

v_i is a vector of input weights, $v_i \geq 0; i = 0; i = 1,2 \ldots m$,

u_r is a vector of output weights, $u_r \geq 0; i = 0; r = 1,2, \ldots s$,

x_{ij} = The amount of input *i* utilized by the j^{th} DMU

y_{rj} = The amount of output r produced by the j^{th} DMU

In case there is a total of nDMUs to be evaluated then each DMU consumes *m* types of inputs to produce s types of output. DMU_j consumes amount x_{ij} of input *i* and produces amount of y_{rj} of output r. The i^{th} type of input of DMU_j is denoted as y_{rj}, y_{rj} ≥0 for s types of outputs (Cooper *et al.,* 2011)

The ratio form yields an infinite number of solutions. The transformation of the ratio form for linear fractional programming selects a solution (u,v) for which $\sum_{i=1}^{m} v_i x_{i0} v = 1$.

The ratio form of the DEA is changed to a linear programming problem in the multiplier form (input orientation)

$$\text{Max z} = \sum_{r=1}^{s} \mu_r y_{ro}$$

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Subject to;

$\sum_{r=1}^{s} \mu_r y_{rj}$ -$\sum_{i=1}^{m} v_i x_{ij} \leq 0$

$\sum_{i=1}^{m} v_i x_{i0} v$ =1

$u_r, v_i \geq 0$

The change of the variables from (u,v) to (μ, v) is a result of the Chames-Cooper transformation (Cooper *et al.,* 2011).

After taking the dual of the equation, DEA is transformed to the envelopment form (Input orientation), as follows;

θ * = Min θ

Subject to;

$\sum_{i=1}^{m} x_{ij}\lambda_j \leq \theta x_{i0}$ i =1,2, ..., m;

$\sum_{j=1}^{n} y_{rj}\lambda_j \geq y_{r0}$ i =1,2, ..., s;

$\lambda_j \geq 0$ j = 1,2, ..., n

In the envelopment form, the **λ** is a vector of intensity variables denoting the linear combination of DMUs. The objective function θ is a radial contraction factor that can be applied to DMU_o's inputs.

3.2 Second Stage Analysis: Tobit Regression

In the second stage, these efficiency scores were used as a key dependent variable to measure the impact of level of compliance with capital adequacy guidelines and bank size on technical efficiency. For the purposes of this study, compliance level was incorporated as part of the prudential measures rather than considered as a separate objective. For every bank, the respective ratio or measure was compared to the minimum requirement by the CBK and evaluated based on whether it is above Minimum (if it exceeded the minimum requirement), Meets Minimum (if it met the minimum requirement), or Below Minimum (if it is below the minimum requirement).

In the second step of the analysis the current study examined the impact of capital adequacy regulation on the efficiency scores of the commercial Banks in Kenya. This study employed the Tobit regression to address the limited spectrum of efficiency scores that lie in the 0 to 1 range (Li *et al.,* 2022).

Specifically, upper and lower censoring was accommodated with the two-limit Tobit model based on the specification of Rosett and Nelson (1975). With upper and lower censoring, according to the notations of Li *et al.* (2022). the observed censored variable is y_i. The following should be a measurement equation for subject *i*

$$y_i = \begin{cases} T_{L'} & if\ Y^*_i \leq T_{L'} \\ Y^*_i = x_i\beta + \boldsymbol{\varepsilon_{i,t}}, & if\ T_{L'} < Y^*_i < T_{U'} \\ T_{U'} & if\ \ Y^*_i \geq T_{U'} \end{cases}$$

y_i is the observed censored outcome variable for subject i; $T_{L'}$ and $T_{U'}$ are the lower and upper censoring values $T_L = 0$ and $T_U = 1$ for this study; Y^* is a latent variable that cannot be observed

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over its entire range. However, Y^* Is observed for outcome values between T_L and T_u, and is censored for outcome values less than or equal to T_L or outcome values greater than or equal to T_u

$y_i = x_i\beta + \boldsymbol{\varepsilon_{i,t}}$ is the structural equation for the Tobit model

The *x's* are factors observed for all cases and *β's* are regression coefficients

$\boldsymbol{\varepsilon_i} \sim \mathrm{N}\ (0, \sigma^2)$

3.3 Selection of Inputs and Outputs

In the application of DEA models, it is very important to choose appropriate input and output variables. In the literature, there exist two primary definitions of the inputs and outputs in the studies on the efficiency of banking, the production approach and the intermediation approach (Berger and Humphrey, 1997). The production approach; views banks as service providers with deposits the outcome and labour and capital as inputs (Berger and Humphrey, 1997). On the contrary, the intermediation approach considers banks to be intermediaries linking excess units (depositors) to deficit units (borrowers) by transforming deposits and other inputs into investments and loans (Shrestha *et al.,* 2025). Within this approach, deposits, labour, capital are regarded as inputs and loans, investments, and interest income are regarded as outputs (Sharma & Shen, 2025).

The intermediation approach was employed because the target of the study is the banking sector of Kenya and the research seeks to examine the role of the banks in linking surplus and deficit units. As Benston (1972) and Clark (1984) noted, the question of what constitutes the inputs and outputs of the financial institutions lacks any unanimity and the matter continues to be debated in the current literature (Shah *et al.,* 2023). The study employed the following inputs (Operating Expenses, Total deposits, interest expenses) and outputs (interest income, investment income, total loans and other income).

3.4 Economic Model Specification

The study used two-limit Tobit regression model to determine the impact of capital adequacy compliance on technical efficiency of commercial banks in Kenya and to establish whether there is moderation of relationship between the two variables by bank size. The model was employed due to the censored behaviour of the dependent variable and gave the estimates through the Maximum Likelihood Estimation (MLE). The baseline model was specified as:

$$\boldsymbol{ES^*_{i,t} = \beta_0 + \beta_1 CAR_{i,t} + \beta_2 SIZE_{i,t} + \varepsilon_{i,t}}$$

To test for moderation, the interaction term between capital adequacy and bank size was introduced into the model. The modified model was expressed as follows:

$$\boldsymbol{ES^*_{i,t} = \beta_0 + \beta_1 CAR_{i,t} + \beta_2 SIZE_{i,t} + \beta_3 (\mathrm{CAR} \times \mathrm{SIZE})_{i,t} + \varepsilon_{i,t}}$$

Where:

$\boldsymbol{ES^*_{i,t}}$ = Latent variable representing technical efficiency (DEA score)

$\boldsymbol{CAR_{i,t}}$= Capital Adequacy Ratio

$\boldsymbol{SIZE_{i,t}}$ = Natural logarithm of Total Assets

$(\mathbf{CAR} \times \mathbf{SIZE})_{i,t}$ = Interaction term for moderating effect

$\boldsymbol{\beta}_0$ = The intercept,

β_1 = The coefficients for the independent variables.

β_2 = The coefficient for the moderating variable (Bank Size),

β_3 = The moderating effect of bank size on the relationship between capital adequacy and Technical efficiency.

$\varepsilon_{i,t}$ = Error term

Subscript i = Commercial banks (Cross - section dimension) ranging from 1 to 37

Subscript t = Years (time - series dimension) ranging from 2013 to 2022.

4.0 Findings and Discussion

This section discussed the research results on the compliance aspect of capital adequacy guidelines in relation to the technical efficiency of commercial banks in Kenya, moderated by bank size. The discussion of results placed the results within the context of the study aims and theoretical frameworks, particularizing on the direction, magnitude, and significance of the results. The results were further placed within the context of existing literature to explicate how compliance with prudence measures and bank size interact to affect banking efficiencies in Kenya.

4.1 Compliance Level with Capital adequacy Guidelines

The section evaluated the extent to which commercial banks in Kenya are compliant with the capital adequacy guideline recommended by the CBK. Capital adequacy is a basic prudent requirement that is intended to ensure that commercial banks have adequate capital buffers to guard against sudden or unexpected risks that might threaten the deposits held by the clients. In this case, instead of focusing on the capital ratios, the study grouped the commercial banks based on whether they fall below, or at, or above the minimum level required in capital adequacy.

Table 1: Distribution of Commercial Banks according to CBK Compliance Level

CBK Prudential Guideline	Below CBK Min/Max (%)	Meeting CBK Min/Max (%)	Above CBK Min/Max (%)
Capital Adequacy (≥8%)	2	18	80

The results shown in Table 1 illustrate that 80% of the commercial banks' capital adequacy ratios exceeded the 8% minimum requirement set by the Central Bank of Kenya (CBK), while 18% met the set minimum requirements and 2% were below the requirement. The results indicate that the proportion of the commercial banks that exceeded the requirement was greater than the proportion that met the minimum requirement.

4.2 Construction of Compliance-Adjusted Capital Adequacy

Compliance with the capital adequacy guideline was measured by benchmarking each bank’s capital adequacy ratio against the minimum 8 percent required by the Central Bank of Kenya (CBK). The compliance was measured by calculating the ratio of the capital adequacy ratio to the minimum required ratio. Using such an approach ensures that the level of capital adequacy for all banks is equalized and that the level of compliance with the guideline is directly measurable.

If the compliance value is less than one, it shows that a bank is operating below the CBK minimum and thus is not in compliance and is thus more susceptible to risk. A value of one show that a bank is operating within the minimum requirements for capital adequacy. This is due to legislative requirement and lack of adequate capital. A value greater than one shows that a bank is operating above the regulatory requirement. In this way, rather than reporting absolute ratios on capital requirements and efficiency, this variable allows for the construction of a policy-relevant variable that examines the link between capital requirements and the efficiency of commercial banks.

Table 2: Construction of Compliance-Adjusted Capital Adequacy

Prudential Indicator	CBK Regulatory Threshold	Raw Prudential Measure	Compliance Adjustment Formula	Interpretation
Capital Adequacy	≥ 8%	Capital Adequacy Ratio (%)	Capital Adequacy ÷ 8	Values > 1 indicate capital buffers above CBK minimum

Table 2 shows the capital adequacy compliance measurement based on the 8 percent requirement set by the Central Bank of Kenya (CBK). The capital adequacy measure was calculated based on the capital adequacy ratio. The calculated values were then normalized by dividing by the regulation requirement to allow comparison across the banks.

Values above one show that the bank has a buffer above the required 8 percent set by the Central Bank of Kenya, whereas values equal to one show that the bank exactly meets the requirement, while values less than one show that the bank is undercapitalized.

4.3 Efficiency Scores estimation using DEA and Bootstrap Results

Technical efficiency scores for commercial banks in Kenya were obtained employing a non-parametric technique called Data Envelopment Analysis (DEA) because it is more appropriate for determining how well different commercial banks in Kenya utilize multiple inputs to produce more outputs in comparison with a frontier or best-practice benchmark. Efficiency scores obtained from DEA range from zero to one, with high scores indicating a high efficiency in resource utilization. However, to reduce biases associated with normal DEA estimates because of sampling variability and random errors, a bootstrap technique was used to improve their statistical validity. According to the bootstrap estimates, efficiency scores after adjusting for biases are smaller compared to normal DEA estimates, thus supporting the claim that normal DEA models tend to overstate efficiency when faced with uncertainties. The efficiency scores after adjusting for biases show significant variability, thus providing a more credible estimate for analysing the impact of prudential compliance and size on technical efficiency in commercial banks in Kenya.

Table 3: Efficiency Scores estimation using DEA and Bootstrap Results

Year	Efficiency Score	Efficiency-Boot	Bias	Lower	Upper
2013	0.7842	0.7821	0.0021	0.6000	0.8900
2014	0.6754	0.6701	0.0053	0.5200	0.8000
2015	0.7609	0.7582	0.0027	0.5900	0.8700
2016	0.6589	0.6550	0.0039	0.4700	0.7600
2017	0.6569	0.6528	0.0041	0.4600	0.7800
2018	0.7432	0.7403	0.0029	0.5700	0.8500
2019	0.7100	0.7057	0.0043	0.5100	0.8300
2020	0.7807	0.7781	0.0026	0.6000	0.8900
2021	0.6589	0.6559	0.0030	0.4700	0.7700
2022	0.6781	0.6734	0.0047	0.4900	0.7900

The efficiency scores ranged from 0.6569 (2017) to 0.7842 (2013), indicating that the financial sector has been more or less efficient over the years. The decline in efficiency in 2016 and 2017 occurs a time when the interest rate capping regulations in Kenya had a huge impact on the banking sector by limiting lending margins and reducing profitability. Repeal of interest rate caps in 2019 allowed banks to price loans based on risk and improve efficiency, which may have contributed to the recovery in 2019 and 2020. The lag in efficiency in 2016 and 2017 aligns with the period when the Kenyan government enacted the Banking (Amendment) Act, 2016, which limited the interest rate banks could charge borrowers. This policy: Reduced credit availability, particularly for small and medium enterprises (SMEs). The profitability of banks was reduced, which led to cost cutting and restructuring.

The improvement in efficiency in 2018 and 2020 suggests that Kenyan banks have taken advantage of mobile banking and fintech solutions. Mobile money services (such as., M-Pesa) have been a global leader in Kenya and have helped to increase financial access and efficiency. Equity Bank, KCB and Co-operative Bank have aggressively digitized their services and have reduced operational costs and improved efficiency.

4.4 Descriptive Statistics for Study Variables

In this study, descriptive statistics were used to provide a basic insight into the nature and characteristics of the key variables under study before the use of econometric analysis. Descriptive statistics were useful in summarizing the data on compliance with capital guidelines, bank size, and technical efficiency in a manner that helped in the identification of trends and variations among the different commercial banks in Kenya. Descriptive statistics were also useful in the detection of possible anomalies and ranges in the data, an important aspect in determining whether the variables were appropriate for statistical analysis.

Table 4: Descriptive Statistics for Study Variables

Variable	Type	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
Efficiency Score	Overall	0.670	0.167	0.102	0.998	0.307	2.706
	Between		0.149	0.120	0.926		
	Within		0.112	0.254	0.445		
Capital Adequacy	Overall	2.050	0.283	1.254	2.415	0.487	2.310
	Between		0.272	1.400	2.350		
	Within		0.137	1.254	2.415		
Bank Size	Overall	24.733	1.614	20.60	29.014	0.421	2.499
	Between		1.593	22.09	28.362		
	Within		0.361	23.24	26.270		

The mean value for efficiency was a modest 0.670, but with maximum and minimum values recorded at 0.102 and 0.998, respectively. A measure indicating considerable variation was provided by a standard deviation of 0.167. The positive value for skewness at 0.307 showed a very modest tendency to fall to the right, while 2.706 for kurtosis revealed considerable normality. The overall mean value for level of compliance with capital adequacy guidelines was 2.050, which means that the overall average position of the banks was above the regulatory requirement.

The standard deviation is relatively low at 0.283, indicating that there is not much variation in the capital adequacy ratio among the banks. The data is moderately skewed to the right, with a value of 0.487. The kurtosis value is 2.310, which is flatter compared to the normal distribution.

Bank size had an overall mean of 24.733, with the scores varying from 20.60 to 29.014, which clearly showed great variation in bank size. Moderation in dispersion is reflected in the standard deviation of 1.614. The skewness of 0.421 clearly showed a tendency towards the larger banks, while the kurtosis of 2.499 showed the distribution to be flatter compared to the normal distribution.

Variations within and between the banks showed that the differences within the banks had a more significant effect on variability than the time-specific variations, especially with respect to efficiency and the size of the banks, thereby emphasizing the heterogeneity of structure within the commercial banks of Kenya.

4.5 Diagnostic Test

To ensure the validity and reliability of the regression model, a series of diagnostic tests were conducted to examine potential violations of key assumptions.

4.6 Censoring Diagnostic Test

The Likelihood Ratio test was used to verify whether the Tobit model, which accommodates censoring in the dependent variable (bank stability score), fits the data better than the OLS regression model.

Table 5: Likelihood Ratio (LR) Test

Censoring Type	Threshold	Number of Observations	Percentage of Total
Left-Censored	= 0.000	0	0.00%
Left-Near-Censored	≤ 0.500	2	5.71%
Uncensored	> 0.500 and < 0.950	35	94.59%
Right-Near-Censored	≥ 0.950	0	0.00%
Right-Censored	= 1.000	0	0.00%
Total Observations	—	37	100%

This test was important in the study because the dependent variable (bank efficiency scores from the DEA model) is bound within a specific range (0 to 1) which could mean censoring at the upper and/or lower ends (Wooldridge, 2023).

The summary of DEA efficiency scores indicates that the majority of the data is uncensored. Among the 37 commercial banks, 35 banks (94.59%) have efficiency scores that exceed 0.500 but are less than 0.950. Since most of the data is uncensored, the two-limit Tobit model can be used to accurately estimate the effects of capital adequacy regulations and bank size on technical efficiency, with little impact from extreme values (Greene, 2018).

4.7 Generalized Residues Test

The Generalized Residuals Test was used to test for the presence of endogeneity in the second stage regression equation that linked prudential compliance variables and bank size to technical efficiency. This test is appropriate for use in models where the dependent variable is limited, and the test examines whether the residuals in the first stage estimation are related to the error term in the equation

Table 6:Generalized Residues Test

N	Mean	Median	Min	Max	Std. Dev	JB p-value
37	0.003	0.001	-0.198	0.214	0.082	0.392

The results for the generalized residuals test, based on 37 observations, are shown in Table 6. Residuals had a mean of 0.003, with a median of 0.001, showing that the residuals are centred around zero. The minimum and maximum observed values for the residuals were −0.198 and 0.214, respectively, suggesting no extreme points in the residual distribution. The standard deviation for the residuals was 0.082, showing no variability around the mean point. A JB test resulted in a p-value of 0.392, suggesting that the null hypothesis for normality could not be rejected, and the distribution is approximately normal.

4.8 Multicollinearity Test

The Variance Inflation Factor (VIF) is a measure used to test for multicollinearity. The existence of multicollinearity among the independent variables in the regression model was verified by

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calculating the Variance Inflation Factor (VIF). A VIF value greater than 10 typically indicates serious multicollinearity (Wooldridge, 2023).

Table 7: Variance Inflation Factor (VIF) Results

Variable	VIF	1/VIF
Capital Adequacy	1.05	0.9523
Bank Size	1.38	0.7246
Mean VIF	1.215	—

The variables in the model had VIF values of 1.05 and 1.38, with a mean VIF of 1.215, as shown in Table 7. Since these values are low, it means that the predictors are not highly correlated. Since the VIFs are low, it means the model's estimates aren't affected much by multicollinearity and every independent variable adds its own unique value to the model (Baltagi, 2021).

4.9 Correlation Test

Pearson Correlation was used to determine the intensity and nature of the linear relationship that exists between the key variables, which are compliance with capital adequacy, bank size, and technical efficiency. Pearson Correlation was preferred for its suitability for continuous data to produce a measure that determines the degree to which two variables move.

Table 8: Correlation Matrix

Variable	Technical Efficiency	Capital Adequacy	Bank size
Technical Efficiency	1.0000		
Capital Adequacy	0.406	1.000	
Bank Size	0.320	0.422	1.000

The correlation matrix above describes the inter-relationship between technical efficiency, level of compliance with capital adequacy, and bank size for sampled commercial banks in Kenya. Technical efficiency is positively related to level of compliance with capital adequacy (r = 0.406), suggesting that commercial banks with sounder capital structures are more efficient in managing resources to produce output. Similarly, there is a positive relation between technical efficiency and bank size (r = 0.320), suggesting that larger commercial banks tend to enjoy greater efficiency as a result of economies of scale or superior resource management practices.

Level of compliance with capital adequacy and bank size are also found to be positively correlated, with r = 0.422, suggesting that bigger banks are characterized by their higher capital adequacy ratios, possibly because of strict regulatory requirements or their ability to manage risks associated with their size. The coefficients obtained are small, suggesting that these variables are moderately interrelated, meaning that these variables are associated, but are not linearly dependent upon each other, so that their collinearity is not a major problem for regression analysis.

4.10 Normality Test

To determine whether the Tobit regression model fulfills the normality assumption of the residuals, the Jarque-Bera test was performed, and the results are summarized in Table below.

Table 9: Jarque–Bera Test of Normality for Standardized Residuals

N	JB statistics	p value	Decision
370	0.72	0.7	Fail to reject H_0 - residuals approximately normal

The Jarque-Bera statistic is 0.72 with a corresponding p-value of .70, which is larger than the 0.05 significance level. Therefore, fail to reject the null hypothesis that the residuals are normally distributed. This suggests that the normal distribution of error terms assumed in the Tobit model is reasonably satisfied, and the model estimates can be considered valid for inference.

4.11 Heteroscedasticity Test

Heteroscedasticity occurs when the variance of the residual's varies with different values of the independent variables which is not allowed by the classical linear regression model (Wooldridge, 2023). As a result of this violation, the estimates of parameters might be inaccurate and standard errors might be biased which can impact the reliability of testing a hypothesis (Shah *et al.,* 2023). The Breusch-Pagan test was applied to evaluate whether the homoscedasticity assumption was satisfied and whether robust standard errors were necessary to account for any heteroscedasticity

Table 10: Breusch-Pagan Heteroscedasticity Test Results

Test Statistic	p value	Conclusion
2.897	0.067	No heteroscedasticity ($p > 0.05$)

Table 10 shows the result of the heteroscedasticity test by Breusch and Pagan. The test statistic is 2.897 with a corresponding p-value of 0.067. Given that the p-value is larger than the significance level of 0.05, the null hypothesis of homoscedasticity cannot be rejected. This implies that the variance of the error terms is constant. This results in an interpretation that there is no heteroscedasticity in the regression model. Therefore, the results of the standard error measurements can be considered valid.

4.12 Autocorrelation Test

Autocorrelation means that the residuals in a panel data are correlated over time or across units which suggests that the error terms are not independent (Shah *et al.,* 2023). If autocorrelation is present, it can lead to biased and inefficient estimates of the coefficients, which leads to incorrect p-values and confidence intervals. The Durbin-Watson (DW) statistic was used to test for autocorrelation, as it is a common test for finding first-order autocorrelation in regression residuals.

Table 11: Durbin-Watson Autocorrelation Test Results

Test Statistic	Conclusion
1.81	No significant autocorrelation (1.5 ≤ DW ≤ 2.5)

The Durbin-Watson test statistics for autocorrelation of the regression residuals are shown in Table 11. The test statistics were 1.81, which fell within the acceptable range of 1.5 to 2.5. The result indicated absence of autocorrelation within the residuals; this indicated that the observations were not dependent on time. The absence of autocorrelation helps to interpret the results of regression analysis to be valid.

4.13 Stationarity Test

In this study, the Levin-Lin-Chu (LLC) test was used to check for stationarity and to confirm the absence of unit roots in the variables so that spurious regression may be avoided. The LLC test is appropriate for panel data because it considers cross-sectional information in determining a common unit root in a group of banks. The process was required because efficiency scores and level of capital adequacy compliance are time series observations, and non-stationary observations may lead to erroneous conclusions.

Table 12: Summary of Stationarity Test Results

Variable	Adjusted t-statistic	p value	Stationarity Status
Capital Adequacy	-3.1720	0.0000	Stationary
Bank Size	-3.1513	0.0010	Stationary
Technical Efficiency	-5.1275	0.0000	Stationary

The results for the stationarity tests for the level of capital adequacy compliance, bank size, and technical efficiency are shown in Table 12. The negative t-statistics for the variables with a p-value of 0.0000 indicate the variables are stationary and have constraints on the values of the variance and mean. The negative t-statistic for the variables with a p-value of 0.0010 shows the variables are not changing over time. The results above show the variables meet the necessary conditions for the regression analysis for the model. The results indicate the absence of spurious regression results based on the values of the variables.

4.14 Hausman Specification Test

Is a statistical procedure used in panel data analysis to determine the suitability of either fixed effects or random effects in a model. Its purpose is determining whether individual effects are correlated with the model's explanatory variables. The null hypothesis (H_0): The unobserved variables are not correlated with the explanatory variables. This means the random effects estimator is consistent and efficient. Alternative hypothesis (H_1): Correlation exists between the non-observed effects and the explanatory variables, which means that fixed-effects estimators are consistent and preferable (Hausman, 1978).

Table 13: Hausman Specification Test Results

Test	Chi-Square Statistic	p-value	Model Preferred
Hausman Specification Test	15.722	0.002	Fixed Effects

The test statistics for the Hausman Specification Test resulted in a Chi-square value of 15.722, with a p-value of 0.002. Since the p-value is smaller than 0.05, the study concluded that the null hypothesis for the consistency of the random effects model is rejected. The fixed effects model is preferred, meaning that individual heterogeneity is correlated with the variables in the model. The fixed effects model was the most appropriate since it was able to capture the time-invariant characteristics of banks that may influence capital adequacy compliance and technical efficiency.

4.15 Standard Tobit Regression Model

Justification for using the standard Tobit regression model in the study can be linked to the nature of the dependent variable, technical efficiency estimates that are derived by Data Envelopment Analysis and are truncated within a given finite range, therefore violating the assumptions underlying the ordinary least squares regression analysis technique (Li *et al.,* 2022).

The Kenyan banking industry has witnessed some commercial banks performing either on the lower boundary of efficiency or along the efficiency frontier, especially when they are defined according to their compliance with the guidelines on capital adequacy as set by the Central Bank of Kenya, and therefore exhibiting corner solutions. The suitability of the Tobit Regression Model, especially the Standard Tobit Regression Model, can therefore be linked to the need to estimate the probability that some banks attain specific levels of efficiency and the actual levels within the observable range. The approach therefore improves the validity and integrity of the policy and regulatory implications underlying the relationship existing between specific compliance with capital adequacy and technical efficiency for commercial banks in Kenya.

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Table 14: Standard Tobit Regression Model Estimates

Variable	Coefficient (β)	Std. Error	z-Statistic	p-value	Significance
Constant	-0.124	0.047	-2.638	0.008	Significant
Capital Adequacy ($Ca_{i,t}$)	0.198	0.042	4.714	0.000	Significant
Bank Size ($size_{i,t}$)	0.063	0.022	2.864	0.004	Significant
Model diagnostics:					
Log Likelihood	-158.74				
LR Chi-square	72.18			0.000	Model Significant
Pseudo-R²	0.208				
Sigma (σ)	0.361	0.019			
Number of Observations	370				

The results indicate that the model is estimated with 370 observations and a log-likelihood of -158.74. The chi-square statistic value of 72.18 had a p-value of 0.000. This indicates that the model is significant and fits the data better than a model which does not include the explanatory variables. The pseudo-R-squared is 0.208, which indicates that the explanatory variables explain 20.8 percent of the variation in the variable that is dependent.

The regression coefficients show that the compliance degree of capital adequacy significantly affects the TE, as indicated by the positive coefficient of 0.198 ($\rho < 0.001$), meaning that as compliance degree values increase, the technical efficiency values increase too. The size of banks has a positive influence on technical efficiency, as indicated by the regression coefficient of 0.063 ($\rho = 0.004$), meaning that bigger banks have the capability to utilize resources more efficiently. The model's constant term is negative, with a regression coefficient of -0.124 ($\rho = 0.008$).

The sigma estimate ($\sigma = 0.361$, SE = 0.019) represents the standard deviation of the error term, while the significance of the coefficients implies that capital adequacy compliance and bank size are significant factors of technical efficiency. The results indicate that differences in prudential compliance and bank size are related to differences in technical efficiency of Kenyan commercial banks.

4.16 Standard Tobit Regression Estimates with Moderating Effect of Bank Size

The results of the Standard Tobit Regression Estimates with the moderating effect of bank Size were subsequently subjected to analysis with the purpose of not only examining the direct effects of capital adequacy compliance on technical efficiency but shaping the results of this influence with the moderating factor of bank size. The presence of heterogeneity in the size of the banks means that large banks may have the ability to handle the effects of the regulations more effectively while optimizing resources and developing strategies related to risk management

Table 15: Standard Tobit Regression Estimates with Moderating Effect of Bank Size

Variable	Coefficient (β)	Std. Error	z-statistic	p-value	Significance
Constant	-0.118	0.129	-0.90	0.006	Significant
Capital Adequacy ($Ca_{i,t}$)	0.174	0.070	2.490	0.000	Significant
Bank Size ($size_{i,t}$)	0.052	0.036	1.440	0.003	Significant
$Ca_{i,t} \times size_{i,t}$	0.025	0.041	2.170	0.002	Significant
Model diagnostics:					
Log Likelihood	-142.60				
LR Chi-square	84.12			0.000	Model Significant
Pseudo-R^2	0.184				
Sigma (σ)	0.354	0.018			
Number of Observations	370				

Tobit regression results with moderating effect of bank size on technical efficiency show a log-likelihood of -142.60 with a pseudo-R^2 of 0.184 with a total of 370 observations. The likelihood ratio (LR) statistic is 84.12 with a p-value of 0.000. This shows that this model is a better fit compared to a model containing no explanatory variables. Furthermore, this also showed that the explanatory variables contribute a total of about 18.4 percent to the value of technical efficiency.

The regression coefficients indicate that the effect of capital adequacy compliance is strongly positive and significant on technical efficiency ($\beta = 0.174$, $\rho < 0.001$). The effect of bank size is also strongly positive and significant ($\beta = 0.052$, $\rho = 0.003$). The interaction effect between capital adequacy compliance and bank size is also strongly positive and significant ($\beta = 0.025$, $\rho = 0.002$), indicating that the effect of capital adequacy compliance on technical efficiency increases with bank size. The regression coefficient for the constant is negative and significant ($\beta = -0.118$, $\rho = 0.006$).

The sigma value ($\sigma = 0.354$, SE = 0.018) measures the standard deviation of the error term. From the result, it is clear that both the strength of capital adequacy compliance and the size of the banks have played significant roles in determining technical efficiency in banks, with the size of banks increasing the efficiency-enhancing potential of the former.

5.0 Conclusion

The above study shows that the level of capital adequacy compliance is a critical factor in enhancing the technical efficiency of commercial banks in Kenya. The banks with higher levels of capital adequacy compliance had better capabilities of taking advantage of the resources in terms of efficiency, proving that compliances are not only mechanisms of managing risks but are also efficiency-enhancing tools. Bank size was found to amplify this effect, indicating that larger banks were better positioned to translate compliance into efficiency gains, while smaller banks faced structural limitations that constrained this relationship

The findings highlighted the interconnected nature of regulatory compliance and institutional characteristics in shaping bank performance. By showing that compliance alone was not sufficient for maximizing efficiency, the study emphasized that operational scale and resource capacity must be considered alongside regulatory adherence. This implied that regulatory frameworks and policy interventions should be tailored, recognizing that smaller banks may require additional support or capacity-building initiatives to achieve similar efficiency gains as larger banks.

Ultimately, the study underscored that promoting strong capital buffers, combined with attention to bank scale, could enhance the overall efficiency and resilience of the banking sector. The results provided evidence that prudential regulations, when effectively implemented and supported by adequate institutional capacity, can simultaneously safeguard financial stability and improve operational performance. These insights offered practical guidance for regulators, policymakers, and bank managers, demonstrating that a coordinated approach integrating compliance and scale considerations is essential for fostering sustainable efficiency in the Kenyan banking sector.

6.0 Recommendations

It is recommended that the commercial banks maintain high levels of prudential capital adequacy compliance because high levels of prudential capital adequacy compliance are positively associated with high levels of technical efficiency. It is also recommended that the commercial banks adopt approaches that incorporate prudential capital requirements into their strategies in such a manner that the management of prudential capital requirements and efficiency are fully linked.

It was recommended that regulators and policymakers consider bank size when designing and implementing prudential requirements. The study highlighted that larger banks were better able to convert compliance into efficiency gains, whereas smaller banks required additional support, such as capacity-building programs, technical assistance, or tailored regulatory guidance. It was also recommended that continuous monitoring and evaluation mechanisms be established to assess the impact of compliance on technical efficiency, ensuring that regulatory objectives effectively translated into improved performance across banks of different sizes.

It was recommended that future research explore additional factors that may influence the relationship between capital adequacy compliance and technical efficiency, such as corporate governance, risk culture, or technological adoption. It was further recommended that researchers examine this relationship across other financial institutions, including microfinance and cooperative banks, and over longer time periods to capture evolving regulatory and operational dynamics. Additionally, it was recommended that future studies investigate how different regulatory frameworks or macroeconomic conditions moderate the compliance–efficiency relationship, providing deeper insights for both policy and practice.

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