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Research Article

Prediction of Banks Efficiency Using Feature Selection Method: Comparison between Selected Machine Learning Models

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This study aims to examine the main determinants of efficiency of both conventional and Islamic Saudi banks and then choose the best fit model among machine learning prediction models (i.e., support vector machine (SVM), Chi-squared automatic interaction detector (Chaid), linear regression, and neural network (NN)). The data were collected from the annual financial reports of Saudi banks from 2014 to 2018. The Saudi banking sector consists of 11 banks, 4 of which are Islamic. In this study, the major financial ratios are subgrouped into the profitability ratios, managerial practices, asset and loans, capital adequacy ratios, and liquidity. First, regression analysis is implemented with efficiency ratio as a dependent variable and the proxies of banks' profitability, liquidity, asset quality, management ratios, and capital adequacy ratios as independent variables. Next, the feature selection is applied for different prediction models. Subsequently, 4 prediction models (i.e., SVM, CHAID, linear regression, and a neural network) were developed to choose the best fit. The performance metrics have also been evaluated. Regression results exhibit that the efficiency of both conventional and Islamic banks is highly affected by profitability, liquidity, and managerial practices. Finally, we choose the best prediction model with the highest R^2 in the training and the testing phases with/out feature selection that is the CHAID model. The best predictors of cost efficiency for Saudi banks are the capital ratios, namely, CAR total and CAR tier 1. Findings are theoretically and practically important to academics, investors, and policymakers. Policymakers can benefit from the novelty of this study in building an early warning system using the CHAID model to predict different financial distress scenarios.

1. Introduction

Banks are the most effective financial institutions with a predominant role in the economic development of any country. This role can be summarized as the intermediary links between surplus and deficit units in the financial system. Banks' efficiency is one of the most vital and essential ratios because it indicates the banks' ability to control their operating expenses and thus achieve the highest profit levels. In addition, having higher Efficiency makes banks more resilient to shocks, which positively and significantly affect their growth and that of the entire economy. In terms of efficiency, the core expression is management; good management is reflected in good efficiency. Literature has proven a significant interrelationship between high-efficiency scores, adequate management, and good corporate governance practices. Banks have also been classified into conventional and Islamic to compare their differences by applying the CAMEL rating model [1, 2].

Saudi Arabia is the leading oil producer and the ninth-largest economy globally. In addition, the country is a G20 member with a strategic location at the heart of significant trade routes crossing three continents and bountiful natural resources. Considered a future-forward economy, Saudi Arabia offers untapped potential and unique business opportunities, further aiming to be an attractive and stimulating investment destination for continuation and expansion in all economic fields. Saudi Vision 2030 mentions that a wide range of economic reforms has succeeded in creating new business opportunities, leveraging the country's critical strategic assets, and driving economic growth and diversification.

Over the past four decades, the Saudi banking system has been solid, if not spectacular. The system has faced various challenges arising from downturns in the domestic economy, turbulence and volatilities in the global financial markets, international financial crises, and the recent global health pandemic [3, 4]. During this period, Saudi banks have managed to stay on course and achieve their current strong position without experiencing a severe financial crisis. Nowadays, Saudi banks are well-positioned in terms of capital, quality of assets, and technology to play an essential role in regional and global markets. In addition, the Saudi baking sector has the leading index in TASI. As the second-largest banking sector in GCC, Saudi banks have eleven public listings at the end of 2021, seven of which are conventional, and the rest are Islamic. Although all Saudi banks provide Sharia-compliant banking products, only the last four are considered fully Sharia-compliant. In contrast, the others offer a mix of Sharia-compliant and conventional banking products and services.

Banks' efficiency is a vital topic that requires a thorough discussion in the literature. As shown in the Literature Review section, scholars rarely investigated the different concepts and types of banks' efficiency. They rather concentrated on the comparison between conventional and Islamic banks in terms of different efficiency types and levels. Fewer still concentrated on conventional and Islamic banks in Saudi Arabia and different GCCs. Although prediction models were proven to have a strong ability to specify the best future parameters, these have been rarely used to build prediction systems for banks' efficiency. Accordingly, the present study fills in this gap by investigating the effect of different financial ratios on the efficiency of both conventional and Islamic Saudi Banks. Subsequently, regression and three machine learning prediction models (i.e., SVM, NN, and CHAID) are applied and compared to find the best fit. Finally, the far-reaching theoretical background and literature review of banks' efficiency are highlighted.

This study is structured as follows: Section 2 presents a literature review. Sections 3 and 4 describe the data and the methodology, respectively. Section 5 discusses the main results. Section 6 presents the conclusions, implications, and future studies.

2. Literature Review

In this section, banks' efficiency is discussed from three scopes: efficiency overview, key determinants of efficiency, conventional and Islamic banks, and machine learning models.

2.1. Efficiency Overview. Literature has investigated various types of efficiency. Minviel and Ben Bouheni [5] examined the technical and managerial efficiency of European banks over a lending channel. These banks showed managerial efficiency was strong, while at specific levels, other banks showed huge percentages of poor management performance. Alrashidi and Alarfaj [6] investigated structural capital efficiency (SCE), intellectual capital efficiency (ICE), and human capital efficiency (HCE) and found a negative relation between the latter two. Meanwhile, Buallay et al. [7] showed a positive relationship between ICE and financial and market performance.

Almaqtari et al. [8] and Al-Homaidi et al. [9] investigated the effect of operating expenses on the profitability of commercial banks as measured by their ROA and ROE. Their findings displayed a significant effect of operating efficiency and other bank-specific factors on profitability. In addition, Al-Homaidi et al. [10] displayed a significant effect of operating efficiency on banks' liquidity.

According to Yin et al. [11], the overall efficiency, productivity, efficiency, and profitability efficiency of Chinese commercial banks showed significant heterogeneity. Nevertheless, Fungáčová et al. [12] found that the big five Chinese banks suffer from low average cost efficiency.

Several researchers also explored the effect of banks' regulations on their efficiency. Ibrahim and Ismail [13] investigated the effect of banks' regulations, institutional variables, economic freedom, and Shariah law parameters on banks' efficiency. Their findings revealed that greater restrictions on Islamic bank activities have a strong significant relationship with bank efficiency and that regulatory quality has a positive effect on Efficiency. In addition, Bace and Ferreira [14] found that having extra activity restrictions can have a significant negative effect on the efficiency of European banks. Government regulation must pay more attention to encourage banks to have more transparent information.

Finally, other researchers focus on cost efficiency as it indicates the proximity of a bank's costs to the efficient cost frontier, which means that as expenses increase, the cost efficiency increases [15–18]. In the present study, we investigate the cost efficiency of conventional and Islamic Saudi banks as the dependent variable.

2.2. Key Determinants of Efficiency. Several scholars study the important determinants of banks' efficiency as follows:

Profitability: In investigating the main drivers of efficiency, Samad [19] revealed that earnings are one such crucial influence for technical and purely technical banks, while Saeed et al. [20] found that ROA and ROE are significant indicators associated with efficiency. Similarly, Dahal and Bhaskar [15] and Ojeyinka and Akinlo [18] showed that ROA as a profitability proxy is one of the key factors on banks' cost efficiency. According to Alrafadi [21], ROA and cost efficiency have a positive relationship. Moreover, Sultana and Rahman [17] proved the significant positive effect of profitability and net interest income on cost efficiency. Siauwijaya [22] determined that both EPS and cost efficiency have positive influences on stock return. Duong [23] found that consolidated banks can enhance the profitability ratios (i.e., ROA and ROE), inducing the outcome that except for operating efficiency ratios, all efficiency measures are not statistically different from zero. Accordingly, *in the present study, the*

hypothesis is that banks' profitability has a significant effect on cost efficiency.

Management Practices: Good management practices increase efficiency through the optimum utilization of all available resources. Moreover, all good practices such as motivation, good leadership, and open communication can enhance employee performance and attain the company objectives.

Saeed et al. [20] showed that management practices have a significant association with efficiency, while Galariotis et al. [24] found that management has a negative effect on the efficiency score of banking systems. The interrelationship between high-efficiency scores, adequate management, and good corporate governance practices has been investigated [25–28]. According to Mohamed et al. [29], the education of managerial staff is negatively associated with inefficiency, that is, efficiency increases as the number of Shariah experts in banks management increases.

The importance of corporate governance as good management practices in the banking sector is similarly investigated [30–32]. However, few scholars emphasize corporate social responsibility (CSR) as one of the governance and managerial practices affecting banks' efficiency. Forgione et al. [27] found a positive effect of CSR on efficiency indicators. Belasri et al. [26] found a positive effect of CSR on banks' efficiency only in developed countries due to their higher investor protection and stronger stockholder orientation. Finally, Ullah [16] showed that managerial practices and corporate governance positively affect cost efficiency. Accordingly, *in this study, the hypothesis is that banks management practices have a significant effect on cost efficiency.*

Assets refer to the use of funds in banks, and loans have the largest number of balances compared with other assets accounts. Various researchers link assets and loans to efficiency. Siddique et al. [33] found that the cost-efficiency ratio and non-performing loans (NPL) are negatively related to bank financial performance. Both Saeed et al. [20] and Samad [19] findings revealed that one of the vital indicators of banks' efficiency is the assets. Moreover, Dahal and Bhaskar [15] and Ojeyinka and Akinlo [18] showed that NPL is among the most crucial drivers on banks' cost efficiency. Galariotis et al. [24] also revealed that NPL and assets negatively affect efficiency scores in strong and weak banking systems. However, technical Efficiency is positively affected by the growth perspective of countries, regardless of the bank's assets and management. Accordingly, *in this study, the hypothesis is that banks' assets have a significant effect on cost efficiency.*

Capital adequacy ratio (CAR) is considered the most crucial indicator for any bank. The bank is strong when capital is solid. The effects of capital on different types of efficiency have been examined. Samad [19] revealed that capital is one of the crucial drivers of technical and purely technical efficiency in banks and that capital and firm size are extensive indicators of a non-linear relationship with efficiency. In addition, various researchers found with a good significance level that CAR not only has a significant association with efficiency but is one of the most crucial drivers influencing banks' cost efficiency [15, 18, 20]. Furthermore, Le et al. [34] categorized retail banks into three technical efficiency levels (i.e., top, medium, and poor) and found that banks' capital adequacy and credit quality are the main drivers of efficiency. Galariotis et al. [24] revealed that capital adequacy is negatively affecting efficiency scores for both strong and weak banking systems, and technical Efficiency is positively affected by the growth perspective of countries. Likewise, Sultana and Rahman [17] and Ereta et al. [35] found a significant negative effect of CAR on cost efficiency. Many other scholars investigated the effect of different risk types on banks' performance, calculating CAR by dividing capital by risk-adjusted assets that include credit, market, and operational ones. Accordingly, Duho et al. [36] investigated these three types of risk and found a significant effect of credit risk in enhancing efficiency and ROE. Market risk also showed an imperative influence on the enhancement of profit efficiency, ROA, and asset turnover. Nevertheless, operational risk had a negative effect on stockholders' returns. Accordingly, *in this study, the hypothesis is that banks' capital has a significant effect on cost efficiency.*

Liquidity and Deposits: Liquidity is a fundamental factor for banks' existence, continuity, and development. Specifically, banks' liquidity determines their ability to meet all their anticipated expenses, such as funding new loans or fulfilling customer account withdrawals. Deposits are crucial and comprise a very low-cost source of funding for banks, which make money by lending to their customers at higher rates. The vital relationship with and effect of liquidity on banks' efficiency have been examined and reveal that the loans to deposits and to total assets are among the most crucial drivers [15, 18, 20]. However, a few researchers found a significant negative effect of liquidity on cost efficiency, which indicates that excess liquidity is associated with excessive cost inefficiency [17, 37, 38]. Accordingly, *in this study, the hypothesis is that banks' liquidity has a significant effect on cost efficiency.*

2.3. Conventional and Islamic Banks

2.3.1. Conventional and Islamic Banks and Efficiency. Conventional and Islamic banks have been widely examined in different efficiency pillars. In technical efficiency, Safiullah and Shamsuddins [39] showed that given their more advanced technology applications, conventional banks are more technically efficient than Islamic ones. However, according to Ahmad [40], technical, allocated, and cost efficiency are higher in Islamic banks than in conventional banks.

Furthermore, Chaffai [41] investigated the efficiency and vulnerability of different bank types to any drop in their lending versus non-lending activities. The findings showed that conventional banks are more vulnerable in lending activities, while Islamic ones are equally vulnerable in lending and non-lending activities. However, when both types are exposed to shocks on lending activities, Islamic banks are less vulnerable than conventional ones. Safiullah [42] studied the effect of Islamic banks' dual board governance and regular board of directors on technical efficiency, which is reduced by the Shariah supervisory board.

Moving to assets and management pillars, few researchers concentrated on the association of assets and management pillars with efficiency. Elsa et al. [43] showed that conventional banks have high-quality assets and are more stable compared with Islamic banks. By contrast, Akber and Dey [44] revealed that conventional banks have better management and asset quality compared with Islamic banks. Salem et al. [45] found that earnings management practices are lower in Islamic banks compared with conventional ones due to audit committee techniques.

In comparing conventional and Islamic banks capital, Bitar et al. [46] found that as the capital and liquidity ratios in banks increase, the efficiency also increases regardless of the type of bank. Hafez [47] showed that the efficiency ratio of Islamic banks has a positive effect on CAR, while that of conventional banks has a negative effect on CAR. Akber and Dey [44] also revealed that Islamic banks have better CAR and liquidity ratios.

In linking risk dimension and efficiency, Musa et al. [48] found that Islamic banks have better efficiency due to their different approaches in risk management and controlled bank operations by Shariah commissions. Chen [49] showed that asset diversification positively affects bank efficiency regardless of type, and specifically, that of Islamic banks increases as the firm size increases. In studying capitalization, insolvency risk, and cost-efficiency, Saeed et al. [50] revealed that lower insolvency risk is accompanied by higher cost efficiency in conventional banks but is the opposite in Islamic banks.

In profitability and liquidity pillars, Alabbad et al. [51], Haddad et al. [52], and Majeed and Zainab [53] showed that Islamic banks maintain significantly higher liquidity than their conventional counterparts. Al-Harbi [54] found a negative effect of credit risk and profitability ratios on the liquidity of Islamic banks. However, CAR ratios have a positive effect on liquidity. Majeed and Zainab [53] and Achsani and Kassim [55] also found that Islamic banks are less profitable than conventional banks. However, Saif-Alyousfi and Saha [56] found that Islamic banks perform better in terms of fee income.

2.3.2. Saudi Conventional and Islamic Banks with Efficiency. Several researchers have examined conventional and Islamic banks in Saudi Arabia and different GCC. In his study, Alsharif [57] found that Islamic banks are riskier, more capitalized, and more liquid but less efficient than conventional banks. The findings showed that cost efficiency is negatively related to bank risk. However, Mortadza et al. [58] found that Saudi Islamic banks are more efficient than conventional Saudi banks.

Kamarudin et al. [59] explored the effect of country governance on the revenue efficiency of Islamic and conventional banks in different countries (Bahrain, UAE, Kuwait, Oman, Qatar, and KSA). Accountability, stability, regulations, and control of corruption enhance revenue efficiency in both types of banks. In addition, Mensi et al. [60] showed that Saudi banks suffer from inefficiency and exhibit long-term memory.

Furthermore, Haque et al. [61] investigated conventional and Islamic Saudi banks using variables of ROA, ROE, and efficiency ratios to determine which bank type is performing better compared with the other types. The results showed that conventional banks have higher ROA and efficiency ratios, while Islamic banks perform better in ROE. Among the Saudi banks, AlRajhi bank has the highest ROA and ROE, while NCB has the highest efficiency ratio.

Naushad [62] found that AlRajhi bank has the highest efficiency score among Saudi Islamic banks. Hassan et al. [63] investigated the technical and purely technical Efficiency of Saudi banks. They found that AL-Rajhi is the most efficient bank, followed by Aljazeera, Inma bank, and then al Bilad bank. Moreover, findings showed that al Bilad bank shows excellent results in terms of efficiency scale despite its small size. Khan et al. [64] showed that ALRajhi bank has the highest score in technical, pure, and scale efficiency of market share and performance. By comparison, Saudi Hollandi and national commercial banks are the top conventional banks. Accordingly, in this study, we focus on exploring the main determinants of efficiency for both conventional and Islamic Saudi banks.

2.4. Machine Learning Models. Different prediction models have been used to predict numerous concepts. An example is the Chi-squared automatic interaction detector (CHAID), which is considered one of the most crucial prediction models [65, 66]. Similarly, Pang et al. [67] built an early warning system using CHAID in three models to predict the loan default of clients in banks. According to Manogna and Mishra [68], CHAID is one of the best two models for predicting the performance of Indian manufacturing firms. Jan [69] and Qasrawi et al. [70] found that the CHAID-CNN model has the highest financial distress prediction accuracy rate. Moreover, the CHAID model is also considered an effective tool to determine the factors that influence student achievements.

Additionally, the neural network (NN) is one of the efficient models that can be used to examine various financial concepts and market indices [2, 4, 71–75]. Other scholars concentrate on comparing different prediction models. Hamal and Senvar [76], Madhu et al. [77], and Aksoy and Botousa [78] compared SVM, NN, and other predation models. Hamal and Senvar [76] used different prediction models (i.e., NN, SVM, and random forest) with/without feature selection methods to predict financial accounting fraud and found that random forest without

feature selection outperforms other models. Madhu et al. [77] revealed that the artificial NN performs better than the SVM in predicting option prices.

Furthermore, Aksoy and Botousa [78] used different models (i.e., NN and SVM) to predict financial failure/success and found that both models had high prediction accuracy rates. The results revealed that before the financial failure, NN outperforms SVM in one-year prediction, but the opposite is true for two-year predictions. Both Gupta et al. [79] and Ismail et al. [80] compared SVM with other different prediction models, finding that SVM can be outperformed. Jin and Zhu [81] applied different models (i.e., NN, SVM, and decision trees) to predict the default risk of loans and showed that the SVM model and other prediction models have equal performance.

Accordingly, in this study, we apply three different machine learning models (i.e., NN, CHAID, and SVM) to choose the best in predicting banks' efficiency.

3. Data and Description

This study aims to investigate the main determinants of banks' efficiency for both conventional and Islamic Saudi banks and then to choose the best fit among machine learning predictions (i.e., SVM, CHAID, linear regression, and NN). The data are gathered from the annual financial reports of Saudi banks for the period of 2014–2018. The Saudi banking sector consists of eleven banks: seven are conventional and four are Islamic. The financial ratios used in this research are subgrouped into banks' profitability ratios, management practices, asset and loans, capital adequacy ratios, and liquidity. To achieve the study goals, we implemented the methodology within three stages. First, the main financial ratios of both conventional and Islamic Saudi banks are calculated. Second, two regression analysis-stepwise methods are carried out to find the main drivers of cost efficiency for each group of conventional and Islamic Saudi banks. Third, the best prediction model among SVM, CHAID, and NN is chosen to predict the cost efficiency of conventional Saudi banks.

As shown in Table 1, the financial ratios of each bank (i.e., the profitability ratios, management practices, asset and loans, capital adequacy ratios, and liquidity) for the period of 2014—2018 are calculated.

The efficiency ratio indicates the ability of banks to utilize their funds and efficiently manage their operating expenses and, more importantly, the managing capabilities to reach the goals of maximizing both profits and shareholders' wealth. According to Table 2 below, the Samba financial group has the highest efficiency ratio. On the other hand, Bank Aljazira has the lowest efficiency ratio.

4. Methodology

To answer the research questions, we start with building a correlation matrix for each bank type and then run a regression model (after solving the multicollinearity problem). Efficiency ratio is the dependent variable, and the proxies of the banks' profitability ratios, management practices, asset and loans, capital adequacy ratios, and liquidity ratios are the independent variables. Subsequently, the feature selection method is applied for different prediction models to specify and select the key variables to construct the prediction models. Next, four prediction models are developed to choose the best fit. Then, the performance metrics are evaluated.

As shown in Figure 1, the methodology begins by calculating the main financial ratios for both conventional and Islamic Saudi banks. Then a regression analysis-stepwise method is applied to find the main drivers of cost efficiency for conventional and Islamic Saudi banks.

5. Analysis Discussion

This section is divided into three parts. The first two are linear regressions with a stepwise method for conventional banks and then for Islamic banks. The third is the building prediction models with/without feature selection method.

5.1. Linear Regression with Stepwise Method for Conventional Banks. To investigate the determinants of efficiency for conventional banks, we calculate the correlation matrix for all independent variables and efficiency ratio. Supplementary Table 1 shows that according to the correlation matrix, the efficiency ratio has a significant negative relationship with the ratios of capital, profit, and revenue per employee, ROA, and EPS. However, the efficiency ratio has a significant positive relationship with LTD.

The regression-stepwise method is run, and the findings showed that among the three models, No. 3 is the best with the highest adjusted R^2 of 87.2% and lowest standard error of approximately 2.43. Model No. 3 is also the best with significant independent variables of business per employee, ROA, and total deposits with VIF less than 10. Table 3 presents the results below.

Table 3 shows that the regression results exhibited that the cost efficiency of Saudi conventional banks is strongly affected by profitability (measured by ROA), liquidity (measured as total deposits), and management achievements (measured by business per employee).

Profitability is the key driver of banks' efficiency [15, 18–20]. Generating more profits reflects good management performance and should come with an increase in the firm's stock price. Consequently, this increase can help achieve the goal of wealth maximization. Increasing bank revenue increases the operating profit margin that enhances the cost-efficiency ratio. According to the analysis, we accept the alternative hypothesis that ROA has a significant effect on decreasing the cost inefficiency, which indicates a high-efficiency level. This importance of profitability in enhancing efficiency is in line with the findings of Alrafadi [21] and Sultana and Rahman [17]. In addition, as found by Majeed and Zainab [53] and Achsani and Kassim [55], conventional banks are more profitable than their Islamic counterparts.

Management practices are the core of any institute. Good management practices enhance the performance and are measured by the business per employee ratio, that is,

Table 1: Operational definitions.

Variables		A	Description
Dependent variable	Cost efficiency	Efficiency ratio	Other operating expenses/net revenue
Independent variables	Profitability	ROA	Net income/average total assets
		ROE	Net income/average total equity
		NII/TA	Net interest income/average total assets
		EPS	Net income/number of shares (disclosed)
		NII/NR	Net interest income/net revenue
	Management practices	Net profit per employee	Net income/number of employees
		Business emp.	Net revenue/number of employees
		Earnings growth	Earnings (n) – earnings ($n-1$)/earning ($n-1$)
	Asset	LL/TE	Reserve (loan losses)/total equity
		LL/TL	Reserve (loan losses)/total loans
	Capital	Book value per share	Total equity/number of shares (disclosed)
		CAR	(Tier 1 capital + tier 2 capital)/risk weighted assets (disclosed)
		Tier 1CAR	(Equity capital + ordinary share capital + intangible assets + audited revenue reserve)/risk weighted assets Disclosed (financials)
	Liquidity	LTD	Total loans/total deposits
		CASA/TD	Current accounts + saving accounts/total deposits
		IID/TD	Interest income deposits/total deposits
		Total deposits	Current deposits + saving deposits + time deposits

Table 2: Banks' efficiency ratios and ranks.

Bank name	Efficiency ratio	Rank
Al Bilad Bank	54.56	10
Al Inma Bank	42.22	9
Al Jazira Bank	58.25	11
Al Rajhi Bank	30.77	3
Arab National Bank	33.31	5
National Commercial Bank	36.66	7
Riyad Bank	35.02	6
Samba Bank	19.20	1
Saudi British Bank	28.92	2
Saudi Fransi Bank	32.83	4
Saudi Investment Bank	41.05	8

dividing net revenue by the number of employees. This indicator shows a significant negative effect on cost inefficiency. Bank management governs various relevant concerns to maximize profits. These concerns include asset/liability, liquidity, and cost management. Accordingly, proper practices as applied by bank management are reflected in managing and maintaining the costs at an acceptable level. Consequently, when management practices are enhanced, the net revenue increases whereas operating expenses and cost inefficiency decreases. In addition, the interrelationship between high-efficiency scores, adequate managerial processes, and good corporate governance practices has been investigated [25, 26, 28]. This result is in contrast with Galoriotis et al. [24] in that management practices have a negative effect on efficiency but is in line with that of Ullah [16] that revealed corporate governance has a positive effect on cost efficiency and Forgione et al. [27] who found a positive effect of CSR on efficiency indicators.

Liquidity, as measured by total deposits, showed a positive effect on bank cost efficiency. The efficiency of conventional banks is calculated by dividing the operating expenses by the net revenue and yields a significant positive effect of total deposits on the banks' cost ratio. As total deposits increase, the interest expense and operating expense also increase, and the score of cost inefficiency increases, indicating extra expenses borne by the bank. The relationship and effect of liquidity on banks' efficiency are found vital, and that loans to deposits and to total assets are among the most crucial drivers of banks' cost efficiency [15, 18, 20]. This result is in contrast to that of Le et al. [34], who stated that banks' liquidity is one of the main drivers of efficiency and in line with those of Sakouvogui and Shaik [37], Sultana and Rahman [17], and Okuda and Aiba [38], who found that excessive liquidity enhances cost inefficiency. According to Alabbad et al. [51], Haddad et al. [52], and Majeed and Zainab [53], Islamic banks maintain significantly higher liquidity than their conventional counterparts.

5.2. Linear Regression with Stepwise Method for Islamic Banks. To investigate the determinants of efficiency for Islamic banks, we calculate the correlation matrix for all independent variables and efficiency ratio. Supplementary Table 2 shows that according to the correlation matrix, the efficiency ratio and LTD have a significant positive relationship. The rest of the variables have a significant negative relation with efficiency ratio except for NII/TA, CAR total, LL/TE, LL/TL, earnings growth, and ROE.

Table 4 shows the applied regression-stepwise method. Among four models, model No.4 is the best with the highest adjusted R^2 95.8% and lowest standard error of

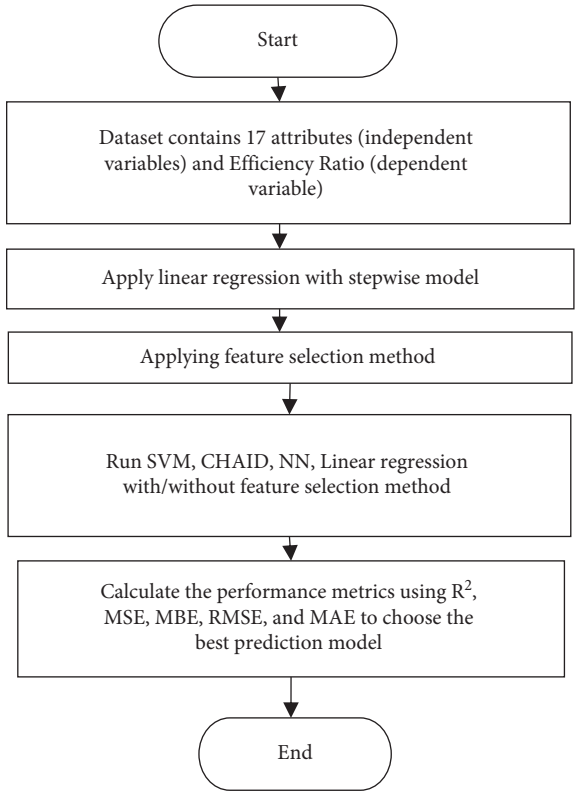

Figure 1: Steps of the methodology.

approximately 2.39. In addition, as shown in Table 4, model No. 4 is the best with significant independent variables of business per employee, EPS, NII/TA, and total deposits with VIF less than 10.

The regression results exhibited that the cost efficiency of Saudi Islamic banks is strongly affected by liquidity (measured by total deposits), management achievements (measured by Business per employee), and profitability (measured by NII/TA and EPS).

Profitability is the result of good management and the efficiency of managing bank funds and expenses. The efficiency of Islamic banks is calculated by dividing operating expenses by net revenues. As shown in Table 4, a significant negative effect of profitability is measured by NII/TA on banks' cost efficiency. As net interest income increases, the net revenues increase, leading to a decrease in cost efficiency. However, the profitability measured by EPS has a significant positive effect on cost efficiency level. The importance of profitability as one of the efficiency drivers specified by various scholars (i.e., [15, 18–20] and the positive results of profitability are in line with those of Alrafadi [21] and Sultana and Rahman [17]). According to Saif-Alyousfi and Saha [56], Islamic banks perform better in terms of fee income. Haque et al. [61] results showed that Islamic banks have less ROA and efficiency ratios compared with conventional banks. Alsharif [57] found that Islamic banks are riskier, more capitalized, and more liquid but less efficient than conventional banks. However, Mortadza et al. [58] revealed that Saudi Islamic banks are more efficient than their conventional counterparts.

Management practices is measured by the business per employee ratio, calculated as a net revenue on the number of employees. As shown in Table 4, management practices have a negative effect on the inefficiency of Islamic banks. As revenues increase, the efficiency cost score decreases, which indicates fewer expenses that the bank bears. The interrelationship between high-efficiency scores, adequate managerial processes, and good corporate governance practices are likewise examined [20, 25–28]. This result is in contrast with that of Galoriotis et al. [24] that management practices have a negative effect on efficiency but consistent with Ullah [16] that corporate governance has a positive effect on cost efficiency and Mohamed et al. [29] that managerial staff education has a negative effect on inefficiency. Akber and Dey [44] showed that conventional banks have better management and asset quality compared with Islamic banks. Moreover, Salem et al. [45] revealed that earnings management practices are lower in Islamic banks compared with their conventional counterparts. Musa et al. [48] found that Islamic banks have better efficiency due to their different approaches in risk management and controlled bank operations by Shariah commissions.

Liquidity is measured by total deposits. The efficiency of Islamic banks is calculated by dividing the operating expenses by net revenues. Table 4 showed a significant negative effect of total deposits on banks' cost efficiency. As total deposits increase, the net revenues increase from their reinvestment. As a result, the cost efficiency score decreases, indicating extra expenses borne by the bank. This result of the negative effect is consistent with Le et al. [34] who found that banks' liquidity is one of the main drivers of efficiency. Similarly, Sakouvogui and Shaik [37], Sultana and Rahman [17], and Okuda and Aiba [38] found that excessive liquidity enhances cost inefficiency. Finally, Alabbad et al. [51], Haddad et al. [52], and Majeed and Zainab [53] showed that Islamic banks maintain significantly higher liquidity than their conventional counterparts.

5.3. Building Prediction Models with/without Feature Selection Method. To achieve our goal of choosing the best prediction model in predicting the banks' cost efficiency, we used the data of conventional banks for their higher number of banks compared with Islamic ones. First, the feature selection model is applied to determine the most significant independent variables to be applied in the prediction models.

Upon application of the feature selection model, only key variables are reassigned to the four prediction models. The predictors are bank name, CAR total, CAR tier 1, net profit per employee, business per employee (net revenue), ROA, NII/NR, non-IID/TD (CASA-based), book value, and basic EPS.

Table 5 shows that the four models are first executed without the result of the feature selection model. The linear regression applied bank name, ROA, and book share; both SVM and NN models have used all variables, while the CHAID model used only the bank name, CAR tier 1, and the year. Figure 2 illustrates the indicators for all models.

Table 3: Summary of conventional banks' efficiency model.

$$DV_{it} = 54.323 - 0.016\,\text{Business Emp}_{it} - 12.275\,\text{ROA}\,it + 2.293E - 05\,\text{Total deposits}_{it} + \varepsilon_{it}$$

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.	Collinearity statistics	
	B	Std. error	Beta			Tolerance	VIF
(Constant)	54.323	2.667		20.366	0.000*		
Business emp.	−0.016	0.002	−0.573	−8.385	0.000*	0.807	1.239
ROA	−12.275	1.573	−0.604	−7.802	0.000*	0.630	1.587
Total deposits	$2.293E-05$	0.000	0.244	3.438	0.002*	0.751	1.332
R^2							0.883
Adjusted R^2							0.872
Sig. F change							0.000*

Note: *Significant at the level of 1%.

Table 4: Summary of Islamic banks' efficiency model.

$$\text{DV}_{it} = 67.811 - 0.001\,\text{Total deposits}_{\,it} - 6.960\,\text{Business EMPit} + 5.690\text{EPS}_{it} - 361.090\text{NII/TA}_{it} + \varepsilon_{it}$$

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.	Collinearity statistics	
	B	Std. error	Beta			Tolerance	VIF
(Constant)	67.811	3.194		21.232	0.000*		
Total deposits	−0.001	0.000	−1.164	−11.564	0.000*	0.219	4.565
Business Emp	−6.960	1.391	−0.258	−5.002	0.000*	0.835	1.197
EPS	5.690	1.317	0.481	4.322	0.001*	0.179	5.572
NII/TA	−361.090	133.126	−0.182	−2.712	0.016**	0.493	2.029
R^2							0.967
Adjusted R^2							0.958
Sig. F change							0.000*

Note: *Significant at the level of 1% and **significant at the level of 5%.

Table 5: Used variable to build each model based on with/without feature selection methods.

Model	Number of selected features
SVM	All variables
CHAID	Bank name, Car_T_1, year
Linear	Bank name, ROA, book share
NN	All variables
FS_SVM	All variables based on feature selection
FS_CHAID	Bank name, CAR total, CAR tier 1
FS_Linear	Bank name, ROA, book share
FS_NN	All variables based on feature selection

Figure 3 illustrates the models and their variables after applying the feature selection model. Accordingly, linear regression used bank name, ROA, and book share variables. Both SVM and NN models applied all variables. However, the CHAID model used only the Bank name, CAR tier 1, and CAR total.

In selecting the best prediction model, we check the overall relationship and error relationship (training and testing data sets) between the real and predicted efficiency ratios with and without feature selection methods, as shown in Figures 4 and 5.

Finally, to choose the best model, we compare R^2 to determine the one with the highest value in the training and testing phases.

Table 6 shows that referring to the results of the training phase, the SVM without feature selection is the best prediction model compared with the NN, which has the lowest R^2. By contrast, with the feature selection method, the NN model has the highest R^2 compared with SVM. As a result, NN and SVM have the best models in the training phase with or without feature selection, respectively.

Moving to the testing phase, we aim to select the best model with the highest R^2 in the testing data set. As shown in Table 7, CHAID without feature selection is the best prediction model compared with the NN, which has the lowest R^2.

However, with the feature selection method, the CHAID model has the highest R^2 compared with SVM, which has the lowest R^2. As a result, the CHAID model is the best in the testing phase without feature selection.

In summary, the best prediction model with and without feature selection model in the testing phase is the CHAID, consistent with various researchers who consider this as one of the most imperative models [65, 66, 68, 70].

Accordingly, the best predictors of cost efficiency for Saudi banks are the capital ratios, CAR total, and CAR tier 1. This result is vigorous given that banks' regulatory capital is the most crucial figure in the entire financial statements and CAR is the key outcome of the BASEL Accords. These values indicate that banks have enough capital or can absorb any expected losses or financial distress that banks may encounter. In addition, most central banks' regulations are

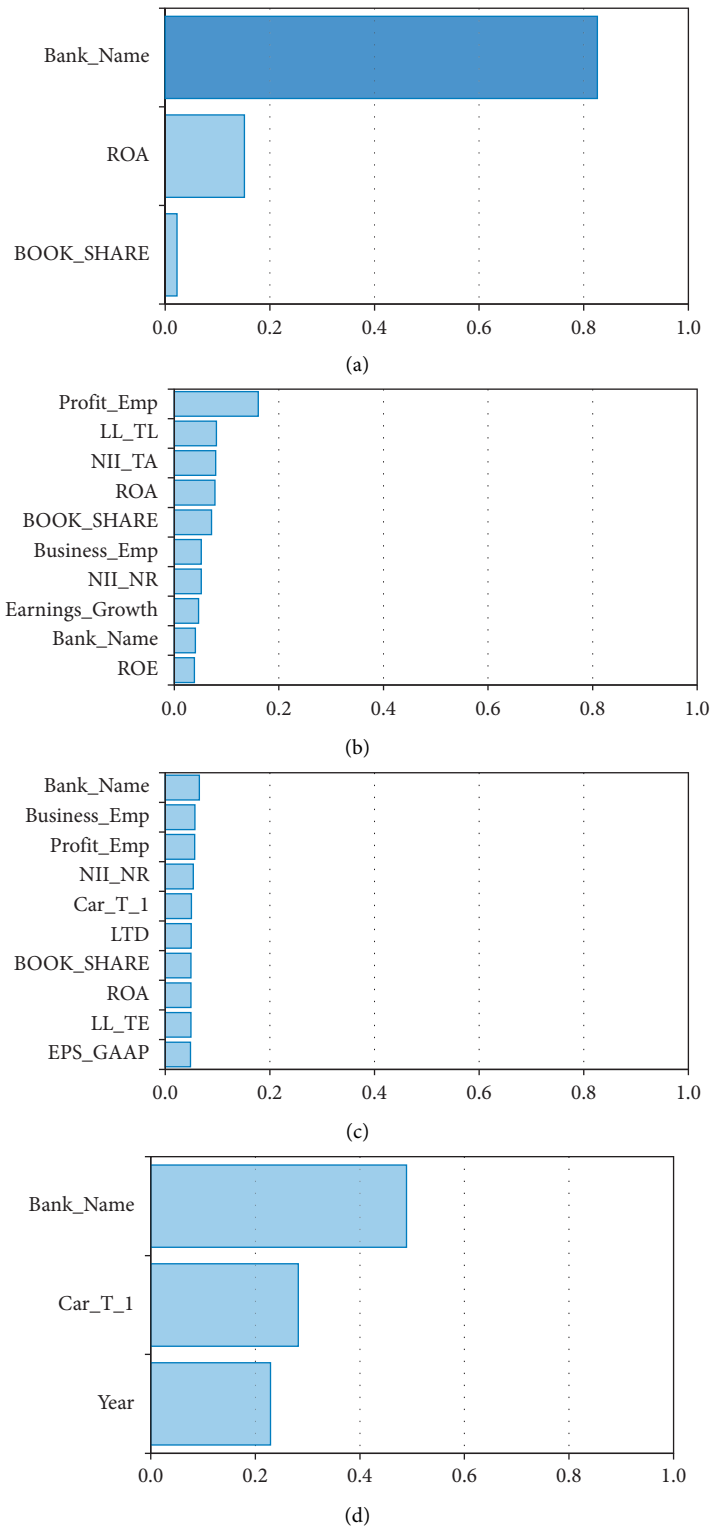

Figure 2: Important predictors by using four prediction models: (a) linear regression, (b) neural network, (c) SVM, and (d) CHAID based on entering all predictors without results of feature selection model.

linked directly to the regulatory capital and capital ratios. Literature found that CAR not only has a significant association with efficiency but is among the most crucial drivers on banks' cost efficiency [15, 18, 20]. This result is consistent with previous studies that capital ratios are dynamic indicators for banks' efficiency, such as Samad [19], Le et al. [34], Galariotis et al. [24], Christopoulos et al. [82], Dahal and Bhaskar [15], Minivel and Bouheni [5], and Ojeyinka and

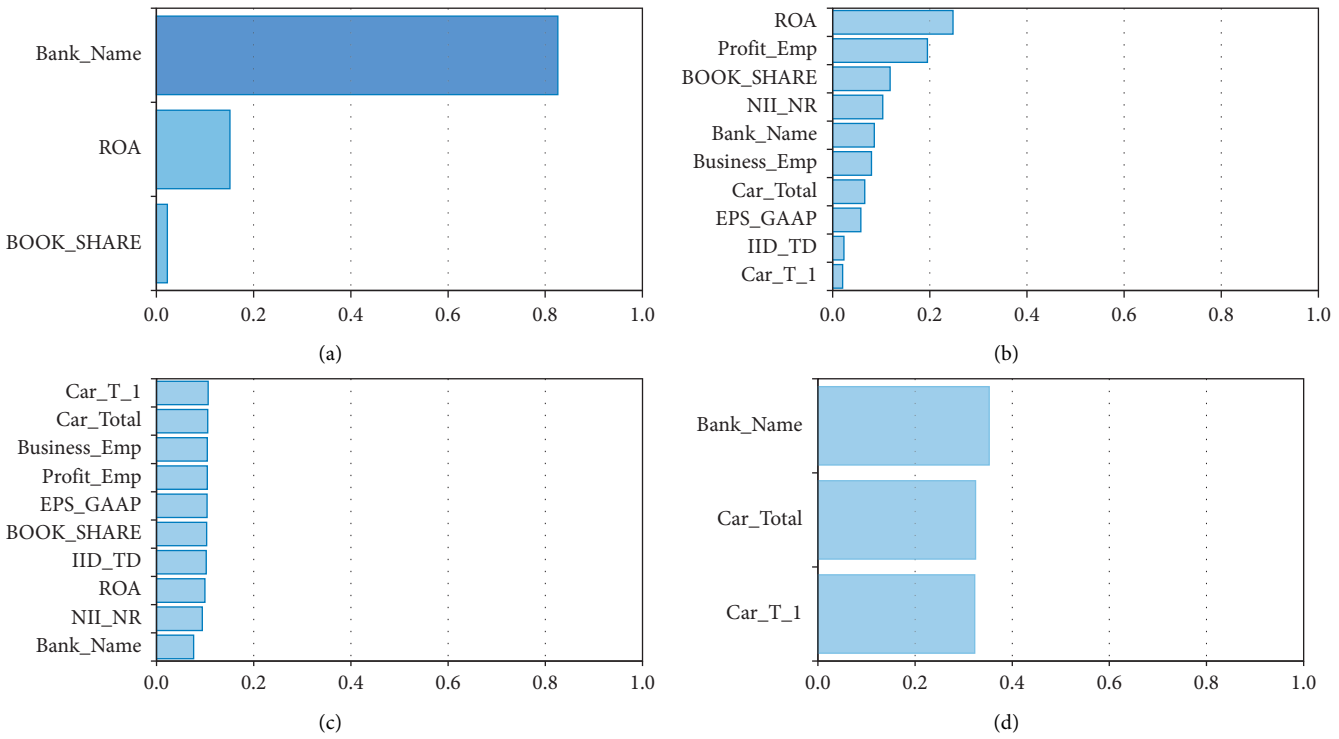

Figure 3: Importance predictors by using four prediction models including (a) linear regression, (b) neural network, (c) SVM, and (d) CHAID based on feature selection model.

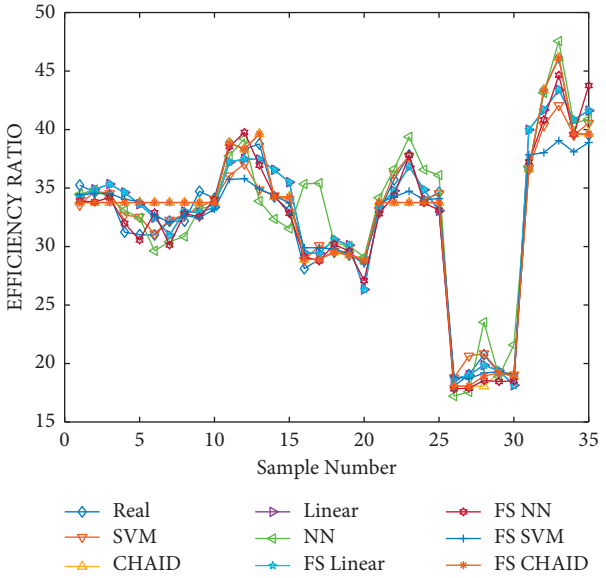

Figure 4: Overall relationship (training and testing data set) between the real and the predicted efficiency ratios with and without feature selection methods.

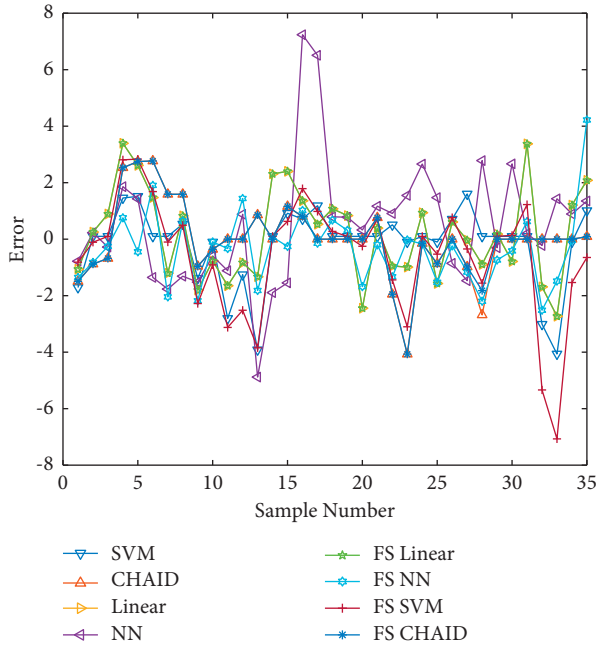

Figure 5: Overall error relationship (training and testing data sets) between the real and predicted values with and without feature selection methods.

Table 6: Results of training data set with and without feature selection model.

	R^2	MSE	MAE	MBE	RMSE
SVM	0.986	1.650	0.736	0.348	1.284
CHAID	0.981	1.582	0.701	0.000	1.258
Linear	0.972	2.312	1.297	0.000	1.521
NN	0.965	3.160	1.296	−0.408	1.778
FS_SVM	0.956	4.754	1.381	0.669	2.180
FS_CHAID	0.981	1.582	0.701	0.000	1.258
FS_Linear	0.972	2.312	1.297	0.000	1.521
FS_NN	0.987	1.237	0.829	0.407	1.112

Table 7: Results of the testing data set with and without feature selection model.

	R^2	MSE	MAE	MBE	RMSE
SVM	0.974	2.835	1.279	−0.300	1.684
CHAID	0.983	2.635	1.381	0.021	1.623
Linear	0.977	3.370	1.556	−0.755	1.836
NN	0.890	11.831	2.755	−0.781	3.440
FS_SVM	0.963	3.916	1.634	0.325	1.979
FS_CHAID	0.985	2.151	1.274	−0.086	1.467
FS_Linear	0.977	3.370	1.556	−0.755	1.836
FS_NN	0.977	3.843	1.595	0.095	1.960

Akinlo [18]. Finally, Sultana and Rahman [17] and Ereta et al. [35] found a significant negative effect of CAR on cost efficiency.

6. Conclusions, Implication, and Future Studies

This study aims to examine the main determinants of banks' efficiency for both conventional and Islamic Saudi banks and then to choose the best fit among machine learning prediction models (i.e., SVM, CHAID, linear regression, and NN). The data were collected from the annual financial reports of Saudi banks during the period 2014–2018. The Saudi banking sector consists of eleven banks: seven are conventional banks and the rest are Islamic. The major financial ratios used in this research are subgrouped into banks' profitability ratios, management practices, asset and loans, capital adequacy ratios, and liquidity. The methodology is implemented by first running a regression analysis with efficiency ratio as a dependent variable and the proxies of banks' profitability, liquidity, asset quality, management ratios, and capital adequacy ratios as independent variables. Next, feature selection is applied for different prediction models. Afterward, four prediction models (i.e., SVM, CHAID, linear regression, and NN) were developed to choose the best fit among them. The performance metrics have likewise been evaluated. The regression results exhibit that conventional banks' efficiency is strongly affected by profitability (measured by ROA), liquidity (measured by total deposits), and management (measured by business per employee). Meanwhile, the results showed that Islamic Saudi banks' efficiency is significantly affected by profitability (measured by NII/TA and EPS), liquidity (measured by total deposits), and management (measured by business per employee). Notably, our results are consistent with the concerned literature review. The final step is to choose the best prediction model with the highest R^2 in the training and the testing phases with and without feature selection. Thus, the best prediction model with and without feature selection in the testing phase is the CHAID, and the best predictors of cost efficiency for Saudi banks are the capital ratios, CAR total, and CAR tier 1.

The findings of this study are theoretically and practically important to academics, stockholders, and policymakers. Banks' executive management applies different strategies to increase their deposits, which is the source of funds that can be used to increase their different financial usages (i.e., loans and investments). Managers must also adopt efficient and effective practices to maximize their profits and maintain liquidity at an acceptable level. In addition, managers must focus on the operating cost by using new techniques and properly allocating resources and thereby achieve wealth maximization of stockholders. Potential and existing stockholders can benefit from this study by investing in shares of banks that have better cost-efficiency ratios. Moreover, policymakers of the Saudi central bank and regulatory bodies can benefit from this study in making extra periodical examinations of banks to check their capital and performance ratios. Central banks and policymakers can use the findings to build an early warning system using the CHAID model for predicting different financial distress.

However, given the current limitations and to expand the results, future studies can focus on and compare different types of Efficiency. Further research can also be primed for the determinants of efficiency for conventional and Islamic banks in GCC. In addition, different techniques can be used in collecting data, which in this study were secondary data without consideration of qualitative information. Research can focus on interviews with bank managers, depositors, and lenders. Finally, different statistical methods may also be applied to calculate the Efficiency and use other models that differ from those in this paper.

Data Availability

The data used to support the findings of this study are available from the author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this study.

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Supplementary Materials

Supplementary Table 1: correlations-conventional banks' efficiency. Supplementary Table 2: correlations-Islamic banks' efficiency. (*Supplementary Materials*)

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