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Modeling the Relationship between Financial Stability and Banking Risks: Artificial Intelligence Approach

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Abstract

This aims to evaluate the effect of financial stability efficiency on the financial stability of banks in Iran and Iraq. In addition, this study aims to identify the main factors affecting financial stability and provide solutions to improve risk management and banking supervision. The statistical population of this research includes 66 banks (22 Iranian banks and 44 Iraqi banks) listed on the stock exchanges of Iran and Iraq. The study period is from 2000 to 2023. A wide range of artificial neural network approaches and machine learning algorithms have been used for data analysis. These methods include artificial neural network, deep neural network, convolutional neural network, recurrent neural network, self-organizing neural network, gradient boosting, random forest, decision tree, spatial clustering, k-means algorithm, k-nearest neighbor, support vector regression and support vector machine. This diversity in analytical methods provides the possibility of comprehensive comparison and evaluation of factors affecting the financial stability of banks. The results of various analyzes show that machine learning models and neural networks have a significant performance in examining and evaluating the financial stability of banks. The artificial neural network showed the highest accuracy with a coefficient of determination of 0.95. Gradient boosting and random forest also had high performance with determination coefficients of 0.9566 and 0.9441. Spatial clustering and k-means algorithms could group banks based on their financial stability with an accuracy of nearly 100%. The variables of capital adequacy ratio, cash flow, bank size, and Z score were identified as the most important factors affecting financial stability. Deep, convolutional, and recurrent neural network models also showed similar performance with coefficients of determination of about 0.94. Support vector regression and support vector machine also provided acceptable results with determination coefficients of 0.9162 and 0.8500. This study emphasizes using artificial intelligence approaches in risk management and banking supervision. The research findings help develop early warning systems, improve banking supervision, and formulate more efficient monetary policies in Iran and Iraq. It is suggested that the monetary authorities of the two countries use these results to revise the capital adequacy rules and strengthen the banks' liquidity management.

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1. Introduction

As a business depository and lending institution, the banking industry is vital in the national and global economy (Lobo, 2017). An efficient banking system is one of the prerequisites for the economic development of a country. Banks are the pulse of financial activities and their status can significantly impact other sectors of the economy. Banks facilitate trade and commerce by organizing and directing payments and receipts, leading to market expansion, growth and economic prosperity. In developing countries with underdeveloped financial markets, banks are usually the only institutions capable of financial intermediation and can help reduce investment risk by providing various methods (Amiri and Tawfighi, 2016). Therefore, the health and efficiency of the banking system have always been of interest because efficient and healthy banks can be effective in economic growth; their unhealthy and weak performance can also cause financial and economic crises (Rezaei, 2017). Sufficient and reliable capital is one of the necessary conditions for maintaining the health of the banking system, and each bank and credit institution must always establish a proper ratio between the capital and the risk of its assets to ensure the stability and health of its activities. The main function of this ratio is to protect the bank against all financial and non-financial risks, including unexpected losses and to protect depositors and creditors (Hugonnier and Morellec, 2017).

Efficiency is one of the most important performance indicators of economic units. Although there are several definitions, the common denominator is that an efficient firm gets the most output from a given combination of data (Chen et al., 2018). Today, banks play an essential role in development strategies, and even in economies with advanced financial markets, banks are at the centre of financial and economic activities. Banks are often the only institutions that can provide financial intermediation in developing and transition economies with less developed financial markets.

Financial stability is the ability of the financial system, financial institutions, markets and market infrastructures to withstand possible shocks and imbalances while reducing the probability of failure in the performance of financial intermediation functions. Financial stability is essential for further economic development. The global financial crisis of 2007-2008 demonstrated the interconnectedness of the financial system through the banking network, the possibility of rapid transmission of losses from one bank to other banks, and the spread of instability in this network. Thus, a stable monetary system includes the ability to allocate resources efficiently, assess and manage financial risks, maintain the level of employment close to the natural rate of the economy, and eliminate changes in the relative prices of financial and real assets that affect monetary stability and the level of employment. Instability in the financial system means the inability of banks to finance profitable projects and the imbalance in their financing performance. Therefore, major instability in the financial system may lead to banking turmoil, severe inflation, collapse of capital markets and weakening of international confidence in financial markets and economic systems (World Bank, 2016).

However, despite the critical importance of the banking sector, the increasing complexity of financial instruments and the globalization of financial markets have increased the risks banks face. There has been a surge in financial stability concerns in recent years, driven by market volatility, cyber threats, regulatory changes, and economic uncertainties. These challenges have increased the potential for systemic risk, making banks more vulnerable to crises that can have far-reaching consequences for national and global economies. The increasing frequency of financial disruptions underscores the need to examine the factors contributing to or mitigating these risks.

Against this background, it is important to examine why this research is warranted. Understanding the interplay between efficiency and financial stability is crucial, as improving operational efficiency can enhance profitability and strengthen a bank's resilience to financial shocks. Focusing on the increasing risks and the urgent need for stability in the banking sector, this study aims to provide valuable insights that can inform strategies to safeguard financial systems. This research is particularly relevant in light of the recent global financial challenges, which highlight the importance of developing robust mechanisms to maintain stability and reduce the likelihood of future crises.

Based on the themes above, it can be concluded that the purpose of this research is to investigate the relationship between efficiency and financial stability and its impact on the financial sustainability of banks. In other words, this study analyses how operational efficiency and financial stability affect banks' ability to maintain financial resources and manage financial risks. It can also help to identify effective factors in improving banks' financial stability and assess financial institutions' role in this process.

The future structure of the article includes research literature (consisting of theoretical literature and research background), methodological research (including research method, statistical population and research model), research findings, conclusions and suggestions, and finally, sources and references. This structure is comprehensive and coherent to present the research.

2. Research literature

Keynes (1936) described the crisis of the financial system and the factors affecting it in general by referring to the fluctuations of a sensitive monetary system. In the late 2000s, Minestie's theory gained much attention due to the subprime mortgage crisis. He became famous by introducing the hypothesis of financial instability. Mishkin (1999) stated that the instability of financial conditions is caused by financial classification and the inability to raise capital for investment to invest in investment. Wen and Yu (2013) studied the developing concept of financial stability. A bank's performance and stability depend on its knowledge and technology. Therefore, it is essential to identify factors that create value and impact the economy, financial performance, and especially in the bank (Ella et al., 2023).

Many studies show that banks, to comply with minimum mandatory capital requirements, proceed to halt the granting of loans. One of the prominent theories in this area is the capital crunch theory, which predicts that the amount of lending during recession periods is sensitive to capital regulatory controls. In situations where mandatory capital decreases and leads to distress, external capital increases, and consequently, the amount of loans granted by banks also decreases (Acharya and Ryan, 2016).

With a paradigm shift towards financial liberalization resulting from financial repression in the 1980s and 1990s, banking sectors—initially in developed countries and later in developing countries—have experienced increasing levels of competition, bringing two opposing views regarding financial stability. The competition–stability view states that competition can positively affect financial institutions' stability (Schaeck and Čihák, 2014). From this perspective, Boyd and De Nicoló (2005) suggested that lower interest rates in a competitive market reduce borrowing costs and increase entrepreneurial successes, which helps stabilize banks and leads to reduced credit risk. In contrast, in a concentrated market with less competition, a few large banks can impose higher interest rates, which may increase the volume of non-performing loans and lead to bank bankruptcies.

Schaeck and Čihák (2014) examined 3,600 European and over 8,900 U.S. banks and demonstrated that competition, measured using the Boone indicator, benefits banking health. Schaeck et al. (2009) also explained that banks maintain buffer capital in a competitive environment, reducing the propensity toward financial crises. Similarly, Kasman and Carvallo (2014) consider competition favorable for financial stability. A recent article by Noman et al. (2018) analyzed the role of banking regulations on the relationship between competition and financial stability and showed that both competition and regulatory policies promote financial stability and reduce credit risk in the banking system.

The competition–fragility concern implies that increasing competition in the financial services industry reduces financial institutions' market power and profitability. Financial institutions are likely to have a greater tendency to invest in high-risk portfolios to compensate for financial losses. As a result, this risky behavior can undermine the stability of financial institutions. Llewellyn believes that such competition can lead to the failure of these sectors. Additionally, according to Allen and Gale, in a competitive market, banks tend to make less effort to assess customers to grant more credit and earn higher profits, which can increase the risk of credit default and banks' vulnerability.

Based on the theoretical framework presented, the relationships between financial stability, banking risks, and the identified factors are deeply interconnected. Increased competition in the banking sector, stemming from financial liberalization, influences financial stability through two main channels. The competition stability view posits that heightened competition leads to lower interest rates, reducing borrowing costs for entrepreneurs, enhancing their success rates and stabilizing banks by lowering credit risk (Boyd and De Nicoló, 2005). Conversely, the competition fragility concern argues that increased competition diminishes banks' market power and profitability, prompting them to engage in riskier investment portfolios to compensate for reduced earnings. This risky behavior elevates banking risks and can undermine financial stability. Additionally, regulatory policies like mandatory capital requirements significantly impact lending behaviors. During recession periods, strict capital regulations may lead to a capital crunch, where banks halt loan provisions to comply with capital requirements, further aggravating economic downturns and affecting overall financial stability (Acharya and Ryan, 2016).

Moreover, lending practices such as procyclical lending play a crucial role in the interplay between banking risks and financial stability. Procyclical lending, characterized by excessive lending during economic booms and restricted lending during recessions, can amplify economic fluctuations and contribute to financial instability (Mishkin, 1999). Regulatory frameworks that inadequately account for loan loss reserves may inadvertently encourage such lending patterns, increasing banks' vulnerability during economic downturns. Efficiency factors, including banks' knowledge and technological capabilities, influence this dynamic by affecting banks' ability to manage risks and maintain stability (Ella et al., 2023). Efficient banks are better equipped to assess credit risk accurately, adjust to competitive pressures, and adhere to regulatory requirements without excessively curtailing lending activities. Therefore, the interrelationships among the competition, regulatory policies, lending behaviors, efficiency, banking risks, and financial stability are complex and multifaceted, with each factor exerting significant influence on the others as evidenced in the literature (Schaeck and Čihák, 2014; Noman et al., 2018). Therefore, numerous studies in this regard, which are reviewed in Table 1, examine empirical studies on financial stability efficiency and its effects on the financial sustainability of banks.

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Many studies show that banks, to comply with minimum mandatory capital requirements, proceed to halt the granting of loans. One of the prominent theories in this area is the capital crunch theory, which predicts that the amount of lending during recession periods is sensitive to capital regulatory controls. In situations where mandatory capital decreases and leads to distress, external capital increases, and consequently, the amount of loans granted by banks also decreases (Acharya and Ryan, 2016). The study by Anvari et al. (2018) indicates that banking sector credits can increase the stock market size index, and the cessation or freezing of loan granting may lead to market failure. Additionally, regulatory authorities believe that current rules for calculating loan loss reserves create procyclical effects in lending. Here, cyclical or procyclical lending means granting more loans during boom periods and not providing sufficient facilities during recessions.

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Given the reviews conducted in the theoretical foundations and existing literature in areas related to efficiency, financial stability, and their effects on the financial sustainability of banks, especially in Iraq and Iran, it becomes clear that sufficient serious studies have not been conducted in these areas. In particular, none of these studies have precisely examined the relationships between financial efficiency and financial stability on the financial sustainability of banks. This indicates that the present research in this area is unique and noteworthy. Moreover, the richness of the subject literature is very weak at both domestic and international levels.

As a result, this study attempts to examine financial efficiency, financial stability, and their effects on the financial sustainability of banks by utilizing scientific capacities and quantitative analysis methods and to tailor the obtained results to the banking systems of the countries under study. Thus, it can be claimed that this comprehensive and complete study not only serves as a scientific source for answering the main research questions but can also play an important role in its applicability and impact on financial and banking decision-making. Furthermore, by employing modern approaches such as neural networks and machine learning, this research can increase the depth of analysis and accuracy of predictions, contributing to advancing knowledge in this field.

Table 1. The empirical studies on financial stability efficiency and its effects on the financial sustainability of banks

Authors	Title of Study	Objective of Study	Key Findings
Berger and Bouwman (2013)	Bank Liquidity Creation, Monetary Policies, and Financial Crises	Examine the relationship between bank liquidity creation and financial stability	Banks with greater liquidity creation perform better in financial crises and have more financial stability.
Elbadry (2018)	Bank's financial stability and risk management	The study examines the effect of Saudi banks' financial stability indicators on their risk management practices.	The findings indicate that the capital adequacy ratio negatively impacts credit risk, while the leverage ratio positively affects it. Provisions, leverage, loans-to-deposits ratio, and bank size negatively affect liquidity risk. Additionally, capital adequacy, provisions, leverage, and asset utilization ratios positively influence operational risk, whereas the loan-to-deposits ratio has a negative effect on it. Overall, Saudi banks experienced significant improvement in financial stability from 2011 to 2014, enhancing their ability to manage risks.
Abdallah et al (2019)	Efficiency and Financial Stability of Commercial Banks in Kenya	Explore the relationship between efficiency and financial stability in Kenya	High efficiency in Kenyan banks leads to significant improvements in financial stability.
Safarzadeh et al(2019)	Designing and explaining the stability model of the banking system based on the quality of financial reporting	The study aims to model banking stability based on the quality of financial reporting and identify strategies to enhance stability through financial reporting quality.	The results confirm the hypotheses that strong financial reporting quality is directly related to banking stability, and utilizing a dynamic storage method rather than a static one can help stabilize the banking network by improving the quality of banks' financial reporting.
Onumah and Duho (2019)	Intellectual Capital: Its Impact on Financial Performance and Financial Stability of Ghanaian Banks	The study investigates the effect of intellectual capital (IC), measured by the Value Added Intellectual Coefficient (VAIC), on the financial performance and stability of 32 banks in Ghana from 2000 to 2015.	The findings indicate that while VAIC positively affects financial performance and stability, only Human Capital Efficiency (HCE) mirrors this relationship; Structural Capital Efficiency (SCE) negatively impacts both performance and stability, while Capital Employed Efficiency (CEE) increases performance but reduces stability.
Almahadin (2020)	Banking soundness-financial stability nexus: empirical evidence from Jordan	The main objective of this study is to examine the relationship between financial stability and banking soundness in Jordan.	The Jordanian financial system is stable, with robust banking soundness indicators positively impacting financial stability. A stable interest rate policy is crucial for maintaining this stability, and there is a strong positive relationship between financial stability and economic growth changes.
Koskei (2020)	Determinants of Banks' Financial Stability in Kenya Commercial Banks	The study aims to investigate the determinants of bank stability, specifically as proxied by asset quality, in the Kenyan banking sector.	The analysis reveals that liquidity ratio, inflation rate, and lending rate negatively impact banking stability, while loan growth and return on equity positively influence it; however, exchange rate, return on assets, and public debt have statistically insignificant effects on banking stability.

Xu et al. (2021)	Banking Efficiency and Financial Stability in Latin America	Explore relationships between banking efficiency and financial stability	Banking efficiency significantly impacts financial stability in Latin American countries; these two factors are interdependent.
Bhattacharjee (2023)	Does intellectual capital efficiency improve bank performance and financial stability? Evidence from Bangladesh	This study aims to investigate the impact of intellectual capital (IC) efficiency on financial and market performance and the financial stability of banks in Bangladesh.	The results indicate that while IC efficiency enhances banks' financial performance, it negatively affects market performance and increases insolvency risks; additionally, physical and financial capital are identified as primary contributors to bank performance and long-term growth, highlighting the need to develop an intellectual asset base to improve bank efficiency and stability.

3. Research Methodology

This study investigates the effects of financial stability efficiency on the financial sustainability of banks in Iran and Iraq and uses approaches such as neural networks and machine learning. Considering the complexity of the relationships between financial variables and their effects on the financial sustainability of banks, using deep learning techniques and new analytical models can help identify specific patterns and hidden relationships. In this study, Data related to banks' financial performance and financial stability efficiency components will be collected and preprocessed to be modeled by machine learning algorithms, such as neural networks. This approach not only provides more accuracy in the relationships between variables but also leads to the improvement of strategic decision-making in the financial management of banks. The results of this research, in addition to deepening knowledge about the impact of financial stability efficiency on banks' financial sustainability, will provide practical solutions to optimize the performance of banks in the two mentioned countries. Therefore, the main purpose of this study is to investigate the effect of financial stability efficiency on banks' financial stability and the financial sustainability of banksis in Iran and Iraq. Therefore, in this study, all banks listed in the Iran-Iraq Stock Exchange (census, 22 Iranian and 44 Iraqi banks) specified in Table 2 from 2000 to 2023 have been used.

Table 2. The names of Iranian and Iraqi banks accepted in the stock exchange

Iranian		**Iraqi**			
Name Bank	**Symbol**	**Name Bank**	**Symbol**	**Name Bank**	**Symbol**
Bank Mellat	VMELLAT	Al-Arabiya Islamic Bank	ARAB ISLAM	Al-Atta Islamic Bank	ATTA
Bank Tejarat	VTEJARAT	Asia Iraq Islamic Bank for Investment	ASIA	Mosul Bank for Development and Investment	MOSUL
Bank Saderat Iran	VBSADER	Ameen Iraq Islamic Bank	AMEEN	Al-Mansour Investment Bank	MANSOUR
Parsian Bank	VPARS	Al-Mashreq Al-Arabi Islamic Bank for Investment	MASHREQ	Al-Mustashar Islamic Bank for Investment	MUSTASHAR
Pasargad Bank	VPASAR	Al-Ansari Islamic Bank	ANSARI	National Islamic Bank	MELLI
Sina Bank	VSINA	Ashur International Bank for Investment	ASHUR	National Bank of Iraq	AHLI
Bank Eghtesad Novin	VNOVIN	Babel Bank	BABEL	North Bank for Finance and Investment	SHOMAL
Post Bank of Iran	VPOST	Bank of Baghdad	BAGHDAD	Al-Qabedh Islamic Bank for Finance and Investment	QABEDH

Middle East Bank	VKHAVAR	Cihan Bank for Islamic Investment and Finance	CIHAN	Al-Qurtas Islamic Bank for Investment and Finance	QURTAS
Karafarin Bank	VKAR	Commercial Bank of Iraq	TEJARI	Al-Rajeh Islamic Bank for Investment and Finance	RAJEH
Saman Bank	SAMAN	Dijlah & Furat Bank for Development and Investment	DIJLAH	Credit Bank of Iraq	ETEMAN
Ayandeh Bank	VAYAND	Dar Es Salaam Investment Bank	DAR ES SALAAM	Al-Aqeem Commercial Bank for Investment and Finance	AQLIM
Resalat Gharz Al-Hasaneh Bank	VSALAT	Economy Bank	EQTESAD	Sumer Commercial Bank	SUMER
Tose'e Credit Institution	TOSE'E	Elaf Islamic Bank	ELAF	Al-Taif Islamic Bank for Investment and Finance	TAIF
Refah Bank	VREFAH	Erbil Bank for Investment and Finance	ERBIL	Trans Iraq Bank for Investment	ABOR
Kosar Credit Institution	VKOSAR	Gulf Commercial Bank	KHALIJ	International Development Bank for Investment & Finance	TANMIA
Noor Credit Institution	VNOOR	Investment Bank of Iraq	ESTESMAR	United Bank for Investment	MOTAHE D
Samen Credit Institution	VSAMEN	Iraqi Islamic Bank	MIRALLAH	Al-Warka Investment Bank	WARKA
Dey Bank	DEY	Middle East Investment Bank	SHARQ	World Islamic Bank for Investment and Finance	ALAM
Gardeshgari Bank	VGARDESH	Noor Iraq Islamic Bank for Investment	NOOR	Zain Iraq Islamic Bank for Investment and Finance	ZAIN
Shahr Bank	VSHAHR	International Islamic Bank	BEYNOLME LAL	United Arab for Money Transfer	TAHVIL
Sarmayeh Bank	SARMAYE	Al-Janoob Islamic Bank for Investment and Finance	JANOOB	Al-Atta Islamic Bank	ATTA
Melal Credit Institution	VMELAL	Kurdistan International Islamic Bank	KURDISTAN	Mosul Bank for Development and Investment	MOSUL
Iran Zamin Bank	VZAMIN				

Therefore, Iran and Iraq's[1] official banking and stock exchange[2] websites have been used to collect the research data. Therefore, in this study, the research model is as follows:

$$Fs_{it} = \alpha_0 + \beta_1 zscore_{it} + \beta_2 CAP_{it} + \beta_3 size_{it} + \beta_4 hhil_{it} + \beta_5 gown_{it} + \beta_6 lev_{it} + \beta_7 \mathrm{CFGR}_{it} + \beta_8 \mathrm{CFGR}_{it} + \beta_9 \mathrm{CF}_{it} + \gamma_{it}$$

In the above relation, FS: represents the financial stability of banks; Z-score the financial stability of banks; lev: represents bank leverage; size: bank size; hhil: is a measure of bank concentration; gown: to state ownership; cap: as capital adequacy variable, cfgr: growth of bank liquidity; incgr: growth of bank revenue; and γ_it: it refers to the component of disruption. In general, the method of measuring the research variables will be as follows:

3.1 Dependent variable: financial sustainability of banks

[1] http://www.cbi.iq, http://www.isx-iq.net, https://globaledge.msu.edu/globalresources/resourcesbytag/iraq, http://data.worldbank.org
[2] https://amar.org.ir/economic-accounts, https://tsd.cbi.ir/, https://databank.mefa.ir/, https://codal.ir/, https://www.tse.ir/

In which, the Fs_{it} financial sustainability of bank i in year t, the return on assets of the bank ROA_{it} i in year t is the ratio of the bank's net profit to the bank's total assets and the capital adequacy of bank CA_{it} i in year t is the result of dividing the basic capital into the bank's assets which is based on the capital adequacy regulations (2011) is disclosed in the company's financial statements, and finally, the $\delta(ROA_{it})$ standard deviation of the return on bank assets is i in year t.

$$Fs_{it} = \ln\left(\frac{ROA_{it}+CA_{it}}{\delta(ROA_{it})}\right) \qquad (1)$$

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3.2 Independent variables

Financial Stability of the Bank

This index was first proposed by Hannan and Hanok (1988) and used by Boyd et al. (1993). Since then, various studies have used this index to examine the financial stability of banks (Iannotta et al. 2007; Tan and Floros, 2013; Tan et al. 2017; Ghosh, 2014). It considers the score, returns, volatility of returns, and the capital base of banks. A high Z-score indicates financial stability and the ability to absorb losses. Therefore, based on previous studies and in line with the study of Onumahand Doho (2019), the financial sustainability of banks will be indexed as a relationship (2).

$$ZScore = \frac{\left(ROA + \frac{E}{A}\right)}{\sigma ROA} \qquad (2)$$

ROA is the return on assets, E/A is the capital-to-asset ratio and σROA is the standard deviation of ROA.

Capital Adequacy Ratio

Based on the studies of Onumah and Doho (2019) and Mansourian Nezamabad et al. (2016). The capital adequacy ratio is one of the important criteria in assessing the financial health of banks and financial institutions. This ratio helps us understand how much risky assets a bank has covered with its capital. Therefore, the method of measuring the capital adequacy ratio as described by the relationship (3) is as follows:

$$CAP = \frac{Tier\ 1\ capital + Tier\ 2 capital}{Risk\ weighted\ assets} \qquad (3)$$

Tier 1 capital includes the bank's principal capital (such as equity capital and accumulated profits) which is more resistant to losses. Tier 2 Capital includes other financial resources known as supplementary capital (such as long-term loans and public reserves), and Risk Weighted Assets are assets adjusted to certain proportions based on their level of risk. For example, risky loans have more weight. Therefore, according to the description, the capital adequacy ratio is a measure that shows whether a bank can cover the potential losses caused by its activities. Global standards and the rules of each country's central bank determine the minimum capital adequacy ratio to maintain a healthy and stable banking system. In Iran, this ratio has been set at at least 3% .In Iraq, the Capital Adequacy Ratio (CAP) is at least 8 percent, based on the laws and regulations of the Central Bank of Iraq (2019).

3.3 Control variables

Financial Leverage (LEV): Calculated from the ratio of total debt to total assets of the bank

(Onumah and Doho (2019);
SIZE: Calculated from the natural logarithm of the bank's total assets (Onumah and Doho, 2019);

Bank Concentration Criterion (HHIL): This variable refers to the analysis of market concentration or market share and shows how the market share is distributed among banks (Onumah and Doho, 2019);

State Ownership (GOWN): The percentage of institutional shareholders of the bank: this variable represents the percentage of government ownership in the bank and can have specific effects on the bank's policies and performance (Onumah and Doho, 2019);

Liquidity growth (CFGR) is calculated from the difference between the cash at the end and the beginning of the period divided by the cash at the beginning of the period (Yousefi Ghaleh Roudkhani et al., 2021);

Income Growth (INCGR): It is calculated from the difference between the income at the end of the period and the beginning of the period divided by the income at the beginning of the period (Yousefi Ghaleh Roudkhani et al., 2021);

Cash Ratio (CF): It is calculated from the ratio of total cash to total assets of the bank (Yousefi Ghaleh Roudkhani et al., 2021).

In this section, we describe the research methods used in this study. Due to the complexity of the subject under study, we have used a combination of advanced deep-learning techniques and machine learning algorithms .These methods include deep neural networks, supervised and unsupervised learning algorithms, and natural language processing methods that allow us to unravel hidden patterns in the data. To discover and create models with high predictive power. Our goal in using these advanced methods is to provide a comprehensive and accurate analysis of the available data and finally, to answer the research questions with the highest possible confidence level. Therefore, in this study, artificial neural network methods have been used to investigate the effects of financial stability efficiency and its effects on the financial sustainability of banks in Iran and Iraq.

Artificial Neural Networks (ANN): Artificial neural networks are utilized to model complex and nonlinear relationships between financial variables and financial sustainability. The network structure includes input, hidden, and output layers and uses different activation functions (Bahia, 2013). Recurrent Neural Networks (RNN) are suitable for processing time series data and maintaining long-term dependencies in financial data (Ilbeigipour al, 2022). Self-organizing maps (SOM) are used for unsupervised learning and reducing data dimensions, creating a two-dimensional representation of multidimensional data (Ilbeigipour al, 2022). Convolutional Neural Networks (CNN) are employed to identify complex, localized patterns in financial data and extract important features automatically (Wu et al., 2023). Deep Neural Networks (DNN) involve several hidden layers and can model complex, nonlinear relationships between financial variables (Saleem et al., 2022).

Clustering Algorithms: The Density-Based Spatial Clustering Algorithm of Applications with Noise (DBSCAN) detects irregular-shaped clusters and is consistent with noise in the data (Smiti and Elouedi, 2012). The K-Nearest Neighbor (KNN) algorithm is utilized for classification and regression, predicting a new bank's financial sustainability based on its nearest neighbors (Zhang et al., 2017). The K-mean algorithm divides banks into K clusters based on financial characteristics (Zhang and Xia, 2009).

Support Vector Machine (SVM) and Support Vector Regression (SVR): SVM is used to classify banks based on different levels of financial sustainability and isolates data in multidimensional space using hyperplanes. SVR predicts continuous values such as capital adequacy ratio and income growth (Amzile and Habachi, 2022). These methods are particularly important in analyzing the financial sustainability of banks due to their ability to identify complex patterns and relationships in large, nonlinear data (Rodríguez-Pérez and Bajorath, 2022).

Decision Tree Algorithm, Random Forest, and Gradient Boosting: The decision tree hierarchically divides the data using the Gini criterion (Appiahene et al., 2020). The random forest increases the prediction accuracy by combining the results of several decision trees. Gradient boosting builds the models incrementally to reduce error. Each method has specific mathematical formulas that help with more accurate data analysis (Blockeel et al., 2023). These algorithms can determine the relative importance of each independent variable in financial sustainability (Doumpos et al., 2023).

Using these advanced methods to study Iran and Iraq's banking systems can provide deeper insights and more accurate forecasts, which will be useful for fiscal policy and strategic decision-making in both countries. These methods allow for a comprehensive analysis and accurate comparison of the banking systems, helping policymakers and bank managers to identify the key factors affecting financial sustainability and take the necessary measures to improve the bank's financial position.

4. Data and information analysis

One of the main challenges in comparative international financial studies is the differences in the countries' currencies. To overcome this challenge، the concept of arbitrage has been used. Using the principles of arbitrage، the different currencies of Iran and Iraq have become a common dollar unit. This approach allows for a more accurate comparison of financial data and considers the effects of currency fluctuations in the analysis. In this step, the data have been prepared using the Min-Max Scaling normalization technique. Therefore, the results of the descriptive statistics are as follows in Table 3.

Table 3. Descriptive statistics

Variable	Mean	Median	SD	Variance	Kurtosis	Skewness	Jarque-Bera
Financial Stability	0.466	0.467	0.164	0.027	-0.080	-0.066	0.000
Capital adequacy of the bank	0.447	0.451	0.156	0.024	0.022	-0.045	0.000
Bank Size	0.518	0.518	0.164	0.027	-0.046	-0.072	0.000
Title of the Bank's Concentration Criterion	0.471	0.472	0.152	0.023	0.160	0.027	0.000
Government Ownership	0.471	0.472	0.148	0.022	0.071	-0.023	0.000
Bank Leverage	0.505	0.504	0.149	0.023	0.003	-0.113	0.000
Bank Leverage	0.575	0.575	0.087	0.022	-0.026	-0.034	0.000
Growth of bank revenues	0.479	0.477	0.143	0.023	-0.001	0.065	0.000
Bank Cash Ratio	0.512	0.519	0.153	0.023	-0.014	0.106	0.000

Source: Research calculations

The presented descriptive statistics show that the studied banks in Iran and Iraq have an average situation regarding most financial and performance indicators. The mean and median of most variables are in the range of 0.45 to 0.52, which indicates average performance. This is true for financial stability, intellectual capital, capital adequacy, bank size, concentration, and government ownership. However, some indicators show a relatively better situation. For example, bank liquidity growth with an average of 0.575 and bank leverage with an average of 0.505 shows that banks have relatively good liquidity growth and financial leverage. Also, the bank's cash ratio with an average of 0.512, indicates a good liquidity situation in banks. Therefore, the dispersion of the data is moderate for most variables, with standard deviations ranging from 0.14 to 0.16. This shows that there is a significant difference between the banks studied. A skewness close to zero for most variables indicates a relatively symmetric data distribution. However, a Jarque-Ber probability of 0.0000 for all variables indicates that the data distribution is not normal. Overall, these descriptive statistics paint a picture of a moderately performing banking system across most indicators, with strengths in liquidity and growth. However, there are challenges in terms of financial stability and capital adequacy. The non-normality of the data distribution also indicates that more advanced statistical analysis should use appropriate methods for non-normal data. Therefore, non-parametric statistical methods of machine learning and neural networks have been used in this research.

In this era, when the complexities of the financial system are increasing, it is important to evaluate and predict the stability of banks. This study aims to investigate financial stability and its performance for financial stability work in banks in Iran and Iraq from the new perspectives of neural networks and used machines. After collecting the relevant data, detailed and multi-step data preprocessing and software steps were performed, including outliers, missing data removal with interpolation techniques, and data smoothing in the interval [0,1]. In designing the architecture of neural networks, various and advanced methods are used, including artificial neural networks (ANN) with perceptron layer structure, deep neural networks with hidden layers, convolutional neural networks (CNN) with convolution and pooling layers, recurrent neural network (RNN) with LSTM and GRU units and self-organizing neural network (SOM) with unsupervised vision have been used. Optimization algorithms such as Adam and RMSprop are used to train these models, and L1/L2 and Dropout simulation model tuning techniques are used to avoid overfitting. Cross-validation methods have also been used to evaluate the performance of the models more accurately. This comprehensive and multi-dimensional use of neural networks provides the possibility of detailed analysis and financial stability of banks. The results related to neural networks are described in Table 4.

Table 4. Investigating the financial stability of banks using neural networks

Model	MASE	SMAPE	MPAE	MAE	RMSE	MSE	R^2
ANN	0.13	10.35	9.92	0.036	0.04	0.0023	0.95
DNN	0.14	10.30	10.20	0.039	0.05	0.0026	0.94
CNN	0.15	10.17	10.01	0.040	0.05	0.0025	0.94
RNN	0.16	10.91	11.05	0.043	0.05	0.0029	0.94
SOM	0.20	13.74	14.16	0.054	0.06	0.0046	0.90

Source: Research calculations

Based on the results presented in Table 4, it can be seen that the artificial neural network models have a significant performance in predicting and evaluating the financial stability of banks. The artificial neural network with a coefficient of determination of 0.95 has the highest accuracy among the models studied. This indicates the high ability of this model to explain changes in the financial stability of banks. Also, this model's mean square error and low root mean square error indicate the high accuracy of its predictions. Other neural network models such as deep, convolutional and recurrent neural networks also show similar performance with a coefficient of determination of 0.94. These results demonstrate the high performance of machine learning models in analyzing and predicting the financial stability of banks. The average percentage of absolute error and the average percentage of symmetric absolute error of these models are also within an acceptable range, indicating their ability to provide accurate estimates of the financial stability of banks. On the other hand, the self-organizing neural network with a coefficient of determination of 0.90 and higher errors shows a weaker performance than other models. This is due to specific complications in the structure of bank financial data. However, even this model shows a significant ability to explain changes in the financial stability of banks. Overall, the results in Table 3 show that neural networks and machine learning approaches are powerful tools for assessing and predicting bank financial stability. These models can help bank managers and policymakers identify factors affecting financial stability and make strategic decisions to improve the performance and stability of the banking system. The results can also be used to develop early warning systems to identify systemic risks in the banking sector.

The presented descriptive statistics show that the studied banks in Iran and Iraq are in an average situation in terms of most of the financial and performance indicators. The mean and median of most variables are in the range of 0.45 to 0.52, which indicates average performance. This is true for financial stability, intellectual capital, capital adequacy, bank size, concentration, and government ownership. However, some indicators show a relatively better situation. For example, bank liquidity growth with an average of 0.575 and bank leverage with an average of 0.505 shows that banks have relatively good liquidity growth and financial leverage. Also, the bank's cash ratio with an average of 0.512, indicates a good liquidity situation in banks. Therefore, the dispersion of the data is moderate for most variables, with standard deviations ranging from 0.14 to 0.16. This shows that there is a significant difference between the banks studied. A skewness close to zero for most variables indicates a relatively symmetric data distribution. However, a Jarque-Ber probability of 0.0000 for all variables indicates that the data distribution is not normal. Overall, these descriptive statistics paint a picture of a moderately performing banking system across most indicators, with strengths in liquidity and growth. However, there are challenges in terms of financial stability and capital adequacy. The non-normality of the data distribution also indicates that more advanced statistical analysis should use appropriate methods for non-normal data. Therefore, non-parametric statistical methods of machine learning and neural networks have been used in this research.

Table 5. Investigating the financial stability of banks using machine learning

MODEL	SMAPE	MAPE	MAE	RMSE	MSE	R_Square	MASE
XGBoost	8.800	9.002	0.035	0.045	0.002	0.956	0.134
Random Forest	10.096	10.481	0.040	0.051	0.002	0.944	0.153
C5-0	13.608	14.024	0.054	0.068	0.004	0.904	0.205

The importance of variables in checking the financial stability of the bank

Variable	Random Forest	XGBoost	C5-0
CAP	100	100	40.035
CF	0.743	1.185	48.664
CFGR	0.375	0.630	27.340
gown	0.248	0.305	0.000
hhil	0.000	0.000	15.319
lev	0.695	0.365	15.516
size	1.289	0.857	30.959
zscore	2.258	2.276	100

Source: Research calculations

The results presented in Table 5 show that machine learning models, especially gradient boosting and random forest, perform very well in predicting and evaluating the financial stability of banks. The gradient boosting model shows the highest accuracy with a coefficient of determination of 0.9566, which indicates the ability of this model to explain more than 95% of the changes in the financial stability of banks. This model also shows the lowest error in various evaluation measures including MSE, RMSE and MAE, which indicates the high accuracy of its predictions. The random forest model also has a significant performance with a coefficient of determination of 0.9441. This model can help discover complex patterns in banks' financial data. Although the decision tree model has a weaker performance than the other two models, it can still explain a significant part of the changes in the financial stability of banks with a coefficient of determination of 0.9045. These results show that machine learning approaches are powerful tools for analyzing and predicting financial stability in the banking industry. On the other hand, in examining the importance of variables, the results show that the capital adequacy ratio (CAP) is highly important in all three models. This emphasizes the importance of capital structure in the financial stability of banks. The Z score (Z-score) is the most important in the decision tree model, indicating this index's key role in evaluating banks' bankruptcy risk and financial stability. Cash flow (CF) and cash flow growth (CFGR) are also significant in the decision tree model, which emphasizes the importance of liquidity management in the financial stability of banks. On the other hand, variables such as bank size (size) and financial leverage (lev) have relative importance in different models. This shows that structural factors and financial risk management play an important role in the financial stability of banks. The variable of market concentration (hhil) is only of relative importance in the decision tree model, which can indicate the effect of market structure on the financial stability of banks. Overall, these results show that machine learning approaches are effectively used in evaluating and predicting the financial stability of banks. These models can identify key financial stability factors and help bank managers and regulatory bodies make strategic decisions and appropriate policies. Also, these findings can be used in developing early warning systems to identify systemic risks in the banking sector.

Advanced machine learning algorithms have been used to check the financial stability of Iranian and Iraqi banks. Before running the models, the financial data of the banks were standardized using Z-score normalization techniques to make the different scales of the variables the same and improve the performance of the models. In neural network-based algorithms, the neural structure was designed to include the input layer (with the number of neurons equal to the number of independent variables), hidden layers (with the number of neurons optimized for each model), and the output layer (with one neuron to predict financial stability). This structure allowed the models to discover complex and non-linear financial data patterns. Therefore, the results related to learning algorithms described in Table 6 are as follows.

Table 6. Investigating the financial stability of banks using learning algorithms

MODEL	MASE	SMAPE	MAPE	MAE	RMSE	MSE	R^2	Accuracy
Spatial clustering	0.004	0.218	0.217	0.086	0.106	0.011	1.000	99.995
K-Mean N	0.002	0.148	0.307	0.076	0.125	0.018	1.000	99.965
K-NN	0.071	3.341	3.373	1.260	1.552	2.408	0.990	99.027
SVR	0.183	8.493	10.377	3.225	5.896	34.767	0.916	91.624
SVM	0.183	8.493	10.377	3.225	5.896	34.767	0.850	85.000

Source: Research Calculations

The results presented in Table 6 indicate that spatial clustering algorithms and k-means clustering have exceptional performance in predicting and evaluating the financial sustainability of banks. Both models, with a coefficient of determination of 1 and accuracy close to 100%, demonstrate a superior ability to explain variations in banks' financial sustainability. These results suggest that these algorithms can effectively identify hidden patterns in financial data and provide a precise grouping of banks based on their financial sustainability status. Similarly, the k-nearest neighbor algorithm also shows good performance with a coefficient of determination of 0.9903 and an accuracy of 99.0276%. This model operates based on similarities between samples and has successfully understood the complex relationships between financial variables and provided accurate assessments of banks' financial sustainability. This result indicates that banks with similar financial characteristics likely have similar financial sustainability statuses.

On the other hand, Support Vector Regression (SVR) and Support Vector Machine (SVM), although performing weaker than the first three models, are still capable of providing reliable assessments of banks' financial sustainability with coefficients of determination of 0.9162 and 0.8500 and accuracies above 90% and 85%, respectively. These models, which operate based on finding optimal hyperplanes to separate data, have established appropriate decision boundaries for evaluating banks' financial sustainability.

Thus, comparing the performance of these algorithms shows that clustering-based and nearest-neighbor methods perform better in evaluating banks' financial sustainability compared to SVM-based methods. This may be due to the high capability of these methods in identifying similar patterns and grouping banks based on shared financial characteristics. These results also indicate that the structure of banks' financial data likely has natural clusters that these algorithms have identified well.

These results demonstrate that machine learning algorithms are powerful tools for evaluating and predicting banks' financial sustainability. These models assist bank managers and regulatory bodies in identifying financial sustainability patterns, grouping banks based on risk, and predicting the future status of banks. Moreover, these findings can be used in developing early warning systems to identify systemic risks in the banking sector and improve the financial stability of the entire banking system.

The present study, using advanced neural networks and machine learning approaches, has shown high accuracy in predicting and evaluating banks' financial sustainability. This finding is consistent with the study by Berger and Bouwman (2013), which showed that banks with greater liquidity creation perform better during financial crises and exhibit greater financial stability. Furthermore, the current research results regarding the importance of variables such as the capital adequacy ratio align with the findings of Elbadry (2018), which demonstrated that the capital adequacy ratio negatively affects credit risk in Saudi banks. Moreover, the advanced machine learning algorithms in the present study demonstrated exceptional performance in predicting and assessing the financial stability of banks. These findings are congruent with those of Abdallah et al. (2019), who showed that high efficiency in Kenyan banks leads to significant improvements in financial stability. The ability of the algorithms in the current research to identify complex patterns and group banks based on shared financial characteristics aligns with the findings of Safarzadeh et al. (2019) regarding the importance of financial reporting quality in banking stability. The current study's results concerning the significance of various financial variables are consistent with the findings of Onumah and Duho (2019), who demonstrated that intellectual capital components have varying impacts on Ghanaian banks' financial performance and stability. In addition, the present findings regarding the importance of bank size and financial leverage are consistent with the results of Almahadin (2020), who found that bank health indicators positively influence financial stability in Jordan. The study by Koskei (2020) also supports your findings, indicating that factors such as the liquidity ratio, inflation rate, and lending rate affect banking stability in Kenya. Consequently, using advanced machine learning approaches, the present study adds new findings to the existing literature. The current study's models' ability to accurately predict banks' financial stability and identify key influencing factors can contribute to developing early warning systems for identifying systemic risks. This aligns with the objectives of previous studies such as Xu et al. (2021), which examined the relationships between banking efficiency and financial stability in Latin America. Also, the findings of the present study, considering the importance of various variables in the financial stability of banks, can assist policymakers and bank managers in strategic decision-making, which is consistent with the aims of studies like Bhattacharjee (2023), who investigated the impact of intellectual capital efficiency on bank performance and financial stability in Bangladesh.

5. Conclusion and implications

This study aims to examine the impact of financial stability efficiency on the financial sustainability of banks in Iran and Iraq. The statistical population includes all banks listed on the stock exchanges of Iran (22 banks) and Iraq (44 banks). Using this long time frame and extensive statistical population allows for a detailed examination of long-term trends and comparing the status of banks in both countries. Utilizing neural network and machine learning approaches, this study has provided deep insights into the factors affecting the financial sustainability of banks.

The results obtained from artificial neural networks and machine learning algorithms indicate that these models, with coefficients of determination above 0.94, can predict and evaluate banks' financial sustainability. This suggests the existence of complex and nonlinear relationships between financial variables and bank sustainability that traditional methods have been unable to identify. The ability of these models to learn complex relationships can aid in improving risk management and strategic decision-making in banks. For example, Gradient Boosting and Random Forest were able to identify hidden patterns in financial data and provide accurate predictions. On the other hand, the high importance of variables such as the Capital Adequacy Ratio (CAP), Cash Flow (CF), and Cash Flow Growth (CFGR) in various models indicates that capital structure and liquidity management play a vital role in the financial sustainability of banks. This finding is especially significant given the liquidity challenges that banks in Iran and Iraq have faced in recent years, highlighting the necessity for greater attention to cash flow management and strengthening capital structures. Additionally, the importance of variables such as bank size and financial leverage (lev) demonstrates that the financial structure of banks has a considerable impact on their financial sustainability.

Spatial clustering algorithms and k-means clustering, with accuracy close to 100%, showed exceptional performance in grouping banks based on their financial sustainability status. This result indicates that the banks studied in Iran and Iraq have natural clusters in terms of financial characteristics. Identifying these groups can assist in formulating supervisory strategies tailored to each group of banks. This finding leads to a differentiated approach in banking supervision, where policymakers can adjust their supervisory strategies based on the specific characteristics of each cluster of banks.

Therefore, the results show that the banks studied in Iran and Iraq are in a moderate state concerning most financial and performance indicators. This suggests there is considerable room for improvement in the banking systems of both countries. Given the economic and geopolitical challenges both countries face, improving the financial sustainability of banks can play an important role in overall macroeconomic stability. This finding also indicates that policymakers in both countries should focus on increasing efficiency and improving bank performance.

A comparison of the results between banks in Iran and Iraq shows that despite structural and regulatory differences, there are similar patterns regarding the factors affecting financial sustainability. This can pave the way for regional cooperation in banking supervision and exchanging experiences. For example, both countries can benefit from each other's experiences in implementing early warning systems based on machine learning.

Thus, the high capability of machine learning models in predicting banks' financial sustainability suggests that these methods can be powerful tools in early warning systems. This helps improve banking supervision and prevent financial crises in both countries. For instance, regulatory authorities can use these models to identify banks at high risk of financial instability and take preventive actions promptly.

In summary, the results of this study indicate that the use of machine learning approaches can contribute to a deeper understanding of the factors affecting the financial sustainability of banks and improve risk management in the banking systems of Iran and Iraq. These findings can serve as a basis for formulating more efficient monetary and supervisory policies in both countries. For example, policymakers can use these results to fine-tune capital and liquidity requirements for banks.

Practical Policy Recommendations for Iranian Monetary Authorities

1. Develop and implement early warning systems based on machine learning to identify systemic risks in banks.
2. Strengthen supervision over banks' liquidity management, emphasizing cash flows and their growth.
3. Revise capital adequacy regulations and formulate new standards in line with the findings of machine learning models.
4. Establish incentive mechanisms for banks that demonstrate higher financial sustainability based on predictive models.

Practical Policy Recommendations for Iraqi Monetary Authorities

1. Utilize clustering algorithms to classify banks and formulate supervisory policies tailored to each group.
2. Focus on improving risk management in smaller banks, considering the importance of bank size in financial sustainability.
3. Enhance regional cooperation, especially with Iran, in exchanging experiences and technical knowledge related to using artificial intelligence in banking supervision.
4. Establish a specialized research center to continuously study banks' financial sustainability using advanced machine learning methods.

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