ASSESSMENT OF RISK MANAGEMENT AND EFFICIENCY OF BANK BRANCHES USING NETWORK DATA ENVELOPMENT ANALYSIS

Jafar Azizi *, Ragif Huseynov **, Maohua Li ***

* Department of Economics, Islamic Azad University, North Tehran Branch, Tehran, Iran
** Department of Economics, Azerbaijan Technological University, Ganja, Azerbaijan
*** *Corresponding author*, Institute for Corporate Social Responsibility, Xi'an Siyuan University, Xi'an, China
Contact details: Xi'an Siyuan University, 28 Shui'an Road Dongjiao Xi'an, Shaanxi, 710038, China

OPEN ACCESS

How to cite this paper: Azizi, J., Huseynov, R., & Li, M. (2023). Assessment of risk management and efficiency of bank branches using network data envelopment analysis [Special issue]. *Journal of Governance & Regulation, 12*(4), 214–226. https://doi.org/10.22495/jgrv12i4siart1

ISSN Online: 2306-6784
ISSN Print: 2220-9352

Received: 29.06.2022
Accepted: 14.11.2023

JEL Classification: J24, J53, H83
DOI: 10.22495/jgrv12i4siart1

Abstract

The purpose of this study is to investigate the efficiency of bank branches by using the data envelopment analysis models (DEA) in three stages, the effect of risk on the efficiency. This study used BCC and CCR indicators. The data used is related to 30 bank branches in 2020. The most crucial goal was simultaneously testing risk and efficiency in three stages. Results showed that in the case of CCR with risk-taking, 17 practical branches with a performance score of 100, and the rest were inefficient. The average risk-taking efficiency is also 0.9. The risk-based BCC model has also been used, with 19 branches with a performance score of 100 and the remainder inefficient. The efficiency of the branches using the CCR model includes 10 efficient branches, and the remaining branches are unproductive. By implementing the BCC model, efficient branches have 13 effective branches, and the remaining inefficiencies that have been effective after applying the risk factor in the second model, are Roodsar Branches and Imam and Chaboksar Blvd. Comparative analysis can help managers recognise where improvement should be prioritised, and inefficient branches become efficient in an operational plan.

Keywords: Bank Branch Performance, Data Envelopment Analysis, DEA, Risk

Authors' individual contribution: Conceptualization — J.A.; Methodology — J.A.; Validation — J.A., R.H., and M.L.; Investigation — J.A., R.H., and M.L.; Resources — J.A.; Data Curation — J.A.; Writing — Original Draft — J.A.; Writing — Review & Editing — J.A., R.H., and M.L.; Visualisation — J.A.; Supervision — J.A.

Declaration of conflicting interests: The Authors declare that there is no conflict of interest.

1. INTRODUCTION

Investing in the Iranian stock market bank shares is attractive for customers (Habibi et al., 2018). Undoubtedly, any activity that requires capital and financial resources requires the intervention of banks and financial institutions. Due to the significant role of banks in most economic activities, the study of the performance (productivity and efficiency) of each bank in the banking system has a special place. However, due to the bank service and the variety of provided services, evaluating their performance has specific problems. Unique methods are required to do so, which needs more accuracy and appropriate ways (Azizi et al., 2010). With the current and future economic conditions, bank management always has to reform and improve banking services, marketing, budgeting, innovation in services, and competition with other banks, ultimately increasing productivity and efficiency among its units and branches. One of the main ways for banks to succeed in improving their production methods and increasing their competitiveness with other banks is their branch network, and one of the primary ways to set up productivity and efficiency improvement programs at the bank level is the existence of an efficient network in the branches (Haghighat & Naseri, 2003). In the current situation, due to the expansion of bank branches all over the country, the construction of new financial and credit institutions, the establishment of private banks, the entry of foreign banks through free trade zones, and finally, the privatisation of banks in Iran, has created a new situation that requires a fundamental review and appropriate restructuring in the branch network of commercial and specialised banks in the country. By doing so, each bank can be aware of its branches' efficiency level, examine the causes of their branches' efficiency and inefficiency, and correct and direct inefficient units with appropriate planning. It is evident that as inefficient branches become more efficient while achieving these goals by reducing the cost of provided services and preventing the waste of scarce resources, we can expect more national benefits to be delivered, minimise the bank losses caused by inefficiency and become more efficient (Tsolas et al., 2020). Bank failure prediction has been a popular topic in credit risk and banking studies for decades. Statistical and machine learning methods have been working well in predicting the probability of bankruptcy for different time horizons before failure. In recent years, bank efficiency has attracted much interest from academic circles, where low productivity or efficiency in banks has been regarded as a potential reason for failure. Low efficiency implies low-quality management of the organisation, which may lead to bad performance in the competitive financial markets. Previous papers linking efficiency measures calculated by data envelopment analysis (DEA) to bank failure prediction have been limited to cross-sectional analyses (Li et al., 2022). The efficiency of banks has a critical role in developing sound financial systems in countries. Data envelopment analysis has witnessed an increase in popularity for modelling the performance efficiency of banks. Such efficiency depends on the appropriate selection of input and output variables. In the literature, no agreement exists on the selection of relevant variables. The disagreement has been ongoing among academic experts, and no diagnostic tools exist to identify variable misspecifications. A cognitive analytics management framework is proposed using three processes to address misspecifications. The cognitive process conducts an extensive review to identify the most common set of variables. The analytics process integrates a random forest method; a simulation method with DEA measurement feedback, and Shannon entropy to select the best DEA model and its relevant variables. Finally, a management process discusses the managerial insights to manage performance and impacts (Bou-Hamad et al., 2022). In today's banking environment, one of the main goals of bank management is to increase shareholder profits by emphasising the bank's performance, but this will often increase the risk level (Yousefvand et al., 2012). The issue of risk management has a profound effect on the performance of banks and has a significant impact on the country's economic development. Due to the expansion of banking and the position of banks as financial intermediaries, risk management in banks is one of the essential issues of banking (Azizi, 2014). Through risk management, banks can best use the current situation. Boubaker examined differences in bank efficiency between banks affiliated with single-bank holding companies and those affiliated with multi-bank holding companies by applying a fuzzy multi-objective two-stage data envelopment analysis technique. Using a sample of US commercial banks covering 1994–2018, the results showed that banks affiliated with multi-bank holding companies are more efficient than those affiliated with single-bank holding companies, suggesting that the former takes advantage of their parents' resources to enhance their efficiency, consistent with the internal capital market theory. They also show that banks with powerful CEOs exhibit lower efficiency than others. Moreover, there is an inverted U-shaped relationship between a multi-bank holding company structure and bank efficiency, suggesting the presence of an optimal number of multi-bank holding subsidiaries that maximises efficiency (Boubaker et al., 2020).

Banks often face some risks, such as market risk, credit, operations, and liquidity. The issue of risk management in banks has a profound effect on the bank's efficiency and has a significant impact on the country's economic growth. Any action to improve and enhance efficiency in the banking environment will improve the flow of savings, investment, and resource allocation. The country's potential, scattered, and hidden facilities will be used for development and public welfare (Panahiyan & Abiyak, 2012). In this study, an attempt was made to examine the simultaneous risk management and efficiency in the branches of Keshavarzi Bank, one of Iran's largest banks. This bank is weaker in terms of competitiveness than other banks and less attractive for investment. Therefore, first, the effects of credit, operational, and liquidity risk will be examined on the efficiency of branches, and then the efficiency and inefficiency of branches will be analysed. In the following, inefficient branches will be identified and improved based on a comparative comparison with efficient branches.

The structure of this paper is as follows. Section 1 is the introduction, in which the issue of research is raised and the importance and necessity of doing it are explained. Section 2 is the literature review, which examines and reports authoritative articles on the topic under discussion. Section 3 is the methodology, which has been used by researchers. Section 4 presents the results analysed based on the research method and primary data. Section 5 provides a discussion, where model output is discussed and hypotheses are tested. Section 6 is the conclusion, which expresses the results and objectives of this research and provides practical suggestions to improve the existing situation.

2. LITERATURE REVIEW

Data envelopment analysis (DEA) is a well-known nonparametric technique for measuring the relative efficiency of a set of homogenous decision-making units (DMUs) with multiple inputs and outputs. DEA is a typical data-based mathematical programming approach widely used for performance evaluations in many areas, such as hospitals, universities, investment companies, banks, the gas industry, etc. The first DEA model, namely CCR[1], was proposed by Charnes et al. (1987). Banker et al. (1984) hesitated in the case of constant return to scale (CRS). Afterwards, Banker et al. (1984) proposed the BCC[2] model for the case of variable return to scale (VRS). The evaluation of DEA is done based on two different models, i.e., envelopment DEA models and multiplier DEA models. The multiplier DEA model is directly related to the weights assigned to input and output data which play an essential role in evaluation. In the conventional multiplier DEA models, each DMU selects suitable individual weights to maximise efficiency. When there is freedom in the weight selection, the same input and output from the different DMUs may have different weights, which may not be rational or acceptable to the decision-makers and managers. In fact, due to the possibility of multiple solutions in multiplier DEA models, the optimal weights of a DMU under evaluation may not have unique, and it can differ from one DMU to others. Cook et al. (1990) and Roll et al. (1991) proposed the idea of using a common set of weights (CSW) to overcome this limitation for the first time. In CSW models, there is no DMU under evaluation, and the weights are obtained by solving a single optimisation problem (Řepková, 2014).

Lahouel et al. (2022) studied the cost-benefit tradeoff of income diversification in banking. Its main objective was to shed light on the non-linear effects of income diversification on the financial stability of a set of European commercial banks during the post-financial crisis period (2010–2019). From an efficiency perspective, they used a three-stage dynamic network slacks-based measure model to assess the financial stability of banks, including non-performing loans as a measure of risk that is carried over between two periods. Then, by performing a panel smooth transition regression model, they investigate the regime-switching behaviour of the relationship between income diversification and bank stability by showing how these variables heterogeneously interact. Their findings show that high levels of income diversification negatively and significantly impact bank financial stability regardless of the diversification index used. Important policy implications arise from their results about the optimality of income diversification and financial stability of European banks (Lahouel et al., 2022).

Omrani et al. (2022) showed the composition method in network data envelopment analysis (NDEA) is a popular method for measuring the efficiency of a two-stage process. The composition method is fractional bi-objective programming that is solved by non-linear programming techniques such as bisection search. Then, they used a method to transform negative data into positive and undesirable outputs into desirable ones. Finally, they developed the proposed model using the fuzzy α-cut approach to incorporate data uncertainty in the linear goal programming (GP) model. A numerical example is solved to validate the proposed model's accuracy. A real case of 22 insurance companies is examined to show the applicability of the proposed model. They also performed a comparative analysis to specify the benchmark and inefficient companies. Comparative analysis can help managers recognise where improvement should be prioritised (Omrani et al., 2022).

Khoshsima and Shahiktashi (2012) measured the impact of credit, operational and liquidity risks on the efficiency of the Iranian banking system. In this study, to evaluate the efficiency and ranking of banks, selecting an optimal model and then identifying the impact of credit, operational, and liquidity risks on the efficiency of the banking system are two parametric approaches with an economic basis and nonparametric basis, which are used by mathematical optimisation. In this regard, 15 banks were studied as the statistical population of the research during 2005–2010. Findings show the difference between parametric and nonparametric methods in evaluating the efficiency and ranking of banks and the relative superiority of the parametric method of stochastic frontier analysis (SFA) over the nonparametric method of multi-edge analysis (MEA). The article's findings also indicate a significant relationship between credit risk, operations, liquidity, and efficiency in the Iranian banking system (Khoshsima & Shahiktashi, 2012).

Tehrani et al. (2005) studied the efficiency of possible linear models, logistics, and artificial neural networks to predict customers' credit risk in the country's banking system. Predictor variables in these models were not the financial ratios of the borrowers, but their significant relationship with credit risk was confirmed by using appropriate statistical tests. Financial and credit data were used for 316 legal customers of the country's banks to design and test the mentioned models. The obtained results in this paper indicate that the relationship between variables in the credit risk forecasting model has not been linear. Therefore, the most appropriate credit risk forecasting models and the most efficient for credit risk forecasting to the order are related to artificial neural networks and logistics models (Tehrani et al., 2005). Epure and Lafuente (2010) examined the impact of risk on banking performance in the Costa Rican banking industry from 1998 to 2007. The authors stated that loans negatively affect productivity and return on assets when the capital adequacy ratio positively impacts profit margins (Epure & Lafuente, 2010). Chen and Pan (2012) examined the credit risk performance of 36 Taiwan commercial banks for the period from 2005 to 2008. The authors examined financial ratios to estimate credit risk and used data envelopment analysis to test hypotheses. The results showed that only one bank could perform the required performance over the entire period and generally found a weak correlation between credit risk and performance (Chen & Pan, 2012).

Chang and Hsieh (2011) examined the relationship between the components of intellectual capital and the three (operational, financial, and market) functions of the Tabuan Exchange in the electronics industry. The adjusted intellectual

[1] In 1978, Charnes, Cooper, and Rohdes presented a model called "CCR", the name of which derived from their initials.
[2] In 1984, Banker along with Charnes and Cooper presented a model called "BCC".

value-added coefficient model has been used to measure intellectual capital. The results showed that the relationship between operational performances is positively related to the capital employed and has no relationship with structural and human capital. The components of intellectual capital also have a negative relationship with the market and financial performance. Research and development expenditures are positively correlated with three functions, and intellectual property positively correlates with operational performance (Chang & Hsieh, 2011).

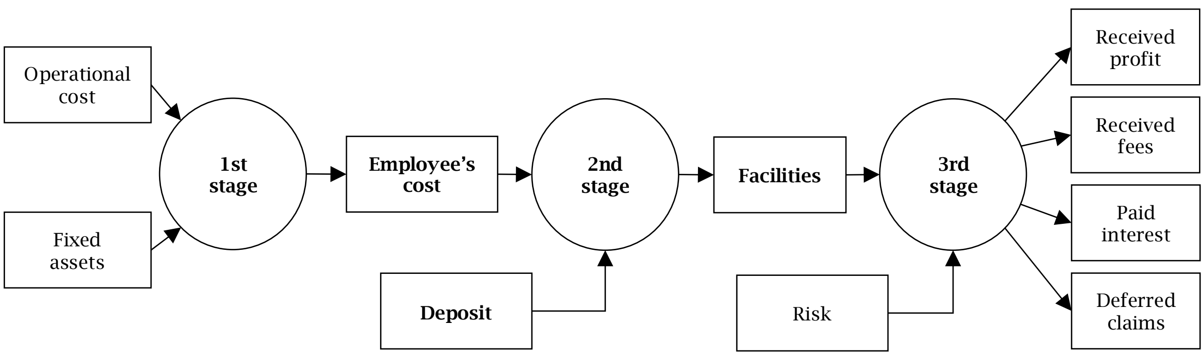
Data envelopment analysis is one of the methods used to measure efficiency. In this way, DMUs, a conceptual view of what constitutes data or output for a decision unit, are needed. This information must also be available to all DMUs. Identifying data and output variables is one of the essential measures in using DEA. Choosing the correct data and outputs plays a vital role in interpreting, using, and accepting the results of data envelopment analysis for managers and other users. Bank branches are service units that use their labour force, equipment, workspace, and deposits to provide various facilities by accepting the risk and generating income from operating expenses. It causes operational costs, personnel costs, building costs, fixed asset costs, etc. We can refer to the sub-sections performance and optimise the final output and initial input in the network data envelopment analysis model.

Zhou et al. (2019) developed a multi-period, multi-stage DEA model in which unused assets were carried over to subsequent periods, fixed assets and employee salaries were regarded as shared inputs for all three stages, and non-performing loans, which were characterised using triangular type-2 fuzzy numbers, were introduced as undesirable outputs to reflect credit risk. The developed model was applied to a case study to evaluate the efficiencies of listed Chinese commercial banks from 2014 to 2016, from which a disparity of inefficiencies was found; that is all banks were found to be generally inefficient; however, the inefficiencies occurred in different stages for different types of banks. Varying optimistic-pessimistic attitudes were applied to identify the overly sensitive banks, and comparisons were conducted to provide managerial insights and verify the superiority of the proposed model. It was concluded that to enhance overall efficiency, banks need to have a reasonable business scale, and adopting a three-stage analytical framework can better identify performance (Zhou et al., 2019).

Data envelopment analysis is one of the methods used to measure efficiency. In this way, DMUs, a conceptual view of what constitutes data or output for a decision unit, are needed. This information must also be available to all DMUs. Identifying data and output variables is one of the essential measures in using DEA. Choosing the correct data and outputs plays a vital role in interpreting, using, and accepting the results of data envelopment analysis for managers and other users. The selection of input and output variables in this study was based on the above studies, including Cook et al. (1990), Roll et al. (1991), Lahouel et al. (2022), Khoshsima and Shahiktashi (2012), and Epure and Lafuente (2010). Bank branches are service units that use their labour force, equipment, workspace, and deposits to provide various facilities by accepting the risk and generating income from operating expenses. Finally, it causes operational costs, personnel costs, building costs, fixed asset costs, etc. In the network data envelopment analysis model, we can refer to the sub-sections performance and optimise the final output and initial input.

Recent advances in the study of dynamic network data envelopment analysis (DNDEA) have provided better insight into the system to improve the efficiency and productivity of a DMU. A network structure of a DMU takes a holistic view of the production technology that connects several divisions internally by intermediate products and uses the carryover flow over time to add a temporal dimension to it (Bansal et al., 2022). Based on the studies of Bansal et al. (2022), Jeon and Lee (2015), Jeon et al. (2011), and Fukuyama and Tan (2022), a three-step method was used in this study. As shown in the diagram below, the cost of operations and fixed assets of stage 1 input and output of this stage include the cost of employees who enter stage 2 with the amount of deposit as independent input, the output of this stage is facilities and as stage 3 inputs enter the next stage with independent risk input. The network outputs include interest received, fees received, interest paid, and overdue receivables considered the final output.

Figure 1. Influence chart of research variables



The researchers' studies in Iran and the world show various methods to study the relationship between risk and performance. Some of these methods are mentioned here. For example, Kargi (2011), Andries (2011), and Akhtar (2010) have studied and analysed the efficiency of the data envelopment analysis method.

3. METHODOLOGY

According to the objectives, the present study is applied research. Based on the above-mentioned studies, the input and output variables, the research method, and the method of analysis were determined. It uses the data envelopment analysis method, which identifies inputs and outputs, viewing records and documents in bank branches. The study's statistical population is the branches of Keshavarzi Bank (30 branches), but the branches of this bank are very diverse. Thus, only the branches of one province (Guilan province) were evaluated. Because the data envelopment analysis technique is one of the valuable tools to measure the efficiency of units with similar structures, the first- and second-degree branches, which are also few, were not considered, and the fifth-degree branches were removed from the sample due to distance from other branches. The statistical population of this study was the branches of Agricultural Bank in Guilan province, which has 30 branches. All 30 branches were studied and accounting information was used for 2020. These variables are divided into two categories of inputs and outputs. For this purpose, a literature review was collected using library studies for a list of variables. After collecting the types of inputs and outputs, it was observed that their number is vast. Therefore, the obtained efficiency for the units understudy will be skewed. All values of inputs and results have been extracted from statistics and information obtained from Keshavarzi Bank branches in Guilan province. Therefore, using the opinion of experts, some insignificant data were deleted, homogeneous data were combined, and finally, the inputs and outputs were determined as follows:

The inputs (including primary, intermediate, and direct inputs) are as follows:

1. *Operating cost:* As the initial input of stage 1, it includes the cost of depreciation of fixed assets, paid commission, travel expenses of office, and others.
2. *Fixed assets* are the initial input of stage 1, including the value of tables, chairs, computers, furniture, and others.
3. *Paid interest* refers to the depositors' funds with the bank as direct input in stage 2, including interest paid.
4. *Credit risk* has been calculated as direct input in stage 3, including the amount of standard deviation in terms of the average profit received by the branches according to the number of facilities granted.
5. *Personnel expenses:* The middle input of stage 2 and the output of stage 1 include salary expenses, overtime, bonuses, holidays, and benefits related to the staff of the bank branches.
6. *Deferred receivables:* As an intermediate input of stage 3 and output of stage 2, including items that have been excluded from the current facility category due to non-repayment of facilities by customers.

The final outputs are as follows:

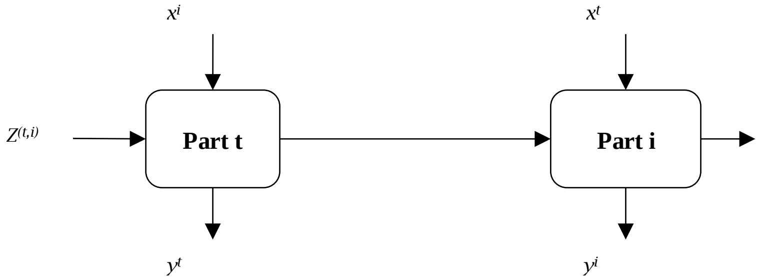
1. *Deposits:* The final output of stage 3, which includes the funds received from customers in the form of opening regular and current *Qarz al-Hasan* deposit accounts and short-term and long-term deposits of branches.
2. *Facilities:* The final output of stage 3, which includes all paid funds to customers in *Mudarabah* contracts, partnerships, instalment sales, *Qarz al-Hasan*, debtors of guarantees, agreement of rewards, *Murabahah,* and debt purchase to make a profit.
3. *Interest received:* The final output of stage 3, which includes the income from the facilities granted to credit customers based on the interest rate announced by the Supreme Council of Money and Credit.
4. *Collected fees:* A final output of stage 3, which includes received fees for issuing bank checks, guaranteed issuance of electronic cards and online services, real estate appraisal fees, project expertise, facility instalments, and more. A summary of the model's inputs and outputs comes at each stage of this study in Table 1.

Table 1. A summary of the model's inputs and outputs at each stage of this study

Inputs	*1st stage*	*2nd stage*	*3rd stage*
Primary	Operational expenses Fixed assets	-	-
Secondary	-	Personnel expenses	Deferred claims
Direct	-	Paid interest	Credit risk

The presented model in the research is a three-step process including inputs and outputs such that the output of stage 1 is the input of stage 2, and the output of stage 2 is the input of stage 3. The network data envelopment analysis model with an underground structure is used in this research. In this case, the input of the whole system enters the first part, and the final output of the system leaves the last part. The parts of each DMU are numbered as follows to evaluate the envelopment analysis of secret network data.

Figure 2. Parts of a data envelopment analysis of a network



Section (1) is where other parts can consume one part of its production, and the rest can be taken out of the system as output. In other words, its output is divided into two parts y^1 and $(k = 2,\dots,m)Z^{(1,k)}$ in which the output y^1 is directly out of the system and $Z^{(1,k)}$ is considered as input to the part $(k = 2,\dots m)k$. The input of section (1) is provided by input sources only (Thaker et al., 2022).

The t-part of the system is called the part that can consume some of its output by the components $(k = t + l,\dots m)$ and remove the rest of its output directly from the system. That is, the output has two parts of y^t and $(k = t + l,\dots m)$, in which y^t is directly out of the system and $(k = 2,\dots,m)Z^{(t,k)}$ can be consumed as input in sections $(k = t + l,\dots m)$. This section can supply some of its input directly from input sources and the rest from sections $t - l,\dots 2{,}1$. So, the inputs of this part can be provided by x', which is directly from the input sources and $(k = 2,\dots,m)Z^{(t,k)}$, which is an output of the parts $(k = t + l,\dots,m)$.

In the CCR model, the purpose is to measure and compare the relative efficiency of organisational units such as bank branches with several inputs and several similar outputs, CCR models are among the models of fixed returns to scale so that increasing inputs leads to increased output. By converting the CCR model to a linear programming model, the input-based CCR model is obtained. In the input-driven CCR model, the evaluation process tries to minimise the inputs by keeping the output level constant, and we are looking for a ratio, in which the inputs are reduced so that the outputs remain unchanged and place the unit at the efficiency limit. Therefore, according to the model inputs and the risk that enters the model in the third stage as direct input. Also, the need for risk management by banks (as financial intermediaries), and finally, reducing risk in bank branches, the input-oriented CCR model has been used in this research. Input and output variables are obtained from the database and balance sheet of the branches. General Algebraic Modeling System (GAMS) software is used for analysis. Efficiency can be obtained from the following model (Matthews, 2013):

$$max \textstyle\sum_{i=l}^{k} U_i Y_o^i$$

$$s.t. \textstyle\sum_{i=l}^{k} V_i X_o^i = 1 \tag{1}$$

$$U_t Y_j^t + \sum_{i=t+l}^{k} W_{(t,i)} Z_j^{(i,j)} - V_t X_j - \sum_{i=1}^{t-l} W_{(i,t)} Z_j^{(i,t)} \le o,\ \ t = l,\dots k\ \ , j = l,\dots,n$$

where, u_i and v_i and $w_{(t,i)}$ are the input, output, and average inputs. Risk is used as input in stage 3 under the heading of credit risk and based on standard deviation, which is calculated from the collected information from the granted facilities by banks and their received interest, as well as the amount of obtained standard deviation obtained in terms of average interest received (Lartey et al., 2021).

To calculate, first $\rho_i = \frac{R_i}{\sum_{i-1}^{n} R_i}$ and $\overline{R'} = \frac{\sum_{i-1}^{n} R_i'}{n}$ should be obtained, where R_i and R_i' are the granted facilities and the received interest from the bank is i, and then the risk amount $\sigma = \sqrt{\sigma^2}$ is calculated by the following equation (Azizi, 2015):

$$\sigma^2 = \sum_{i-1}^{n} (R_i' - \overline{R_i'})^2 \times \rho_i \tag{2}$$

4. RESULTS

An efficient banking system significantly impacts economic growth, reducing unemployment and controlling inflation. Hence, one of the basic corrective movements in the country's economy is to reform the structure of the banking system and performance analysis as a suitable criterion for evaluating and studying the performances of this industry's enterprises. However, one of the essential principles for assessing the performance of economic units is to choose the suitable evaluation model and determine the correct inputs and outputs. Efficiency and risk are two necessary and fundamental categories in the banking industry. The motivation of the bank to manage a risk starts from where the relevant risk causes a decrease in efficiency. The risk management issue in the bank not only has a profound effect on the bank's efficiency, but it also has a significant impact on the country's economic growth. For this purpose, 30 branches of Keshavarzi Bank in the Guilan region were evaluated. We are looking for a ratio in the bank branches where the outputs should increase, and the unit should reach the efficiency limit without changing the inputs. Therefore, this study uses the output-driven data envelopment analysis (CCR model), which is first in a fixed-scale return mode and then is changed from a fixed-scale. Still, because the country's banking system is constantly tasked according to rules and regulations, the monetary system's strategic policies, and the economy are changing, the branches' efficiency in the mode of return on a variable scale and the input-axis method (BCC model) was used. The risk was added as an input to each model in the next step, and the results were compared. GAMS software was used for calculations. Initially, all values of inputs and outputs were extracted from statistics and collected information from Keshavarzi Bank branches in Guilan province, and they were entered according to the presented model.

4.1. Implementation of data envelopment analysis model using CCR output-based method

This model, which seeks to maximise output by keeping inputs constant, is first considered in the first step without considering the risk and then with the consideration of the risk. In the third stage of the model, risk is entered as input to the model. And then risk management and performance in efficient branches are described. Therefore, according to the characteristics of the model, deferred receivables are considered as an input indicator. Table 2 shows the results of the CCR model without the factor of risk. According to the obtained results in Table 2, after implementing the data envelopment analysis model, 10 branches, including Rasht Bazaar, Talesh, Khomam, Rasht Municipality, Somehsara, Shariati-Rasht, Rahimabad, Payambar-e-Azam, Masal and Sangar are efficient, and the rest of the branches are inefficient.

Table 2. Branch efficiency score based on the CCR model

No.	*Branch*	*Efficiency rate*	*Description*	*No.*	*Branch*	*Efficiency rate*	*Description*
1	Roudsar	0.9238	Inefficient	16	Somehsara	1	Efficient
2	Fooman	0.898163	Inefficient	17	Rezvanshahr	0.759072	Inefficient
3	Astara	0.659929	Inefficient	18	Shariatirasht	1	Efficient
4	Bazzar Rasht	1	Efficient	19	Khoshkibijar	0.719437	Inefficient
5	Talesh	1	Efficient	20	Chaboksar	0.963583	Inefficient
6	Ghaszian Anzali	0.904585	Inefficient	21	Takhti St., Rasht	0.930221	Inefficient
7	Khomam	1	Efficient	22	Kianshahr port	0.849623	Inefficient
8	Kashef hayajan	0.702765	Inefficient	23	Rahim-Abad	1	Efficient
9	Manjil	0.80902	Inefficient	24	Shahid Ansari	0.665315	Inefficient
10	Bistoon	0.818585	Inefficient	25	Payambar Azam	1	Efficient
11	Imam Boulevard	0.73689	Inefficient	26	Shahid Beheshti	0.743661	Inefficient
12	Rasht Municipality	1	Efficient	27	Shohada St.	0.590955	Inefficient
13	Razi Square	0.639152	Inefficient	28	22nd Bahmn	0.601563	Inefficient
14	Astaneh Ashrafi	0.762937	Inefficient	29	Masal	1	Efficient
15	Amlesh	0.764739	Inefficient	30	Sangar	1	Efficient
Average efficiency						**0.848133**	
STDEV						**0.126656**	

Source: Authors' elaboration.

The average efficiency is 0.8481 and the standard deviation is 0.1266. In the data envelopment analysis method, the reference set is used to identify the branches with the best performance, which are the branch models with poor performance. The reference set for any branch with less than 100% efficiency includes branches with 100% efficiency with which the inefficient branch can be directly compared. This means that the member sets of the reference set have the same combination of inputs and outputs, and the reference set for each inefficient unit consists of one or a variety of two or more efficient units which are introduced as a model. Reference units for each inefficient unit are recognised based on non-zero highlighted values resulting from model solving (except for the highlighted value of the first constraint). A virtual unit of the inefficient unit comprises a balanced combination of inputs and outputs. Thus, when inefficient and efficient branches are recognised according to the data, the inefficient branches can reach efficient branches. The share of each efficient branch in forming virtual units for each inefficient branch depends on the weight of the reference branch composition. According to Table 3, by combining reference branch weights with an efficiency of 100, inefficient branch model units will be obtained.

Table 3. Reference set of inefficient branches and their weight in each CCR model

No.	Branches	Branch code	Reference branches	Reference branches combination	No.	Branches	Branch code	Reference branches	Reference branches combination
1	Roudsar	60	Bazaar Rasht	0.36938573	15	Amlash	142	Bazaar Rasht	0.30013436
			Sahriati Rasht	0.74100438				Rahimabad	0.65343846
			Rahim Abad	0.36987423				Masal	0.10848911
			Payambar Azam	0.003785				Sangar	0.05766772
2	Fooman	70	Bazaar Rahst	0.22898427	16	Somehsara	200	1	1
			Talesh	0.12341551	17	Rezvanshahr	291	Bazaar Rasht	0.23433305
			Rahimabad	0.35707011				Talesh	0.7693401
			Sangar	0.81597171				Khomam	0.1102693
3	Astara	71	Bazaar Rasht	0.11701823				Rahim Abad	0.53691416
			Talesh	0.21328032	18	Shariati Rasht	877	Shariati Rasht	1
			Rahimabad	0.728232205				Bazaar Rasht	0.34573232
			Sangar	0.8342692	19	Khoshbijar	968	Talesh	0.09269768
4	Bazaar Rasht	108	Bazaar Rasht	1				Khomam	0.00895064
5	Talesh	132	Talesh	1				Rahimabad	0.5528129
6	Ghazian Anzali	188	Bazaar Rasht	0.58582068	20	Chaboksar	1058	Bazaar Rasht	0.55089484
			Khomam	0.17971443				Talesh	0.00237186
			Rahimabad	0/35496719				Khomam	0.06107487
7	Khomam	237	1	1				Rahimabad	0.06344227
8	Kashef Lahijan	329	Bazaar Rasht	0.48082111	21	Takhti St. Rasht	Rasht	Bazaar Rasht	0.32202558
			Khomam	0.22745521				Rasht Municipality	0.16122482
			Rahimabad	0.64854593				Rahimabad	0.51214434
9	Manjil	381	Bazaar Rasht	0.51728692	22	Kianshahr port	1124	Bazaar Rasht	0.32231672
			Khomam	0.17910362				Khomam	0.17432527
			Rahimabad	0.46154229				Rahimabad	0.42004271
10	Bistoon	502	Khomam	0.61240277	23	Rahimabad	127	Rahimabad	1
			Rahimabad	0.52580405	24	Shahid Ansari	1938	Bazaar Rasht	0.15702608
11	Imam Khomeini Boulevard	695	Bazaar Rasht	0.29495989				Talesh	0.08916319
			Talesh	0.00083612				Khomam	0.12190013
			Khomam	0.0885774				Rahimabad	0.65374796
			Rahimabad	1.19760862				Payambar Azam	1
12	Rasht municipality	1508	Rasht municipality	1				Bazaar Rasht	0.31291836
13	Razi Square	1831	Bazaar Rasht	0.38619563	26	Shahid Beheshti	1599	Khomam	0.01581959
			Rahimabad	0.9315109				Rahimabad	0.5833001
			Masal	0.04124282	27	Shohada St.	806	Talesh	0.0162717
			Sangar	0.21525025				Rahimabad	0.53908656
14	Astaneh Ashrafiyeh	66	Bazaar Rasht	0.03591158				Sangar	0.094020656
			Talesh	0.3753953	28	22nd Bahman	1878	Rasht municipality	0.41673786
			Rahimabad	0.33551637				Rahimabad	0.050460544
15	Amlash	142	Bazaar Rasht	0.30013436	29	Masal	610	Masal	1
					30	Sangar	299	Sangar	1

Source: Authors' elaboration.

For example, the model units of the inefficient branch of Ghazian Anzali are the efficient branches of Bazaar Rasht, Khomam, and Rahimabad, and from the combination of reference units, a virtual unit related to the inefficient unit is created. Non-zero highlighted values represent the ratio of the variety of reference units to build the virtual unit. The results of solving the model of the Ghazian Anzali branch indicate the inefficiency with a score of 90.0, and the reference branches are the efficient branches of Bazaar Rasht, Khomam, and Rahimabad according to the non-zero highlighted price. Therefore, the weighted average of outputs and inputs of the model unit for the Ghazian Anzali branch is obtained using the obtained weights (highlighted parts) as follows.

The score of the model unit's operating cost: 0.585 (the operational costs of the Bazaar Rasht branch) + 0.179 (the operational costs of the Khomam Branch) + 0.357 (the operational costs of the Rahimabad branch) = 289.

Similarly, the weighted average of model unit inputs, including fixed assets, personnel costs, dividends, and deferred claims, is obtained.

Model unit deposit score: 0.585 (deposit of the Bazaar Rasht branch) + 0.179 (deposit of the Khomam branch) + 0.354 (deposit of the Rahimabad branch) = 134450.

Similarly, the weighted average of the model unit outputs, including facilities, received interest, and fees is obtained for other outputs. One of the features of the data envelopment analysis method is providing a plan and solution to improve the units' performance. First, the improvement point or target for each output variable was calculated by considering the CCR model. The actual input and output values correspond precisely to the target values for efficient units, indicating that the program continues as planned. However, inefficient branches have not achieved the set objectives and the optimal point (image points) in the variable under consideration. For example, the Astara branch's amount of deposits, facilities, and income are less than the optimal amount and the target. Therefore, to reach the optimal point and the desired efficiency limit, the deposits, facilities, and income index should increase by 51.53%, 51.53%, and 129,09%, respectively, which means that first, they should try to increase the deposit and then allocate it for the customers to earn profit and income. It is worth noting that in some branches, deferred receivables have a negative deviation, which indicates that the outstanding receivables of the branch should be reduced. In the third step, by entering the risk as an independent input for 30 branches, the efficiency of the branches is measured. After implementing the data envelopment analysis model, according to the risk factor in Table 4, it was concluded that 17 branches are efficient, and the rest of the branches are inefficient. These 17 efficient branches are Roodsar, Astara, Bazaar Rasht, Talesh, Ghazian Anzali, Khomam, Kashef Lahijan, Rasht Municipality, Soomehsara, Shariati Rasht, KhoshkBijar, Chaboksar, Kiashahr Port, Rahimaabad, the Payambar Azam, Masal and Sangar.

Table 4. Efficiency score with entering risk in 3rd stage of the CCR model

No.	*Branch*	*Efficiency score*	*Description*	*No.*	*Branches*	*Efficiency score*	*Description*
1	Roodsar	1	Efficient	16	Somehsara	1	Efficient
2	Fooman	0.917530675	Inefficient	17	Rezvanshahr	0.833239544	Inefficient
3	Astara	1	Efficient	18	Shariati Rasht	1	Efficient
4	Bazaar Rasht	1	Efficient	19	Khoshkbijar	1	Efficient
5	Talesh	1	Efficient	20	Chaboksar	1	Efficient
6	Ghazian Anzali	1	Efficient	21	Takhti Rasht St.	0.938129381	Inefficient
7	Khomam	1	Efficient	22	Kianshahr port	1	Efficient
8	Kashef lahijan	1	Efficient	23	Rahimabad	1	Efficient
9	Manjil	0.932656844	Inefficient	24	Shahid Ansari	0.735363141	Inefficient
10	Bistoon	0.81858133	Inefficient	25	Payambar azam	1	Efficient
11	Imam Boulevard	0.769589231	Inefficient	26	Shahid Beheshti	0.748960087	Inefficient
12	Rasht municipality	1	Efficient	27	Shohada St	0.603723257	Inefficient
13	Razi Square	0.716158607	Inefficient	28	22nd Bahman	0.601562901	Inefficient
14	Astaneh Ashrafiyeh	0.76292685	Inefficient	29	Masal	1	Efficient
15	Amlash	0.804089135	Inefficient	30	Sangar	1	Efficient
Average efficiency					**0.906083699**		
STDEV					**0.111109527**		

Source: Authors' elaboration.

The average efficiency without taking the risk factor into account is 0.848, and with taking the risk factor into account, it is 0.9061, and the standard deviation is 0.1111. Hence, risk and its management are essential factors in evaluating bank branches' performance. While assessing the branches by considering the risk factor, some branches like Rudsar, Astara, Kashef Lahijan, Khoshkbijar, Chaboksar, and Kiashahr port have become inefficient. With the entry of the risk index in stage 3 as an independent input, the number of efficient branches has increased, and subsequently, the number of branches that is as a model of the efficient unit has also increased, so that in some branches, such as Razi Square the number of model units reaches 6.

In the CCR model with risk, it is shown that in inefficient branches, the degree of deviation from the goals of the variables is determined, which inefficient branches must achieve to achieve the goal. To reach the efficient border in the Bistoon branch, the need to reduce risk is 32% and increase deposit; Facilities and income are 22%, 23%, and 29%, respectively. It also requires a reduction of deferred receivables by 25%. The Roodsar branch is inefficient without taking the risk factor into account because it has not been able to attract deposits and is equally inefficient in paying the facilities. Hence, it deviates from the target income. Still, taking the risk factor into account is efficient because attracting deposits and non-deviation with a suitable amount of risk has led to the total allocation of facilities and earnings. The Fooman branch is inefficient without taking the risk factor into account because the expected profit compared to the payment facility is low in this branch, and it has a significant deviation. This branch is also inefficient in taking the risk factor into account.

Considering that this branch has taken a very high risk, it should earn the minimum target income, which is not fulfilled, and the income has a deviation from the target. Astara branch is inefficient without considering the risk factor because it has high overdue receivables due to payment facilities. Due to the lack of total allocation of resources and non-receipt of receivables, the branch has earned a lower income than the target. So by applying the risk factor, it will become efficient, and because of its low risk, the earned income will be higher than the average received profit. Bazaar Rasht branch is efficient without considering the risk factor because it has low deferred receivables. The amount of allocated resources and facilities is desirable, has reached the set goals, and has no deviation.

In most cases, this branch is part of reference branches, and with the entry of risk, this branch remains efficient because it can tolerate high risk by absorbing the resources equal to the paid facilities. This branch has a high amount of deferred claims, but it successfully earns. Talesh branch is efficient without taking the risk factor into account due to the high absorption of resources and payment of profits. Still, it has also achieved the desired goals of allocating resources and earning profit. It is also one of the model branches in most cases. This branch is efficient in considering the risk factor because it has high-risk tolerance while absorbing resources for the paid facilities. Although it has high deferred claims, it has performed well in earning income. Ghanian branch was inefficient without taking the risk factor into account because it could not earn a significant amount of income due to high personnel costs and interest payments for attracting resources (attracting customers for high-interest payments), which indicates non-allocation resources and payment of facilities. But this branch is efficient considering the risk factor. Because it has absorbed high deposits for the low amount of risk it has taken, it has attracted a large number of deposits and earned a reasonable profit by entirely allocating the facilities. Khomam branch is efficient without considering the risk factor and is the model of most branches. Because of the operating costs and fixed assets, it has absorbed a considerable amount of resources with the help of its personnel. It has reached earning the target income by paying facilities. This branch is efficient even by considering the risk factor because it has a lower risk. It has been able to adjust its performance to obtain the highest return from the risk incurred has acted in the direction of good deposit, and is successful in customer orientation.

Kashif Lahijan branch is inefficient without considering the risk factor. Because in addition to the lack of total absorption of deposits with high-interest payments, the lack of total allocation of resources and the existence of deviations in the payment of facilities has led to the lack of full realisation of the desired income. But with the entry of risk, it is efficient because it can pay for the complete facilities earn interest, and reimburse its expenses by bearing a negligible risk. Manjil branch is inefficient without taking the risk factor into account due to the attracted deposits, paid interest, and the number of low payment facilities, which is not efficient with the entry of risk because the amount of paid interest to attract resources is deviant from the goals and paying the facilities will not compensate the loses. The Boston branch is inefficient without taking the risk factor into account. Due to its high deferred receivables, it pays fewer facilities and has a deviation in attracting resources and earning income. Because it has high deferred receivables, it has not been able to bear the increased risk. It has paid fewer facilities, which has earned less profit; the other branches are analysed in the same way according to the information in the table.

Selecting an evaluation model from a data envelopment analysis data set and incorporating additional features into the model to provide a more realistic evaluation is perhaps one of the most critical parts of the job. Banks and operating units in the financial services sector are financial intermediaries that receive deposits from customers and consider the resulting debt as an asset and lend it to other customers in return for those resources; they pay profit to depositors and receive interest from borrowers. In the bank's intermediary attitude, the two leading roles are to receive and distribute resources efficiently and facilitate investors' activities. In doing so, making more profit requires using various inputs with variable amounts by adopting a strategy in which the variable outputs are removed while facing competition between banks.

4.2. Implementation of data envelopment analysis model using BCC output based method

Considering that scale returns indicate the relationship between changes in inputs and outputs of production, it can be said that the service system is an enterprise, so in this study, according to scale returns, the BCC model has been used in Table 5. As can be seen, 13 of the branches are efficient and the rest are inefficient. In the following part, the risk will be entered into the BCC model as an independent entry in the third stage, and the results are reported in Table 6. The results indicate that 19 branches are efficient.

Table 5. Efficiency evaluation table by the entering based method in BCC model

No.	*Branch*	*Efficiency score*	*Description*	*No.*	*Branch*	*Efficiency score*	*Description*
1	Roodsar	1.0000	Efficient	16	Somehsara	1.0000	Efficient
2	Fooman	0.9737	Inefficient	17	Rezvanshahr	0.7622	Inefficient
3	Astara	0.8115	Inefficient	18	Shariati Rasht	1.0000	Efficient
4	Bazaar Rasht	1.0000	Efficient	19	Khoshkbijar	0.7195	Inefficient
5	Talesh	1.0000	Efficient	20	Chaboksar	1.0000	Efficient
6	Ghazian anzali	0.9549	Inefficient	21	Takhti Rasht St.	0.9309	Inefficient
7	Khomam	1.0000	Efficient	22	Kiashahr port	0.8665	Inefficient
8	Kashef Lahijan	0.7905	Inefficient	23	Rahimabad	1.0000	Efficient
9	Manjil	0.8711	Inefficient	24	Shahid Ansari	0.6686	Inefficient
10	Bistoon	0.8746	Inefficient	25	Payambar Azam	1.0000	Efficient
11	Imam Boulevard	1.0000	Efficient	26	Shahid Beheshti	0.7530	Inefficient
12	Rasht Municipality	1.0000	Efficient	27	Shohada St.	0.6088	Inefficient
13	Razi Square	0.7998	Inefficient	28	22nd Bahman	0.6084	Inefficient
14	Astaneh Ashrafiyeh	0.7778	Inefficient	29	Masal	1.0000	Efficient
15	Amlash	0.8075	Inefficient	30	Sangar	1.0000	Efficient
Average efficiency					**0.886648276**		
STDEV					**0.115388109**		

Source: Authors' elaboration.

Table 6. Efficiency evaluation in the BCC model by entering the risk

No.	*Branch*	*Efficiency score*	*Description*	*No.*	*Branch*	*Efficiency score*	*Description*
1	Roodsar	1	Efficient	16	Somehsara	1	Efficient
2	Fooman	0.98933	Inefficient	17	Rezvanshahr	0.84959	Inefficient
3	Astara	1	Efficient	18	Shariati Rasht	1	Efficient
4	Bazaar Rasht	1	Efficient	19	Khoshkbijar	1	Efficient
5	Talesh	1	Efficient	20	Chaboksar	1	Efficient
6	Ghazian anzali	1	Efficient	21	Takhti Rasht St.	0.93949	Inefficient
7	Khomam	1	Efficient	22	Kiashahr port	1	Efficient
8	Kashef Lahijan	1	Efficient	23	Rahimabad	1	Efficient
9	Manjil	1	Efficient	24	Shahid Ansari	0.7741	Inefficient
10	Bistoon	0.87456	Inefficient	25	Payambar Azam	1	Efficient
11	Imam Boulevard	1	Efficient	26	Shahid Beheshti	0.75571	Inefficient
12	Rasht Municipality	1	Efficient	27	Shohada St.	0.60881	Inefficient
13	Razi Square	0.98609	Inefficient	28	22nd Bahman	0.60843	Inefficient
14	Astaneh Ashrafiyeh	0.77784	Inefficient	29	Masal	1	Efficient
15	Amlash	0.82005	Inefficient	30	Sangar	1	Efficient
Average efficiency					**0.9328**		
STDEV					**0.092887333**		

Source: Authors' elaboration.

5. DISCUSSION

After implementing the data envelopment analysis model in CCR mode and taking the risk factor into account for 30 branches in Keshavarzi Bank of Guilan province, 17 branches including Roodsar, Astara, Bazaar Rasht, Talesh, Ghazian Anzali, Khomam, Kashef Lahijan, Rasht Municipality, Soomehsara, Shariati Rasht, Khoshkbijar, Chabaksar, Kiashahr port, Rahimaabad, Payambar Azam, Masal, and Sangar were efficient with the efficiency score of 100 and the rest of the branches were inefficient. Also, the average efficiency with the risk factor is 90.0. Considering the role of the bank and the existence of internal and external factors related to the banking industry and continuous changes in inputs and outputs, the BCC model has been used with a risk factor, which includes 19 branches, including Roodsar, Astara, Bazaar Rasht, Talesh, Ghazian Anzali, Khomam, Kashef Lahijan, Manjil, Imam Boulevard, Rasht Municipality, Soomehsara, Shariati Rasht, Khoshkbijar, Chaboksar, Kiashahr port, Rahimaabad, Payambar Azam, Masal and Sangar with an efficiency score of 100 are efficient, and the rest are inefficient. Manjil and Imam Khomeini Boulevard branches have also reached efficiency in the second model. The efficiency of the branches with the use of the CCR model includes 10 branches in Bazaar Rasht, Talesh, Khomam, Rasht Municipality, Soomehsara, and Shariati Rasht, Rahima Abad, Payambar-e-Azam (PBUH), Masal and Sangar, Kara and the rest of the branches are inefficient. With the implementation of the BCC model, Kara branches include 13 branches, Rudsar, Bazaar Rasht, Talesh, Khomem, Boulevard Imam, Rasht Municipality, Soomehsara, Shariati Rasht, Chaboksar, Rahimabad, Payambar Azam, Masal and Sangar, are efficient branches, and the rest are inefficient. Roodsar, Imam Boulevard, and Chaboksar have also reached efficiency in the second model. The average efficiency is 0.9328 and the standard deviation is 0.09289. In the CCR model, the Shohada St. branch, with an efficiency score of 59.0, has the lowest efficiency among inefficient branches. In the CCR model, by taking the risk factor into account, the Shohada St. branch and 22nd Bahman, with an efficiency score of 60.0, are the most inefficient branches, and in the BCC model, the mentioned branches are among the most inefficient branches.

6. CONCLUSION

By considering the research results and the amount of calculated efficiency, the risk is an essential factor in evaluating the performance of Keshavarzi Bank branches in Guilan province. So, by taking the risk factor into account, the total capacity of the capacity and facility allocation has been used. In these branches, the income is earned by accrediting and measuring the ability of customers' credit. If the branches take a high risk, they will face an increase in deferred receivables and a decrease in income, and they will deviate from the goals of the output variables. The reasons for the efficiency of efficient branches are to bear the risk of paying the facilities and earning the expected profit, or the branches have taken a little risk but have a higher return than their incurred risk. Also, the reasons for the inefficiency of the branches, despite the risk, are that with very high-risk tolerance due to lack of accreditation and lack of review of the customer's financial ability, the branch could not obtain the minimum expected profit and the bank's receivables were transferred to non-current class. Therefore, because banks are risk-taking organisations, risk-taking is necessary for future profitability. There are various risk exposure reasons in the banking industry. Credit risk control is recognised as the essential requirement for effective management and the development of accreditation and culture-building methods. The use of these methods and degree institutions is very beneficial, and all of the factors mentioned above need the continuation of the credit risk management system. The review and control of technical and financial indicators, business, documents, and financial strength are some of the most critical issues of risk management, and to do so, the branch should be considered as a whole so that despite the existence of standard indicators in performance evaluation, with a comprehensive analysis of all factors, to improve the efficiency and performance of the branch. Finally, it is suggested that branch managers use the opinions of banking experts to decide on the allocation of other influential variables and pay attention to calculations. Based on the obtained results, this study corresponds with the research conducted by Akhtar (2010), Bansal et al. (2022), Boubaker et al. (2020), Chen and Pan (2012), Lahouel et al. (2022), Thaker et al. (2022), and other researchers.

The recommendations of this study can be as follows:

1. For branches that have low efficiency, the first step is to reconsider their credit risk.
2. The capital structure, human resources, and credit policies of inefficient branches should be adjusted based on the reference and efficient branch.
3. Encouraging inefficient branch managers to make the branch efficient in a short period of time.
4. Based on the results, we found that bank managers must foster cost management (such as the cost of opening an account, creating a loan document package, or handling a specific type of transaction) if they intend to improve their efficiency in the modern banking industry. In addition, in order to predict efficiency more precisely, bank managers should have a more accurate planning of the liquidity allocated to branches as a quasi-fixed input (output). Finally, in order to better predict performance, bank managers must accurately measure the capital adequacy and asset quality of their branches at the end of each financial period.

The most important limitation was the unavailability of bank information, due to the confidentiality and security of the information. Considering that bank shares are offered in the stock market, naturally bank shares will be more expensive if their branches have higher efficiency. If the bank can increase the efficiency of its branches, it will be more attractive and therefore more profitable.

REFERENCES

1. Akhtar, M. H. (2010). Technical efficiency and productivity growth of Saudi banks: A data envelopment analysis approach. *Global Business Review, 11*(2), 119–133. https://doi.org/10.1177/097215091001100201
2. Andries, A. M. (2011). The determinants of bank efficiency and productivity growth in the Central and Eastern European banking systems. *Eastern European Economics, 49*(6), 38–59. https://doi.org/10.2753/EEE0012-8775490603
3. Azizi, J. (2014). Determining of potential demand for drought insurance and effective factors in Iran. *Journal of Agricultural Economics, 8*(1), 191–204. https://www.iranianjae.ir/article_9927.html?lang=en
4. Azizi, J. (2015). Evaluation of the efficiency of the agricultural bank branches by using data envelopment analysis and the determination of a consolidated index: The case study Mazandaran Province. *Agricultural Economics, 9*(1), 1–14. https://civilica.com/doc/763281
5. Azizi, J., Taleghani, M., Esmaeilpoor, F., & Chegini, M. G. (2010). Effect of the quality costing system on implementation and execution of optimum total quality management. *International Journal of Business and Management, 5*(8), 19–26. https://doi.org/10.5539/ijbm.v5n8p19
6. Banker, R. D., Charnes, A., & Cooper, W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Manage Science, 30*(9), 1031–1142. https://doi.org/10.1287/mnsc.30.9.1078
7. Bansal, P., Mehra, A., & Kumar, S. (2022). Dynamic metafrontier Malmquist–Luenberger productivity index in network DEA: An application to banking data. *Computational Economics, 59,* 297–324. https://doi.org/10.1007/s10614-020-10071-9
8. Boubaker, S., Do, D. T., Hammami, H., & Ly, K. C. (2020). The role of bank affiliation in bank efficiency: A fuzzy multi-objective data envelopment analysis approach. *Annals of Operations Research, 311*(1), 611–639. https://doi.org/10.1007/s10479-020-03817-z
9. Bou-Hamad, I., Anouze, A. L., & Osman, I. H. (2022). A cognitive analytics management framework to select input and output variables for data envelopment analysis modeling of performance efficiency of banks using random forest and entropy of information. *Annals of Operations Research, 308*(1), 63–92. https://doi.org/10.1007/s10479-021-04024-0
10. Chang, W. S., & Hsieh, J. J. (2011). Intellectual capital and value creation — Is innovation capital a missing link? *International Journal of Business and Management, 6*(2), 3–12. https://doi.org/10.5539/ijbm.v6n2p3
11. Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research, 2*(6), 429–444. https://doi.org/10.1016/0377-2217(78)90138-8
12. Chen, K.-C., & Pan, C.-Y. (2012). An empirical study of credit risk efficiency of banking industry in Taiwan. *Journal of Chinese Management Review, 15*(1), 1–16. http://cmr.ba.ouhk.edu.hk/cmr/webjournal/v15n1/CMR326E11.pdf
13. Cook, W. D., Roll, Y., & Kazakov, A. (1990). A DEA model for measuring the relative efficiency of highway maintenance patrols. *INFOR: Information Systems and Operational Research, 28*(2), 113–124. https://doi.org/10.1080/03155986.1990.11732125
14. Epure, M., & Lafuente, E. (2010). Monitoring bank performance in the presence of risk. *Barcelona GSE Working Paper Series, 3*(1), 23–30. https://upcommons.upc.edu/bitstream/handle/2117/27455/Epure_&_Lafuente_GSE%20WP613.pdf
15. Fukuyama, H., & Tan, Y. (2022). Deconstructing three-stage overall efficiency into input, output and stability efficiency components with consideration of market power and loan loss provision: An application to Chinese banks. *Finance & Economics, 27*(1), 953–974. https://doi.org/10.1002/ijfe.2185
16. Habibi, Y., Azizi, J., & Shal, F. K. (2018). Role of insurance in broiler farms risk management (A case study of Rudbar County). *International Journal of Agricultural Management and Development, 8*(1), 321–328. https://ijamad.rasht.iau.ir/article_527240_ae18528fa2f0d9440c5a6c88acc0a66c.pdf
17. Haghighat, J., & Naseri, N. (2003). Studying the efficiency of banking system by the usage of data envelopment analysis (A case study of Keshavarzi Bank). *Economic Researches Journal, 8*(9), 135–171.
18. Jeon, I., & Lee, H. (2015). Performance evaluation of R&D commercialisation: A DEA-based three-stage model of R&BD performance. *Journal of Korean Institute of Industrial Engineers, 41*(5), 425–438. https://doi.org/10.7232/JKIIE.2015.41.5.425
19. Jeon, J., Kim, C., & Lee, H. (2011). Measuring efficiency of total productive maintenance (TPM): A three-stage data envelopment analysis (DEA) approach. *Total Quality Management & Business Excellence, 22*(8), 911–924. https://doi.org/10.1080/14783363.2011.593865
20. Kargi, P. (2011). *Credit risk and the performance of Nigerian banks*. Ahmadu University. https://www.academia.edu/8637351/CREDIT_RISK_AND_THE_PERFORMANCE_OF_NIGERIAN_BANKS_BY
21. Khoshsima, R., & Shahiktashi, M. (2012). The effects of credit, operational and cash risks on Iran's banking system. *Budget and Planning Journal, 17*(4), 69–95.
22. Lahouel, B. B., Taleb, L., & Kossaic, M. (2022). Nonlinearities between bank stability and income diversification: A dynamic network data envelopment analysis approach. *Expert Systems with Applications, 207*(1), Article 117776. https://doi.org/10.1016/j.eswa.2022.117776
23. Lartey, T., James, G. A., & Danso, A. (2021). Interbank funding, bank risk exposure and performance in the UK: A three-stage network DEA approach. *International Review of Financial Analysis, 75*(1), Article 101753. https://doi.org/10.1016/j.irfa.2021.101753
24. Li, Z., Feng, C., & Tang, Y. (2022). Bank efficiency and failure prediction: A nonparametric and dynamic model based on data envelopment analysis. *Annals of Operations Research, 315*(7), 279–315. https://doi.org/10.1007/s10479-022-04597-4
25. Matthews, K. (2013). Risk management and managerial efficiency in Chinese banks: A network DEA framework. *Omega, 41*(2), 207–215. https://doi.org/10.1016/j.omega.2012.06.003
26. Omrani, H., Emrouznejad, A., Shams, A., & Fahimi, M. (2022). Evaluation of insurance companies considering uncertainty: A multi-objective network data envelopment analysis model with negative data and undesirable outputs. *Socio-Economic Planning Sciences, 82*(Part B), Article 101306. https://doi.org/10.1016/j.seps.2022.101306

27. Panahiyan, H., & Abiyak, H. (2012). Explaining the risk effect on the banking efficiency by the use of efficiency calculation and data envelopment analysis. *Journal of Accounting and Auditing Researches, 17*(4), 54–70.
28. Řepková, I. (2014). Efficiency of the Czech banking sector employing the DEA window analysis approach. *Procedia Economics and Finance, 12,* 587–596. https://doi.org/10.1016/S2212-5671(14)00383-9
29. Roll, Y., Cook, W. D., & Golany, B. (1991). Controlling factor weights in data envelopment analysis. *IIE Transactions, 23*(1), 2–9. https://doi.org/10.1080/07408179108963835
30. Tehrani, R., Fallah, S., & Mirfaez, D. (2005). Designing and explaining the credit risk model in country's banking system. *Social and Humanity Science of Shiraz University, 47*(2), 45–46.
31. Thaker, K., Charles, V., Pant, A., & Gherman, T. (2022). A DEA and random forest regression approach to studying bank efficiency and corporate governance. *Journal of the Operational Research Society, 73*(6), 1258–1277. https://doi.org/10.1080/01605682.2021.1907239
32. Tsolas, I. E., Charles, V., & Gherman, T. (2020). Supporting better practice benchmarking: A DEA-ANN approach to bank branch performance assessment. *Expert Systems with Applications, 160*(1), Article 113599. https://doi.org/10.1016/j.eswa.2020.113599
33. Yousefvand, R., Zarei, M., & Farahnak, A. (2012). Studying the risk management effects on the efficiency of private banks, a case study of Ansar bank branches of Guilan Province. (pp. 132-142). Islamic Azad University.
34. Zhou, X., Xu, Z., Chai, J., Yao, L., Wang, S., & Lev, B. (2019). Efficiency evaluation for banking systems under uncertainty: A multi-period three-stage DEA model. *Omega, 85*(2), 68–82. https://doi.org/10.1016/j.omega.2018.05.012