Journal of System Management (JSM)
Online ISSN: 2538-1571, Print ISSN: 2322-2301
11(2), 2025, pp. 65-80

Received: 10/08/2024
Accepted: 18/10/2024

RESEARCH ARTICLE **Open Access**

Applying Preferred Information of the Decision Maker with Production Trade-Offs in the Process of Evaluating the Performance of Banks

Javad Gerami [1]

Abstract
One of the methods to apply preferred information of the decision maker (DM) in the process of evaluating the efficiency of banks is the method of production trade-offs in data envelopment analysis (DEA). In this paper, we propose a two stage network DEA framework for incorporating value-judgments in the form of production trade-offs to analyze the efficiency of banks. We obtain technical and cost efficiency from banks based on bank manager's opinion. We use the production trade-off method to consider the importance of each of the inputs, intermediate measure and outputs relative to each other to evaluate the performance of commercial banks. We show that by changing the production trade-offs matrix, the technical and cost efficiency scores of banks also change. We propose efficient targets for inefficient banks. At the end, we bring the results of the paper.
Keywords: Data envelopment analysis; Banking; Two stage; Preferred information; production trade-offs.

Introduction

The banking industry is one of the most influential industries in the economic markets. This industry is run by private government in different countries. Banks play an important role in the economy of a country. The performance of banks is of special importance for senior economic managers. For this reason, senior managers are always looking for a proper evaluation of the set of banks under their management. One of the techniques to evaluate the performance of a set of banks is DEA. This technique was initially presented by Charnes et al. (1984) based on mathematical programming. In the DEA, all banks can be evaluated in the same conditions. Banks with the best performance are known as efficient banks and other banks are inefficient. Another strength of DEA in evaluating the performance of banks is to provide a suitable target for inefficient banks. Inefficient banks should bring their activity level to the activity level of efficient banks. In the process of evaluating the performance of banks, applying the opinion of bank managers is important. Because from the point of view of the bank management, some inputs and outputs in the evaluation process are more important than other inputs and outputs. There are several methods in DEA in order to consider the importance of inputs and outputs relative to each other in the banks' performance evaluation model. One of these methods is the production trade-offs method. Using this method, we can apply the importance of inputs and outputs to each other based on the opinion of managers in the evaluation model (Podinovski 2016).

The conventional DEA model does not incorporate a DM's preferences or value judgments in the evaluation process (Joro & Korhonen, 2015). Podinovski (2004) suggested production trade-offs method to incorporate DM's preferences in envelopment DEA model. He shown that it is

1. Associate Professor, Department of Mathematics, Shiraz branch, Islamic Azad University, Shiraz, Iran
(Corresponding Author: Geramijavad@gmail.com)

equivalent to weight restrictions method in multiplier DEA model. Podinovski and Bouzdine-Chameeva (2015) shown how the technology thinking helps to prevent of the constitution of infeasible/inconsistent production relations. They investigated consistent weight restrictions in DEA. Podinovski and Argyris (2024) proposed production trade-offs in models of DEA with ratio inputs and outputs. They applied their approach for evaluating schools in England.

Traditional DEA models considered only the initial inputs and final outputs of the decision making units (DMUs) in the performance evaluation process and did not consider the intermediate measures. But DEA models based on the network structure consider these intermediate measures in the performance evaluation process. In order to analyze the performance of the two-stage network systems, we must measure the overall efficiency of the whole system and identify divisional efficiencies of the two stages. Also, we must obtain frontier projections for the inefficient DMUs (Yin et al. 2020, Kao 2024). Kaveh et al. (2020) developed appropriate marketing strategies in the form of scenario-based strategic planning in the life insurance market of mellat insurance company. They developed system dynamics and network DEA to formulate marketing strategies and the causal-loop diagram and then the flow-stock diagram for scenario-based strategic planning. Shojaie et al. (2022) proposed a comprehensive approach for evaluating efficiency in complex networks by integrating network DEA with the Malmquist productivity index. Their method developed the inherent challenge of accommodating negative data within the network efficiency evaluation framework. Marzban et al. (2022) proposed a best and most efficient ordering policies for different levels of the perishable food supply chain network in order to maximize the overall profit of the chain. They minimize social and environmental damage. Their supply chain includes a four-level supply chain of suppliers, manufacturers, distributors and retailers. Shirouyehzad et al. (2024) evaluated the performance of the organization based on the total quality management CSFs and knowledge management CSFs. They analyzed and identified critical success factors of total quality management for evaluating organizational performance using a framework based on the knowledge management approach. They used data mining algorithms and a DEA model to evaluate the organizational performance by considering the success factors of knowledge management as inputs and success factors of total quality management as outputs. Nematizadeh et al. (2024) proposed an Alternative prioritization method in the presence of contextual variables. They applied their models for performance evaluation of provincial gas companies in Iran from 2013 to 2016.

In this paper, according to the structure of the banks under evaluation, we use two-stage DEA models to evaluate the performance of commercial banks. Different models have been presented in DEA to measure the performance of the two-stage network structure. However, each of these models is not necessarily suitable. In this paper, we present a suitable two-stage network DEA model for measuring the efficiency of banks. This model makes it possible to sensitivity analysis of the results in the presence of production trade-offs. By solving this model, we can calculate the efficiency scores of the first, second stages and overall efficiency score simultaneously for banks. This model somehow has a low amount of calculations. The model obtains the relationships between the efficiency scores of each banks in the first, second and overall stages. The model also provides efficient targets corresponding to inefficient banks. The model takes into account the relationship between production trade-offs between inputs, intermediate measures and outputs and their importance in the production process.

The concept of cost efficiency firstly was introduced by Farrell (1975). The cost efficiency of a DMU as the ratio of minimum cost for the production of current outputs with input prices paid by itself to the actually observed cost. In cost efficiency models, outputs of the target DMU are evaluated by the minimum cost. Tone (2002) developed the cost efficiency evaluation model with different prices of inputs. Lozano (2013) proposed scale and cost efficiency analysis of networks of processes. Gerami et al. (2024) proposed fuzzy cost, revenue efficiency assessment and target setting in fuzzy DEA based on the directional distance function approach. One of the important issues in evaluating the efficiency of banks is to consider economic indicators. Because these indicators are very important for the bank's senior managers. In this paper, we present another model to evaluate the performance of banks based on the concept of cost efficiency. This model is introduced for two-stage network structure in DEA. The model takes into account the importance of inputs and outputs relative to each other based on the opinion of bank managers in the cost efficiency evaluation process based on the production trade-offs.

It can be said that the main contribution of this paper is as follows. In this paper, we propose bank performance evaluation models based on the two-stage network structure and concepts of technical and cost efficiency in DEA. The models consider the relationships of production trade-offs to apply the importance of each of the inputs, intermediate measures and outputs relative to each other in the performance evaluation process of banks. The models provide efficiency scores and efficient targets corresponding to inefficient banks.

The continuation of this paper is organized as follows. In the section 2, we present the methodology of the research, in the section 3, we use the proposed approach in this paper to evaluate a set of commercial banks in Iran. In the section 4, we present the results of the paper.

Literature Review

In this section, we examine some of the studies conducted in the fields in the field banking efficiency in DEA. There is an increasing number of studies to comprehensively examine the performance in the banking industry. Studies can be mainly divided into three streams: efficiency analysis (Tan and Floros, 2018, Fukuyama and Tan, 2022a, b), focusing on profitability analysis (Fang et al., 2019) and sustainability analysis (Tan et al. 2017). These three streams of study are in line with the three topics including bank profitability, cost management and stability in the banking industry. Fukuyama and Matousek (2011) developed a two-stage DEA model to obtain cost, technical, and allocative efficiency in the Turkish banking industry. Wanke and Barros (2014) applied a two-stage DEA model for measuring efficiency in the Brazilian banking industry. Wang et al. (2014) proposed a two-stage DEA network model that divided the production process into deposit production and profit earning. Fixed assets and labor were applied to create bank deposits in the first stage, and in the second stage, desirable and undesirable outputs were produced. An et al. (2015) proposed a two-stage DEA model present undesirable output for measuring slacks-based efficiency for commercial banks in China. Wanke et al. (2016) assessed productive efficiency of banks using integrated Fuzzy-DEA and bootstrapping. They applied their approach for Mozambican banks. Fukuyama and Matousek (2017) proposed a two-stage network DEA model for evaluating cost and revenue efficiency in Japanese banking industry. Wanke et al. (2018) proposed a comparison between stochastic DEA and fuzzy DEA approaches and revisiting efficiency in Angolan banks. Izadikhah et al. (2018) proposed a two-stage network DEA model. They divided each DMU into two sub-DMUs. Their model allows partial consumption of the sub-DMU's intermediate measurement in stage one by the sub-DMU in stage two and benefits from the advantage of assigning the initial input to one of the two sub-DMUs. Zhou et al. (2019) developed a multi-period three-stage DEA model for evaluating efficiency evaluation of banking systems under uncertainty. Konara et al. (2019) evaluate the efficiency of banks for eight emerging market economies by using DEA models. Henriques et al. (2020) proposed a systematic review of the literature on the topic focusing on the banking industry. They analyzed 59 articles and divided them into ten classes covering different perspectives of two-stage DEA studies, such as economic context, geographical area of banking units, methodological characteristics and type of models, internal or external. Liu et al. (2020) proposed a new technological heterogeneity and target setting of intermediate output. They applied their approach to performance analysis of Chinese commercial banks. Xu and Zhou (2021) proposed a two-stage AR-DEA model to assess the efficiency of financial supply chain in Chinese commercial banks. Fukuyama and Tan (2022) presented a three-stage network DEA model. They estimated three different types of efficiencies, contains input efficiency, stability efficiency and output efficiency, they applied their model for measuring efficiency of banks in japan. Wanke et al. (2023) developed a new stochastic multi-criteria decision making to evaluate the performance of the Asian banking industry based on the sign decomposition. Fukuyama et al. (2023) proposed a dynamic network DEA with a sequential structure and behavioral-causal analysis. They applied approach in the Chinese banking industry. Kraidi et al. (2024) proposed a weight-restricted approach on constant returns to scale DEA models. They investigated efficiency of internet banking in Turkey.

Preliminaries

In this section, we consider the two-stage process in which each DMU consume only the inputs from the first stage to product the final outputs in the second stage via intermediate measures. Assume, we have n DMUs with a two-stage network structure as Figure 1.

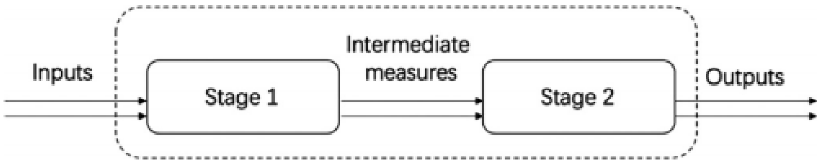

Figure 1. *Two-stage network system*

Let we have n DMUs as $DMU_j = (X_j, Z_j, Y_j)$, $j = 1, \dots, n$ in the productions process as in Figure 1. Assume the input vector from the first stage corresponds to DMU_j, $j = 1, \dots, n$ is as $X_j = (x_{1j}, \dots, x_{mj})$. The vector $Z_j = (z_{1j}, \dots, z_{Dj})$ is intermediate products, furthermore, the intermediate products are the outputs of stage 1 as well as the inputs of stage 2. The output vector of the second stage is $Y_j = (y_{1j}, \dots, y_{sj})$.

Consider T judgements judgement production trade-offs as

$(M_t^1, N_t^1, M_t^2, N_t^2)$, $t = 1, \dots, K$. (1)

We consider the vectors M_t^1, N_t^1 modify the inputs and intermediate products of production unit in the stage 1 respectively. Also, the vectors M_t^2, N_t^2 modify the intermediate products and outputs of production unit in the stage 2 respectively. Assume $\in R_+^m$, $W^1 \in R_+^D$ are the weight vectors correspond to the components of input and intermediate products in the stage 1 respectively. Also, $W^2 \in R_+^D$, $U \in R_+^s$ are the weight vectors correspond to the components of intermediate products and output in the stage 2 respectively. The corresponding weight restrictions on inputs, intermediate products and output, as follows.

Stage 1: $W_1^T M_t^1 - V^T N_t^1 \leq 0,\ t = 1, \dots, K,$ (4)

Stage 2: $U^T M_t^2 - W_2^T N_t^2 \leq 0,\ t = 1, \dots, K,$ (5)

We consider the vectors $M_t^1, N_t^1, M_t^2, N_t^2$ non-zero, then productions trade-offs are linked homogenous.

In this part, we propose the input-oriented envelopment two stage network DEA model with production trade-offs of inputs, intermediate measures and outputs for measuring the technical efficiency score of $DMU_o = (X_o, Z_o, Y_o)$ as under evaluation DMU as follows.

$$
\begin{aligned}
&\min \ \theta_{TR} \\
&s.t. \ \sum_{j=1}^{n} \lambda_j x_{ij} + \sum_{t=1}^{K} \pi_{it}^1 N_{it}^1 + q_i^1 \le \theta_{TR}\, x_{io,}\ i = 1, \dots, m, \\
&\quad \sum_{j=1}^{n} \lambda_j z_{dj} + \sum_{t=1}^{K} \pi_{it}^1 M_{dt}^1 \ge \theta_{TR}^2\, z_{do,} \quad d = 1, \dots, D, \\
&\quad \sum_{j=1}^{n} \mu_j z_{dj} + \sum_{t=1}^{K} \pi_{it}^2 N_{dt}^2 + q_d^2 \le \theta_{TR}^2\, z_{do,}\ d = 1, \dots, D, \\
&\quad \sum_{j=1}^{n} \mu_j y_{rj} + \sum_{t=1}^{K} \pi_{it}^2 M_{dt}^2 \ge y_{ro,} \quad r = 1, \dots, s, \qquad (6) \\
&\quad \sum_{j=1}^{n} \lambda_j = 1,\ \lambda_j \ge 0, j = 1, \dots, n, \\
&\quad \sum_{j=1}^{n} \mu_j = 1, \mu_j \ge 0, j = 1, \dots, n, \\
&\quad \sum_{j=1}^{n} \lambda_j x_{ij} + \sum_{t=1}^{K} \pi_{it}^1 N_{it}^1 + q_i^1 \ge 0,\ i = 1, \dots, m, \\
&\quad \sum_{j=1}^{n} \mu_j z_{dj} + \sum_{t=1}^{K} \pi_{it}^2 N_{dt}^2 + q_d^2 \ge 0, d = 1, \dots, D, \\
&\qquad \pi_{it}^1, \pi_{it}^2 \ge 0, i = 1, \dots, m, t = 1, \dots, K, \\
&\qquad q_i^1, q_d^2 \ge 0, i = 1, \dots, m, d = 1, \dots, D.
\end{aligned}
$$

In model (6) λ_j and μ_j are intensity vectors corresponding to DMU_j, $j = 1, \dots, n$. θ_{TR} and θ_{TR}^2 are contraction variables in the whole process and stage 2 respectively.

In model (6), the expressions $\sum_{j=}^{n} \lambda_j X_j$ and $\sum_{j=}^{n} \lambda_j Z_j$ show an arbitrary DMU in production technology under variable returns to scale (VRS) technology. The expressions $\sum_{t=1}^{K} \pi_t^1 N_t^1$ and $\sum_{t=1}^{K} \pi_t^1 M_t^1$ modify this DMU by using production trade-offs (M_t^1, N_t^1), $t = 1, \dots, K$ in some proportions $\pi_t^1 \ge 0$ in the stage 1. Similarly, the expressions $\sum_{j=}^{n} \mu_j Z_j$ and $\sum_{j=}^{n} \mu_j Y_j$ show an arbitrary DMU in production technology under VRS technology. The expressions $\sum_{t=1}^{K} \pi_t^2 N_t^2$ and $\sum_{t=1}^{K} \pi_t^2 M_t^2$ modify this DMU by using production trade-offs (M_t^2, N_t^2), $t = 1, \dots, K$ in some proportions $\pi_t^2 \ge 0$ in the stage 2. And in this way, a new DMU is created in the process. The resulting DMU changes by increasing its inputs and decreasing its outputs.

Suppose $\left(\lambda^*, \mu^*, \theta_{TO}^*, \theta_{TO}^{2*}, \pi_t^{1^*}, \pi_t^{2^*}, q^{1^*}, q^{2^*}\right)$ is an optimal solution obtained from model (6). In this case, we define the efficiency score of first stage as follows.

$\theta_{TR}^{1*} = \frac{\theta_{TR}^*}{\theta_{TR}^{2*}}$.

That it is equivalent to $\theta_{TR}^* = \theta_{TR}^{1*} \times \theta_{TR}^{2*}$.

In this case, θ_{TR}^*, θ_{TR}^{1*}, θ_{TR}^{2*} show the efficiency scores of two stage network DEA in the overall, stage 1 and stage 2 respectively.

Definition 1. DMU_o is called (weakly) efficient in evaluation with model (1) if and only if $\theta_{TR}^* = 1$.

Definition 2. DMU_o is called (weakly) efficient in evaluation with model (1) in the first and second stages, respectively, if and only if $\theta_{TR}^{1*} = 1$, $\theta_{TR}^{2*} = 1$.

The frontier projection for $DMU_o = (X_o, Z_o, Y_o)$ based on model (6) was presented as $(\theta_{TR}^* X_o, \theta_{TR}^{2*} Z_o, Y_o)$. The efficient target (target operation point) corresponding to DMU_o is defined as follows.

$\left(\sum_{j=1}^{n} \lambda_j^* X_j + \sum_{t=1}^{K} \pi_t^{1^*} N_t^1 + q^{1^*}, \sum_{j=1}^{n} \lambda_j^* z_j + \sum_{t=1}^{K} \pi_t^{1^*} M_{dt}^1, \sum_{j=1}^{n} \mu_j^* z_j + \sum_{t=1}^{K} \pi_t^{2^*} N_t^2 + q^{2^*}, \sum_{j=1}^{n} \mu_j^* Y_j + \sum_{t=1}^{K} \pi_t^{2^*} M_{dt}^2 \right)$.

The cost efficiency models, we evaluated the capability of producing observed outputs for under evaluation DMU by considering its minimum cost. In this paper, in order to evaluate the performance of commercial banks, we use the concept of cost efficiency. We consider the situation where input, output data and their corresponding input prices are known exactly for each DMU. Let c_i be the price of input i. We can therefore formulate the cost minimization relational two stage network DEA model. Considering that the studied banks have a two stage network structure, therefore, we use the cost efficiency evaluation models for the two-stage network structure in DEA. In order to include the opinion of the bank's senior managers in the evaluation process, we use the production trade-offs method described in the previous section in these models. Now we present performance evaluation models of DMUs with a two-stage network structure in the presence of production trade-offs based on the concept of cost efficiency. We measure the cost efficiency score of $DMU_o = (X_o, Y_o)$ as under evaluation DMU with production trade-offs as follows.

$$\begin{aligned}
&\min \ \sum_{i=1}^{m} c_i x_i \\
&s.t. \ \sum_{j=1}^{n} \lambda_j x_{ij} + \sum_{t=1}^{K} \pi_{it}^1 N_{it}^1 + q_i^1 \le x_{i,} \ i = 1, \dots, m, \\
&\quad \sum_{j=1}^{n} \lambda_j z_{dj} + \sum_{t=1}^{K} \pi_{it}^1 M_{dt}^1 \ge z_{do,} \quad d = 1, \dots, D, \\
&\quad \sum_{j=1}^{n} \mu_j z_{dj} + \sum_{t=1}^{K} \pi_{it}^2 N_{dt}^2 + q_d^2 \le z_{do,} \ d = 1, \dots, D, \\
&\quad \sum_{j=1}^{n} \mu_j y_{rj} + \sum_{t=1}^{K} \pi_{it}^2 M_{dt}^2 \ge y_{ro,} \quad r = 1, \dots, s, \qquad (7) \\
&\quad \sum_{j=1}^{n} \lambda_j = 1, \ \lambda_j \ge 0, j = 1, \dots, n, \\
&\quad \sum_{j=1}^{n} \mu_j = 1, \mu_j \ge 0, j = 1, \dots, n, \\
&\quad \sum_{j=1}^{n} \lambda_j x_{ij} + \sum_{t=1}^{K} \pi_{it}^1 N_{it}^1 + q_i^1 \ge 0, \ i = 1, \dots, m, \\
&\quad \sum_{j=1}^{n} \mu_j z_{dj} + \sum_{t=1}^{K} \pi_{it}^2 N_{dt}^2 + q_d^2 \ge 0, d = 1, \dots, D, \\
&\qquad \pi_{it}^1, \pi_{it}^2 \ge 0, i = 1, \dots, m, t = 1, \dots, K, \\
&\qquad x_i \ge 0, q_i^1 \ge 0, q_d^2 \ge 0, i = 1, \dots, m, d = 1, \dots, D.
\end{aligned}$$

Let $X' = (x_1', \dots, x_m')$ is the optimal solution of model (8). We measure the minimum production cost of DMU_o with production trade-offs as follows.

$$CE_{TO}^{Two-stage} = \frac{c^t X'}{c^t X_o} = \frac{\sum_{i=1}^{m} c_i x_i'}{\sum_{i=1}^{m} c_i x_{io}} \qquad (8)$$

Definition 3. The cost efficiency score with production trade-offs corresponding to $DMU_o = (X_o, Z_o, Y_o)$ is defined as the ratio of minimum cost to the actual cost namely $CE_{TO}^{Two-stage} = \frac{c^t X'}{c^t X_o} = \frac{\sum_{i=1}^{m} c_i x_i'}{\sum_{i=1}^{m} c_i x_{io}}$. If $CE_{TO}^{Two-stage} = 1$ then DMU_o is called DEA cost efficient with production trade-offs. Otherwise we call this DMU as DEA cost inefficient.

Suppose $\left(X', \lambda', \mu', \pi_t^{1'}, \pi_t^{2'}, q^{1'}, q^{2'}\right)$ is an optimal solution obtained from model (8).
The cost efficient target operation point corresponding to DMU_o is defined as follows.
$\left(\sum_{j=1}^{n} \lambda_j' X_j + \sum_{t=1}^{K} \pi_t^{1'} N_t^1 + d_1', \sum_{j=1}^{n} \mu_j' Y_j + \sum_{t=1}^{K} \pi_t^{2'} M_{dt}^2 \right)$.
The cost efficiency $CE_{TO}^{Two-stage}$ of DMU_o is therefore the ratio of this minimum cost to the observed cost.

Application to banking industry

Banking industry is a set of activities in banking operations, including policymaking, planning, organization and implementation. In simple words, the management of equipping and allocating resources in the money market is called banking. Banks often do marketing to be successful in providing their services. But unfortunately, due to the lack of familiarity with bank marketing, they only use the traditional marketing trends in a completely scattered and unrelated manner with the main goal of the bank. The banking industry is very important in all countries because this institution provides financial support at the micro and macro levels of society. At the macro level, large national and government projects are supported by bank funds. At the micro level, the life of entrepreneurial companies depends on the financial resources of banks. A bank should react appropriately to evidence from marketing research. Marketing of banking services should be considered for success. Considering the importance of performance evaluation in the banking industry, in this study we will evaluate the performance of a group of banks in Iran. In this evaluation, we have used the data set related to 26 branches of commercial banks in Iran. These banks operate in a competitive market. A commercial bank can generally be considered as a two-stage network system as shown in Figure. 1.

Each commercial bank branch is regarded as a two-stage system which contains the fund system and the profit-earning system.

In this evaluation we consider three inputs, two intermediate measures and three outputs.

Inputs include personnel expenses, interest expenses and non-interest expenses

Personnel expenses includes the costs that the bank pays for its personnel during this evaluation period. These costs include salaries, insurance, benefits and bonuses, overtime, insurance and medical treatment.

Interest expenses is the amount of interest paid to bank customers. Customers leave their deposits with the bank based on a specific contract. The bank receives interest for each deposit. The total amount paid to customers during the assessment period for these deposits is called net interest expense.

Non-interest expenses: These costs include costs that are not directly related to attracting and maintaining deposit funds. These costs include the bank's costs in various cases, including building rent, costs related to the maintenance of bank properties, current costs of the bank, costs of creating and maintaining software and hardware facilities, service costs such as water and electricity, gas, and energy costs.

Three final outputs were also considered in this evaluation. These **final outputs** include net interest income, non-interest income, and total deposits.

Net interest income: These incomes include the income that the bank earns from providing loan facilities to customers. This interest rate is determined by the bank based on this contract with customers. These incomes are the result of subtracting the total amount received from customers from the loan amount given to them. The total amount of net interest income for each of the banks is considered a desirable output. The bigger the amount of these revenues, the more income the bank can earn.

Non-interest incomes: These incomes include bank incomes other than bank interest. These incomes include the income earned from customers from various services, including various fees, income from the transfer of various funds by customers, ATM machines, income from interbank transfers, income from Internet services, fees related to sending SMS to customers, etc.

Intermediate products are total deposits and other raised funds.

Total deposits: These deposits include current deposits, short-term deposits, and long-term deposits. The larger the total amount of deposits, the higher the liquidity of the bank, and the bank can pay facilities to its customers, and as a result, it can receive higher interest from the place of payment of facilities. The bank pays a small interest rate for short-term deposits but pays more interest for long-term deposits. But they do not pay interest on current deposits. The more time the deposits are available to the bank and the larger their amount, the greater the bank's liquidity will be, and the bank can pay facilities to its customers from the deposits and earn a larger profit from the interest on the facilities.

Other raised funds

Collected funds include deposits and other types of funds that are used at the end of the first period in the second period of banks' performance. In each bank, the main function of the fund system is to use personnel expenses, interest expenses and non-interest expenses to collect funds (including deposits and other types of funds) and total deposits while the profit-making system uses the funds generated total deposits and from the fund system to make a net interest income, non-interest income, and total deposits.

The evaluation period includes two six-month periods in 2023. that the information of the banks is included in the performance of the banks in the first six-month period as the first stage and the second six-month period as the second stage. The unit of data measurement is **million tomans**.

We show two-stage structure of the banking system in Figure 2.

Figure 2. *Two-stage network system of each Bank branch*

Due to the insistence of the central bank management, we refrained from mentioning the names of these banks and only displayed the banks with numbers B01 to B26. We show, first intermediate measure and two intermediate measure as Z1 and Z2 respectively and first output and two output as Y1 and Y2 respectively. The data of banks are in the Table 1.

Table 1.
The data set of banks.

Banks	I1	I2	I3	Z1	Z2	Y1	Y2
B01	706.11	4964.98	2295.47	84910.43	121397.35	3375.49	1823.66
B02	1163.53	6437.86	2397.95	125485.59	153598.42	3654.69	1354.86
B03	814.74	3594.34	1458.03	73688.18	87150.98	2026.87	881.29
B04	559.52	2113.61	918.15	41620.94	47256.73	1014.31	483.06
B05	191.49	581.74	559.54	20941.49	29024.25	1135.97	587.35
B06	61.07	301.35	119.78	4028.6	5107.74	167.79	51.97
B07	26.71	81.5	46.3	1446.43	1626.97	49.5	14.97
B08	1264.08	7776.84	4370.98	152217.1	203023.54	7509.36	3025.94
B09	1097.68	5509.15	3026.66	102269.66	145699.02	4581.77	2012.86
B10	428.72	1836.86	840.49	29504.74	39785.7	934.43	475.17
B11	328.16	1830.39	626.62	34519.17	41051.2	1010.68	437.62
B12	430.02	1605.51	694.01	29574.75	34585.62	703.43	444.92
B13	293.46	2218.46	1092.69	26800.74	40731.43	1599.64	923.2
B14	119.3	589.55	234.74	9522.36	11051.6	269.33	185.28
B15	764.14	2109.24	1661.71	34542.3	58787.21	2331.14	1159.57
B16	160.78	778.92	252.77	11894.47	13331.91	272.93	118.91
B17	923.73	4823.48	1588.27	93365.78	110188.5	2333.58	1204.25
B18	102.17	647.96	376.14	7668.84	11802.97	481.47	253.39
B19	206.56	668.69	428.55	13317.42	24474.01	844.28	405.4
B20	6481.54	21373.2	11362.32	434320.03	556800.72	14424.78	5180.93
B21	153.18	611.43	468.76	16561.85	28004.53	932.58	286.87
B22	9.7	59.66	25.04	1039.59	1450.69	35.34	8.82
B23	113.81	483.12	237.46	7836.36	9057.15	311.46	154.81
B24	14.88	91.2	34.41	1508.76	1850.82	45.78	14.43
B25	291.01	1332.09	689.56	25628.59	31293.41	676.68	379.66
B26	445.86	3421.65	997.06	59781.53	73048.58	1517.09	698.37

At first, we consider two different weight restrictions to solve models (6) and (7). We select production trade-offs matrixes $M_t^1, N_t^1, M_t^2, N_t^2$ as follows.

Production trade-offs 1: $N_1^1 = \begin{pmatrix} 1 \\ 0 \\ 2 \end{pmatrix}, M_1^1 = \begin{pmatrix} 2 \\ 1 \end{pmatrix},$

$N_1^2 = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, M_1^2 = \begin{pmatrix} 2 \\ 0 \end{pmatrix}.$

Then $i = 3, r = 2, d = 2, t = 1$.
The weight restriction corresponding to these matrixes on the components of inputs, intermediate products and output are as follows.
$2w_2 + w_1 - 1v_1 - 2v_3 \leq 0$.
$2u_1 - 1w_1 \leq 0$.

where u_1, u_2, w_1, w_2, v_1, v_2 and v_3 are weights corresponding to the components of inputs, intermediate products and output, respectively. In this weight restriction, the importance corresponding to the intermediate products and inputs is like this the sum of two times the second intermediate product and one time the first intermediate product is less than or equal to the sum of one time the firs input and two times the three input. Also, the importance corresponding to the outputs and intermediate products is like this two times the first output is less than or equal to one time the first intermediate product. In this way, the importance of inputs and outputs, according to the opinion of bank managers, is included in the technical and cost evaluation models. The results of models (6) are in the Tables 2 and 3.

According to Table 2, by considering trade-offs 1, in the stage 1, banks B05, B08, B17, B20, B21, B22 and B26 are technical efficient and the other banks are inefficient. in the stage 2, banks B07, B08, B13, B15, B18, B20 and B22 are technical efficient and the other banks are inefficient. Banks B08, B20 and B22 are only overall technical efficient banks. The corresponding ranking of banks based on their technical efficiency scores is given in parentheses in Table 2.

Table 2.
The technical efficiency scores with trade-offs 1

Banks	first stage	second stage	Overall
B01	0.9996(2)	0.907(2)	0.9067 (3)
B02	0.9737(5)	0.481(16)	0.4683(17)
B03	0.9626(7)	0.4466(19)	0.4299(20)
B04	0.8975(9)	0.4597(17)	0.4126(22)
B05	1(1)	0.9036(4)	0.9089(2)
B06	0.6948(19)	0.6277(9)	0.4361(19)
B07	0.8617(10)	1(1)	0.8617(5)
B08	1(1)	1(1)	1(1)
B09	0.973(6)	0.8638(6)	0.8405(7)
B10	0.7417(17)	0.5374(13)	0.3986(23)
B11	0.9792(4)	0.4813(15)	0.4713(16)
B12	0.8431(12)	0.5804(10)	0.4894(15)
B13	0.7867(15)	1(1)	0.7867(9)
B14	0.7856(16)	0.8049 (8)	0.6324(11)
B15	0.83(13)	1(1)	0.83(8)
B16	0.8516(11)	0.4548(18)	0.3873(24)
B17	1(1)	0.5649(11)	0.5666(13)
B18	0.6589(20)	1(1)	0.6589(10)
B19	0.9332(8)	0.906(3)	0.8455(6)
B20	1(1)	1(1)	1(1)
B21	1(1)	0.5327(14)	0.5505(14)
B22	1(1)	1(1)	1(1)
B23	0.7094(18)	0.8386(7)	0.5949(12)
B24	0.9829(3)	0.885(5)	0.8699(4)
B25	0.8062(14)	0.5514(12)	0.4446(18)
B26	1(1)	0.4247(20)	0.4292(21)

In the Figure 3, we compare the technical efficiency scores of banks based on the model (6), in the stage 1, stage 2 and overall with production trade-offs 1.

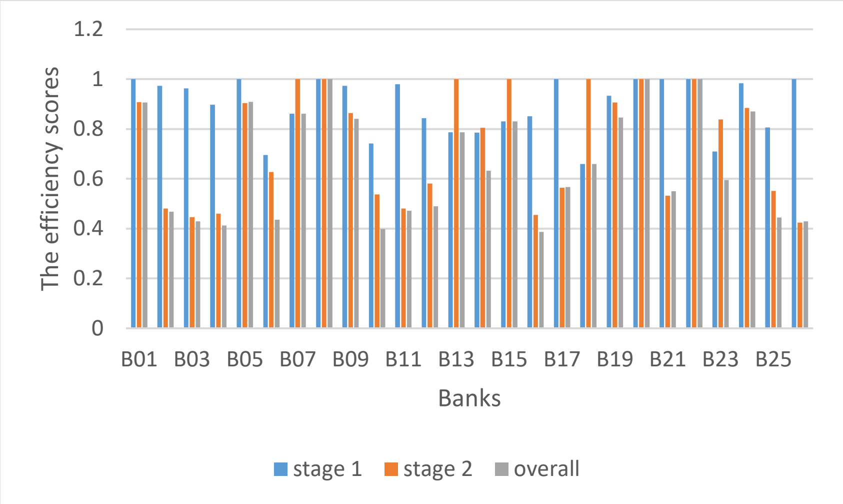

Figure 3. *The comparing the technical efficiency of banks*

The efficient targets (benchmarks or efficient operating points) corresponding to all banks are listed in Table 3. Inefficient banks should bring the level of inputs, intermediate measures and outputs to the level of their corresponding targets according to Table 3.

Table 3.
The technical efficient targets with trade-offs 1

Banks	I1	I2	I3	Z1	Z2	Y1	Y2
B01	640.2062	4464.117	2062.102	77015.05	110109.2	3375.49	1823.66
B02	544.9372	3015.16	1123.076	60357.52	73879.56	3654.69	1354.86
B03	320.4112	1545.187	626.7989	32908.93	38921.38	2026.87	881.29
B04	185.153	871.9798	378.7871	19131.63	21722.2	1014.31	483.06
B05	174.0461	528.7459	507.3028	18922.78	26226.39	1135.97	587.35
B06	24.2899	131.4266	52.2392	2528.782	3206.166	167.79	51.97
B07	15.3981	70.2266	39.8956	1446.43	1626.97	49.5	14.97
B08	1264.08	7776.84	4370.98	152217.1	203023.5	7509.36	3025.94
B09	922.626	4630.571	2543.979	88342.31	124731	4581.77	2012.86
B10	152.8688	732.1759	335.0209	15856.29	21381.44	934.43	475.17
B11	154.6731	862.726	295.3476	16615.55	19759.69	1010.68	437.62
B12	166.1528	785.6571	339.6141	17166.45	20074.97	703.43	444.92
B13	230.874	1268.776	685.8786	26800.74	40731.43	1599.64	923.2
B14	74.4255	372.8233	148.4463	7665.009	8895.968	269.33	185.28
B15	634.2563	1750.725	1345.144	34542.3	58787.21	2331.14	1159.57
B16	45.6944	301.6855	97.901	5409.497	6063.231	272.93	118.91
B17	518.8896	2733.143	899.9663	52737.82	62240.16	2333.58	1204.25
B18	67.3233	338.8879	190.3525	7668.84	11802.97	481.47	253.39
B19	123.6443	565.3483	362.3204	12065.25	18368.14	844.28	405.4
B20	6481.54	21373.2	11362.32	434320	556800.7	14424.78	5180.93
B21	84.333	336.6219	254.2746	8822.745	13248.94	932.58	286.87
B22	9.7	59.66	25.04	1039.59	1450.69	35.34	8.82
B23	62.7269	287.4292	141.2753	6571.704	7595.479	311.46	154.81
B24	11.8949	76.5789	29.9316	1335.204	1637.915	45.78	14.43
B25	129.376	592.2149	306.5617	14132.64	17256.45	676.68	379.66
B26	190.4813	1453.15	427.9265	25387.17	31021.24	1517.09	698.37

Now we determine the price of inputs in measuring cost efficiency. At first, to determine the first input price, i.e. the personnel expenses, it is calculated by dividing the average salary and weekly benefits of that bank's employees by a 40-hour work week. This information is obtained from the statistics and informatics department of that bank. This price was equal to **10** million Tomans.

As can be seen, interest expenses are the expenses incurred by the bank for borrowed funds and represents the expenses payable for deposits and other borrowed funds. Therefore, interest expenses are related to the attraction and maintenance of depositor's funds. To determine the price of interest expenses in this study, we divide the total interest paid to bank customers for deposits during the evaluation period by the total number of customers. This price was equal to **7** million Tomans.

Also non-interest expenses represent the operational expenses of the bank, the expenses of converting deposits into loans. Non-interest expenses include all operational and overhead expenses of the bank, such as benefits, professional and administrative services, equipment and other expenses. In order to determine the price of inputs in measuring cost efficiency, in order to determine the price of non-interest expenses in this study, we divide the total cost incurred by this bank for building rent, bank property maintenance, bank current, creating and maintaining software and hardware facilities, energy by the period of 12 months. This price was set at 5 million Tomans.

Now, in order to evaluate the cost efficiency of banks, we solve model (7). Considering the production trade-offs on input, intermediate measures and outputs, the manager's opinion can be included in the cost efficiency evaluation process of banks. The results of model (7) are shown in Table 4.

Due to the importance of inputs, we use models in the input oriented in this evaluation. The results are given in the Table 4. The second, third and fourth columns of Table 4 show the optimal level of inputs based on the cost efficiency model corresponding to banks. The optimal input level indicates the amount of specific input to the units in order to reach the cost efficiency level of the banks. The fifth and the sixth columns contain the total cost observed and the total minimum cost assigned to the bank in the cost efficiency evaluation process. The last column shows the cost efficiency scores. As can be seen banks B02, B05, B08, B20, B21, and B22 are cost efficient and other banks are cost inefficient under VRS technology.

Table 4.
The results of cost efficiency of banks with production trade-offs 1

Bank	Optimal inputs level			Total minimum cost	Total observed cost	Cost efficiency
B01	745.9732	4435.002	2551.044	51259.97	53293.31	0.9618(4)
B02	1163.53	6437.86	2397.95	68690.07	68690.07	1 (1)
B03	681.9232	3536.387	1487.092	39009.4	40597.93	0.9609(5)
B04	383.7653	1740.116	923.1885	20634.41	24981.22	0.826(9)
B05	191.49	581.74	559.54	8784.78	8784.78	1 (1)
B06	37.0025	138.0697	105.315	1863.089	3319.05	0.5613(20)
B07	13.4162	70.3325	35.9664	806.3215	1069.1	0.7542(11)
B08	1264.08	7776.84	4370.98	88933.58	88933.58	1(1)
B09	900.2235	5429.931	3092.874	62476.12	64674.15	0.966(3)
B10	266.4145	1056.391	757.8111	13847.94	21347.67	0.6487(15)
B11	317.7338	1342.304	798.3038	16564.99	19227.43	0.8615(8)
B12	271.7611	1065.339	711.356	13731.76	19008.82	0.7224(14)
B13	237.2827	1125.027	759.6167	14046.1	23927.27	0.587(18)
B14	87.1842	282.1857	252.8595	4111.439	6493.55	0.6332(16)
B15	348.5672	1871.696	1155.09	22362.99	30714.63	0.7281(13)
B16	108.8518	344.4125	316.5666	5082.238	8324.09	0.6105(17)
B17	864.8834	4638.644	1833.123	50284.95	50943.01	0.9871(2)

Bank	Optimal inputs level			Total minimum cost	Total observed cost	Cost efficiency
B18	70.6456	267.0039	209.2887	3621.927	7438.12	0.4869(21)
B19	134.1033	538.0683	409.7643	7156.333	8889.18	0.8051(10)
B20	6481.54	21373.2	11362.32	271239.4	271239.4	1(1)
B21	153.18	611.43	468.76	8155.61	8155.61	1(1)
B22	9.7	59.66	25.04	639.82	639.82	1(1)
B23	71.7838	237.9574	207.579	3421.435	5707.24	0.5995(19)
B24	13.9855	71.9676	37.6404	831.8304	959.25	0.8672(7)
B25	235.0702	844.2916	641.9627	11470.56	15682.53	0.7314(12)
B26	552.6206	2757.395	1242.543	31040.69	33395.45	0.9295(6)

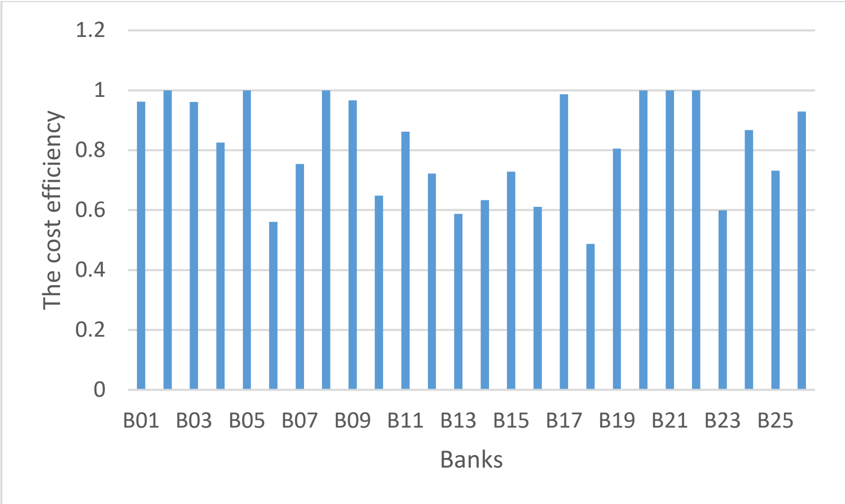

Figure 4. *The comparing the cost efficiency of bank*

In the Figure 4, we compare the cost efficiency scores of banks based on the model (7) with production trade-offs 1.

In order to sensitivity analysis of the results related to technical and cost efficiency measurement models namely models (6) and (7) to the change of production trade-offs matrices, we select production trade-offs matrixes $M_t^1, N_t^1, M_t^2, N_t^2$ as follows.

Production trade-offs 2: $N_1^1 = \begin{pmatrix} 1 \\ -0.8 \\ -0.7 \end{pmatrix}, M_1^1 = \begin{pmatrix} 1 \\ 7 \end{pmatrix},$

$N_1^2 = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, M_1^2 = \begin{pmatrix} 2 \\ 0 \end{pmatrix}.$

Then $i = 3, r = 2, d = 2, t = 1$.

The weight restriction corresponding to these matrixes on the components of inputs, intermediate products and output are as follows.

$7w_2 + 1w_1 - 1v_1 + 0.8v_2 + 0.7v_3 \leq 0.$

$2u_1 - 1w_1 \leq 0.$

The results of model (6) and (7) by selecting production trade-offs 2 given in the Tables 5, 6 and 7.

Table 5.
The technical efficiency scores with trade-offs 2

Banks	first stage	second stage	Overall
B01	0.9996 (2)	0.907(2)	0.9067(3)
B02	0.9737(4)	0.481(17)	0.4683(15)
B03	0.9312(8)	0.4466(20)	0.4159(21)
B04	0.8425(10)	0.4597 (18)	0.3873(22)
B05	1 (1)	0.9036(4)	0.9078(2)
B06	0.6762(20)	0.6277(10)	0.4245(20)
B07	0.7856(15)	1(1)	0.7856(7)

Banks	first stage	second stage	Overall
B08	1(1)	1(1)	1(1)
B09	0.9524(7)	0.8638(6)	0.8227(5)
B10	0.7045(18)	0.5374(14)	0.3786(23)
B11	0.9681(5)	0.4813(16)	0.466(16)
B12	0.7883(11)	0.5804(11)	0.4576(17)
B13	0.7867(14)	1(1)	0.7867(6)
B14	0.7741(16)	0.8049(8)	0.6231(11)
B15	0.7517(17)	1(1)	0.7517(9)
B16	0.7951(13)	0.4548(19)	0.3616(24)
B17	0.989(3)	0.5649(12)	0.5586(13)
B18	0.6589(21)	1(1)	0.6589(10)
B19	0.856 (9)	0.906(3)	0.7755(8)
B20	1(1)	1(1)	1(1)
B21	1 (1)	0.5327(15)	0.5505(14)
B22	1(1)	1(1)	1(1)
B23	0.6922(19)	0.8386(7)	0.5805(12)
B24	0.964(6)	0.885(5)	0.8531(4)
B25	0.8016(12)	0.5514(13)	0.442(18)
B26	1 (1)	0.4247(21)	0.4287(19)

According to Table 5, by considering trade-offs 2, in the stage 1, banks B05, B08, B20, B21, B22 and B26 are technical efficient and the other banks are inefficient. In the stage 2, Banks B07, B08, B13, B15, B18, B20 and B22 are technical efficient and the other banks are inefficient. Banks B08, B20 and B22 are only overall technical efficient banks. The corresponding ranking of banks based on their technical efficiency scores is given in parentheses in Table 5.

Table 6.
The technical efficient targets with trade-offs 2

Banks	I1	I2	I3	Z1	Z2	Y1	Y2
B01	640.2062	4501.58	2081.225	77015.05	110109.2	3375.49	1823.66
B02	544.9372	3015.16	1123.076	60357.52	73879.56	3654.69	1354.86
B03	338.8419	1494.849	606.3795	32908.93	38921.38	2026.87	881.29
B04	216.6859	818.5401	355.573	19131.63	21722.2	1014.31	483.06
B05	173.8415	528.1244	507.9705	18922.78	26226.39	1135.97	587.35
B06	25.9232	127.918	50.8446	2528.782	3206.166	167.79	51.97
B07	20.9824	64.0234	36.3716	1446.43	1626.97	49.5	14.97
B08	1264.08	7776.84	4370.98	152217.1	203023.5	7509.36	3025.94
B09	903.0818	4532.48	2490.09	88342.31	124731	4581.77	2012.86
B10	162.3112	695.426	318.2053	15856.29	21381.44	934.43	475.17
B11	152.9109	852.897	291.9827	16615.55	19759.69	1010.68	437.62
B12	196.7582	734.6106	317.5484	17166.45	20074.97	703.43	444.92
B13	230.874	1745.331	859.6527	26800.74	40731.43	1599.64	923.2
B14	74.3361	367.35	146.2671	7665.009	8895.968	269.33	185.28
B15	574.3722	1585.428	1249.038	34542.3	58787.21	2331.14	1159.57
B16	58.1366	281.6504	91.3993	5409.497	6063.231	272.93	118.91
B17	516.0257	2694.553	887.2594	52737.82	62240.16	2333.58	1204.25
B18	67.3233	426.9628	247.8514	7668.84	11802.97	481.47	253.39
B19	160.1824	518.5533	332.3304	12065.25	18368.14	844.28	405.4
B20	6481.54	21373.2	11362.32	434320	556800.7	14424.78	5180.93
B21	84.333	336.6219	258.0751	8822.745	13248.94	932.58	286.87
B22	9.7	59.66	25.04	1039.59	1450.69	35.34	8.82
B23	66.0671	280.4526	137.8463	6571.704	7595.479	311.46	154.81
B24	12.694	77.8017	29.3548	1335.204	1637.915	45.78	14.43
B25	128.6287	588.7943	304.791	14132.64	17256.45	676.68	379.66
B26	191.144	1466.891	427.4481	25387.17	31021.24	1517.09	698.37

Table 7

The results of cost efficiency of banks with production trade-offs 2

Bank	Optimal inputs level			Total minimum cost	Total observed cost	Cost efficiency
B01	3274.69	1990.691	0	46681.73	53293.31	0.8759(8)
B02	1163.53	6437.86	2397.95	68690.07	68690.07	1(1)
B03	681.9232	3536.387	1487.092	39009.4	40597.93	0.9609(4)
B04	383.7653	1740.116	923.1885	20634.41	24981.22	0.826(11)
B05	191.49	581.74	559.54	8784.78	8784.78	1(1)
B06	37.0025	138.0697	105.315	1863.089	3319.05	0.5613(21)
B07	13.4162	70.3325	35.9664	806.3215	1069.1	0.7542(12)
B08	4130.733	5566.59	1314.255	86844.73	88933.58	0.9765(3)
B09	3931.776	2523.759	0	56984.07	64674.15	0.8811(7)
B10	366.2043	979.2512	641.2464	13723.03	21347.67	0.6428(16)
B11	317.7338	1342.304	798.3038	16564.99	19227.43	0.8615(10)
B12	271.7611	1065.339	711.356	13731.76	19008.82	0.7224(14)
B13	1051.938	213.5533	78.7959	12408.23	23927.27	0.5186(22)
B14	87.1842	282.1857	252.8595	4111.439	6493.55	0.6332(18)
B15	1733.417	265.7516	0	19194.43	30714.63	0.6249(17)
B16	108.8518	344.4125	316.5666	5082.238	8324.09	0.6105(20)
B17	864.8834	4638.644	1833.123	50284.95	50943.01	0.9871(2)
B18	276.3195	61.735	51.9188	3454.934	7438.12	0.4645(23)
B19	629.3349	49.4734	0	6639.663	8889.18	0.7469(13)
B20	6481.54	21373.2	11362.32	271239.4	271239.4	1(1)
B21	765.8163	0	0.0059	7658.193	8155.61	0.939(5)
B22	9.7	59.66	25.04	639.82	639.82	1(1)
B23	71.7838	237.9574	207.579	3421.435	5707.24	0.5995(19)
B24	13.9855	71.9676	37.6404	831.8304	959.25	0.8672(9)
B25	235.0702	844.2916	641.9627	11470.56	15682.53	0.7314(15)
B26	552.6206	2757.395	1242.543	31040.69	33395.45	0.9295(6)

The last column of Table 7 shows the cost efficiency scores of model (7) by considering production trade-offs 2. As can be seen banks B02, B05, B20, and B22 are cost efficient and other banks are cost inefficient under VRS technology.

Conclusions and Future Research Directions

One of the ways to include the DM's preferred information in the performance evaluation process in DEA is the production trade-off method. In this method, we consider the importance of inputs and outputs relative to each other in the performance evaluation model. This degree of importance is determined by the DM. Banks are one of the most important and influential institutions in the economic system of a country. These institutions are related to different industries. Evaluating their performance is also important for economic managers. In this paper, we evaluated the efficiency score of banks based on the superior information of senior bank managers. In this regard, we used the of production trade-off method in order to apply the superiority of inputs and outputs in the evaluation process of banks. The considered structure is the two stage network structure in DEA. We presented models for evaluating the performance of banks based on the concepts of technical and cost efficiency. We obtained the ranking corresponding to the banks based on the efficiency scores. Also, in order to the sensitivity analysis of the results relative to the change of production trade-off matrixes, we selected these matrixes differently and obtained the results of technical and cost efficiency measurement models for these different choices. As future works, we can develop the models presented in this paper for other two-stage network structure to evaluate the performance of banks, and we can also obtain the models presented for other methods of weight restrictions.

Availability of data
All data used in this paper are available per request.

Conflicts of Interest
The authors declare no conflict of interest.

References

An, Q., Chen, H., Wu, J., Liang, L. (2015). Measuring slacks-based efficiency for commercial banks in China by using a two-stage DEA model with undesirable output. Annals of Operations Research, 235(1), 13–35. https://doi.org/10.1007/s10479-015-1987-1

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

Farrell, M.J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society*, Series A (General), 120, 253-290. https://www.jstor.org/stable/2343100

Fang, J., Lau, C.-K. M., Lu, Z., Tan, Y., & Zhang, H. (2019). Bank performance in China: A Perspective from Bank efficiency, risk-taking and market competition. *Pacific-Basin Finance Journal*, 56, 290–309. https://doi.org/10.1016/j.pacfin.2019.06.011

Fukuyama, H., & Matousek, R. (2011). Efficiency of Turkish banking: Two-stage network system. Variable returns to scale model. *Journal of International Financial Markets, Institutions and Money*, 21, 75–91. https://doi.org/10.1016/j.intfin.2010.08.004

Fukuyama, H., & Matousek, R. (2017). Modelling bank performance: A network DEA approach. *European Journal of Operational Research*, 259, 721–732. https://doi.org/10.1016/j.ejor.2016.10.044

Fukuyama, H., & Tan, Y. (2022a). Deconstructing three-stage over efficiency into input, output and stability efficiency components with consideration of market power and loan loss provision: An application to Chinese banks. *International Journal of Finance and Economics*, 27, 953–974. https://doi.org/10.1002/ijfe.2185

Fukuyama, H., & Tan, Y. (2022b). Implementing strategic disposability for performance evaluation: Innovation, stability, profitability and corporate social responsibility in Chinese banking. *European Journal of Operational Research*, 296, 652–668. https://doi.org/10.1016/j.ejor.2021.04.022

Fukuyama, H., Tsionas, M., & Tan, Y. (2023). Dynamic network data envelopment analysis with a sequential structure and behavioral-causal analysis: Application to the Chinese banking industry. *European Journal of Operational Research*, 307, 1360–1373. https://doi.org/10.1016/j.ejor.2021.04.022

Gerami, J., Mozaffari, M. R., Wanke, P., & Tan, Y. (2024). Fuzzy cost, revenue efficiency assessment and target setting in fuzzy DEA: a fuzzy directional distance function approach. *Journal of Modelling in Management*, 19(1), 240-287. https://doi.org/10.1108/JM2-05-2022-0121

Henriques, I. C., Sobreiro, V. A., Kimura, H., & Mariano, E. B. (2020). Two-stage DEA in banks: Terminological controversies and future directions. *Expert Systems with Applications*, 161 113632. https://doi.org/10.1016/j.eswa.2020.113632.

Izadikhah, M., Tavana, M., Di Caprio, D., & Santos-Arteaga, F. J. (2018). A novel two-stage DEA production model with freely distributed initial inputs and shared intermediate outputs. *Expert Systems with Applications*, 99, 213–230. https://doi.org/ 10.1016/j.eswa.2017.11.005

Joro, T., & Korhonen, P. (2015). Extension of data envelopment analysis with preference information. *New York: International series in operations research & management science, Springer*. https://doi.org/10.1007/978-1-4899-7528-7_6

Kao, Ch. (2024). Maximum slacks-based measure of efficiency in network data envelopment analysis: A case of garment manufacturing. *Omega*, 123, 102989. https://doi.org/10.1016/j.omega.2023.102989

Kaveh, M., Ardakani, S. S., & Tabatabaeenasab, S. M. (2020). Marketing Strategy Evaluation by Integrating Dynamic Systems Modeling and Network Data Envelopment Analysis. *Journal of System Management*, 1, 019-034. DOI: 10.30495/jsm.2020.673643

Kraidi, A. A., Daneshvar, S., &, Adesina, K. A. (2024). Weight-restricted approach on constant returns to scale DEA models: Efficiency of internet banking in Turkey. Heliyon, 10, 31008.

Konara, P., Tan, Y., & Johnes, J. (2019). FDI and heterogeneity in bank efficiency: Evidence from emerging markets. *Research in International Business and Finance*, 49, 100–113. https://doi.org/10.1016/j.ribaf.2019.02.008

Liu, X., Yang, F., & Wu, J. (2020). DEA considering technological heterogeneity and intermediate output target setting: the performance analysis of Chinese commercial banks. *Annals of Operations Research*, 291, 605–26. https://doi.org/10.1007/s10479-019-03413-w

Marzban, Sh., Shafiee, M., & Mozaffari, M. R. (2022). Four-stage Supply Chain Design for Perishable Products and evaluate it by Considering the Triple Dimensions of Sustainability. *Journal of System Management*, 8(4), 109-132. DOI: 10.30495/jsm.2022.1966734.1684

Nematizadeh, M., Amirteimoori, A., Kordrostami, S., & Khoshandam, L. (2024). An Alternative Prioritization Method in the Presence of Contextual Variables: A case on Gas Companies. *Journal of System Management*, 10(3), 119-128. https://sanad.iau.ir/en/Article/918287

Podinovski, V. V. (2004). Production trade-offs and weight restrictions in data envelopment analysis. *Journal of the Operational Research Society*, 55 (12), 1311–1322. https://doi.org/10.1057/palgrave.jors.2601794.

Podinovski, V. V., & Bouzdine-Chameeva, T. (2013). Weight restrictions and free production in data envelopment analysis. *Operations Research*, 61 (2), 426–437. https://doi.org/10.1287/opre.1120.1122.

Podinovski, V.V., & Bouzdine-Chameeva, T. (2015). Consistent weight restrictions in data envelopment analysis. *European Journal of Operational Research*, 244(1), 201–209. https://doi.org/10.1016/j.ejor.2015.01.037.

Podinovski, V.V. (2016). Optimal Weights in DEA Models with Weight Restrictions. *European Journal of Operational Research*, 254(3), 916-924. https://doi.org/10.1016/j.ejor.2016.04.035.

Podinovski,V.V., Wu, J., & Argyris, N. (2024). Production trade-offs in models of data envelopment analysis with ratio inputs and outputs: An application to schools in England. *European Journal of Operational Research*. 313 (1), 359-372. https://doi.org/10.1016/j.ejor.2023.08.019.

Shirouyehzad, H., Irannejad, N., Shahin, A. (2024). Evaluating the Performance of the Organization based on the Total Quality Management CSF*s and Knowledge Management CSFs; The case of MSL Company. *Journal of System Management*, 10(2), 33-49. DOI: 10.30495/jsm.2023.1997100.1880

Shojaie, S. E., Sadjadi, S. J., & Tavakkoli-Moghaddam, R. (2024). Malmquist Productivity Index under Network Structure and Negative Data: An Application to Banking Industry. *Journal of System Management*, 10(3), 107-118. https://sanad.iau.ir/Journal/sjsm/Article/918428

Tan, Y., & Floros, C. (2018). Risk, competition and efficiency in banking: Evidence from China. *Global Finance Journal*, 35, 223–236. https://doi.org/10.1016/j. gfj.2017.12.001

Tan, Y., Floros, C., & Anchor, J. (2017). The Profitability of Chinese banks: Impacts of risk, competition and efficiency. *Review of Accounting and Finance*, 16, 86–105. https://doi.org/10.1108/RAF-05-2015-0072

Tone, K. (2002). A strange case of the cost and allocative efficiencies in DEA. *Journal of the Operational Research Society*, 53, 1225-1231. https://doi.org/10.1057/palgrave.jors.2601438

Wanke, P., & Barros, C. (2014). Two-stage DEA: An application to major Brazilian banks. *Expert Systems with Applications*, 41, 2337–2344. https://doi.org/10.1016/j. eswa.2013.09.031

Wanke, P., Barros, C. P., & Emrouznejad, A. (2016). Assessing productive efficiency of banks using integrated Fuzzy-DEA and bootstrapping: A case of Mozambican banks. *European Journal of Operational Research*, 249, 378–389. https://doi.org/10.1016/j. ejor.2015.10.018

Wanke, P., Barros, C. P., & Emrouznejad, A. (2018). A comparison between stochastic DEA and fuzzy DEA approaches: Revisiting efficiency in Angolan banks. *RAIRO-Operations Research*, 52, 285–303. https://doi.org/10.1051/ro/2016065

Wang, K., Huang, W., Wu, J., & Liu, Y. N. (2014). Efficiency measures of the Chinese commercial banking system using an additive two-stage DEA. *Omega*, 44, 5–20. https://doi.org/10.1016/j.omega.2013.09.005

Xu, G., Zhou, Z. (2021). Assessing the efficiency of financial supply chain for Chinese commercial banks: a two-stage AR-DEA model. Industrial Management & Data Systems. 121(4), 894–920. https://doi.org/10.1108/IMDS-01-2020-0022

Yin, P., Chu, J., Wu, J., Ding, J., Yang, M., & Wang, Y. (2020). A DEA-based two-stage network approach for hotel performance analysis: An internal cooperation perspective. *Omega*, 93, 102035. https://doi.org/10.1016/j.omega.2019.02.004

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*, 85:68–82. https://doi.org/10.1016/j.omega.2018.05.012