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Overall efficiency of operational process with undesirable outputs containing both series and parallel processes: A SBM network DEA model

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Abstract

This paper proposes a new slacks-based measure network data envelopment analysis (SBM-NDEA) model with undesirable outputs to evaluate the performance of production processes that have complex structure containing both series and parallel processes. We demonstrate the proposed approach by evaluating Chinese commercial banks during 2012-2016. The operational process of these banks could be divided into deposit producing and deposit utilizing processes connected serially, while deposit utilizing process is further divided into profit generating and deposit reserve interest earning processes, which are parallel. The overall efficiency is decomposed into deposit producing and deposit utilizing efficiency. Deposit utilizing efficiency is further decomposed into profit generating and deposit reserve interest earning efficiency, respectively. Our empirical results suggest that the overall inefficiency is mainly from the profit generating process. The results also estimate the adjustment of variables for the network process of an inefficient bank.

Keywords: Data Envelopment Analysis; Series and parallel network; Chinese commercial banks; SBM-NDEA model

1. Introduction

The banking industry is an important sector in national economy. Since 1978, the Chinese banking industry has developed rapidly and has played more and more vital role in the development of national economy. The Chinese banking system is comprised of four types of banks, including stated-owned commercial banks (e.g. Bank of China, China Construction

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Bank, Industry and Commercial Bank of China), joint-stock commercial banks (e.g. China Minsheng Bank, China Everbright Bank) and city commercial banks (e.g. Ningbo Bank, Nanjing Bank). By 2020, the four state-owned commercial banks were ranked top 10 among the global banks based on the total assets. Industry and Commercial Bank of China was ranked top 1 with total assets of 4,027 billion US dollars among these banks. However, the Chinese commercial banks still face many problems, e.g., the small-scale and small market share of joint-stock commercial banks and city commercial banks, fierce completion with foreign banks (Shi et al., 2017). The completion pressure from foreign banks is especially fierce since China entered World Trade Organization (WTO), in year 2001, and started to open up financial sector ever since (Asmild and Matthews, 2012; Wang et al., 2014a). Thus, in order to improve competitiveness, it is necessary for Chinese commercial banks to measure and improve the operational efficiencies.

In the existing literatures (Emrouznejad and Yang, 2018), there are mainly two approaches for modeling bank's efficiency, i.e., stochastic frontier analysis (SFA) and data envelopment analysis (DEA). Stochastic frontier analysis (SFA) is a parametric approach (Chen, 2002; Stead and Wheat, 2020), it needs to pre-estimate the production function. SFA could only be applied to the system with single output. Data envelopment analysis (DEA), as a non-parametric approach, it requires no prior assumptions on the variable's underlying functional relationships. It could be applied to measure the efficiency of DMUs with multiple inputs and multiple outputs. The Chinese commercial banks have complex operational process with multiple inputs and outputs. Thus, DEA is more suitable for measuring the efficiencies of banks and chosen as the approach for evaluating the efficiencies of Chinese commercial banks in this paper.

In many previous literatures, DEA has been widely applied to measure bank's efficiency. There are two streams of research on the banking efficiency by DEA models. One stream is black-box DEA approach, and the other stream is two-stage DEA approach. Many papers measure banking efficiency by applying black-box DEA models (Avkiran, 2006; Staub et al., 2010).These models deem the bank's operational process as a black-box and ignore a bank's internal structure.

The papers on banking efficiency by two-stage DEA approach analyze the operational process of the banks, which use inputs to produce intermediates in the first process and the intermediates are then used in the second process to generate outputs. In previous literature, some two-stage DEA models and related variants are proposed to evaluate efficiencies of banks (Henriques et al., 2020). Seiford and Zhu (1999) firstly divided the banks' production process into profitability stage and marketability stage and proposed to evaluate the banks' efficiencies by standard two-stage DEA models. Fukuyama and Weber (2010) proposed a slacks-based inefficiency measure for a two-stage system to evaluate the performance of Japanese banks. The approach is then applied to measure efficiency of Turkish banking (Fukuyama et al., 2011). An et al. (2015) proposed to evaluate the performance of Chinese commercial banks by two-stage SBM model. Wang et al. (2014) applied the additive two-stage DEA to evaluate the performance of Chinese commercial banks. Wanke and Barros (2014) applied centralized two-stage DEA models to measure the efficiency of major Brazilian banks. Kwon and Li (2015) combined DEA and back propagation neural network (BPNN) to propose a DEA-neural network approach and applied the approach to efficiency evaluation of large U.S. banks. Xu and Zhou (2020) proposed a two-stage AR-DEA model by adding Assurance region (AR) restrictions to two-stage DEA model to analyze the efficiencies of 26 Chinese commercial banks. These studies have considered the internal structure of banks as a two-stage production process.

To evaluate the operational efficiencies of Chinese commercial banks, it is necessary to analyze the internal structure of banks' operation. Thus, the efficiencies of sub-processes could be identified, which could explain the reasons for overall inefficiency and provides decision maker the information of improving operational efficiency. In practice, a bank attracts deposits from public. Some deposits are saved as legal deposit reserve and excess reserve in the People's Bank of China[2], and others are utilized to invest in some business activities or grant a loan to enterprises or individuals. Thus, the operational process of Chinese Commercial banks could be deemed as a network structure as depicted in Fig.1.

[2] In legal, the People's Bank of China asks the commercial banks to deposit legal deposit reserve in the People's Bank of China according to the statutory deposit reserve ratio. Statutory deposit reserve ratio is the ratio of legal deposit reserve and deposit of commercial banks (or financial institutions), which is set by the People's Bank of China. Excess reserve is the deposit of commercial banks (or financial institutions) in excess of legal deposit reserve.
The People's Bank of China pays interest to commercial banks (or financial institutions) based on their deposit reserve.

As shown in Fig.1, the operational process of Chinese commercial banks is divided into deposit producing and deposit utilizing processes connected serially, and deposit utilizing process is further divided into profit generating and deposit reserve interest earning processes, which are parallel.

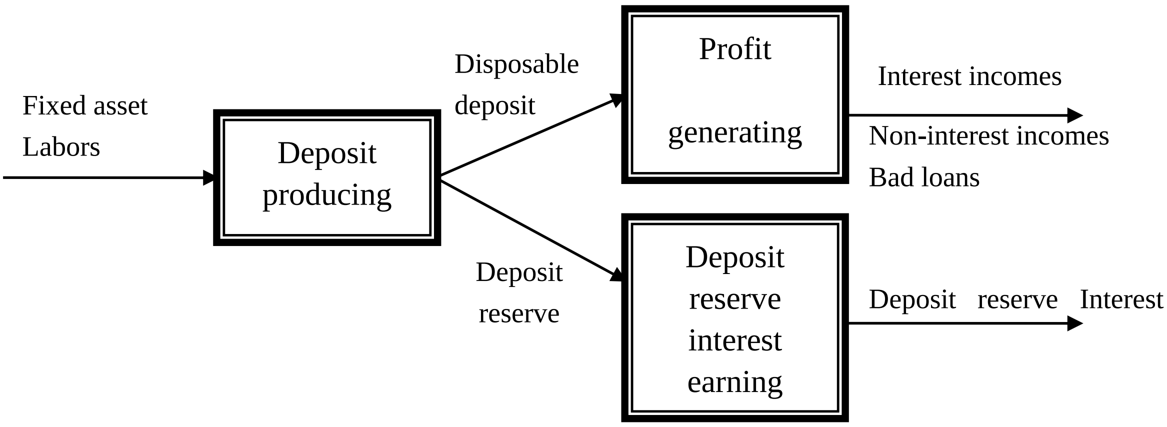

Fig 1. Operational framework of Chinese Commercial banks

In the deposit producing process, banks utilize fixed assets and labor as inputs to absorb deposits. In the deposit reserve interest earning process, some deposits are saved in the People's Bank of China as deposit reserve, which could generate deposit reserve interest. The other deposits are utilized in the profit generating process to generate two desirable outputs (non-interest incomes, interest incomes) and an undesirable output - bad loans. Thus, the operation process of Chinese commercial banks is a network structure. In such case, the performance of bank’s each sub-process should be evaluated.

In the existing literature, many models for evaluating the efficiency of network systems have been proposed (Kao, 2014), such as independent model (Seiford and Zhu, 1999; Zhu, 2000), ratio-form system efficiency model (Kao and Hwang, 2008; Kao, 2009; Chen et al. 2012; Guo et al. 2020; Ma et al. 2020), ratio-form process efficiency model (Cook et al. 2010; Wang and Chin, (2010); Wu and Birge, (2012)), game theoretic model (Chen et al. 2006; Zha and Liang, 2010; Shi et al. 2020), slacks-based measure model (Tone and Tsutsui, 2009; Kao, 2014; Zha et al. 2016; Zarei et al. 2018; Yang et al. 2021) and so on. Two or three stage Slack-Based network DEA have also been applied for evaluation of banks (Mahmoudabadi and Emrouznejad, 2019; Li et al. 2018). In Zha et al. (2016)' s paper, they applied two-stage

SBM approach to evaluate the efficiencies of Chinese commercial banks. They divide the banks' operational process as two processes - productivity process and profitability process. The deposits in the first process are invested in some business activities to gain profitability in the second process. In reality, not all deposits could be used to do investments, a part of deposits should be deposited as deposit reserve in the People's Bank of China. Thus, we divide the operational process of banks into deposit producing and deposit utilizing processes connected serially, and further divide the deposit utilizing process into parallel processes - profit generating and deposit reserve interest earning processes. The operational process of banks has a network structure. We should develop method to model the network structure. As slacks-based measure network data envelopment analysis (SBM-NDEA) model is a non-radial approach, which could obtain all the slacks of inputs, intermediates, desirable outputs and undesirable outputs when optimizing a DMU's efficiency (Tone & Tsutsui, 2009; Zhou et al. 2018; An et al. 2015), the approach is adopted in the paper.

To reasonably measure the operational efficiencies of the banks, we proposed a new slacks-based measure network data envelopment analysis (SBM-NDEA) model to measure the efficiencies of Chinese Commercial Banks considering "fixed link" to the intermediate products and considering the undesirable outputs. In the previous literature on banking efficiency evaluation, many papers deem the operational process of Chinese Commercial Banks as a two-stage process, where deposits are intermediates. In reality, not all the deposits could be utilized by banks. According to the government policy, banks must save some deposits in the People's Bank of China as deposit reserve, which could generate deposit reserve interest. And, other deposits could be utilized by the commercial banks. Thus, it is necessary to consider the deposit reserve, and divide the deposit utilizing process as two sub-systems. By this approach, the operational process of Chinese Commercial Banks is divided into deposit producing and deposit utilizing processes connected serially, while deposit utilizing process is further divided into profit generating and deposit reserve interest earning processes, which are parallel. The overall efficiency could be divided into deposit producing efficiency, profit generating efficiency and deposit reserve interest earning efficiency. The efficiency results could provide more decision information regarding the sources of Chinese Commercial banks' inefficiencies. This may provide decision makers more accurate information on the source of bank's inefficiency. For example, if the overall efficiency of a bank is low, deposit producing efficiency and profit generating efficiency are all efficient but deposit reserve interest earning efficiency is low, then the bank should pay more attention to the deposit reserve interest earning to improve the efficiency.

Although, we used an application of banking but the model proposed in this paper could be applied to any productions systems with network structure containing both series and parallel.

The rest of the paper is organized as follows. In section 2, network SBM model for performance measurement of Chinese Commercial banks is proposed. Efficiency results of the Chinese Commercial banks during 2012-2016 are described in section 3. Section 4 concludes the paper.

2. Network SBM model for performance measurement of Chinese Commercial banks

In this study, the operational process of Chinese banking system is divided into deposit producing and deposit utilizing processes connected serially, and deposit utilizing process is further divided into profit generating and deposit reserve interest earning processes, which are parallel. Thus, we consider a network system in which the outputs of the first process are the inputs of the second and third process. And, in the second process, some undesirable outputs are produced together with desirable outputs. The operational process of Chinese banking system is depicted in Fig.2.

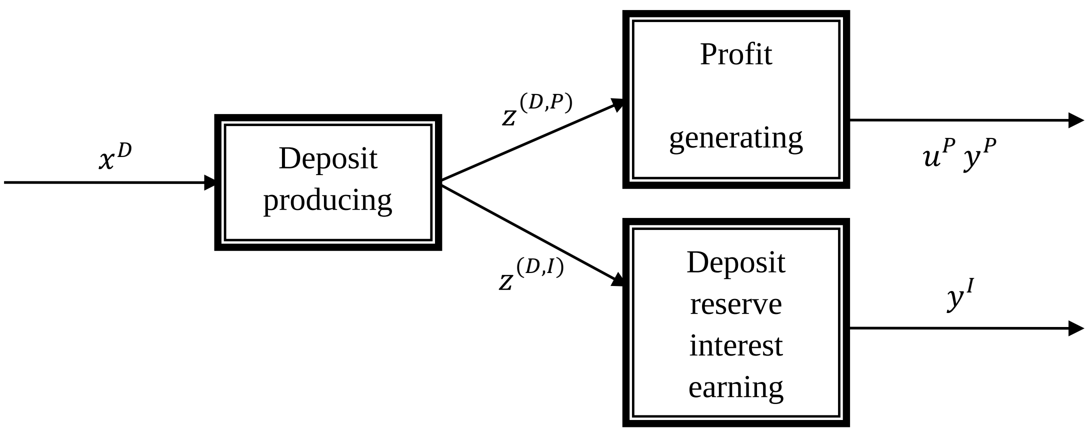

Fig 2. Network DEA for banking efficiency evaluation

Assume that there are n DMUs in Chinese banking system, denoted as $DMU_j(j = 1, \dots, n)$. Each DMU contains a network system. Suppose in the deposit producing process, each DMU uses M inputs $x_{ij}^{D}(\mathrm{i} = 1, \dots, \mathrm{M})$ to produce intermediates. The intermediates from the deposit producing process are also the inputs to the deposit utilizing process and are divided into two parts, i.e., $z_{h_P j}^{(D,P)}(h_P = 1, \dots, H_P)$ and $z_{h_I j}^{(D,I)}(h_I = 1, \dots, H_I)$. $z_{h_P j}^{(D,P)}(h_P = 1, \dots, H_P)$ and $z_{h_I j}^{(D,I)}(h_I = 1, \dots, H_I)$ are consumed by profit generating process and deposit reserve interest earning process, respectively. The final outputs of profit generating process are desirable outputs- $y_{r_P j}^{P}(r_P = 1, \dots, S_P)$ and undesirable outputs - $u_{b_P j}^{P}(b_P = 1, \dots, B_P)$, and the final outputs of deposit reserve interest earning process are $y_{r_I j}^{I}(r_I = 1, \dots, S_I)$. Here, the superscripts represent the process, D represents the deposit producing process, $(D, P)$the intermediates acting both as the outputs of deposit producing process and inputs of the profit generating process, (D, I) the intermediates acting both as the outputs of deposit producing process and inputs of deposit reserve interest earning process, P the profit generating process and I the deposit reserve earning interest process.

It is worth noting that when evaluating the bank's operational efficiency, the network structure of the banks should be considered. The efficiency results could provide more accurate information for banks' management. It's vital for the success of a bank's overall operations. The bank's management could make the overall operation process efficient by utilizing inputs and improving desirable outputs and reducing undesirable outputs within the network DEA framework.

As the bank's deposit producing process, profit generating process and deposit reserve interest earning processes are interdependent, it's better to jointly evaluate these three processes and calculate related efficiency indicators simultaneously. We develop Tone's network slacks-based measure approach (Tone and Tsutsui, 2009) with undesirable outputs to propose a new network slacks-based measure approach that considers the intermediates among these three processes which characterize the network structure of the bank's operational process. The proposed approach takes inputs, intermediates, desirable outputs and undesirable outputs in bank's operations. Our approach extends the network DEA model by considering the multi-stage processes connected both serially and in parallel, and considers the undesirable outputs. Let's explain the procedure: Firstly, we define the production possibility set in model (1), (2), and (3), including the inputs, intermediates and outputs. Secondly, based on the network production possibility set T^N defined, the overall efficiency of banks by the network SBM approach is proposed in model (4). Finally, the overall efficiency of the bank decomposed into deposit producing efficiency, deposit reserve interest earning efficiency and profit generating efficiency based on the optimal solutions of model (4). Regarding the inputs, intermediates and outputs, the overall network operational possibility set of banks could be defined as follows:

$$T^N = \{(x^D, z^{(D,P)}, z^{(D,I)}, y^P, u^P, y^I)\} \quad (1)$$

$$\sum_{j=1}^{N} \tau_j^D x_{ij}^D \le x_i^D, \mathrm{i} = 1, \ldots, \mathrm{M} \quad (1.1)$$

$$\sum_{j=1}^{N} \tau_j^D z_{h_P j}^{(D,P)} \ge z_{h_P}^{(D,P)}, h_P = 1, \ldots, H_P \quad (1.2)$$

$$\sum_{j=1}^{N} \tau_j^P z_{h_P j}^{(D,P)} \le z_{h_P}^{(D,P)}, h_P = 1, \ldots, H_P \quad (1.3)$$

$$\sum_{j=1}^{N} \tau_j^P y_{r_P j}^P \ge y_{r_P}^P, r_P = 1, \ldots, S_P \quad (1.4)$$

$$\sum_{j=1}^{N} \tau_j^P u_{b_P j}^P \le u_{b_P}^P, b_P = 1, \ldots, B_P \quad (1.5)$$

$$\sum_{j=1}^{N} \tau_j^D z_{h_I j}^{(D,I)} \ge z_{h_P}^{(D,I)}, h_I = 1, \ldots, H_I \quad (1.6)$$

$$\sum_{j=1}^{N} \tau_j^I z_{h_I j}^{(D,I)} \le z_{h_I}^{(D,I)}, h_I = 1, \ldots, H_I \quad (1.7)$$

$$\sum_{j=1}^{N} \tau_j^I y_{r_I j}^I \ge y_{r_I}^I, r_I = 1, \ldots, S_I \quad (1.8)$$

$$\tau_j^D, \tau_j^P, \tau_j^I \ge 0, j = 1, \ldots, n\} \quad (1.9)$$

Where τ_j^D, τ_j^P and τ_j^I are the intensity vectors to the deposit producing process, profit generating process and deposit reserve interest earning process, respectively. In above equation, the production possibility sets are assumed to be constant returns to scale (CRS). If variable returns to scale (VRS) is assumed, then the following three constraints are added in equation (1):

$$\sum_{j=1}^{N} \tau_j^D = 1$$

$$\sum_{j=1}^{N} \tau_j^P = 1 \quad (2)$$

$$\sum_{j=1}^{N} \tau_j^I = 1$$

As the intermediate $z_{h_P j}^{(D,P)}$ acts both as the output of the deposit producing process and the input of the profit generating process, and the intermediate $z_{h_I j}^{(D,I)}$ acts both as the output of the deposit producing process and the input of deposit reserve interest earning process. $z_{h_P j}^{(D,P)}$ could be freely adjusted and consistent between the deposit producing process and the profit generating process, and it is vice versa for $z_{h_I j}^{(D,I)}$. The free intermediates (links) could be constrained by the following constraints:

$$\sum_{j=1}^{N} \tau_j^D z_{h_P j}^{(D,P)} = \sum_{j=1}^{N} \tau_j^P z_{h_P j}^{(D,P)}, \forall h_P$$

$$\sum_{j=1}^{N} \tau_j^D z_{h_I j}^{(D,I)} = \sum_{j=1}^{N} \tau_j^I z_{h_I j}^{(D,I)}, \forall h_I \quad (3)$$

In the deposit producing process, a bank usually intends to improve its desirable outputs (deposit) while maintaining the inputs (fixed assets and labor) unchanged, or reduces its inputs at given level of outputs, or simultaneously increases outputs and reduce inputs. In the profit generating process, a bank usually intends to improve the desirable outputs (non-interest incomes and interest incomes) as much as possible and reduce the undesirable output (non-performing loans) as much as possible simultaneously. And in the deposit reserve interest earning process, a bank usually intends to maximize the desirable output (interest of deposit reserve). Thus, we should consider these three aspects when evaluating the performance of the banks. Based on the network production possibility set T^N defined above, the overall efficiency of banks by the network SBM approach could be represented as follows:

$$\underset{\theta_k, \tau_j^D, \tau_j^P, \tau_j^I, s_i^{D-}, s_{r_P}^{P+}, s_{b_P}^{P-}, s_{r_I}^{I+}}{\text{Min}} \quad \theta_k\left(x^D, z^{(D,P)}, z^{(D,I)}, y^P, u^P, y^I\right)$$

$$= \text{Min} \; \frac{w_D\left(1-\frac{1}{M}\sum_{i=1}^{M}\frac{s_i^{D-}}{x_{ik}^D}\right)+w_P\left(1-\frac{1}{B_P}\sum_{b_P=1}^{B_P}\frac{s_{b_P}^{P-}}{u_{b_P k}^P}\right)+w_I}{w_D+w_P\left(1+\frac{1}{S_P}\sum_{r_P=1}^{S_P}\frac{s_{r_P}^{P+}}{y_{r_P k}^P}\right)+w_I\left(1+\frac{1}{S_I}\sum_{r_I=1}^{S_I}\frac{s_{r_I}^{I+}}{y_{r_I k}^I}\right)} \quad (4)$$

s.t.

$$\sum_{j=1}^{N} \tau_j^D x_{ij}^D = x_{ik}^D - s_i^{D-}, \text{i} = 1, \ldots, \text{M} \quad (4.1)$$

$$\sum_{j=1}^{N} \tau_j^D z_{h_P j}^{(D,P)} = \sum_{j=1}^{N} \tau_j^P z_{h_P j}^{(D,P)} \quad (4.2)$$

$$\sum_{j=1}^{N} \tau_j^P z_{h_P j}^{(D,P)} = z_{h_P k}^{(D,P)}, h_P = 1, \dots, H_P \tag{4.3}$$

$$\sum_{j=1}^{N} \tau_j^P y_{r_P j}^P = y_{r_P k}^P + s_{r_P}^{P+}, r_P = 1, \dots, S_P \tag{4.4}$$

$$\sum_{j=1}^{N} \tau_j^P u_{b_P j}^P = u_{b_P k}^P - s_{b_P}^{P-}, b_P = 1, \dots, B_P \tag{4.5}$$

$$\sum_{j=1}^{N} \tau_j^D z_{h_I j}^{(D,I)} = \sum_{j=1}^{N} \tau_j^I z_{h_I j}^{(D,I)} \tag{4.6}$$

$$\sum_{j=1}^{N} \tau_j^I z_{h_I j}^{(D,I)} = z_{h_I k}^{(D,I)}, h_I = 1, \dots, H_I \tag{4.7}$$

$$\sum_{j=1}^{N} \tau_j^I y_{r_I j}^I = y_{r_I k}^I + s_{r_I}^{I+}, r_I = 1, \dots, S_I \tag{4.8}$$

$$\tau_j^D, \tau_j^P, \tau_j^I \geq 0, j = 1, \dots, n \tag{4.9}$$

$$s_i^{D-}, s_{r_P}^{P+}, s_{b_P}^{P-}, s_{r_I}^{I+} \geq 0, \forall i, r_P, b_P, r_I \tag{4.10}$$

The optimal value of model (4) θ_k^* is the overall efficiency of DMU k. In model (4), s_i^{D-}, $s_{r_P}^{P+}$, $s_{b_P}^{P-}$, $s_{r_I}^{I+}$ are slacks corresponding to inputs, intermediates between the deposit producing process and the profit generating process, intermediates between deposit producing process and interest of deposit reserve earning process, desirable outputs of profit generating process, undesirable outputs of profit generating process and outputs of deposit reserve interest earning process, respectively. w_D, w_P and w_I in the objective function represent the weights of the deposit producing process, profit generating process and deposit reserve interest earning process, respectively. These three weights satisfy the condition that $w_D + w_P + w_I = 1$. They are exogenously and represent the importance of certain stage (Chen et al. 2009). It could be seen that the undesirable output (non-performing loans) is deemed as inputs in constraint (4.5) and in objective function. Because we want it as small as possible, it has the same characteristics as inputs (Seiford and Zhu, 2002). In this model we assumes "fixed link" to the intermediate products and constant returns to scale (CRS). If VRS is assumed, then equation (2) should be added to the constraints.

Model (4) is a fractional program model. Thus, it is hard to solve. We can solve this problem by using Charnes–Cooper transformation (Charnes et al. 1978) by a new variable t.

$$\mathrm{t} = \left[w_D + w_P\left(1 + \frac{1}{S_P}\sum_{r_P=1}^{S_P}\frac{s_{r_P}^{P+}}{y_{r_P k}^P}\right) + w_I\left(1 + \frac{1}{S_I}\sum_{r_I=1}^{S_I}\frac{s_{r_I}^{I+}}{y_{r_I k}^I}\right)\right]^{-1} \tag{5}$$

$$\mathrm{t} = \left[1 + \frac{w_P}{S_P}\sum_{r_P=1}^{S_P}\frac{s_{r_P}^{P+}}{y_{r_P k_P}^P} + \frac{w_I}{S_I}\sum_{r_I=1}^{S_I}\frac{s_{r_I}^{I+}}{y_{r_I k}^I}\right]^{-1} \tag{6}$$

By multiplying t by the constraints, and the denominator and nominator of the objective function, model (4) could be transformed to an equivalent linear program as following model (7):

$$\min_{\theta_k, \tau_j^D, \tau_j^P, \tau_j^I, s_i^{D-}, s_{r_P}^{P+}, s_{b_P}^{P-}, s_{r_I}^{I+}} \xi_k\left(x^D, z^{(D,P)}, z^{(D,I)}, y^P, u^P, y^I\right) \quad (7)$$

$$= \text{Min} \quad t - \frac{w_D}{M}\sum_{i=1}^{M}\frac{\hat{s}_i^{D-}}{x_{ik}^D} - \frac{w_P}{B_P}\sum_{b_P=1}^{B_P}\frac{\hat{s}_{b_P}^{P-}}{u_{b_Pk}^P}$$

$$\text{s.t.}\, t + \frac{w_P}{S_P}\sum_{r_P=1}^{S_P}\frac{\hat{s}_{r_P}^{P+}}{y_{r_Pk_P}^P} + \frac{w_I}{S_I}\sum_{r_I=1}^{S_I}\frac{\hat{s}_{r_I}^{I+}}{y_{r_Ik}^I} = 1 \quad (7.1)$$

$$\sum_{j=1}^{N}\hat{\tau}_j^D x_{ij}^D = t x_{ik}^D - \hat{s}_i^{D-}, i = 1, \ldots, M \quad (7.2)$$

$$\sum_{j=1}^{N}\hat{\tau}_j^D z_{h_Pj}^{(D,P)} = \sum_{j=1}^{N}\hat{\tau}_j^P z_{h_Pj}^{(D,P)}, h_P = 1, \ldots, H_P \quad (7.3)$$

$$\sum_{j=1}^{N}\hat{\tau}_j^P z_{h_Pj}^{(D,P)} = \mathrm{t} z_{h_Pk}^{(D,P)}, h_P = 1, \ldots, H_P \quad (7.4)$$

$$\sum_{j=1}^{N}\hat{\tau}_j^P y_{r_Pj}^P = t y_{r_Pk}^P + \hat{s}_{r_P}^{P+}, r_P = 1, \ldots, S_P \quad (7.5)$$

$$\sum_{j=1}^{N}\hat{\tau}_j^P u_{b_Pj}^P = t u_{b_Pk}^P - \hat{s}_{b_P}^{P-}, b_P = 1, \ldots, B_P \quad (7.6)$$

$$\sum_{j=1}^{N}\hat{\tau}_j^D z_{h_Ij}^{(D,I)} = \sum_{j=1}^{N}\hat{\tau}_j^I z_{h_Ij}^{(D,I)}, h_I = 1, \ldots, H_I \quad (7.7)$$

$$\sum_{j=1}^{N}\hat{\tau}_j^I z_{h_Ij}^{(D,I)} = t z_{h_Ik}^{(D,I)}, h_I = 1, \ldots, H_I \quad (7.8)$$

$$\sum_{j=1}^{N}\hat{\tau}_j^I y_{r_Ij}^I = t y_{r_Ik}^I + \hat{s}_{r_I}^{I+}, r_I = 1, \ldots, S_I \quad (7.9)$$

$$\hat{\tau}_j^D, \hat{\tau}_j^P, \hat{\tau}_j^I \geq 0, j = 1, \ldots, n \quad (7.10)$$

$$\hat{s}_i^{D-}, \hat{s}_{h_P}^{(D,P)+}, \hat{s}_{h_I}^{(D,I)+}, \hat{s}_{r_P}^{P+}, \hat{s}_{b_P}^{P-}, \hat{s}_{r_I}^{I+} \geq 0, \forall i, h_P, h_I, r_P, b_P, r_I \quad (7.11)$$

Where $\hat{\tau}_j^D = t\tau_j^D$, $\hat{\tau}_j^P = t\tau_j^P$, $\hat{\tau}_j^I = t\tau_j^I$, $\hat{s}_i^{D-} = ts_i^{D-}$, $\hat{s}_{r_P}^{P+} = ts_{r_P}^{P+}$, $\hat{s}_{b_P}^{P-} = ts_{b_P}^{P-}$, $\hat{s}_{r_I}^{I+} = ts_{r_I}^{I+}$. The optimal solution of model (7) ξ_k^* is the same as the optimal solution of model (4) θ_k^*, i.e., $\theta_k^* = \xi_k^*$. The optimal value of model (7) are $\left(t^*, \hat{\tau}_j^{D*}, \hat{\tau}_j^{P*}, \hat{\tau}_j^{I*}, \hat{s}_i^{D-*}, \hat{s}_{r_P}^{P+*}, \hat{s}_{b_P}^{P-*}, \hat{s}_{r_I}^{I+*}\right)$. And, the optimal value of model (4) could be calculated by $\tau_j^{D*} = \hat{\tau}_j^{D*}/t^*$, $\tau_j^{P*} = \hat{\tau}_j^P/t^*$, $\tau_j^{I*} = \hat{\tau}_j^{I*}/t^*$,$s_i^{D-*} = \hat{s}_i^{D-*}/t^*$, $s_{r_P}^{P+*} = \hat{s}_{r_P}^{P+*}/t^*$, $s_{b_P}^{P-*} = \hat{s}_{b_P}^{P-}/t^*$, $s_{r_I}^{I+} = \hat{s}_{r_I}^{I+}/t^*$.

Let

$$\pi^D = \mathrm{t} - \frac{1}{M}\sum_{i=1}^{M}\frac{\hat{s}_i^{D-*}}{x_{ik}^D} \quad (8)$$

$$\pi^P = t - \frac{1}{B_P}\sum_{b_P=1}^{B_P}\frac{\hat{s}_{b_P}^{P-*}}{7u_{b_P k}^P} \tag{9}$$

$$\varphi^D = t \tag{10}$$

$$\varphi^P = t + \frac{1}{S_P}\sum_{r_P=1}^{S_P}\frac{\hat{s}_{r_P}^{P+*}}{y_{r_P k}^P} \tag{11}$$

$$\varphi^I = 1 + \frac{1}{S_I}\sum_{r_I=1}^{S_I}\frac{\hat{s}_{r_I}^{I+}}{y_{r_I k}^I}. \tag{12}$$

By solving model (7), the overall efficiency ξ_k^* could be obtained. As for efficiencies of three processes, the efficiency of the deposit producing process, profit generating process and deposit reserve interest earning process could be obtained by π^{D*}/φ^{D*}, π^{P*}/φ^{P*}, and t^*/φ^{I*}, respectively.

The definitions of the overall efficiency and the efficiencies of three processes is provided as follows:

Definition 1. (Bank overall efficiency, OE). θ_k^* is referred to the bank overall efficiency of bank k . If and only if $\theta_k^* = 1$ and all slacks are zero (i.e., $s_i^{D-*} = 0$, $s_{r_P}^{P+*} = 0$, $s_{b_P}^{P-*} = 0$, $s_{r_I}^{I+*} = 0$), bank k is overall efficient.

Definition 2. (Deposit producing efficiency, DPE). Based on model (4), the deposit producing efficiency of bank k (θ_k^{D*}) is defined as

$$\theta_k^{D*} = 1 - \frac{1}{M}\sum_{\mathrm{i}=1}^{M}\frac{s_i^{D-*}}{x_{ik}^D}. \tag{13}$$

Bank k is efficient in the deposit producing process if and only if the slacks are all zero, i.e., $s_i^{D-*} = 0$.

Definition 3. (Deposit utilizing efficiency, DUE). Based on model (4), the deposit utilizing efficiency of bank k (θ_k^{P*}) is defined as

$$\theta_k^{U*} = \frac{w_P\left(1-\frac{1}{B_P}\sum_{bp=1}^{B_P}\frac{s_{bP}^{P-*}}{u_{bpk}^P}\right)+w_I}{w_P\left(1+\frac{1}{S_P}\sum_{rp=1}^{S_P}\frac{s_{rP}^{P+*}}{y_{rpk}^P}\right)+w_I\left(1+\frac{1}{S_I}\sum_{r_I=1}^{S_I}\frac{s_{r_I}^{I+*}}{y_{r_I k}^I}\right)} \tag{14}$$

Bank k is efficient in the deposit utilizing process if and only if the slacks are all zero, i.e., $s_{r_P}^{P+*} = 0$, $s_{r_I}^{I+*} = 0$, and $s_{b_P}^{P-*} = 0$.

Definition 4. (Profit generating efficiency, PGE). Based on model (4), the Profit generating efficiency of bank k (θ_k^{P*}) is defined as

$$\theta_k^{P*} = \frac{1-\frac{1}{B_P}\sum_{b_P=1}^{B_P}\frac{s_{b_P}^{P-*}}{u_{b_Pk}^{P}}}{1+\frac{1}{S_P}\sum_{r_P=1}^{S_P}\frac{s_{r_P}^{P+*}}{y_{r_Pk}^{P}}}. \tag{15}$$

Bank k is efficient in the profit generating process if and only if the slacks are all zero, i.e., $s_{r_P}^{P+*} = 0$ and $s_{b_P}^{P-*} = 0$.

Definition 5. (Deposit reserve interest earning efficiency, DIE). Based on model (4), the deposit reserve interest earning efficiency of bank k (θ_k^{I*}) is defined as

$$\theta_k^{I*} = \frac{1}{1+\frac{1}{S_I}\sum_{r_I=1}^{S_I}\frac{s_{r_I}^{I+}}{y_{r_Ik}^{I}}} \tag{16}$$

Bank k is efficient in the interest of deposit reserve earning process if and only if the slacks are all zero, i.e., $s_{h_I}^{(D,I)+*} = 0$and $s_{r_I}^{I+*} = 0$.

Based on these definitions, the relation between the overall efficiency and the efficiencies of three sub-systems can be explained as follows: the overall efficiency (i.e. θ_k^*) is the weighted sum of the efficiencies of three sub-systems (i.e. $\theta_k^{D*}, \theta_k^{P*}, \theta_k^{I*}$).

3. Empirical results - Efficiency analysis of Chinese Commercial banks

In this section, the proposed SBM-NDEA model considering undesirable outputs is applied to 16 stock-listed commercial banks in China. The proposed method considers the intermediates between production and deposit utilizing process, and the multi-stage processes connected both serially and in parallel. If the connections between all the sub-processes are ignored, the results of the performance evaluation would be biased (Kao, 2014). The proposed approach explicitly considers the deposit producing process, the profit generating process and deposit reserve interest earning process simultaneously. Thus, it is appropriate for evaluating the performance of Chinese Commercial banks.

3.1 Variables and data

In our paper, 16 stock-listed Chinese Commercial banks over periods of 2012-2016 are considered. These banks are grouped into three categories: 4 stated-owned banks (SOB), 9 joint-stock commercial banks (JSB) and 3 city commercial banks. These “Big four” state owned banks are Bank of China (BOC), China Construction Bank (CCB), Industry and Commercial Bank of China (ICBC) and Agriculture Bank of China (ABC). The 9 joint-stock commercial banks are Ping An Bank (PAB), Shanghai Pudong Development Bank (SPDB), Hua Xia Bank (HXB), China Minsheng Bank (CMBC), China Merchants Bank (CMB), Industrial Bank (IB), Bank of Communications (BCM), China Everbright Bank (CEB) and China CITIC Bank (CNCB). The 3 city commercial banks are Ningbo Bank (NBB), Nanjing Bank (NJB) and Beijing Bank (BJB).

As for the selection of inputs, intermediates and outputs of banks, there are three approaches in the existing literature on the efficiency evaluation of banks by DEA (Fethi and Pasiouras, 2010), i.e., production approach, intermediate approach and profitability approach. The production approach is to assess a bank’s ability to produce services and products (i.e., deposits, loans, and others) by using labors and other resources. The intermediate approach deems the operational process of banks as intermediate process and treats deposits as inputs (Paradi and Zhu, 2013). The profitability approach is applied to evaluate a bank’s ability to convert the expenses into revenues. In practice, each bank pursues profits by using inputs. In our study, fixed assets (x1) and labor (x2) are selected as inputs, disposable deposit (z1) and deposit reserve(z2) are selected as outputs in the deposit producing process. Fixed assets (x1) refers to the asset value of physical capital, and labor (x2), which refers to the payments to the number of full-time employees hired. In the profit generating process, disposable deposit is an intermediate input, non-interest incomes (y1) and interest incomes (y2) are selected as desirable outputs, and non-performing loans or bad loans (y3) is selected as undesirable output. Here, non-interest incomes (y1) includes fees, commissions, investment and other business income, interest incomes (y2) is incomes that are primarily derived from loans, non-performing loans (y3) are problem loans for which borrowers are unable to make repayment. Bank deposits is current deposits and time deposits, which is divided into two parts - disposable deposit (z1) and deposit reserve (z2). In the deposit reserve interest earning process, deposit reserve is an intermediate input and deposit reserve interest is selected as output. It is noted that the variable-labor is the cost of labor. The variables are selected based on the profitability approach as the outputs are defined from the view of revenue and the inputs are defined from the view of cost. The method of selecting variable of banks has been used in many previous literatures, e.g. (Drake et al. 2006; Pasiouras, 2008; Zha et al. 2016). The data of these 16 Chinese Commercial banks during the period of 2012 to 2016 are collected from Wind database, the annual reports of banks and China Financial Yearbook.

The descriptive statistics of all inputs, intermediates and outputs are documented in Table 1. It could be seen that the mean fixed assets, labor and disposable deposit increased from 2012 to 2016. The mean deposit reserve, non-interest incomes, interest incomes, non-performing loans deposit reserve interest all fluctuated during the period.

Table 1. The descriptive statics of inputs, intermediates and outputs

Variables	**Statistics**	**2012**	**2013**	**2014**	**2015**	**2016**
fixed assets	Mean	423.72	485.98	554.21	610.24	677.05
	Stdv	563.82	629.52	700.67	749.86	803.02
	Maximum	1503.24	1607.04	1962.38	2215.02	2436.19
	Minimum	21.73	21.88	33.52	45.00	54.19
labor	Mean	122.72	124.87	130.26	135.97	139.60
	Stdv	137.40	134.49	128.14	126.57	127.28
	Maximum	476.97	455.73	405.11	398.90	399.02
	Minimum	4.97	3.33	3.89	11.51	18.63
Disposable deposit	Mean	32130.73	35396.41	37929.03	41646.54	46697.13
	Stdv	35697.27	38440.53	40624.86	43692.04	49355.05
	Maximum	108802.21	116966.60	124452.81	132697.80	147950.01
	Minimum	1702.13	2093.28	2513.56	2969.98	4346.94
Deposit reserve	Mean	7875.15	8594.64	9357.21	9332.37	9456.85
	Stdv	9216.99	9757.66	10250.54	10008.58	10194.82
	Maximum	27626.89	29241.65	31113.20	30121.59	30303.01
	Minimum	316.21	373.64	459.50	551.76	586.88
non-interest incomes	Mean	349.71	521.62	505.12	594.97	695.06
	Stdv	426.18	469.01	520.99	568.46	655.45
	Maximum	1191.17	1516.22	1653.70	1897.80	2040.45
	Minimum	11.26	13.82	20.02	39.00	53.91
interest incomes	Mean	2203.80	2420.80	2807.30	2946.83	2736.54
	Stdv	2146.22	2257.55	2534.65	2604.51	2320.16
	Maximum	6796.73	7216.24	8014.95	8239.12	7468.02
	Minimum	161.67	200.55	273.30	308.94	327.23
non-performing loans	Mean	250.27	297.30	415.93	615.35	723.16
	Stdv	306.74	340.54	457.13	692.72	753.50

	Maximum	858.48	936.89	1249.70	2128.67	2308.34
	Minimum	10.44	13.08	16.39	20.82	27.65
Deposit reserve interest	Mean	124.42	131.08	140.79	140.98	139.18
	Stdv	150.24	148.68	157.55	155.62	151.15
	Maximum	431.23	454.87	483.84	478.67	446.78
	Minimum	5.74	7.13	8.45	9.37	10.31

3.2 Efficiency analysis of Chinese Commercial banks

By solving model (7), we can obtain the efficiency results of the overall efficiency, deposit producing efficiency, the profit generating efficiency and deposit reserve interest earning efficiency during period of 2012 to 2016. The overall efficiency results of Chinese Commercial banks are documented in Table 2.

Table 2. The overall efficiency results of banks in China

Bank	2012	2013	2014	2015	2016	Mean	Rank
PAB	0.7059	0.9771	0.9810	0.9703	0.9006	0.9070	1
SPDB	0.7114	0.9202	0.7690	0.7200	0.7651	0.7771	6
HXB	0.5393	0.6539	0.6321	0.5801	0.5652	0.5941	15
CMBC	0.8297	0.7990	0.7258	0.7117	0.7009	0.7534	8
CMB	0.7174	0.8535	0.8033	0.7460	0.7437	0.7728	7
IB	0.8375	0.8257	0.7675	0.7655	0.7140	0.7820	5
ABC	0.5704	0.5307	0.5689	0.5213	0.5057	0.5394	16
BCM	0.6463	0.7084	0.7723	0.7257	0.7224	0.7150	9
ICBC	0.7107	0.6944	0.7330	0.6494	0.6481	0.6871	11
CEB	0.5902	0.6739	0.6720	0.6662	0.6601	0.6525	12
CCB	0.6485	0.6297	0.6435	0.6088	0.6121	0.6285	13
BOC	0.7436	0.5545	0.6112	0.5778	0.5840	0.6142	14
CNBC	0.6497	0.7264	0.6760	0.7670	0.6422	0.6923	10
NBB	0.5712	1.0000	0.8337	0.7661	0.9262	0.8194	3
NJB	0.7937	0.7075	1.0000	0.9349	0.8924	0.8657	2
BJB	0.7435	0.9657	0.8264	0.7389	0.6787	0.7906	4
Mean	0.6881	0.7638	0.7510	0.7156	0.7038	0.7245	

From Table 2, it can be seen that most banks increased their overall efficiencies from 2012 to 2013 and fluctuated during the period from 2014 to 2016, such asPAB, SPDB, HXB, CMB, BCM, CEB, CNCB, NBB and BJB. Two banks -CMBC and IB decreased the overall efficiencies during 2012-2016. Other banks' overall efficiencies fluctuated during the period.

As for the efficient banks, NBB was efficient in year 2013, NJB was efficient in year 2014.In order to investigate the efficiency differences of three categories of Chinese Commercial banks, we present the average overall efficiencies of the three categories graphically in Fig.3.

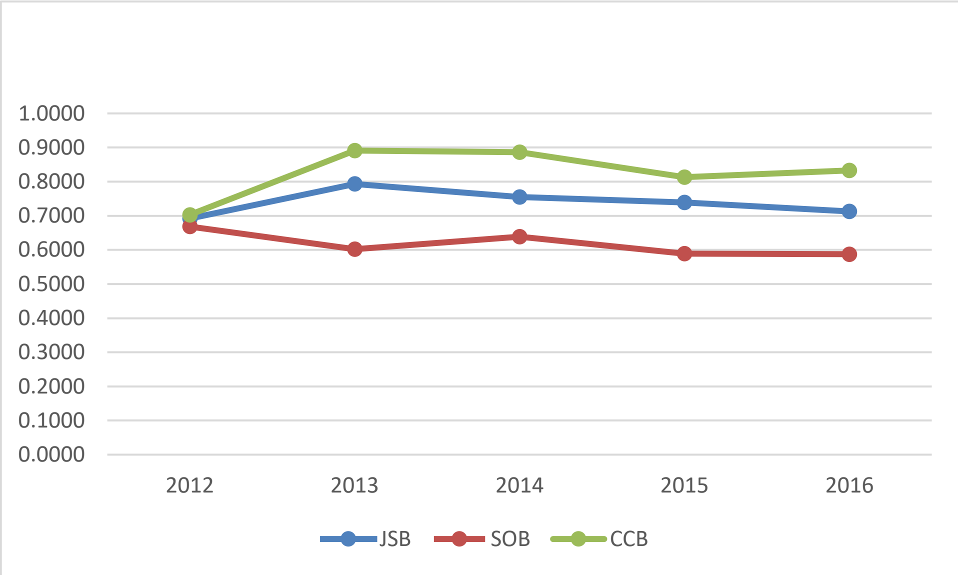

Fig 3. The average overall efficiencies of three categories of banks

It could be seen from Fig. 3 that the average overall efficiencies of CCB and JSB increase from 0.7028 and 0.6919 in 2012 to 0.8911 and 0.7931 in 2013, respectively, and decrease to 0.8324 and 0.7127. The overall efficiency of SOB decreases from 0.6683 in 2012 to 0.6023 in 2013, and fluctuates in last three years. CCB has higher overall efficiency than that of SOB and JSB excluding year 2012. It means that SOB performs the best during period of 2013 to 2016.

Table 3. The deposit producing efficiency results of banks in China

Bank	**2012**	**2013**	**2014**	**2015**	**2016**	**Mean**	**Rank**
PAB	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1
SPDB	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1
HXB	0.6111	0.6184	0.5277	0.5229	0.5850	0.5730	15
CMBC	0.7228	0.5340	0.5047	0.5212	0.5502	0.5666	16
CMB	0.8110	1.0000	1.0000	1.0000	1.0000	0.9622	6
IB	0.8575	0.7529	0.6481	0.6572	0.6353	0.7102	9
ABC	0.5827	0.6160	0.5303	0.6062	0.7059	0.6082	13
BCM	0.8941	1.0000	1.0000	1.0000	1.0000	0.9788	5
ICBC	1.0000	0.9747	0.8502	0.7310	1.0000	0.9112	7
CEB	0.5275	0.5373	0.5156	0.6608	0.7993	0.6081	14
CCB	0.8027	0.5890	0.6080	0.6726	0.8046	0.6954	10
BOC	1.0000	0.6073	0.5320	0.5723	0.6697	0.6763	12

CNBC	0.8198	0.7556	0.7529	1.0000	1.0000	0.8657	8
NBB	0.4061	1.0000	0.5667	0.4706	1.0000	0.6887	11
NJB	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1
BJB	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1
Mean	0.8147	0.8116	0.7523	0.7759	0.8594		

The deposit producing efficiencies results are given in Table 3. It could be found that six banks (i.e., PAB, SPDB, ICBC, BOC, NJB and BJB) were efficient in 2012, seven banks (i.e., PAB, SPDB, CMB, BCM, NBB, NJB and BJB) were efficient in 2013, six banks (i.e., PAB, SPDB, CMB, BCM, NJB and BJB) were efficient in 2014, seven banks (i.e., PAB, SPDB, CMB, BCM, CNCB, NJB and BJB) were efficient in 2015,nine banks (i.e., PAB, SPDB, CMB, BCM, ICBC, CNCB, NBB, NJB and BJB) were efficient in 2016. And, PAB, SPDB, NJB and BJB are efficient in these five years. The average deposit producing efficiencies of these 16 banks decrease from 2011 to 2013 and then increase from 2013 to 2016. The average of deposit producing efficiencies of 16 banks in all five years are larger than 0.75.As for the efficiency differences of three categories of Chinese Commercial banks, we also depict the average deposit producing efficiencies of the three categories graphically in Fig.4.

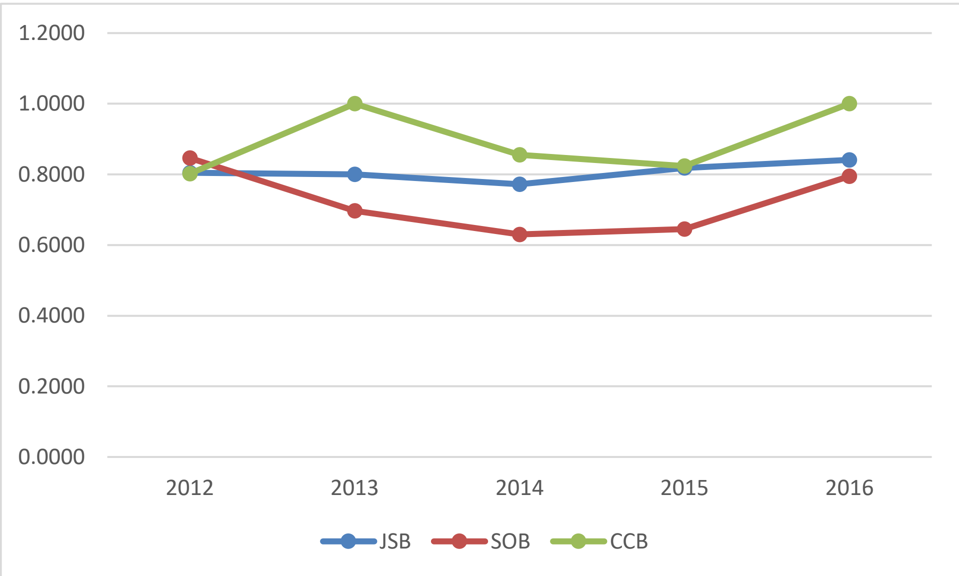

Fig 4. The average deposit producing efficiencies of three categories of banks

It could be found in Fig. 4 that the average deposit producing efficiencies of JSB and SOB decease from 2012 to 2014 and increase in later years, and the average deposit producing efficiency of CCB increases from 0.8049 in 2012 to 0.9998 in 2013 and fluctuates in later years.

Table 4. The deposit utilizing results of banks in China

Bank	2012	2013	2014	2015	2016	Mean	Rank
PAB	0.5858	0.9660	0.9718	0.9558	0.8510	0.8661	2
SPDB	0.6079	0.8849	0.6754	0.6082	0.6711	0.6895	8
HXB	0.5143	0.6674	0.6772	0.6046	0.5570	0.6041	13
CMBC	0.8765	0.9210	0.8160	0.7867	0.7580	0.8316	3
CMB	0.6816	0.7953	0.7300	0.6520	0.6524	0.7023	7
IB	0.8292	0.8569	0.8163	0.8092	0.7433	0.8110	5
ABC	0.5653	0.5042	0.5809	0.4918	0.4401	0.5164	16
BCM	0.5486	0.5970	0.6862	0.6154	0.6029	0.6100	11
ICBC	0.5997	0.5973	0.6866	0.6184	0.5212	0.6046	12
CEB	0.6151	0.7305	0.7396	0.6684	0.6039	0.6715	9
CCB	0.5890	0.5888	0.6576	0.5846	0.5406	0.5921	14
BOC	0.6440	0.5372	0.6408	0.5797	0.5541	0.5912	15
CNBC	0.5880	0.7152	0.6459	0.6802	0.5159	0.6290	10
NBB	0.6395	1.0000	0.9621	0.8988	0.8932	0.8787	1
NJB	0.7029	0.6150	1.0000	0.9055	0.8469	0.8141	4
BJB	0.6464	0.9494	0.7604	0.6301	0.5625	0.7097	6
Mean	0.6396	0.7454	0.7529	0.6931	0.6446		

The deposit utilizing efficiency of 16 Chinese Commercial banks could be calculated by model (7) and (14). The results of deposit utilizing efficiency are listed in Table 4. It shows that the average deposit utilizing efficiency increase from 0.6692 in 2012 to 0.9075 in 2014 and decrease in later years. By comparing the results in Table 4 with that in Table 3, we could find that the average deposit producing efficiencies are larger than the average deposit utilizing efficiencies in all years except for 2014 (0.8556 vs 0.9075). It indicates that the 16 Chinese Commercial banks don’t perform well in deposit utilizing process. The average deposit utilizing efficiencies of three categories are depicted in Fig. 5.

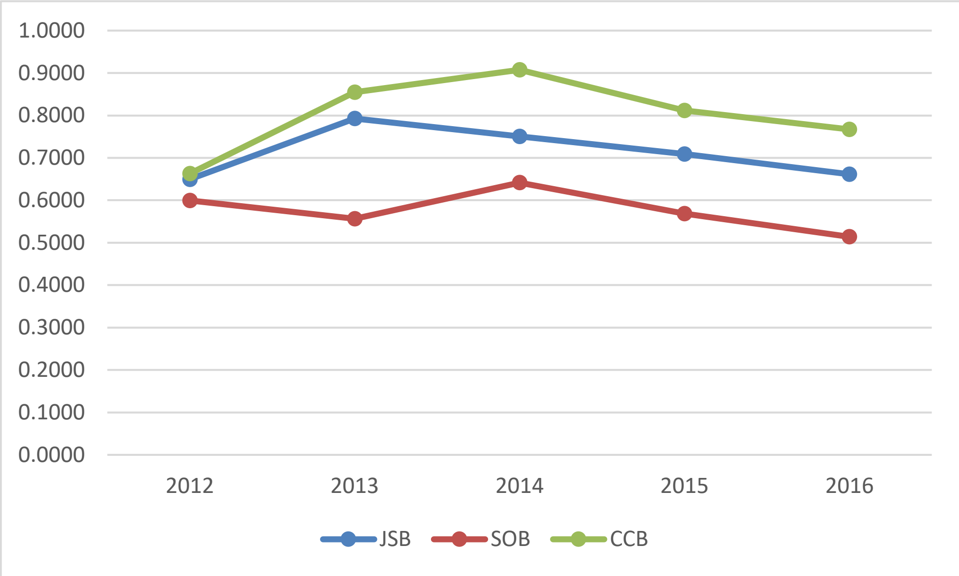

Fig 5. The average deposit utilizing efficiencies of three categories of banks

In Fig. 5, the average deposit utilizing efficiency of CCB is the largest. The average deposit utilizing efficiency of CCB increases from 0.6692 in 2012 to 0.9075 in 2014 and decreases in later years. The average deposit utilizing efficiency of JSB increases from 0.6497 in 2012 to 0.7927 in 2013 and decreases in later years. The average deposit utilizing efficiency of SOB decreases from 0.5995 in 2012 to 0.5569 and fluctuates in later years.

In order to investigate the inefficiency of the deposit utilizing process, we decompose the deposit utilizing efficiency into profit generating efficiency and deposit reserve interest earning efficiency, which are showed in Table 5 and Table 6, respectively.

Table 5. The profit generating results of banks in China

Bank	**2012**	**2013**	**2014**	**2015**	**2016**	**Mean**	**Rank**
PAB	0.3492	0.9575	1.0000	0.9138	0.7019	0.7845	6
SPDB	0.4449	1.0000	0.6608	0.5237	0.6755	0.6610	7
HXB	0.2965	0.5534	0.5227	0.3855	0.3301	0.4177	15
CMBC	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1
CMB	0.6429	1.0000	0.8663	0.6905	0.7661	0.7932	4
IB	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1
ABC	0.2556	0.3173	0.4403	0.2641	0.2102	0.2975	16
BCM	0.3193	0.4324	0.5729	0.4634	0.3828	0.4341	13
ICBC	0.4296	0.4508	0.5871	0.4749	0.3431	0.4571	12
CEB	0.4466	0.6665	0.6792	0.5659	0.4971	0.5711	10
CCB	0.4066	0.4340	0.5409	0.4160	0.3643	0.4324	14
BOC	0.5369	0.4080	0.5750	0.4902	0.4661	0.4953	11

CNBC	0.4452	0.6933	0.6142	0.7856	0.4384	0.5954	9
NBB	0.4244	1.0000	1.0000	1.0000	1.0000	0.8849	3
NJB	0.5007	0.4527	1.0000	1.0000	1.0000	0.7907	5
BJB	0.4638	1.0000	0.6803	0.5105	0.4446	0.6198	8
Mean	0.4976	0.7104	0.7337	0.6553	0.6013		

It could be found in Table 5 that the average profit generating efficiency increases from 0.463 in 2012 to 0.8934 in 2014 and decreases in later years.

Table 6. The Deposit reserve interest earning results of banks in China

Bank	**2012**	**2013**	**2014**	**2015**	**2016**	**Mean**	**Rank**
PAB	0.8293	0.9748	0.9452	1.0000	1.0000	0.9499	1
SPDB	0.8160	0.7935	0.6855	0.6644	0.6681	0.7255	11
HXB	0.7911	0.7899	0.8133	0.7895	0.7427	0.7853	6
CMBC	0.7802	0.8535	0.6891	0.6484	0.6103	0.7163	12
CMB	0.7153	0.6601	0.6344	0.6255	0.5807	0.6432	16
IB	0.7083	0.7496	0.6896	0.6796	0.5915	0.6837	13
ABC	1.0000	0.7976	0.8047	0.7628	0.7056	0.8141	4
BCM	0.7631	0.7598	0.8177	0.7455	0.7830	0.7738	7
ICBC	0.7712	0.7812	0.7839	0.7639	0.6773	0.7555	8
CEB	0.7747	0.7882	0.7896	0.7481	0.6761	0.7553	9
CCB	0.7705	0.7722	0.7655	0.7472	0.6932	0.7497	10
BOC	0.7413	0.6737	0.6977	0.6541	0.6230	0.6780	14
CNBC	0.7341	0.7353	0.6681	0.6124	0.5618	0.6623	15
NBB	0.8841	1.0000	0.9269	0.8163	0.8071	0.8869	2
NJB	0.9260	0.9311	1.0000	0.8272	0.7344	0.8837	3
BJB	0.8956	0.9037	0.8618	0.7162	0.6596	0.8074	5
Mean	0.8063	0.8103	0.7858	0.7376	0.6947		

From Table 6, it can be seen that the average deposit reserve interest earning efficiency increases from 0.9019 in 2012 to 0.9449 in 2013 and decreases in later years. Thus, the average profit generating efficiency and the average deposit reserve interest earning efficiency both have increasing tendency in first two years. In the first three years, the average profit generating efficiency is larger than the average deposit reserve interest earning efficiency, and it is adverse in later two years. It indicates that the profit generating process performs well first three years and the deposit reserve interest earning process performs well in last two years.

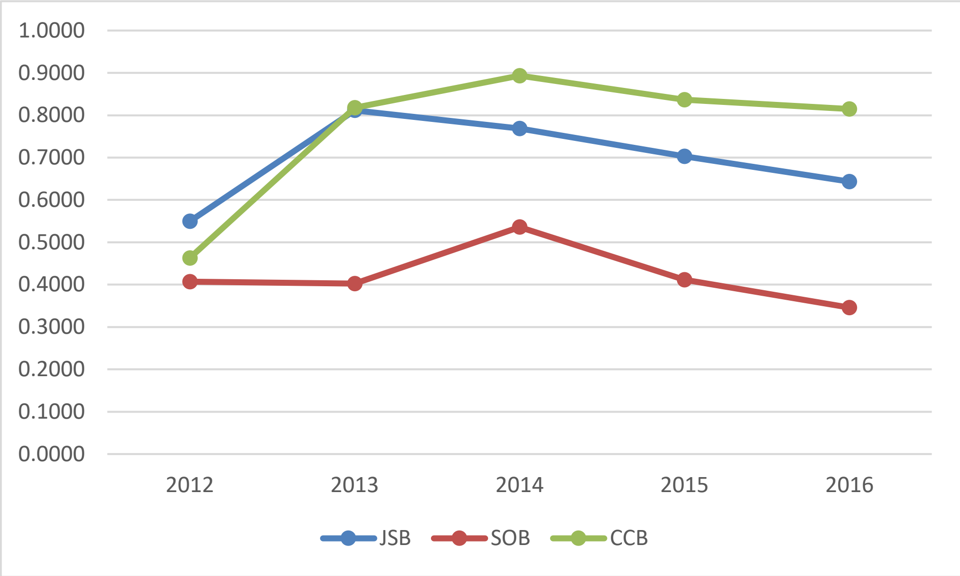

Fig 6. The average profit generating efficiencies of three categories of banks

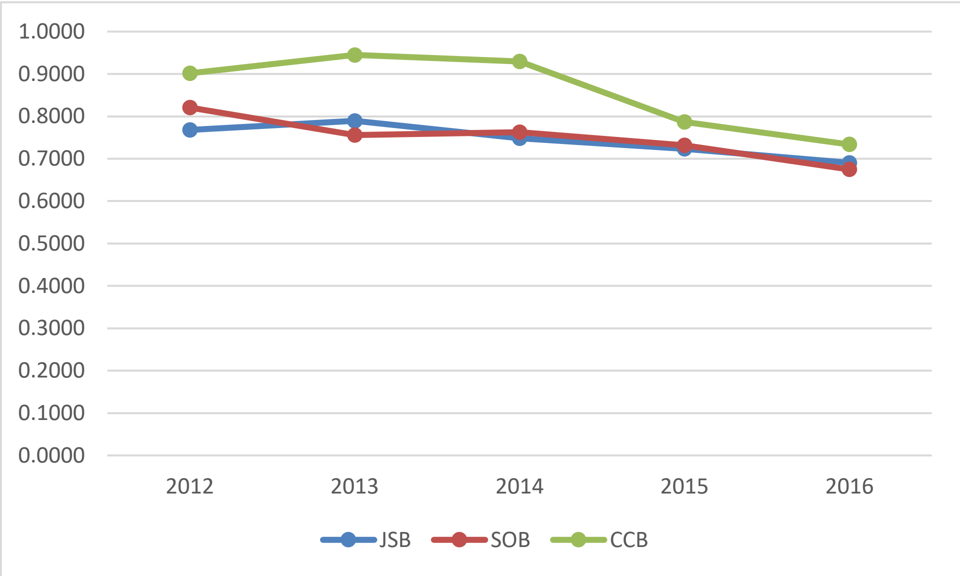

Fig 7. The average deposit reserve interest earning efficiencies of three categories of banks

Figure 6 and Figure 7 shows the changes of the average profit generating efficiencies and the average deposit reserve interest earning efficiencies of three categories during period of 2012 to 2016. It shows that the average profit generating efficiencies of CCB and SOB increase from 2012 to 2014 and decrease in subsequent years. The average profit generating efficiencies of JSB increases from 0.5494 in 2012 to 0.8114 in 2013 and decreases in subsequent years. As for the average deposit reserve interest earning efficiencies of three categories, the average deposit reserve interest earning efficiencies of JSB and SOB are stable in the period of 2012 to 2016. But the average deposit reserve interest earning efficiency of

CCB is stable from 2012 to 2014, decreases evidently in subsequent years.

3.3 Adjustments in variables

The slacks of inputs, intermediates and outputs could be obtained by our proposed approach. As the page limitation, only the results of slacks in 2016 are listed. The slacks of inputs, intermediates, and outputs in year 2016 are documented in each column in Table 7.

Table 7. Adjustments in variables in 2016

Bank	Fixed assets	Labor	Disposable deposit	Deposit reserve	non-interest incomes	interest incomes	non-performing loans	Deposit reserve interest
PAB	0.00	0.00	0.00	0.00	0.00	0.00	76.62	0.00
SPDB	0.00	0.00	0.00	0.00	0.00	0.00	169.30	36.87
HXB	14.27	57.47	0.00	0.00	26.29	25.83	129.50	11.50
CMBC	270.41	27.76	0.00	0.00	0.00	0.00	0.00	44.45
CMB	0.00	0.00	0.00	0.00	355.95	0.00	102.78	58.99
IB	33.08	80.56	0.00	0.00	0.00	0.00	0.00	40.74
ABC	744.04	47.59	0.00	0.00	3216.62	811.66	1514.41	163.84
BCM	0.00	0.00	0.00	0.00	193.04	11.96	374.36	37.97
ICBC	0.00	0.00	0.00	0.00	3669.40	200.78	1176.93	212.84
CEB	0.31	31.04	0.00	0.00	0.00	0.00	144.33	25.42
CCB	664.80	0.00	0.00	0.00	3052.64	63.75	973.71	174.86
BOC	1225.25	10.00	0.00	0.00	2751.71	0.00	604.84	180.52
CNBC	0.00	0.00	0.00	0.00	218.57	0.00	249.42	59.01
NBB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.46
NJB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.81
BJB	0.00	0.00	0.00	0.00	0.00	49.55	50.79	12.50

The banks with null slacks in all variables are deemed as efficient banks. In deposit producing process, six banks (HXB, CMBC, IB, ABC, CCB and BOC) have potential input savings of fixed asset, and five banks (HXB, CMBC, IB, ABC and BOC) have potential input savings of labor. In the profit generating process, eight banks (HXB, CMBC, IB, ABC, BCM, ICBC, CCB, BOC and CNBC)have potential output increases of interest incomes, six banks (HXB, ABC, BCM, ICBC, CCB and BJB) have potential output increases of non-interest incomes, and twelve banks (PAB, SPDB,HXB, CMB, ABC, BCM, ICBC, CEB, CCB, BOC, CNBC and BJB) have potential reduction of non-performing loans. In order to explain how a bank achieves to be efficient by adjusting the slacks of variables, we take CMCB as an example. In order to be efficient in 2016, CMCB should reduce its fix assets by 270.41 units and reduce its payments to the labors by 27.76 units, and increase the deposit reserve interest by 44.45 units.

4. Conclusions and direction for future research

In this paper, we studied the performance of Chinese Commercial banks during 2012-2016.The operational process of Chinese Commercial banks is divided into deposit producing and deposit utilizing processes connected serially, and deposit utilizing process is further divided into profit generating and deposit reserve interest earning processes, which are parallel. We propose a new slacks-based measure network data envelopment analysis (SBM-NDEA) model to evaluate the performance of Chinese Commercial banks assuming "fixed link" to the intermediate products and considering the undesirable outputs. As the proposed approach considers the deposit reserve and considers the Chinese Commercial bank’s internal structure in the efficiency evaluation, it could provide more accurate information regarding the efficiency improvement for the decision makers.

The empirical results show that most banks increased their overall efficiencies from 2012 to 2013 and fluctuated during the period from 2014 to 2016. The average deposit producing efficiencies are larger than the average deposit utilizing efficiencies in all years except for 2014. It indicates that the 16 Chinese Commercial banks don’t perform well in deposit utilizing process. As for the deposit utilizing process, the average profit generating efficiency is larger than the average deposit reserve interest earning efficiency in the first three years and it is adverse in later two years. It indicates that the profit generating process performs well first three years and the deposit reserve interest earning process performs well in last two years. Thus, in the first three years, the banks should devote to improve the efficiency of deposit reserve interest earning process, and the banks should devote to improve the efficiency of profit generating process in last two years. Moreover, the slacks of inputs, intermediates and outputs are given, which could provide managers a target for determining future strategies to improve the operational efficiencies of Chinese Commercial banks.

Some factors may influence the banks’ operational efficiencies. As pointed by Avkiran (2009), interest rates may influence a bank’s efficiency. We have not considered the influential factors of bank's operational efficiency or processes' efficiencies. This may be a direction for future research. Besides, we only selected 16 listed Chinese Commercial banks for efficiency evaluation, some foreign banks in China may be included in the efficiency analysis in the future to find the gaps between Chinese Commercial banks and foreign banks in China.

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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, 13-35.

Asmild, M., & Matthews, K. (2012). Multi-directional efficiency analysis of efficiency patterns in Chinese banks 1997-2008. European Journal of Operational Research, 219, 434-441.

Avkiran N.K. (2009). Removing the impact of environment with units-invariant efficient frontier analysis: an illustrative case study with intertemporal panel data. Omega, 37(3), 535–44.

Avkiran, N.K. (2006). Developing foreign bank efficiency models for DEA grounded in finance theory. Socio-Economic Planning Sciences, 40(4), 275-296.

Charnes A., Cooper W.W., & Rhodes E. (1978). Measuring the efficiency of decision making units. European Journal of Operational Research, 2(6), 429–444.

Chen Y , Cook W. D. , Li N., & Zhu J. (2009). Additive efficiency decomposition in two-stage DEA. European Journal of Operational Research, 196(3), 1170-1176.

Chen, C., Zhu, J., Yu, J. Y., & Noori, H. (2012). A new methodology for evaluating sustainable product design performance with two-stage network data envelopment analysis. European Journal of Operational Research, 221, 348–359.

Chen, T.Y. (2002). A comparison of chance-constrained DEA and stochastic frontier analysis: bank efficiency in Taiwan Journal of the Operational Research Society, 53(5), 492-500.

Chen, Y., Liang, L., & Yang, F. (2006). A DEA game model approach to supply chain efficiency. Annals of Operations Research, 145, 5–13.

Cook, W. D., Liang, L., & Zhu, J. (2010). Measuring performance of two-stage network structures by DEA: A review and future perspective. Omega, 38, 423–430.

Drake L., Hall M.J., & Simper R. (2006). The impact of macroeconomic and regulatory factors on bank efficiency: a non-parametric analysis of Hong Kong's banking system. Journal of Banking & Finance, 30(5),1443–1466.

Emrouznejad, A., G. L. Yang (2018) A survey and analysis of the first 40 years of scholarly literature in DEA: 1978-2016, Socio-Economic Planning Sciences, 61 (1): 4-8

Fethi M.D., & Pasiouras F. (2010). Assessing bank efficiency and performance with operational research and artificial intelligence techniques: a survey. European Journal of Operational Research, 204, 189–198.

Fukuyama, H., & Matousek, R. (2011). Efficiency of Turkish banking: Two-stage network system. Variable returns to scale model. Journal of International Financial Markets Institutions & Money, 21(1),75-91.

Fukuyama, H., & Weber, W. (2010). A slacks-based inefficiency measure for a two-stage system with bad outputs. Omega, 38(5), 398-409.

Guo C., Zhang J. & Zhang L., (2020). Two-stage additive network DEA: Duality, frontier projection and divisional efficiency. Expert Systems with Applications, 157, 1-11.

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, 1-31.

Kao C. (2014). Efficiency decomposition in network data envelopment analysis with slacks-based measures. European Journal of Operational Research, 255, 949-962.

Kao C, &Hwang S.N. (2008). Efficiency decomposition in two-stage data envelopment analysis: an application to non-life insurance companies in Taiwan. European Journal of Operational Research, 185(1), 418–29.

Kao, C. (2009). Efficiency decomposition in network data envelopment analysis: A relational model. European Journal of Operational Research, 192, 949–962.

Kao, C., 2014. Network data envelopment analysis: A review. European Journal of Operational Research, 239, 1-16.

Kwon, H.B., & Lee, J. (2015). Two-stage production modeling of large U.S. banks: A DEA-neural network approach. Expert Systems with Applications, 42(19), 6758-6766.

Li, Y., Shi, X., Emrouznejad, A. & Liang L. (2018). Environmental performance evaluation of Chinese industrial systems: a network SBM approach. Journal of the Operational Research Society, 69 (6), 825–839.

Mahmoudabadi, M. Z., A. Emrouznejad (2019) Comprehensive Performance Evaluation of Banking Branches: A Three-Stage Slacks-Based Measure (SBM) Data Envelopment Analysis, International Review of Economics and Finance, 64, 359–376.

Ma J., Qi L., Deng L., (2020). Efficiency measurement and decomposition in hybrid two-stage DEA with additional inputs. Expert Systems with Applications, 79, 348-357.

Paradi J.C., & Zhu H. (2013). A survey on bank branch efficiency and performance research with data envelopment analysis. Omega, 41, 61–79.

Pasiouras F. (2008). International evidence on the impact of regulations and supervision on banks' technical efficiency: an application of two-stage data envelopment analysis. Review of Quantitative Finance and Accounting, 30(2), 187–223.

Seiford L.M., & Zhu J. (2002). Modeling undesirable factors in efficiency evaluation. European Journal of Operational Research, 142, 16-20.

Seiford, L.M., Zhu, J. (1999). Profitability and Marketability of the Top 55 U.S. Commercial Banks. Management Science, 45(9), 1270–1288.

Shi, X., Emrouznejad, A., Jin, M., & Yang F. (2020). A new parallel fuzzy data envelopment analysis model for parallel systems with two components based on Stackelberg game theory. Fuzzy Optimization and Decision Making 19, 311–332.

Shi, X., Li, Y., Emrouznejad, A., Xie, J., & Liang, L. (2017). Estimation of potential gains from bank mergers: A novel two-stage cost efficiency DEA model. Journal of the Operational Research Society, 68, 1045-1055.

Staub, R.B., Souza, G.D.S.E., &Tabak, B.M. (2010). Evolution of bank efficiency in Brazil: A DEA approach. European Journal of Operational Research, 202(1), 204-213.

Stead, A.D., & Wheat, P. (2020). The case for the use of multiple imputation missing data methods in stochastic frontier analysis with illustration using English local highway data. European Journal of Operational Research, 280, 59-77.

Tone K., & Tsutsui M. (2010).Dynamic DEA: A slacks-based measure approach. Omega, 38(3-4),145–56.

Tone K., &Tsutsui M. (2009). Network DEA: A slacks-based measure approach. European Journal of Operational Research, 197(1), 243–252.

Tone, K., & Tsutsui, M. (2014). Dynamic DEA with network structure: A slacks-based measure approach. Omega, 42, 124–131

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.

Wang, Y. M., & Chin, K. S. (2010). Some alternative DEA models for two-stage process. Expert Systems with Applications, 37, 8799–8808.

Wanke, P., & Barros, C. (2014). Two-stage DEA: An application to major Brazilian banks. Expert Systems with Applications, 41, 2337-2344.

Wu, D. D., & Birge, J. R. (2012). Serial chain merger evaluation model and application to mortgage banking. Decision Sciences, 43, 5–35.

Xu, G., & Zhou, Z. (2020). Assessing the efficiency of financial supply chain for Chinese Commercial banks: a two-stage AR-DEA model. Industrial Management & Data Systems, online.

Yang F., Wang D., Zhao L. & Wei F., (2021). Efficiency evaluation for regional industrial water use and wastewater treatment systems in China: A dynamic interactive network slacks-based measure model. Journal of Environmental Management, 279, 1-11.

Zarei, M., A. Azar, & A. Emrouznejad (2018), A novel multilevel network slacks-based measure with an application in electric utility companies, Energy, 158: 1120-1129

Zha Y., Liang N., Wu M., & Bian Y. (2016). Efficiency evaluation of banks in China: A dynamic two-stage slacks-based measure approach. Omega, 60, 60-72.

Zha, Y., & Liang, L. (2010). Two-stage cooperation model with input freely distributed among the stages. European Journal of Operational Research, 205, 332–338.

Zhou X., Luo R., Yao L., Cao S., Wang S., Lev B. (2018). Assessing integrated water use and wastewater treatment systems in China: A mixed network structure two-stage SBM DEA model. Journal of Cleaner Production, 185, 533-546.

Zhu J. (2000). Multi-factor performance measure model with an application to Fortune 500 companies. European Journal of Operational Research, 123(1),105-124.