CEEP-BIT WORKING PAPER SERIES

Efficiency measures of the Chinese commercial banking system using an additive two-stage DEA

Ke Wang, Wei Huang
Jie Wu, Ying-Nan Liu

Working Paper 68
http://ceep.bit.edu.cn/english/publications/wp/index.htm

Center for Energy and Environmental Policy Research
Beijing Institute of Technology
No.5 Zhongguancun South Street, Haidian District
Beijing 100081
August 2014

This paper can be cited as: *Wang K, Huang W, Wu J, and Liu Y-N. 2014. Efficiency measures of the Chinese commercial banking system using an additive two-stage DEA. CEEP-BIT Working Paper.*

The authors gratefully acknowledge the support from the National Natural Science Foundation of China (71101011) and the Basic Scientific Research Foundation of BIT (20122142015). This paper was partially finished while Ke Wang was visiting University of Illinois at Urbana-Champaign, and Wang thanks the China Scholarship Council for financial support. The views expressed herein are those of the authors and do not necessarily reflect the views of the Center for Energy and Environmental Policy Research.

The Center for Energy and Environmental Policy Research, Beijing Institute of Technology (CEEP-BIT), was established in 2009. CEEP-BIT conducts researches on energy economics, climate policy and environmental management to provide scientific basis for public and private decisions in strategy planning and management. CEEP-BIT serves as the platform for the international exchange in the area of energy and environmental policy.

Currently, CEEP-BIT Ranks 82, top 5% institutions in the field of Energy Economics at IDEAS （http://ideas.repec.org/top/top.ene.htm), and Ranks 104, top 5% institutions in the field of Environmental Economics at IDEAS (http://ideas.repec.org/ top/top.env.html).

Yi-Ming Wei
Director of Center for Energy and Environmental Policy Research, Beijing Institute of Technology

For more information, please contact the office:

Address:
Director of Center for Energy and Environmental Policy Research
Beijing Institute of Technology
No.5 Zhongguancun South Street
Haidian District, Beijing 100081, P.R. China

Access:
Tel: +86-10-6891-8551
Fax: +86-10-6891-8651
Email: ceeper@vip.163.com
Website: http://ceep.bit.edu.cn/english/index.htm

Efficiency measures of the Chinese commercial banking system using an additive two-stage DEA

Ke Wang [a,*], Wei Huang [b], Jie Wu [c], Ying-Nan Liu [d]

Abstract: Measuring and improving the efficiency of the Chinese commercial banking system has recently attracted increasing interest. Few studies, however, have adopted the two-stage network DEA to explore this issue in the Chinese context. Because the entire operational process of the banking system could be divided into two sub-processes (deposit producing and profit earning), the evaluation of the sub-process efficiencies could be used to assist in identifying the sources of the inefficiency of the entire banking system. In this study, we utilize the network DEA approach to disaggregate, evaluate and test the efficiencies of 16 major Chinese commercial banks during the third round of the Chinese banking reform period (2003-2011) with the variable returns to scale setting and the consideration of undesirable/bad output. The main findings of this study are as follows: i) the two-stage DEA model is more effective than the conventional black box DEA model in identifying the inefficiency of banking system, and the inefficiency of the Chinese banking system primarily results from the inefficiency of its deposit producing sub-process; ii) the overall efficiency of the Chinese banking system improves over the study period because of the reform; iii) the state-owned commercial banks (SOBs) appear to be more overall efficient than the joint-stock commercial banks (JSBs) only in the pre-reform period, and the efficiency difference between the SOBs and the JSBs is reduced over the post-reform period; iv) the disposal of non-performing loans (NPLs) from the Chinese banking system in general explains its efficiency improvement, and the joint-equity reform of the SOBs specifically increases their efficiencies.

Keywords: Chinese commercial banks; Data envelopment analysis (DEA); Efficiency decomposition; Two-stage DEA

[a,*]Ke Wang
School of Management and Economics, Beijing Institute of Technology, 5 South Zhongguancun Street, Beijing 100081, P.R. China
e-mail: kewang2083@gmail.com
Corresponding author

[b]Wei Huang
Department of Risk Management and Insurance, University of International Business and Economics, Beijing 100029, P.R. China

[c]Jie Wu
School of Management, University of Science and Technology of China, 96 Jinzhai Road, Hefei, Anhui Province, 230026, P. R. China

[d]Ying-Nan Liu
Department of Physics and Astronomy, University of Waterloo, 200 University Avenue West, Waterloo, Ontario N2L3G1, Canada

1 Introduction

The banking industry plays an increasingly critical role in the development of the financial system. The service efficiency and quality provided by banks not only have significant effects on the economic growth of a country but also influence every aspect of people's daily lives. As the opening of financial markets occurs and technology improvements emerge, the Chinese banking system has achieved rapid development, and synchronously, the competition among the Chinese banks and between the Chinese domestic banks and the foreign banks has become fierce [1,2]. By 2012, the Chinese Big Four commercial banks, i.e., Bank of China (BOC), Agriculture Bank of China (ABC), China Construction Bank (CCB), and Industrial and Commercial Bank of China (ICBC), were all in the top ten list of the world's largest banks according to market capitalization. Specially, ICBC and CCB were rated as the top two largest banks in the world. From the perspective of strategic management, it is important for Chinese banks to continuously conduct self-checking of their efficiency, which may contribute to their long-term performance improvement.

The past three decades have witnessed significant changes in the Chinese banking system as it has reformed gradually and received tremendous successes in deregulation, corporate governance reform, non-performing loans disposition, risk management enhancement, and performance and efficiency improvement. These changes have been particularly marked over the past decade, which has been characterized a period of fluctuations in the Chinese economy, the real estate investment boom, the widespread global financial crisis that began in 2007, and the unforeseen series of natural disasters in 2008 in China. In addition, domestic banks have had to compete with foreign banks since China joined the World Trade Organization (WTO) in 2001. Particularly since 2006, with a five-year grace period of WTO elapsing, more essential banking reform has been triggered to impel Chinese banks to confront foreign competition. The Chinese Big Four state-owned commercial banks (SOBs), which dominate the Chinese banking market, have conducted joint-equity reforms from wholly state-owned commercial banks to state-controlled joint-stock commercial banks by successfully making their initial public offering (IPO) in the Shanghai and Hong Kong Stock Exchanges. Meanwhile, the joint-stock commercial banks (JSBs), such as China CITIC Bank, China Minsheng Bank and China Merchants Bank, also experienced a period of rapid growth through the strengthening of internal control and risk management, the acceleration of service and product innovation, improvements in corporate governance mechanisms, and the integration of business and management processes. Therefore, it will be of interest to investigate the performance of the Chinese banking system for both bank managers and scholars to gain deeper insight into the efficiency states, changes and differences between the SOBs and JSBs in the Chinese banking market.

Because the banking system is a multiple-input and multiple-output organization, an appropriate multiple criteria evaluation technique is essential to comprehensively and objectively measures its efficiency. Data envelopment analysis (DEA) is a well-known approach for measuring the performance of decision making units (DMUs). This method is also commonly used in the efficiency measures of banking systems. A large number of studies of Chinese bank efficiencies using DEA have been published in Chinese language journals, and there are also many studies in international scholarly journals for non-Chinese readers (e.g., [2-11,50]).

However, despite a wealth of studies investigating bank efficiency in China, it is difficult to

extrapolate and obtain clear information on efficiency evaluation and comparison in the Chinese bank system. First, for the same set of institutions during the similar observation period, the extant studies have shown mixed or contradictory results regarding the relative efficiency of the SOBs and JSBs. Luo and Yao [8] and Ariff and Can [4] have shown that the JSBs, on average, have higher technical, cost and profit efficiency than the SOBs. However, Chen et al. [3] and Laurenceson and Qin [5] have shown the opposite. Other studies include Fung and Leung [10], who found that compared with the JSBs, the SOBs have an insignificant advantage on pure technical efficiencies and a significant disadvantage on technical and scale efficiencies; furthermore, Yao et al. [6] indicated that the Big Four are not necessarily less efficient than the JSBs and that two of the four major SOBs actually outperform most of their JSB counterparts.

Second, for the efficiency change in the Chinese banking system, the prior research also shows inconsistent results. Yao et al. [6] indicated that the total factor productivity (TFP) of all banks experienced a significant annual rise during the 1998-2005 period; however, the study of Chen et al. showed that the technical and allocative efficiency of the Chinese banks decreased gradually from 1997 to 2000 [3]. Furthermore, Luo and Yao [8] noted that most of the listed Chinese commercial banks (the SOBs and JSBs) that they evaluated achieved higher efficiency levels in their IPO years, but the efficiency of half of these banks decreased after the IPO years during the 1999-2008 period.

Third, most studies analyzing efficiency in the Chinese banking system only consider the operational process to be a black box, and only the initial inputs and the final outputs are the focus of investigation, but the complicated operational process inside of the black box is typically ignored. Much less information is disseminated in the existing research literature with regard to process-specific guidance on improving the efficiency of the Chinese banks compared with the findings available for banks in other nations.

The main goals of this study are to help fill these gaps in the literature. First, we consider the production process of banks to be a network structure and apply a newly developed two-stage DEA model [12,13] to divide the entire system's efficiency into several efficiencies of linked sub-processes. Second, we measure the two-stage overall efficiency of the Chinese banks over the recent 2003-2011 period to identify the source of the banking inefficiency and to provide a more detailed explanation of the changes and differences in efficiency for the Chinese banks. Third, we investigate whether the Chinese banking market reform improved the efficiency of the Chinese banking system, whether the SOBs outperformed the JSBs (or the reverse) during the reform period, whether the reform specifically improved the efficiencies of the Big Four SOBs, and what the determinants of the efficiency of the Chinese banking system may be and how these factors affected the efficiency changes and differences.

This study makes two main contributions to the literature. First, to our knowledge, this study is the first to develop this type of two-stage approach to investigate the efficiency effects of ownership type in the study of the Chinese bank sector[1]. This research extends the literature on

[1] To our knowledge, few studies have evaluated the efficiency of the banking system by utilizing a network DEA approach (e.g., [15-17,49]), and we find only one study that measured risk management-related performance of the Chinese banks under a network DEA framework [2].

banking efficiency evaluation and inefficiency identification by developing the two-stage DEA model. Second, the paper not only provides reliable and up-to-date information on the efficiency of the Chinese bank industry but also assists us in understanding how to improve banking efficiency, hence offering important guidance for policy design and implementation in the future development of the industry.

The remainder of this study is organized as follows. Section 2 presents background information on the recent change in Chinese financial market and the reform of the Chinese banking system. In section 3, we review some of the research literature on bank efficiency in China. The two-stage DEA model and related techniques are illustrated in Section 4. Section 5 interprets the data sources, describes the variables, and presents the hypotheses. The empirical results and discussions are provided in Section 6. Lastly, Section 7 concludes this study.

2 Chinese financial market changes and banking system reforms

As a developing country and transitional economy, China and its financial market have changed dramatically during the last three decades. The financial reform of the Chinese banking system was divided into three stages by the China Banking Regulatory Commission. During the 1978-1993 period, Chinese financial system began the first round of reform in which the monopolistic position of the People's Bank of China (PBC, which is now the central bank of China) was removed with the establishment or reestablishment of four specialized banks that took over the commercial banking business from the PBC. These four wholly state-owned specialized banks, commonly named the 'Big Four', were Bank of China (BOC), Agriculture Bank of China (ABC), China Construction Bank (CCB), and Industrial and Commercial Bank of China (ICBC), which operated, respectively, in foreign currency transactions, providing credits to the rural sector, fixed-assets investment in construction sector, and commercial and industrial business [11]. At that time, the Big Four were not fully profit-oriented banks but still carried political obligations and were occasionally hampered by government intervention. Therefore, these banks accumulated a great number of non-performing loans (NPLs) because of the implementation of the policy to support weak state-owned enterprises [48]. Over-employment was another problem for the Big Four because they had to follow the directives to employ members of the People's Liberation Army (PLA) on completion of their tours of duty [11].

To alleviate these problems, the second round of financial reform was launched in 1994. The Chinese government established three policy banks to take over policy-related business from the Big Four state-owned banks and aimed to transform them into fully commercial banks. The government also initialed four asset management companies to strip the Big Four of a large number of NPLs. In addition, beginning in 1986, a number of national and regional joint-stock commercial banks were approved to open in the Chinese banking system in an attempt to decrease the monopoly power of the Big Four in the market [14]. Furthermore, this period witnessed the introduction of the Central Bank Law and the Commercial Bank Law as well as the adoption of new accounting principles that follow the International Accounting Standards, aiming to provide a normal financial market and construct a legal commercial banking system [8].

In 2001, China joined the WTO, and its financial sector was gradually opened to external

competition. Since 2006, all foreign banks were allowed to conduct RMB business and were treated on a theoretically equal basis with domestic banks. During this period, the Chinese government launched the third round of reform aimed at improving the efficiency and competitiveness of domestic banks, especially the Big Four SOBs. First, the government provided a considerable quantity of foreign exchange reserves to the SOBs to replenish the capital funds and reinforce their capital structures. Second, the SOBs were gradually transformed into conventional state-controlled joint-stock commercial banks by establishing a modern corporate system and by bringing in foreign strategic investors to improve internal governance [9]. Third, to further improve the governance and external monitoring of domestic banks, the Chinese government encouraged them to be listed on stock exchanges both on and off the Chinese Mainland. Between 2005 and 2010, all of the Big Four SOBs had successfully issued IPOs in the Hong Kong and Shanghai Stock Exchanges [6].

At present, China and its banking sector have largely weathered the financial crisis without the emergence of systemic risk and the subsequent government support as observed in the West. The reform of the Chinese financial market is ongoing, and the Chinese banking system is considered to be more market oriented than before. The diversification of banks into other areas of the financial service sector is indicative of the maturation of the banking sector and its development. However, the contestability of the SOBs is still not high, and the market share of the JSBs remains small. Whether the efficiency of the Chinese banking system has continued to benefit from the financial reform remains to be seen.

3 Literature on bank efficiencies in China

With the modern frontier efficiency methodologies, including parametric and non-parametric approaches, typically regarded as good instruments for analyzing the performance of financial institutions, the growth in bank efficiency research has been explosive. Berger and Humphrey [18] surveyed 130 studies in the financial industry alone. However, the early studies on bank efficiency focused on European countries, the United States and Japan. In recent years, developing and transition countries have achieved rapid economic growth, and market-oriented banking reform has drawn the attention of a great deal of empirical research. A wealth of literature on bank efficiency in transition and developing countries has been established during the last decade [19-30]. As a result, more attention has been devoted to research on bank efficiency in China. DEA has been widely applied in studies of bank efficiency in China. To the best of our knowledge, there are approximately 20 studies of the Chinese banking efficiency measure based on DEA-related methods that have been published in English journals and that are available to non-Chinese readers. Among these studies, approximately half of them focus on technology efficiency as measured by standard CCR or BCC models. We also briefly discuss a few recent studies of the Chinese bank efficiency and reform with mixed or contradictory results.

3.1 Efficiency changes and determinants of efficiencies

Most studies of the Chinese banking efficiency have focused on efficiency changes during their study periods and have attempted to investigate the factors that may influence bank efficiency. Chen et al. [3] investigated the effects of deregulation on banking efficiency during the 1993-2000 period. Their results revealed that the overall efficiency of the Chinese banks increased from the early 1990s to 1996 but that the deregulation that began in 1995 had a

significant influence on this progress. However, efficiency declined gradually during the 1997-2000 period as a result of the Asian financial crisis, the worldwide economy slowdown, and an increase in NPLs to SOBs. Technical efficiency continuously dominated allocative efficiency for the Chinese banks. Ariff and Can [4] also studied the effects of deregulation and banking reform on banking efficiency during the 1995-2004 period. The authors found that profit efficiency was lower than cost efficiency for all Chinese banks. On average, profit efficiency remarkably increased while cost efficiency remained almost unimproved over the study period. The researchers also indicated that banks with lower efficiency appeared to be more risky and that banks that were more profitable and paid more attention to fee-based activities tended to be more efficient.

Fung and Leung [10] specifically investigated the efficiency changes for the Big Four SOBs over the 1996-2005 period. These authors indicated that the capital injections from government to the SOBs in 1998 increased their interest incomes and decreased their costs, which may have led to the improvement of the overall technical efficiency of the SOBs during the 1997-1998 period. In 2000, the four bank asset management companies purchased a large number of NPLs from the Big Four banks that should have increased their efficiencies. However, the technical efficiency of the Big Four actually decreased after 2000. The researchers explained that this efficiency decrease may have resulted from the different methods for disposing of overdue problem loans for a period of less than or more than one year.

3.2 Bank ownership and efficiency difference

A number of studies have compared the efficiency of the Chinese banks across different bank ownership types and bank sizes. There are two different conclusions regarding the efficiency difference between the SOBs and other banks (including the JSBs). Some studies have noted that the SOBs have outperformed other Chinese banks. Chen et al. [3] showed that from 1993 to 2000, state-owned banks had a relatively higher mean efficiency score than joint-stock banks and investment banks and that large banks and small banks were the most efficient. Yao et al. [6] further indicated that during the 1998-2005 period, especially over the reform period from 2004 to 2005, three large SOBs (CCB, BOC and ICBC) had the highest technical efficiency and emerged as Chinese best performing banks, even better performing than many JSBs. The reduction of over-employment, the improvement of lending strategies, and the gradually steering away from government intervention improved the efficiency of the SOBs. However, the JSBs suffered from the lack of scale economy because they were not of sufficient size to have a large branch network as their SOBs counterparts have.

Other studies concluded that the JSBs outperformed the SOBs. The results of Fung and Leung [10] indicated that during their study period from 1996 to 2005, although the Big Four had a slightly higher pure technical efficiency than other banks, the difference between them was not significant. By contrast, the Big Four had statistically significant lower technical and scale efficiencies than other banks. Similarly, Ariff and Can [4] also concluded that over the 1995-2004 period, the JSBs on average were more cost- and profit-efficient than the SOBs and that the lower efficiency of the SOBs likely resulted from their higher rates of NPLs.

Differing from the pooled data utilized in the above studies, two other studies that measured and

compared the efficiencies of the SOBs and JSBs utilized sub-set data for separate study periods. Asmild and Matthews [11] measured the Chinese banking efficiency during 1997-2008 in several sub-samples of data sets: the pre-reform (1997-2002) and post-reform (2003-2008) sub-samples, as well as moving 4-year window sub-samples. Their results showed that the JSBs were significantly more efficient than the SOBs in both the pre-reform and post-reform periods; however, the JSBs were significantly higher ranked than the SOBs in the windows of earlier years (1997-2003), although the difference between them subsequently became insignificant in later years (2004-2008). Matthews and Zhang [9] provided a similar result indicating that for the first half of their study period (1998-2002), the JSBs outperformed the SOBs, but this performance was not sustained in the second half of the period (2003-2007).

3.3 Regulatory reform, corporate events and bank efficiencies

There are several studies in the literature specifically relating the efficiency measures to the deregulation and reform of the Chinese banking market and to corporate events, such as stock listing and importing foreign investment of the Chinese banks. The results provided by Chen et al. revealed that the 1995 deregulation enhanced the performance of the Chinese banks, especially early in the deregulation period [3]. Laurenceson and Qin [5] investigated whether foreign investment had explanatory power with respect to the Chinese banking efficiency. These authors found that both foreign investment and public listing had positive effects on the cost efficiency of the Chinese banks. Luo and Yao [8] indicated that banking efficiency in China has tended to improve after stock listing and that, on average, IPO has been an important and significant factor in assisting the Chinese banks in raising their average efficiency by 4%.

In summary, existing studies of the Chinese banking efficiency in general have indicated that the financial market reform has benefited the Chinese banking performance, but the financial crises during the last two decades may have caused a decrease in efficiency; meanwhile, the conclusions regarding banking efficiency fluctuation and the determinants of efficiency change are mixed, especially for the last decade. The literature on efficiency changes before and after the recent banking reform remain insufficient. Furthermore, conclusions regarding the difference in efficiency between different bank ownership types are also mixed. Whether the SOBs outperform the JSBs or the reverse remains a controversial issue.

Therefore, in this study, we will utilize the two-stage DEA model to disaggregate and measure the efficiency of the Chinese major SOBs and JSBs, i.e., 16 Chinese commercial banks, for the period of the third round of reform (2003-2011). Bank deposits are treated as the intermediate input/output in the present study to avoid the dilemma of the production or intermediation approach, and NPLs are included in the evaluation as the undesirable outputs. In this study, we primarily focus on the following issues: whether the Chinese banking market reform improved the efficiency of the Chinese banking system; whether the SOBs outperformed the JSBs (or the reverse) during the reform period; whether the reform, which was marked by public listing, specifically improved the efficiencies of the Big Four SOBs; and what the determinants of the efficiency of the Chinese banking system are and how these factors may have affected efficiency changes and differences.

4 Methodology: additive two-stage DEA model

4.1 Two-stage DEA model and the treatment of deposits

To obtain more reliable and detailed performance evaluation information, DMUs can be regarded as having a network structure, and the complicated process of the entire production can be divided into several sub-processes or sub-stages in which some intermediate products are considered outputs of one sub-stage and are then treated as inputs of the other sub-stage. For example, as discussed in the studies of Sexton [33], Chen and Zhu [34], Chen et al. [35], and Kao [36], DMUs can be divided into a "two-stage structure" in which the outputs of the first sub-stage are used as inputs in the second sub-stage. These intermediate outputs/inputs are further defined as intermediate measures [13].

The production process of the banking system is a typical two-stage process: the deposit-producing sub-process and the profit-earning sub-process. In the deposit-producing process, labor and physical capital are utilized by banks to raise deposits. These deposits are regarded as intermediate products of banks. In the profit-earning process, the intermediate products of deposits from the deposit-producing process are further applied to raise profits through loan and other activities. Hence, for a banking efficiency measure, Seiford and Zhu [15] presented the first two-stage DEA model to evaluate the marketability and profitability of US commercial banks. Because they used the standard DEA method to evaluate the efficiency of each stage independently, the efficiency measures did not reflect any relationship between the entire process and its components.

Kao and Hwang [12] then developed a relational two-stage DEA model that considers a series relationship when evaluating the efficiencies of insurance companies. These researchers proposed that the overall efficiency score of the entire process is the product of its two sub-process efficiency scores. Kao and Hwang's efficiency measure was considered more meaningful and reasonable but still had one limitation with respect to its constant returns to scale (CRS) setting [12]. The CRS assumption is valid only when all DMUs are operating at an optimal scale, and the application of VRS setting will be more appropriate in banking efficiency evaluation. Because the observed Chinese banks differ in size and because Chinese financial market is not fully developed and hence perfect competition is unlikely [3], the presumption that all banks under evaluation are already operating at an optimal scale may not be relevant.

Chen et al. [13] developed an alternative two-stage DEA method, which is an additive approach assuming that the overall efficiency of the entire process is a weighted average of its sub-stages efficiencies rather than a product of them. When calculating the overall efficiency, the authors employed importance-weighted arithmetic means in which the weights represent the relative importance of the performance of sub-stages in the performance of the entire process. Therefore, the approach of Chen et al. [13] is referred to as the additive approach. The additive approach enables the measurement of efficiency under both the CRS and VRS settings. In addition, because bank deposits may be better modeled as an intermediate input/output under the DEA framework, the two-stage DEA model is more appropriate to characterize the bank operation process. Therefore, in this study, we will study the efficiencies of the Chinese commercial banks based on the additive two-stage DEA approach, and we treat the deposits as intermediate measures. The overall efficiency and the sub-process efficiencies of the banking system are all measured to assist in identifying the source that causes inefficiency in the entire system.

4.2 Additive two-stage DEA model and the treatment of undesirable outputs

To model two-stage processes more generally to allow for a VRS setting, Chen et al. [13] proposed an additive two-stage DEA framework in which the overall efficiency of the entire process was decomposed into the weighted average of the two sub-stage efficiencies. The overall efficiency can be obtained through the following model (1):

$$
\begin{aligned}
\max \quad & \sum_{r=1}^{s} \mu_r y_{rj_0} + u^2 + \sum_{t=1}^{p} \pi_t z_{tj_0} + u^1 = E_0 \\
\text{s.t.} \quad & \sum_{t=1}^{p} \pi_t z_{tj} + u^1 - \sum_{i=1}^{m} \omega_i x_{ij} \leqslant 0,\ j = 1,\ldots,n, \\
& \sum_{r=1}^{s} \mu_r y_{rj} + u^2 - \sum_{t=1}^{p} \pi_t z_{tj} \leqslant 0,\ j = 1,\ldots,n, \\
& \sum_{i=1}^{m} \omega_i x_{ij_0} + \sum_{t=1}^{p} \pi_t z_{tj_0} = 1, \\
& \omega_i, \mu_r, \pi_t \geqslant 0, i = 1,\ldots,m, r = 1,\ldots,s, t = 1,\ldots,p, \\
& u^1, u^2 \text{ free in sign.}
\end{aligned}
\qquad (1)
$$

In model (1), there are n DMUs; each DMU has m inputs x_{ij} and p outputs z_{tj} of the first sub-stage. Then, outputs z_{tj} are fed into the second sub-stage as its inputs. Moreover, the second sub-stage has another s outputs y_{rj}. ω_i, μ_r and π_t are the multipliers related to x_{ij}, y_{rj} and z_{tj}, respectively. u^1 and u^2 are free variables associated with z_{tj} and y_{rj}, respectively. E_0 is the efficiency score of the DMU under evaluation.

After obtaining the optimal solution of model (1), the efficiencies for the two sub-stages can be calculated. However, the optimal solution obtained from model (1) may not be unique. Therefore, the decomposition of overall efficiency into the efficiencies of the sub-processes may not be unique either. To find a set of appropriate multipliers that yields the maximized efficiency score of sub-stage 1 (or sub-stage 2) while maintaining the overall efficiency score unchanged, the following procedure could be utilized: given the overall efficiency score E_0 obtained from model (1), either the stage 1 efficiency score E_0^1 or that of stage 2, E_0^2, could be calculated first, and the efficiency score of the other stages could then be derived from the overall efficiency score and the initially evaluated efficiency score. For example, if the stage 2 efficiency score is given the priority of being calculated first, then model (2) yields an efficiency score as follows:

$$
\begin{aligned}
\max \quad & \sum_{r=1}^{s} \mu_r y_{rj_0} + u^2 = E_0^2 \\
\text{s.t.} \quad & \sum_{t=1}^{p} \pi_t z_{tj} + u^1 - \sum_{i=1}^{m} \omega_i x_{ij} \leqslant 0,\ j = 1,\ldots,n, \\
& \sum_{r=1}^{s} \mu_r y_{rj} + u^2 - \sum_{t=1}^{p} \pi_t z_{tj} \leqslant 0,\ j = 1,\ldots,n, \\
& \sum_{t=1}^{p} \pi_t z_{tj_0} = 1, \\
& \sum_{r=1}^{s} \mu_r y_{rj_0} + u^2 + u^1 - E_0 \sum_{i=1}^{m} \omega_i x_{ij_0} = E_0 - 1, \\
& \omega_i, \mu_r, \pi_t \geqslant 0, i = 1,\ldots,m, r = 1,\ldots,s, t = 1,\ldots,p, \\
& u^1, u^2 \text{ free in sign.}
\end{aligned}
\qquad (2)
$$

The efficiency of stage 1 is then calculated as follows:

$$E_0^1 = \frac{E_0 - w_2 \cdot E_0^2}{w_1}, \quad w_1 = \frac{\sum_{i=1}^{m} v_i x_{ij_0}}{\sum_{i=1}^{m} v_i x_{ij_0} + \sum_{t=1}^{p} \eta_t z_{tj_0}}, \quad w_2 = \frac{\sum_{t=1}^{p} \eta_t z_{tj_0}}{\sum_{i=1}^{m} v_i x_{ij_0} + \sum_{t=1}^{p} \eta_t z_{tj_0}}. \qquad (3)$$

Here, w_1 and w_2 are the weights that represent the relative importance of the performance of two sub-stages to the overall performance of each DMU. Chen et al. [13] indicated that the size of a sub-stage can reflect its relative importance, and the portion of total resources consumed by each stage can be the representation of its size.

As considered by Fukuyama and Weber [16], some loans may become non-performing, meaning that they may become unable to be partially or even fully repaid by borrowers. Therefore, these non-performing loans should be treated as bad outputs or undesirable outputs. In this study, non-performing loans are treated as undesirable outputs rather than as inputs, which should be reduced to improve the efficiency of a bank, to be consistent with the physical process, as a bank cannot produce non-performing loans until the deposits are utilized to produce loans.

In the second sub-stage, when the non-performing loans occur, they should be regarded as undesirable outputs. Obviously, we wish to increase the good outputs $y_{rj}, r \in G$ and, simultaneously, to decrease the bad outputs $y_{rj}, r \in B$ to improve performance. Here, G denotes the set of subscript of desirable output, and B denotes the set of subscript of undesirable or bad output. For this purpose, Hailu and Veeman [37] proposed a DEA model in which the undesirable outputs are treated as detrimental inputs. The authors claimed that their model satisfies variable returns to scale the weak disposability of outputs are imposed, but this model was challenged by Färe and Grosskopf [38]. The latter authors raised a case against Hailu and Veeman [37], and Hailu [39] replied by concluding that their model could provide a more acceptable result in that there are fewer efficient observations than the model suggested by Färe and Grosskopf [38].

Furthermore, Seiford and Zhu [40] also proposed a translation method to address the undesirable outputs in which each undesirable output is first multiplied by "-1" and an appropriate translation vector v is then added to the negative undesirable outputs to make them positive. That is, $\bar{y}_{rj} = -y_{rj} + v_r > 0, r \in B,$ which could be achieved by choosing $v_r = \max_j \{y_{rj}\} + 1, r \in B.$ In the VRS setting, this transformation provide the identical efficient frontier.

Färe and Grosskopf [41] commented on this translation method and noted that the approach of Seiford and Zhu [40] and their directional distance function approach yield different results because the former is not translation invariant. Seiford and Zhu [42] then replied, admitting that the results obtained by Seiford and Zhu [40] were "different", and they proposed an alternative model incorporating undesirable outputs. However, the approach of Färe and Grosskopf [38,41] also has some disadvantages in that the evaluation results rely strongly on the choice of directional distance function. Different functions may lead to starkly different efficiency scores for the same DMU, and the choice of directional distance functions depends on the subjective preference and judgment of the evaluator.

As the controversy on how to model undesirable outputs under a DEA framework still exists, no agreement has been achieved in the literature as to which of these approaches mentioned above is preferable; in principle, all of the possibilities mentioned above have advantages and disadvantages. For this study, we chose the approach of Seiford and Zhu [40,42], which is more appropriate for addressing non-performing loans in the second stage to make the evaluating process consistent with the operating process of a bank. Therefore, model (1) is extended to model (4):

$$
\begin{aligned}
\max\ & \sum_{r\in G}\mu_r y_{rj_0}+\sum_{r\in B}\mu_r \bar{y}_{rj_0}+u^2+\sum_{t=1}^{p}\pi_t z_{tj_0}+u^1=E_0\\
\text{s.t.}\ & \sum_{t=1}^{p}\pi_t z_{tj}+u^1-\sum_{i=1}^{m}\omega_i x_{ij}\leqslant 0,\ j=1,\ldots,n,\\
& \sum_{r\in G}\mu_r y_{rj}+\sum_{r\in B}\mu_r \bar{y}_{rj}+u^2-\sum_{t=1}^{p}\pi_t z_{tj}\leqslant 0,\ j=1,\ldots,n,\\
& \sum_{i=1}^{m}\omega_i x_{ij_0}+\sum_{t=1}^{p}\pi_t z_{tj_0}=1,\\
& \omega_i,\mu_r,\pi_t\geqslant 0, i=1,\ldots,m, r=1,\ldots,s, t=1,\ldots,p,\\
& u^1,u^2 \text{ free in sign.}
\end{aligned}
\tag{4}
$$

Once we obtain the overall efficiency, an extended model (5) of model (2) could be developed to determine the efficiency of stage 2:

$$
\begin{aligned}
\max\ & \sum_{r\in G}\mu_r y_{rj_0}+\sum_{r\in B}\mu_r \bar{y}_{rj_0}+u^2=E_0^2\\
\text{s.t.}\ & \sum_{t=1}^{p}\pi_t z_{tj}+u^1-\sum_{i=1}^{m}\omega_i x_{ij}\leqslant 0,\ j=1,\ldots,n,\\
& \sum_{r\in G}\mu_r y_{rj}+\sum_{r\in B}\mu_r \bar{y}_{rj}+u^2-\sum_{t=1}^{p}\pi_t z_{tj}\leqslant 0,\ j=1,\ldots,n,\\
& \sum_{t=1}^{p}\pi_t z_{tj_0}=1,\\
& \sum_{r\in G}\mu_r y_{rj_0}+\sum_{r\in B}\mu_r \bar{y}_{rj_0}+u^2+u^1-E_0\sum_{i=1}^{m}\omega_i x_{ij_0}=E_0-1,\\
& \omega_i,\mu_r,\pi_t\geqslant 0, i=1,\ldots,m, r=1,\ldots,s, t=1,\ldots,p,\\
& u^1,u^2 \text{ free in sign.}
\end{aligned}
\tag{5}
$$

Then, the efficiency of stage 1 could be derived in a similar manner as in (3).

5 Data, variables and hypotheses

5.1 Input and output selection

The input and output selections for the Chinese bank efficiency measures differ depending on the research objectives. However, with the exception of deposits, there is generally agreement regarding the main categories of inputs and outputs for banking efficiency measures [43]. For example, traditional inputs include physical capital and labor, and traditional outputs include total loans, other earning assets or investments [4,14]. Luo and Yao [8] further disaggregated other earning assets into various categories, such as short- and long-term investments, deposits with central banks, and other investments. In addition, some studies have also included non-interest income as additional outputs and adopted interest income rather than loans [6,10].

However, there is a controversy in the literature with respect to the role of deposits—that is, whether to treat deposits as outputs or inputs of the banking system, which depends on whether to treat the banking system as a production process or as an intermediation process. The former treats deposits as outputs, and the latter considers deposits to be inputs [44]. Berger and Humphrey [18] argued that neither of these two approaches can fully capture the dual role of banks because deposits provide banks with "raw material" for investment and provide "liquidity, safekeeping and payment services to depositors". More recently, some studies have adopted another concept to treat deposits in efficiency measures of financial institutions under a newly developed network DEA structure [2,12,13,15-17]. Under the network DEA model, deposits are treated as an intermediate product, i.e., they are first treated as outputs of the previous sub-process and then treated as inputs of the following sub-process. The operation process of the banking system is divided into two sub-processes that respectively represent its production process (deposit-producing process using labors and capitals) and its intermediation process (income and profit-earning process using loanable deposits), and the intermediate inputs/outputs of deposits link these two sub-processes.

Another issue pertaining to input and output selection for banking efficiency measures involves handling bad loans or non-performing loans (NPLs). Obviously, NPLs is an output, but it is not desirable for a bank to have more NPLs than its peers have. Thus, NPLs should be treated as a bad output or undesirable output and minimized for a bank to improve its efficiency. However, a limited number of studies have considered NPLs under a network DEA structure. Fukuyama and Weber [16] proposed a slack-based network DEA model to evaluate bank's efficiency, where the bad loans were treated as an undesirable output of the bank's sub-process of final output production. In the only study that we found on the Chinese bank efficiency evaluation under a network DEA structure, NPLs were treated as a primary input of a bank's third sub-stage of final output production [2]. As indicated by Fukuyama and Weber [16], it is more appropriate to treat NPLs as an undesirable output rather than as an input of a bank's final output production sub-process under a network DEA framework to ensure that the efficiency evaluation process is consistent with the physical operation process of a bank, in which a bank could not produce non-performing loans until the deposits are utilized to produce loans[2].

Lastly, for the purpose of including the most appropriate and significant items of the banking system and considering the most commonly used variables for efficiency evaluation in the literature, this study regards the inputs of the banking system (the inputs of the first sub-process) as i) fixed assets (x_1), which refer to the asset value of physical capital, and ii) labor (x_2), which refers to the number of full-time employees hired. The outputs of the banking system (the outputs of the second sub-process) are as follows: i) non-interest incomes (y_1), which includes fees, commissions, investment and other business income; ii) interest incomes (y_2), which refers to incomes that are primarily derived from loans; and iii) non-performing loans or bad loans (y_3), which are problem loans for which borrowers are unable to make repayment. Bank deposits (z), which include current deposits and time deposits, are treated as intermediate inputs/outputs in this study. The two-stage DEA structure for banking efficiency evaluation and the inputs, outputs, and intermediate measure selection are shown in Figure 1.

[Insert Figure 1 here]

[2] In this study, we model NPLs as undesirable outputs of the second sub-stage of the bank operational process, and we apply Seiford and Zhu[40]'s translation method to handle the undesirable outputs.

5.2 Data and sample

Our study consists of financial and management data for 16 main Chinese commercial banks over the 2003-2011 period (144 observations). These 16 banks are divided into two groups of 4 SOBs (Big Four) and 12 JSBs. The Big Four (BOC, ABC, ICBC and CCB) together with Bank of Communications (BOCOM) are considered the 5 largest Chinese banks. The total assets are more than 10,000 billion RMB for each of the Big Four banks in 2011, and these 5 large banks dominate the Chinese banking market. The remaining 11 banks are China CITIC Bank (CNCB), China Minsheng Bank (CMBC), China Merchants Bank (CMB), Shanghai Pudong Development Bank (SPDB), Guangdong Development Bank (GDB), Hua Xia Bank (HXB), Industrial Bank (IB), Shenzhen Development Bank (SDB), Evergrowing Bank (EGB), China Zheshang Bank (CZB), and China Everbright Bank (CEB). These banks are known as medium or small banks whose total assets are between 300 and 3,000 billion RMB.

All data for these banks were obtained from Fitch-Thompson Bankscope, official sources of bank annual reports, and the Yearly Statistics Book of China's Finance. The descriptive statistics of the inputs, intermediate measures, and outputs of these 144 observations are presented in Table 1.

[Insert Table 1 here]

5.3 Several hypotheses

As noted above, in the third round of the Chinese banking reform (2003-2011), the Big Four SOBs were transformed into state-controlled joint-stock commercial banks and listed on stock exchanges; a number of NPLs were stripped, and overstaffing was reduced for the SOBs. Furthermore, foreign banks were allowed to expand RMB business in Chinese market, and the domestic banking business of the SOBs and the JSBs was opened to external competition. The results of these and other reforms to the Chinese banking market should have effected changes in the efficiency of the Chinese banking system during this period. In addition, because the SOBs still carry different objectives and encounter different constraints relative to those confronted by the JSBs, a systematic efficiency difference may exist between these two groups of banks. These conditions raise the following series of hypotheses.

Hypothesis 1. The third round of banking reform has generally had a significant effect on the efficiency of the Chinese commercial banks, and the joint-equity reform marked by public listing had a particularly positive effect on the efficiency of the Big Four SOBs.

During the last decade, the Chinese financial market has experienced a gradual deregulation from government control and the opening of banking business to foreign participation. The Big Four SOBs were transformed into joint-stock companies, accepted foreign commercial banks as strategic investors and respectively launched the IPO on stock exchanges in 2005 (CCB), 2006 (BOC and ICBC) and 2010 (ABC). Meanwhile, the JSBs began a new round of reforms to improve operating efficiencies. However, this effort was briefly interrupted in 2007 and 2008 because of the widespread global financial crisis that began in 2007. Therefore, we are interested

in whether the reforms of the Chinese commercial banks led to a promotion of banking efficiency, whether the joint-equity reform and public listing of the Big Four SOBs positively affected their efficiencies, and whether the global financial crisis restricted this promotion.

Hypothesis 2. The SOBs are more efficient than the JSBs, whether in the overall production process or in the deposit-producing and profit-earning sub-processes.

In the 1980s, the establishment of four specialized banks removed the monopolistic position in the Chinese financial market form Chinese central bank, the People's Bank of China. These four banks are the Big Four SOBs. Moreover, in the 1980s, several other commercial banks, such as Bank of Communications, China CITIC Bank, China Merchants Bank, Guangdong Development Bank, Industrial Bank, and Shenzhen Development Bank, which classified as JSBs, were being established. We consider the possibility that the JSBs may be more efficient than the SOBs because the latter are required by the government to contribute more to national and regional development rather than focusing only on profit making, i.e., the SOBs are more likely to be involved with government intervention. However, during the period of joint-equity reform for the SOBs, large numbers of problematic assets of these banks were transferred, and moreover, some of them received a given mass of capital injections from the central government. Furthermore, the JSBs appeared to have suffered from the lack of scale economies, as they do not have the large branch networks that their SOB counterparts have. Therefore, it is unclear whether the state-owned banks are more or less efficient than the joint-stock banks. In this study, we are interested in determining whether ownership structure has influenced the efficiency of the Chinese commercial banks.

Hypothesis 3. The disposal of NPLs has a significant influence on the measurement of the efficiency of the Chinese commercial banks.

Before the financial market reform, the Chinese banking system had been left with an overhang of NPLs, particularly for the SOBs who had to carry political and social obligations, such as supporting weak state-owned enterprises. During the reform, a large number of NPLs were written off or absorbed by the asset management companies from the Big Four SOBs and other JSBs. For instance, by the end of 2005, the ratio of NPLs to total loans of the three largest SOBs (CCB, BOC and ICBC) had been reduced from more than 33% in 1999 to less than 6%. During the 2003-2008 period, more than 1,200 billion NPLs at face value were sold, and 90% of them were NPLs of the Big Four SOBs. Therefore, whether the NPLs are included or excluded from the evaluation may affect efficiency measures for the Chinese banks[3]. In the study, we are

[3] During the reform period of the first tranche in 1999, the asset management companies obtained the NPLs from the Chinese banks and sold bonds back to the banks at par while paying a much lower return, and then in the second tranche in 2000-2001, the asset management companies swapped the NPLs for bonds at a discount but still paid a rate of interest to the banks. Thus, the disposal of the NPLs will slightly increase interest earnings and slightly increase efficiency, but the asset values of the Chinese banks will decrease for the loan portfolio, and the other earning assets will also decrease. In such a case, it does not necessarily support Hypothesis 3 that the disposal of NPLs by the asset management companies during 1999 and 2001 helped to improve the efficiency of the Chinese banks. However, in the case of the period examined in this study (2003-2011), there were no asset management operations. Removing NPLs from the evaluation reflects the writing off of the NPLs from the Chinese banks, but there is no change in interest earnings. Thus, excluding NPLs from the outputs will show a decrease in efficiency, but the results differ from the experiment regarding the operations of the asset management companies. In addition,

interested in determining whether the high ratio of NPLs and the rapid striping off of NPLs from the SOBs and JSBs have influenced the efficiency of the Chinese commercial banks.

Because we apply the additive two-stage DEA model to measure banking efficiency and treat bank deposits as intermediation input/output, the efficiency evaluation results are further compared with those form the traditional black box DEA model under both the production and intermediation approaches. We are also interested in testing whether there are significant efficiency differences between these approaches. In addition, the two-stage DEA model provides not only the overall efficiency measures of banking system but also its sub-process efficiency measures. Therefore, we test the above hypotheses on both the overall efficiency level and the sub-process efficiency level.

6 Results and discussions

Both the overall efficiency and the sub-process efficiency of the system can be obtained from the additive two-stage DEA model. The first sub-process efficiency measures the performance of the banking system in producing deposits, whereas the second sub-process efficiency measures its performance in generating profit. The overall efficiency scores E_0 of the Chinese banks are obtained by applying model (4), and the sub-process efficiency scores E_0^1 and E_0^2 for the deposit-producing and profit-earning processes are calculated using model (5) and equation (3). For comparison, we also calculate the black box model efficiency E_0^b of all banks by ignoring the intermediate measures and applying both production and intermediation approaches under the traditional DEA model. Bank deposits are treated as outputs under the production approach and as inputs under the intermediation approach.

6.1 Two-stage model overall efficiency and black box model efficiency

We first consider utilizing the pooled data, in which all 144 observations for 16 banks over the 9-year study period (2003-2011) are pooled into one data set for efficiency evaluation. Table 2 documents the efficiency scores and ranks (for selected years) of the black box model (under both the production and intermediation approaches) and the overall efficiency of the two-stage model for 16 Chinese commercial banks that are measured by the traditional BCC model and two-stage model (4), respectively. Figure 2 depicts the annual average of the efficiency scores. Table 2 indicates that there are fewer efficient DMUs identified by the two-stage model (6 DMUs exhibit efficient) than the black box models (16 and 15 DMUs are efficient, respectively, under the production and intermediation approaches), and the efficiency scores measured by the black box model are higher than those of the two-stage model on average during the study period. This result implies that the conventional black box DEA model may overestimate the efficiency of ignoring the intermediate input/output measures in the banking system or arbitrarily treating deposits as initial input or final output of the system. Furthermore, the two-stage DEA model is found to be more effective in identifying the inefficiencies of the banking system. These differences between the two types of models are graphically confirmed in Figure 2 and are further tested and illustrated in the last two rows of Table 4. That is, on average, both the production approach efficiency and the intermediation approach efficiency are higher than the

---

because translated NPLs, which are treated as desirable outputs, are utilized in this study, removing the translated NPLs from the set of outputs will reduce the positive effect of writing off the original NPLs from the banks under evaluation.

two-stage overall efficiency at the significance levels of 1% and 5%, respectively, under the Wilcoxon matched-pairs signed-ranks test (also known as the Wilcoxon test; see Daniel [45] for this test).

In addition, the results shown in Table 4 indicate that both the production approach efficiencies and the intermediation approach efficiencies in each year from 2003 to 2011 are all higher than the two-stage overall efficiencies. The Kruskal-Wallis test (also known as the K-W test; see Hollander and Wolfe [46] for this test) is utilized here, and it further statistically confirms (at the 1% or 5% level) that the production approach efficiencies are significantly higher than the two-stage overall efficiencies in each year of the 2006-2011 period and that the intermediation approach efficiencies are significantly higher than the two-stage overall efficiencies in each year of the 2003-2009 period. However, the higher production approach efficiencies compared with the two-stage overall efficiencies during 2003 and 2005 are not significant. Therefore, we can conclude that the efficiency given by the black box model is generally greater than that by the two-stage model for the Chinese banking system in nearly all years of our study period: hence, a traditional black box DEA model may overestimate the Chinese banking efficiency.

[Insert Table 2, 3, 4 and Figure 2 here]

6.2 Overall efficiency changes for the Chinese banks

Regarding the overall efficiency of the two-stage model, Table 2 shows that five banks performed efficiently in specific years: EGB and CZB in 2003, as well as ICBC, BOC, SPDB and EGB in 2009. More banks appear with higher efficiencies in 2007-2011 than in 2003-2006. On average, as Figure 3 depicts, the overall efficiency appears to slightly decrease from 2003 to 2005 and then continuously increase after 2006. Concerning the statistics, the K-W test confirms that the efficiency fluctuation during the 2003-2011 period is significant, which is shown in the second column and the fourth row of Table 5. However, the above comparison and test may be somewhat inappropriate if all observations for different years are pooled and evaluated against a single frontier. Charnes et al. [47] indicated that the efficiency frontier for different years may have shifted during the study period; therefore, the benchmarks on the pooled data frontier may not be attainable and appropriate for all observations. To solve this potential problem, following Asmild and Matthews [11], we further measure banking efficiency in sub-samples of the data set separately: i) the pre-reform and post-reform sub-samples (2003-2006 and 2007-2011) and ii) a series sub-samples of moving 3-year windows. Charnes et al. [47] proposed that a window width of three or four time periods tends to yield the best balance of informativeness and stability in the efficiency measure. Therefore, in this study, 3-year width windows are applied.

The efficiency scores and the conclusions of the K-W test are provided in the third and fourth rows of Table 5 and illustrated in Figure 4 (two-period sub-sample data) and Figure 5 (3-year window analysis data), respectively. The results of Table 5 and Figures 4-5 show that when the two-period sub-sample data are used, the overall efficiency of the Chinese banking system is found to significantly increase during both the pre-reform and post-reform periods. The 3-year window analysis further indicates that the significant efficiency increases in these two periods primarily occurred because of the significant efficiency increases during the last one or two years of these two periods (2005-2006 and 2009-2011). This result lends support to the first half of Hypothesis 1, indicating that the third round of banking reform in China significantly affected

the efficiency of the Chinese banking system during the entire reform period and that the Chinese commercial banks generally did experience an obvious performance improvement during the 2005-2006 and 2009-2011 periods.

[Insert Table 5 and Figure 3-5 here]

6.3 Overall efficiency and sub-stage efficiencies of the Chinese banks

Model (5) and equation (3) decompose the overall efficiency into sub-stage efficiencies for the deposit-producing and profit-earning processes of the Chinese banking system, which are shown in Table 3. The efficiency scores and ranks in Tables 2 and 3 indicate that the overall efficiency E_0 is no greater than its corresponding efficiencies of the deposit-producing sub-process E_0^1 or the profit-earning sub-process E_0^2, as E_0 is the weighted arithmetic mean of E_0^1 and E_0^2. We noted that most banks have a lower E_0^1 than E_0^2, and in the annual average efficiency, E_0^1 are lower than E_0^2 for six years in the study period. This result indicates that for most years of the study period, the profit-earning sub-process of the banking system outperformed the deposit-producing sub-process. Therefore, the comparatively low overall efficiency of the entire operational process of the Chinese commercial banks is primarily caused by the comparatively low efficiency of the deposit-producing sub-process. Notably, there are five banks that performed efficiently in both sub-processes, with unity overall efficiency scores: ICBC, BOC, and SPDB in 2011; EGB in 2003 and 2011; and CZB in 2003. Furthermore, there are also several banks that performed efficiently in only one of the sub-processes (e.g., CMB in 2009 for deposit-producing efficiency and CCB in 2008 for profit-earning efficiency), which are also shown in Table 3.

To obtain more information regarding the relationship between overall efficiency and sub-process efficiency, focusing on the ranks of the average efficiency scores for each bank will be more informative. The ranks are also documented in Table 3. It can be observed that most banks have similar ranks in E_0, E_0^1 and E_0^2. This observation implies that the entire process performance is equally attributed to the performances of the two sub-processes. However, there still exist four banks that have large gaps in their ranks. The ranks of the deposit-producing sub-process are unsatisfactory compared with the ranks of the profit-earning sub-process for IB and BOCOM. In contrast, SPDB and CEB performed dissatisfactory in the profit-earning sub-process compared with the deposit-producing sub-process. The ranks of overall efficiency are closer to the ranks of the deposit-producing sub-process, which again indicates that the inefficiency of the Chinese banks was primarily driven by the inefficiency of the deposit-producing sub-process. Therefore, we could conclude that separating overall efficiency into the efficiency of its components may assist a bank in identifying the sub-process in which the inefficiency arises.

Table 5 and Figures 3-5 further illustrate the efficiency changes for two sub-processes, the deposit-producing and profit-earning processes. The efficiency scores and K-W test results shown in the fifth to eighth rows of Table 5 indicate that under the two-period sub-sample, the deposit-producing efficiency of the Chinese banking system increased significantly in both the pre-reform and post-reform periods; the profit-earning process of the Chinese banking system also experienced a significant efficiency improvement during the pre-reform period. In addition, under the 3-year window analysis, the efficiency increase from 2005 to 2006 was significant for

the deposit-producing process. The profit-earning efficiency changes under the 3-year window analysis are somewhat complex. This efficiency significantly increased from 2003 to 2005 and temporarily decreased in 2006 and 2009; subsequently, it has continually increased since 2010.

In the pre-reform period, the stock of deposits for the Chinese banking system increased by approximately 40% on average, especially for the JSBs, whose deposits increased more than 45% from 2003 to 2006. In addition, the number of employees in the Chinese banks decreased by approximately 6% during the same period, primarily because of the 10% layoffs of the SOBs. Meanwhile, the total fixed assets of the Chinese banks remained stable. This situation may have led to the increased efficiency of the deposit-producing sub-process from 2003 to 2006. However, compared to the labor reduction, the decrease in NPLs for the Chinese banks, especially for the SOBs, was more pronounced, i.e., the total amount of NPLs was reduced by 33% and 7% for the SOBs and the JSBs, respectively, during 2003-2006. The sudden disposal of NPLs may explain the increased efficiency of the profit-earning sub-process during this period. In addition, the interest incomes of both the SOBs and JSBs also experienced an obvious increase, which was greater than the increase in deposit, during the 2003-2006 period.

During the post-reform period, the stock of deposits of the Chinese banks continue their rapid growth, and the growth rate of this period was higher than that of the per-reform period. On average, the deposits of the JSBs increased by approximately 150% during the 2007-2011 period, and the SOBs experienced an 87% deposit increase. This finding may explain the significant deposit-producing efficiency improvement observed during this period. Moreover, during the post-reform period, the NPL disposal process began to slow. During the 2008-2011 period, the rate of decrease in NPLs was 8%, which was approximately 50% lower than the rate during the pre-reform and early post-reform periods (2003-2007). Furthermore, in the early and later post-reform periods, the steady increase in interest income and non-interest income together improved the profit-earning efficiency, but this increase was temporarily interrupted in 2009. This finding may explained by the effect of the global financial crisis extended to 2008, which resulted in the decreases in interest incomes in both the SOBs and JSBs during the 2008-2009 period.

Furthermore, by analyzing the relationship between significant or insignificant changes in the overall efficiency and the sub-process efficiencies documented in Table 5 and illustrated in Figures 4 and 5, one could recognize that the increase in the overall efficiency from 2005 to 2006 was primarily caused by the increase in deposit-producing efficiency and that the increase in the overall efficiency from 2009 to 2011 was driven by the increase in the efficiency of the profit-earning sub-process. In contrast, the insignificant changes in the overall efficiency for the period from 2007 to 2009 are the results of the opposite directional changes of the sub-process efficiencies.

The above results supported the first half of Hypothesis 1 for deposit-producing efficiency during the later years of the pre-reform period and for profit-earning efficiency during the last two years of the post-reform period. This conclusion provides some support that the third round of reform of the Chinese banking market generally enhanced the performance of the Chinese commercial banks both in their deposit-producing and profit-earning sub-processes and indicates that the

widespread global financial crisis that began in 2007 may have interrupted the overall efficiency improvement process of the Chinese banking system, especially through its profit-earning sub-process.

6.4 Efficiency comparisons of SOBs and JSBs

To compare the efficiencies of the SOBs and the JSBs, we first consider the pooled data set and utilize the black box DEA model. Table 6 compares the average respective efficiency scores for the SOBs and the JSBs for each year during the study period. Figure 6 indicates that under the intermediation approach, the SOBs are more black box-efficient than the JSBs in the entire study period, with only one exception in 2005. Under the production approach, the JSBs are more black box-efficient than the SOBs before 2007, but following that year, the efficiencies of SOBs are higher. However, the Wilcoxon test results shown in the last column of Table 6 indicate that neither of the black box efficiency differences between the JSBs and the SOBs is significant. In Figure 6, we further observe that the increase and decrease trends of black box efficiency under these two evaluation approaches are somewhat different, especially in the early years of the pre-reform period and during the global financial crisis period. This phenomenon may explain the inconsistent efficiency evaluation results for the Chinese banks in the literature, as previous studies have utilized different methods to treat the banking system as a production or intermediation process.

[Insert Table 6 and Figure 6 here]

Because the black box model evaluation results are inconsistent under the production and intermediation approaches, we then utilize the evaluation results of the two-stage DEA model and consider both the pooled data set and separated sub-sample data sets. The comparisons are shown in Table 7 and illustrated in Figures 7-9. Differing from the black box efficiency results, the average overall efficiency and average sub-process efficiencies for the SOBs are higher than those of the JSBs during nearly the entire study period. Figure 7 illustrates that using the pooled data, the SOBs appeared to be more efficient than the JSBs in both the overall efficiency and the sub-process efficiencies during the later years of the pre-reform period and over the entire post-reform period. In addition, the overall efficiency dominance and the deposit-producing efficiency dominance of the SOBs to the JSBs are significantly confirmed through the Wilcoxon test (shown in the third column of Table 7). This conclusion partially supports Hypothesis 2 for overall efficiency and deposit-producing efficiency during the study period but rejects this hypothesis for profit-earning efficiency in the same period.

[Insert Table 7 and Figure 7-9 here]

Again, one may argue that comparing all observations using the pooled data and taking the single frontier as a benchmark may be inappropriate. Therefore, further comparisons and tests in two-period data sets are shown in the fourth and fifth columns of Table 7 and are illustrated in Figure 8, which indicate that the SOBs are significantly more efficient than the JSBs on overall efficiency and sub-process efficiencies only in the pre-reform period. There is no obvious efficiency difference between the SOBs and the JSBs in the post-reform period. Thus, we could reject Hypothesis 2 because during the post-reform period, there is no significant efficiency difference between the SOBs and the JSBs at the overall process or sub-process levels.

A more detailed comparisons and tests using a 3-year window analysis data set are shown in the last nine columns of Table 7. Together with Figure 9, the comparisons imply that the SOBs are significantly more efficient than the JSBs only in the early years of the pre-reform period, but the efficiency difference subsequently becomes insignificant, except for one year (2009). This result provides evidence that the efficiency differences between the SOBs and the JSBs decreased over our study period, which can also be clearly observed in Figure 9, especially for the overall efficiency and deposit-producing efficiency.

The relationships between the overall efficiency and sub-process efficiencies of the SBOs and the JSBs illustrated in Figure 9 reveal that during the early pre-reform period, the higher overall efficiency performance of the SOBs relative to the JSBs is driven by both the higher deposit-producing and higher-profit earning efficiencies of the SOBs compared with the JSBs; furthermore, the significant efficiency improvements of the JSBs in 2005-2006 (in the deposit-producing process), 2003-2005 and 2009-2011 (in the profit-earning process) narrowed the overall efficiency gap between the SOBs and the JSBs. The amount of deposits for the JSBs increased at a higher rate than that for the SOBs since 2005 and thus accelerated the promotion of deposit-producing efficiency for the JSBs. However, the interest income of the JSBs increased by more than 150% during the 2003-2006 period, which also accelerated the improvement in the profit-earning efficiency of these banks. This finding may explain the decrease in the difference observed in the overall efficiency of the SOBs and the JSBs. In addition, during the 2007-2009 period, the SOBs appear to have been less affected by the global financial crisis than their JSB counterparts, as the JSBs experienced a faster profit-earning efficiency decrease than the SOBs did.

6.5 Influence of NPLs on efficiency measures of the Chinese banks

Among the six variables of inputs, outputs and the intermediate measure, the amount of NPLs of the Chinese banks experienced the most evident changes during the study period by decreasing approximately 78% on average for all 16 Chinese commercial banks. Because NPLs were written off and absorbed by the asset management companies for the Big Four SOBs and some of the JSBs, the amount of NPLs of the SOBs and the JSBs in 2011 were only 18% and 75%, respectively, of those in 2003. As noted above, the sudden disposal of NPLs may lead to increases in efficiency for the banking system as measured by the DEA model of this study. Therefore, in this section, we further examine the influence of NPLs on the efficiency measure of the Chinese banking system.

Table 8 shows the average overall and profit-earning efficiency changes when NPLs are excluded from the evaluation, which indicates that nearly all banks suffered a slight efficiency decrease when excluding the measure of NPLs and that the most statistically significant efficiency decrease appears in the profit-earning efficiency of the JSBs (-3.71%), followed by the overall efficiency of the JSBs (-1.60%). For the specific bank, whether the measure of NPLs are included in the evaluation may lead to significant efficiency differences. For example, the profit-earning efficiency of EGB in 2011 decreased 49% when excluding the measure of NPLs; the profit-earning efficiency of ABC also experienced a decrease of 32% in 2003 when the measure of NPLs was excluded from evaluation. The above analyses partially support

Hypothesis 3; therefore, we should not ignore the influence of NPLs in evaluation. As shown in the last row of Table 8 and as explained in Section 5.3, the consideration of NPLs and their sudden disposal from the Chinese banking system generally improved the overall efficiency of the entire Chinese banking system and specifically improved the profit-earning efficiency of some SOBs and JSBs.

[Insert Table 8 here]

6.6 Influence of joint-equity reform on the efficiencies of SOBs

The public listing of SOBs indicates that these banks have accomplished their joint-equity reform. Therefore, we compare the efficiencies of the Big Four SOBs immediately before and after their IPO year to test whether the reform and listing positively affected their efficiencies.

Table 9 compares the efficiency scores of ICBC, ABC, BOC and CCB[4]. For ABC and CCB, both their overall efficiencies and their sub-process efficiencies increased in their IPO year, and the increasing continued one year after the IPO. Similarly, the overall efficiencies and deposit-producing efficiencies of ICBC and BOC continued increasing throughout the entire three years of the IPO period. However, the profit-earning efficiencies of ICBC and BOC slightly decreased in their IPO year. Nevertheless, the decreases appear to be temporary, and in the year after the IPO, their profit-earning efficiencies began to increase and exceed their pre-IPO levels.

In summary, as Table 9 shows, although the profit-earning efficiencies of two SOBs fluctuated during IPO periods, the efficiency scores of all twelve observations in the year after the IPO are higher than those in the year before the IPO. Therefore, we can accept the second half of Hypothesis 1 that the joint-equity reform of SOBs improved their performance immediately after stock exchange listing.

[Insert Table 9 here]

7 Conclusions

Over the last ten years, the Chinese commercial banks have adopted significant reforms, with the four major state-owned commercial banks gradually completing their joint-equity reform and other Chinese commercial banks experiencing a strong growth period. Therefore, it may be interesting for both academics and practitioners to measure the performance of the banking system and to detect its weak areas to ascertain how to devote an appropriate effort to improve the performance of the banking system. At present, several DEA-based studies of the efficiency evaluation of the Chinese banking system have been published, but the evaluation results in the literature are mixed or even contradictory; the literature on the efficiency changes that occurred before and after the recent banking reform are insufficient, and conclusions regarding the efficiency difference between different types of banks are mixed.

[4] CCB was listed on the Shanghai Stock Exchange in 2005 and then on the Hong Kong Stock Exchange in 2007; BOC and ICBC were simultaneously listed on the Shanghai and Hong Kong Stock Exchanges in 2006; and ABC was simultaneously listed on these two Stock Exchanges in 2010. Therefore, the IPO year of ICBC, ABC, BOC and CCB used in this study were 2006, 2010, 2006 and 2005, respectively.

We consider the operational process of a banking system as a typical two-stage process, and the overall efficiency of the whole banking system could be decomposed into its sub-process efficiencies. In addition, the evaluation of the sub-process efficiencies assists in identifying the sources of the inefficiency of the entire banking system. Therefore, in this study, we utilize the additive two-stage DEA approach to measure the overall and sub-process efficiencies of 16 major Chinese commercial banks during the third round of the Chinese banking reform period (2003-2011).

The performance evaluation of the Chinese commercial banking system in this study first indicates that the two-stage DEA model is more effective than the conventional black box DEA model in identifying the inefficiency of the banking system, as decomposing the overall efficiency into the sub-process efficiencies helps to identify the source of inefficiency. Second, the evaluation results show that the inefficiency of the Chinese banking system was primarily driven by the inefficiency of its deposit-producing sub-process.

Three hypotheses regarding the efficiency changes over time and efficiency differences between different groups of banks were tested. First, the overall efficiency increase in the Chinese banking system was confirmed for both the pre-reform and post-reform periods, which indicated that the Chinese banking reform significantly improved its performance. The evaluation of sub-process efficiency further explained that the significant overall efficiency increase was caused by the significant efficiency increase of the deposit-producing process during 2005-2006 and the profit-earning process during 2009-2011. The decrease in labor in the pre-reform period and the increase of deposits during the pre-reform and the post-reform periods for the Chinese banking system are considered the main reasons for deposit-producing efficiency improvements during the study period. Moreover, the sudden stripping of NPLs from the Chinese banking system, which is considered one of the most important banking reform policies conducted, in the pre-reform and early post-reform periods, as well as the interest income increase during the later post-reform period explained the profit-earning efficiency increase observed during the study period. In addition, the decrease in the interest income of the Chinese banking system caused by the effect of the global financial crisis in 2008 explained the temporary reduction in profit-earning efficiency that occurred from 2008 to 2009.

Second, the SOBs appeared to be more overall efficient than the JSBs only in the pre-reform period, which is caused by the dominance of the SOBs relative to the JSBs in both the deposit-producing and profit-earning processes. However, over the post-reform period, there are no significant overall efficiency and sub-process efficiency differences between these two groups of banks. The test results indicated that the efficiency differences between the SOBs and the JSBs decreased over the study period and that the significant deposit-producing efficiency improvement in 2005-2006 as well as the significant profit-earning efficiency improvements in 2003-2005 and 2009-2011 narrowed the overall efficiency gap between the SOBs and the JSBs.

Third, the examination of the influence of NPLs on the efficiency measures has shown that the Chinese banking system generally suffered a slight decrease in efficiency when we excluded the measure of NPLs, and for a specific bank, whether including the measure of NPLs in the efficiency measure may lead to significant different evaluation results. Therefore, the measure of

NPLs should not be ignored in such evaluations because the disposal of NPLs from the Chinese banking system, especially from the SOBs, neatly explained the efficiency increase observed during the recent reform period.

Lastly, the test of the efficiency changes of the SOBs before and after their joint-equity reforms revealed that the accomplishment of the reforms of the SOBs, marked by their public listing, immediately improved their efficiencies.

Acknowledgements

The authors gratefully acknowledge the support from the National Natural Science Foundation of China (71101011) and the Basic Scientific Research Foundation of BIT (20122142015). This paper was partially finished while Ke Wang was visiting University of Illinois at Urbana-Champaign, and Wang thanks the China Scholarship Council for financial support.

Reference

[1] L. Xu, C.T. Lin, Can Chinese banks compete after accession to WTO? Journal of Asian Economics 18 (2007) 883-903.

[2] K. Matthews, Risk management and managerial efficiency in Chinese banks: A network DEA framework. Omega 41 (2013) 207-215.

[3] X. Chen, M. Skully, K. Brown, Banking efficiency in China: Application of DEA to pre-and post-deregulation eras: 1993-2000, China Economic Review 16 (2005) 229-245.

[4] M. Ariff, L. Can, Cost and profit efficiency of Chinese banks: a non-parametric analysis, China Economic Review 19 (2008) 260-273.

[5] J. Laurenceson, F. Qin, Has minority foreign investment in China's banks improved their cost efficiency? China & World Economy 16 (2008) 57-74.

[6] S. Yao, Z. Han, G. Feng, Ownership reform, foreign competition and efficiency of Chinese commercial banks: A non-parametric approach, The World Economy 31 (2008) 1310-1326.

[7] N.K. Avkiran, H. Morita, Benchmarking firm performance from a multiple-stakeholder perspective with an application to Chinese banking, Omega 38 (2010) 501-508.

[8] D. Luo, S. Yao, World financial crisis and the rise of Chinese commercial banks: an efficient analysis using DEA, Applied financial economics 20 (2010) 1515-1530.

[9] K. Matthews, N. Zhang, Bank productivity in China 1997–2007: Measurement and convergence, China Economic review 21 (2010) 617-628.

[10] M.K. Fung, M.K. Leung, X-efficiency and convergence of productivity among the national commercial banks in China, The 19th China economic association (UK) annual Conference, April 1-2, 2011, University of Cambridge, UK.

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

[12] C. Kao, S.N. Hwang, Efficiency decomposition in two-stage data envelopment analysis: an application to non-life insurance companies in Taiwan, European Journal of Operational

Research 185 (2008) 418-429.

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

[14] T.P. Chang, J.L. Hu, R.Y. Chou, L. Sun, The sources of bank productivity growth in China during 2002-2009: A disaggregation view, Journal of Banking & Finance 36 (2012) 1997-2006.

[15] L.M. Seiford, J. Zhu, Profitability and marketability of the top 55 US commercial banks, Management Science 45 (1999) 1270-1288.

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

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

[18] A.N. Berger, D. Humphrey, Efficiency of financial institutions: International survey and directions for future research, European Journal of Operational Research 98 (1997) 175-212.

[19] A.N. Berger, I. Hasan, M. Zhou, Bank ownership and efficiency in China: What will happen in the world's largest nation? Journal of Banking and Finance 33 (2009) 113-130.

[20] S. Fries, A. Taci, Cost efficiency of banks in transition: Evidence from 289 banks in 15 post-communist countries, Journal of Banking and Finance 29 (2005) 55-81.

[21] J.P. Bonin, I. Hasan, P. Wachtel, Bank performance, efficiency and ownership in transition countries, Journal of Banking and Finance 29 (2005) 31-53.

[22] A.N. Berger, G.R.G. Clarke, R. Cull, L. Klapper, G.F. Udell, Corporate governance and bank performance: A joint analysis of the static, selection, and dynamic effects of domestic, foreign, and state ownership, Journal of Banking and Finance 29 (2005) 2179-2221.

[23] E. Bonaccorsi di Patti, D. Hardy, Financial sector liberalization, bank privatization, and efficiency: Evidence from Pakistan, Journal of Banking and Finance 29 (2005) 2381-2406.

[24] A. Bhattacharya, C.A.K. Lovell, P. Sahay, The Impact of liberalization on the productive efficiency of Indian commercial banks, European Journal of Operational Research 98 (1997) 332-345.

[25] J.P. Bonin, I. Hasan, P. Wachtel, Privatization matters: Bank efficiency in transition countries, Journal of Banking and Finance 29 (2005) 2155-2178.

[26] H.S. Yildirim, G.C. Philippatos, Efficiency of banks: Recent evidence from the transition economies of Europe: 1993-2000, The European Journal of Finance 13 (2007) 123-143.

[27] A.N. Berger, I. Hasan, L.F. Klapper, Further evidence on the link between finance and growth: An international analysis of community banking and economic performance, Journal of Financial Services Research 25 (2004) 169-202.

[28] C. Jiang, S. Yao, Banking reform and efficiency in China: 1995-2008, Research paper 2010/11, The University of Nottingham, 2010.

[29] N. Boubakri, J.C. Cosset, K. Fischer, O. Guedhami, Privatization and bank performance in developing countries, Journal of Banking and Finance 29 (2005) 2015-2041.

[30] J. Williams, N. Nguyen, Financial liberalization, crisis, and restructuring: A comparative

study of bank performance and bank governance in South East Asia, Journal of Banking and Finance 29 (2005) 2119-2154.

[31] X. Fu, S. Heffernan, Cost X-efficiency in China's banking sector, China Economic Review 18 (2007) 35-53.

[32] X. Fu, S. Heffernan, The effects of reform on China's bank structure and performance, Journal of Banking and Finance 33 (2009) 39-52.

[33] T.R. Sexton, H.F. Lewis, Two-stage DEA: An application to major league baseball, Journal of Productivity Analysis 19 (2003) 227-249.

[34] Y. Chen, J. Zhu, Measuring information technology's indirect impact on firm performance, Information Technology and Management Journal 5 (2004) 9-22.

[35] Y. Chen, L. Liang, F. Yang, J. Zhu, Evaluation of information technology investment: A data envelopment analysis approach, Computers and Operations Research 33 (2006) 1368-1379.

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

[37] A. Hailu, T. Veeman, Non-parametric productivity analysis with undesirable outputs: an application to Canadian pulp and paper industry, American Journal of Agricultural Economics 83 (2001) 605-616.

[38] R. Färe, S. Grosskopf, Non-parametric productivity analysis with undesirable outputs: Comment, American Journal of Agricultural Economics 85 (2003) 1070-1074.

[39] A. Hailu, Nonparametric productivity analysis with undesirable outputs: reply, American Journal of Agricultural Economics 85 (2003) 1075-1077.

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

[41] R. Färe, S. Grosskopf, Modeling undesirable factors in efficiency evaluation: Comment, European Journal of Operational Research 157(2004) 242-245.

[42] L.M. Seiford, J. Zhu, A response to comments on modeling undesirable factors in efficiency evaluation, European Journal of Operational Research 161 (2005) 579-581.

[43] M.D. Fethi, F. Pasiouras, Assessing bank efficiency and performance with operational research and artificial intelligence techniques: A survey, European Journal of Operational Research 204 (2010) 189-198.

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

[45] W.W. Daniel, Applied non parametric statistic, Houghton Mifflin, Boston, 1978.

[46] M. Hollander, D.A. Wolfe, Nonparametric Statistical Methods, John Wiley & Sons Inc., New York, 1999.

[47] A. Charnes, W.W. Cooper, A.Y. Lewin, L.M. Seiford, Data envelopment analysis: Theory, methodology, and application, Kluwer Academic Publishers, Norwell, 1994.

[48] C.P. Barros, Z. Chen, Q.B. Liang, N. Peypoch, Technical efficiency in the Chinese banking sector, Economic Modelling 28 (2011) 2083-2089.

[49] S. Akther, H. Fukuyama, W.L. Weber, Estimating two-stage network Slacks-based

inefficiency: An application to Bangladesh banking, Omega 41 (2013) 88-96.

[50] N.K. Avkiran, Association of DEA super-efficiency estimates with financial ratios: Investigating the case for Chinese banks. Omega 39 (2011) 323-334.

Table and figure captions

Table 1 Descriptive statistics of the inputs, intermediate measures, and outputs of 16 Chinese commercial banks (2003-2011)
Table 2 Black box model efficiency and two-stage model overall efficiency for Chinese commercial banks (pooled)
Table 3 Sub-stage efficiency for Chinese commercial banks (pooled)
Table 4 Average efficiency of black box model and two-stage model for Chinese commercial banks and the significance of the rank test for group differences (pooled)
Table 5 Overall and sub-stage efficiency for Chinese commercial banks and the significance of the rank test for group differences (pooled and sub-samples)
Table 6 Average efficiency of black box model for SOBs and JSBs and the significance of the rank test for group differences (pooled)
Table 7 Average overall and sub-stage efficiency for SOBs and JSBs and the significance of the rank test for group differences (pooled and sub-samples)
Table 8 Average overall and profit-earning efficiency changes when excluding the NPLs (pooled)
Table 9 Efficiency comparisons of three SOBs before and after IPO

Fig 1 Two-stage DEA for banking efficiency evaluation
Fig 2 Average efficiency of black box model and two-stage model across the entire study period
Fig 3 Average overall and sub-stage efficiency across the entire study period
Fig 4 Average overall and sub-stage efficiency during the pre-reform and post-reform periods
Fig 5 Average overall and sub-stage efficiency under a 3-year window analysis
Fig 6 Average black box model efficiency (intermediate and production approaches) for SOBs and JSBs across the entire study period
Fig 7 Average overall and sub-stage efficiency for SOBs and JSBs across the entire study period
Fig 8 Average overall and sub-stage efficiency for SOBs and JSBs during the pre-reform and post-reform periods
Fig 9 Average overall and sub-stage efficiency for SOBs and JSBs under a 3-year window analysis

Table 1 Descriptive statistics of the inputs, intermediate measures, and outputs of 16 Chinese commercial banks (2003-2011)

Stage	Variables	Bank type	Year	2003	2004	2005	2006	2007	2008	2009	2010	2011
Stage 1 inputs	Fixed assets (x_1) Billions of RMB	SOB	Mean	67.2	65.5	67.5	73.1	74.7	86.7	98.1	108.0	120.8
			S.D.	18.1	13.2	18.2	16.7	11.3	16.8	17.2	18.7	19.4
		JSB	Mean	5.0	5.4	5.4	5.8	6.6	7.5	8.2	9.3	10.4
			S.D.	5.9	6.2	6.6	6.9	8.5	7.5	7.8	8.8	9.4
	Labors (x_2) Thousands of workers	SOB	Mean	367.1	350.2	342.6	332.3	341.4	343.8	348.8	358.7	368.9
			S.D.	118.5	111.6	105.6	90.9	92.2	86.3	81.4	75.6	72.0
		JSB	Mean	11.5	11.8	13.0	15.0	17.7	20.8	23.0	26.9	30.6
			S.D.	14.5	14.2	14.9	15.7	17.5	20.2	20.5	22.1	23.2
Intermediate measures	Deposits (z) Billions of RMB	SOB	Mean	3847.9	4209.4	4759.4	5520.5	6355.3	7480.4	9231.7	10476.8	11897.0
			S.D.	508.9	847.2	888.0	1030.2	1180.7	1307.7	1271.5	1295.7	1457.3
		JSB	Mean	386.8	389.9	402.8	563.9	703.0	868.4	1136.2	1423.1	1753.6
			S.D.	252.1	276.4	345.1	411.9	506.3	643.7	808.8	957.6	1099.6
Stage 2 outputs	Interest income (y_1) Billions of RMB	SOB	Mean	83.7	99.0	110.5	135.4	182.0	211.3	199.6	248.0	300.8
			S.D.	10.4	13.9	34.7	21.3	33.5	42.8	37.7	45.0	55.2
		JSB	Mean	5.3	8.2	9.9	13.7	20.0	26.2	25.6	34.8	45.7
			S.D.	3.5	6.7	8.3	10.4	14.4	18.2	17.9	23.3	29.1
	Non-interest income (y_2) Billions of RMB	SOB	Mean	12.7	14.2	16.7	16.5	27.8	40.9	56.1	67.3	91.3
			S.D.	6.6	5.3	4.6	4.1	4.4	16.6	10.8	11.5	14.0
		JSB	Mean	0.7	1.0	1.4	1.2	2.4	3.6	4.5	6.1	9.0
			S.D.	0.8	0.9	1.2	1.2	2.7	3.3	4.2	5.7	7.7
	Bad loans (y_3) Billions of RMB	SOB	Mean	403.8	418.6	273.1	270.7	276.5	103.3	89.2	75.6	73.6
			S.D.	351.3	371.4	312.6	318.4	361.7	22.2	21.8	17.1	10.0
		JSB	Mean	8.9	10.3	10.4	8.3	9.4	7.8	7.4	6.9	6.7
			S.D.	8.2	8.4	7.8	7.0	7.0	6.8	6.6	6.4	5.6

S.D. indicates standard deviation.

Table 2 Black box model efficiency and two-stage model overall efficiency for Chinese commercial banks (pooled)

Bank	Black box model efficiency (production approach)						Black box model efficiency (intermediation approach)						Additive two-stage model overall efficiency					
	2003	2006	2009	2011	2003-2011 mean	rank	2003	2006	2009	2011	2003-2011 mean	rank	2003	2006	2009	2011	2003-2011 mean	rank
ICBC	0.319	0.581	0.942	1.000	0.722	8	0.624	0.723	0.761	1.000	0.810	9	0.419	0.642	0.844	1.000	0.743	2
ABC	0.303	0.628	0.685	0.785	0.579	14	0.675	0.584	0.600	0.913	0.668	14	0.433	0.610	0.648	0.846	0.614	8
BOC	0.340	0.445	0.788	1.000	0.611	13	0.645	0.812	0.917	1.000	0.854	3	0.466	0.568	0.842	1.000	0.690	4
CCB	0.462	0.729	0.956	1.000	0.798	4	0.644	0.849	0.816	1.000	0.873	2	0.508	0.734	0.873	0.991	0.784	1
BOCOM	0.169	0.335	0.645	0.972	0.482	16	0.365	0.673	0.669	0.876	0.683	13	0.204	0.410	0.642	0.857	0.509	15
CNCB	0.337	0.677	0.837	1.000	0.730	7	0.511	0.767	0.807	1.000	0.802	10	0.335	0.550	0.706	0.878	0.612	9
CMBC	1.000	0.497	0.682	1.000	0.787	5	1.000	0.630	0.765	1.000	0.850	4	0.707	0.450	0.627	0.872	0.626	7
HXB	0.357	0.604	0.720	0.827	0.641	11	0.528	0.699	0.707	0.885	0.731	12	0.350	0.489	0.580	0.678	0.527	14
CMB	0.353	0.516	0.716	1.000	0.627	12	0.522	0.659	0.668	1.000	0.740	11	0.312	0.490	0.615	0.915	0.563	10
IB	0.501	0.856	1.000	1.000	0.814	3	0.401	0.936	1.000	0.910	0.848	5	0.414	0.496	0.668	0.863	0.561	11
SPDB	0.754	0.771	0.833	1.000	0.817	2	0.524	0.837	0.816	1.000	0.833	7	0.532	0.609	0.707	1.000	0.666	5
SDB	0.425	0.647	1.000	1.000	0.754	6	0.486	0.807	1.000	1.000	0.825	8	0.376	0.522	0.731	0.739	0.561	12
EGB	1.000	0.457	0.628	1.000	0.711	9	1.000	0.488	0.739	1.000	0.838	6	1.000	0.432	0.523	1.000	0.636	6
CZB	1.000	0.796	0.703	1.000	0.820	1	1.000	0.908	0.695	1.000	0.892	1	1.000	0.713	0.539	0.773	0.709	3
CEB	0.665	0.649	0.683	0.739	0.652	10	0.308	0.598	0.608	0.825	0.621	16	0.465	0.517	0.580	0.679	0.546	13
GDB	0.269	0.394	0.550	0.736	0.523	15	0.310	0.486	0.599	0.831	0.626	15	0.258	0.363	0.471	0.623	0.447	16

Table 3 Sub-stage efficiency for Chinese commercial banks (pooled)

Bank	Stage 1 deposit producing efficiency							Stage 2 profit earning efficiency						
	2003	2005	2007	2009	2011	2003-2011 mean	rank	2003	2005	2007	2009	2011	2003-2011 mean	rank
ICBC	0.320	0.449	0.751	0.930	1.000	0.700	3	0.625	0.799	0.882	0.762	1.000	0.816	4
ABC	0.245	0.480	0.617	0.676	0.787	0.572	11	1.000	0.431	0.728	0.613	0.913	0.708	7
BOC	0.602	0.382	0.482	0.773	1.000	0.605	7	0.227	0.801	0.936	0.913	1.000	0.822	3
CCB	0.399	0.505	0.739	0.940	0.980	0.707	2	0.676	0.857	0.984	0.812	1.000	0.884	1
BOCOM	0.169	0.268	0.199	0.621	0.948	0.437	15	0.365	0.615	0.798	0.660	0.796	0.664	10
CNCB	0.292	0.436	0.649	0.828	0.960	0.599	8	0.491	0.550	0.702	0.578	0.799	0.650	13
CMBC	1.000	0.319	0.464	0.618	0.763	0.660	5	0.375	0.872	0.690	0.639	1.000	0.680	8
HXB	0.307	0.388	0.524	0.657	0.691	0.525	13	0.500	0.559	0.600	0.492	0.662	0.563	14
CMB	0.264	0.325	0.509	1.000	0.764	0.572	10	0.522	0.605	0.782	0.819	1.000	0.730	6
IB	0.451	0.271	0.293	0.470	0.922	0.478	14	0.327	1.000	1.000	1.000	0.806	0.787	5
SPDB	0.678	0.351	0.719	1.000	1.000	0.727	1	0.312	0.813	0.630	0.772	1.000	0.663	11
SDB	0.355	0.276	0.579	0.832	0.882	0.554	12	0.438	0.688	0.762	0.645	0.605	0.652	12
EGB	1.000	0.544	0.410	0.510	1.000	0.627	6	1.000	1.000	0.540	0.553	1.000	0.679	9
CZB	1.000	0.690	0.539	0.526	0.745	0.674	4	1.000	0.836	0.765	0.575	0.818	0.824	2
CEB	0.631	0.428	0.589	0.631	0.672	0.575	9	0.195	0.377	0.595	0.515	0.689	0.497	16
GDB	0.247	0.326	0.422	0.443	0.536	0.396	16	0.309	0.537	0.665	0.514	0.747	0.563	15
mean	0.498	0.402	0.530	0.716	0.853	0.588	-	0.483	0.709	0.754	0.679	0.865	0.699	-

Table 4 Average efficiency of black box model and two-stage model for Chinese commercial banks and the significance of the rank test for group differences (pooled)

Average efficiency	2003	2004	2005	2006	2007	2008	2009	2010	2011	2003-2011 mean
Black box model efficiency (production approach)	0.516	0.503	0.536	0.599	0.721	0.786	0.773	0.851	0.941	0.692
Black box model efficiency (intermediation approach)	0.596	0.661	0.735	0.716	0.840	0.917	0.760	0.849	0.953	0.781
Two-stage model efficiency (overall efficiency)	0.486	0.476	0.476	0.537	0.613	0.661	0.662	0.739	0.857	0.612
Production approach efficiency > two stage overall efficiency	INSIG	INSIG	INSIG	SIG*	SIG**	SIG**	SIG**	SIG**	SIG*	SIG#
Intermediation approach efficiency > two stage overall efficiency	SIG*	SIG**	SIG**	SIG**	SIG**	SIG**	SIG*	SIG**	SIG*	SIG##

SIG and INSIG indicate significant and insignificant; * and ** indicate significance at 5% and 1% levels under K-W test; # and ## indicate significance at 5% and 1% levels under Wilcoxon test.

Table 5 Overall and sub-stage efficiency for Chinese commercial banks and the significance of the rank test for group differences (pooled and sub-samples)

	Whole period	Pre-reform period				Post-reform period					3-year window analysis								
	2003-2011	2003	2004	2005	2006	2007	2008	2009	2010	2011	2003	2004	2005	2006	2007	2008	2009	2010	2011
Overall efficiency	0.612	0.606	0.604	0.621	0.753	0.703	0.731	0.717	0.775	0.880	0.625	0.679	0.710	0.780	0.806	0.813	0.791	0.843	0.899
Efficiency change	SIG**	+SIG**				+SIG**					N/A	INSIG	INSIG	+SIG**	INSIG	INSIG	INSIG		+SIG**
Deposit producing efficiency	0.588	0.569	0.529	0.557	0.717	0.660	0.659	0.777	0.837	0.887	0.610	0.650	0.661	0.814	0.826	0.799	0.841	0.859	0.887
Efficiency change	SIG**	+SIG**				+SIG**					N/A	INSIG	INSIG	+SIG**	INSIG	INSIG	INSIG		INSIG
Profit earning efficiency	0.699	0.635	0.739	0.842	0.834	0.735	0.845	0.691	0.744	0.870	0.636	0.729	0.828	0.737	0.782	0.786	0.726	0.819	0.916
Efficiency change	SIG**	+SIG**				INSIG					N/A	+SIG**	+SIG**	-SIG*	INSIG	INSIG	-SIG*	+SIG**	+SIG**

+ and – indicate efficiency increase and decrease; SIG and INSIG indicate significant and insignificant; * and ** indicate significance at 5% and 1% levels under K-W test.

Table 6 Average efficiency of black box model for SOBs and JSBs and the significance of the rank test for group differences (pooled)

Average efficiency	Bank type	2003	2004	2005	2006	2007	2008	2009	2010	2011	2003-2011 mean	Efficiency difference between SOB and JSB
Black box model efficiency (intermediation approach)	SOB	0.647	0.709	0.698	0.742	0.873	0.929	0.773	0.859	0.978	0.801	INSIG
	JSB	0.580	0.645	0.747	0.707	0.829	0.912	0.756	0.846	0.944	0.774	
Black box model efficiency (production approach)	SOB	0.356	0.429	0.491	0.596	0.736	0.807	0.842	0.896	0.946	0.678	INSIG
	JSB	0.569	0.528	0.551	0.600	0.716	0.779	0.750	0.836	0.940	0.697	

INSIG indicate insignificant under K-W test.

Table 7 Average overall and sub-stage efficiency for SOBs and JSBs and the significance of the rank test for group differences (pooled and sub-samples)

Average efficiency	Bank type	Whole study period	Three periods		3-year window analysis								
		2003-2011	Pre-reform 2003-2006	Post-reform 2007-2011	2003	2004	2005	2006	2007	2008	2009	2010	2011
Overall efficiency	SOB	0.708	0.847	0.840	0.812	0.847	0.853	0.853	0.878	0.877	0.864	0.912	0.960
	JSB	0.580	0.579	0.735	0.562	0.623	0.662	0.755	0.782	0.792	0.767	0.819	0.878
	SOB > JSB	SIG#	SIG*	SIG*	SIG*	SIG*	SIG*	INSIG	INSIG	INSIG	SIG*	INSIG	INSIG
Deposit producing efficiency	SOB	0.646	0.799	0.815	0.753	0.816	0.821	0.853	0.866	0.846	0.902	0.912	0.942
	JSB	0.569	0.524	0.747	0.562	0.594	0.607	0.800	0.812	0.784	0.821	0.841	0.868
	SOB > JSB	SIG#	SIG*	SIG*	SIG*	SIG*	SIG*	INSIG	INSIG	INSIG	SIG*	INSIG	INSIG
Profit earning efficiency	SOB	0.807	0.916	0.837	0.897	0.881	0.896	0.858	0.842	0.766	0.798	0.915	0.981
	JSB	0.663	0.711	0.757	0.549	0.678	0.805	0.697	0.761	0.793	0.702	0.788	0.894
	SOB > JSB	INSIG	SIG*	INSIG	SIG*	SIG*	INSIG	SIG*	INSIG	INSIG	INSIG	INSIG	INSIG

SIG and INSIG indicate significant and insignificant; # indicate significance at 5% level under Wilcoxon test; * and ** indicate significance at 5% and 1% levels under K-W test.

Table 8 Average overall and profit-earning efficiency changes when excluding the NPLs (pooled)

	Overall efficiency			Profit earning efficiency		
	All banks	SOB	JSB	All banks	SOB	JSB
Average efficiency change	-1.12%	0.04%	-1.60%	-2.78%	-0.80%	-3.71%
With NPLs > without NPLs	INSIG	INSIG	SIG##	INSIG	SIG#	SIG#

SIG and INSIG indicate significant and insignificant; ## and # respectively indicate significance at 1% and 5% levels under Wilcoxon test.

Table 9 Efficiency comparisons of three SOBs before and after IPO

Bank	Efficiency	One year before IPO	IPO year	One year after IPO
ICBC	Overall efficiency	0.582	0.642	0.815
	Deposit producing efficiency	0.449	0.567	0.751
	Profit earning efficiency	0.799	0.744	0.882
ABC	Overall efficiency	0.648	0.723	0.846
	Deposit producing efficiency	0.676	0.703	0.787
	Profit earning efficiency	0.613	0.747	0.913
BOC	Overall efficiency	0.471	0.538	0.568
	Deposit producing efficiency	0.307	0.382	0.409
	Profit earning efficiency	0.802	0.801	0.836
CCB	Overall efficiency	0.591	0.658	0.734
	Deposit producing efficiency	0.411	0.505	0.620
	Profit earning efficiency	0.855	0.857	0.866

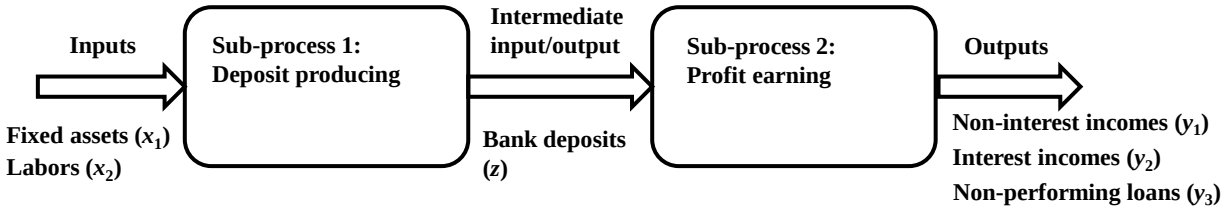

Fig 1 Two-stage DEA for banking efficiency evaluation

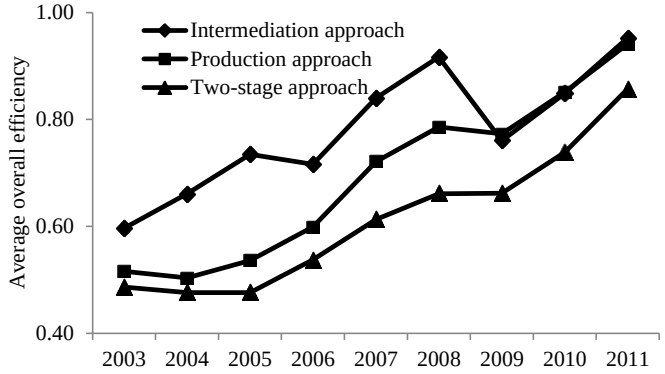

Fig 2 Average efficiency of black box model and two-stage model across the entire study period

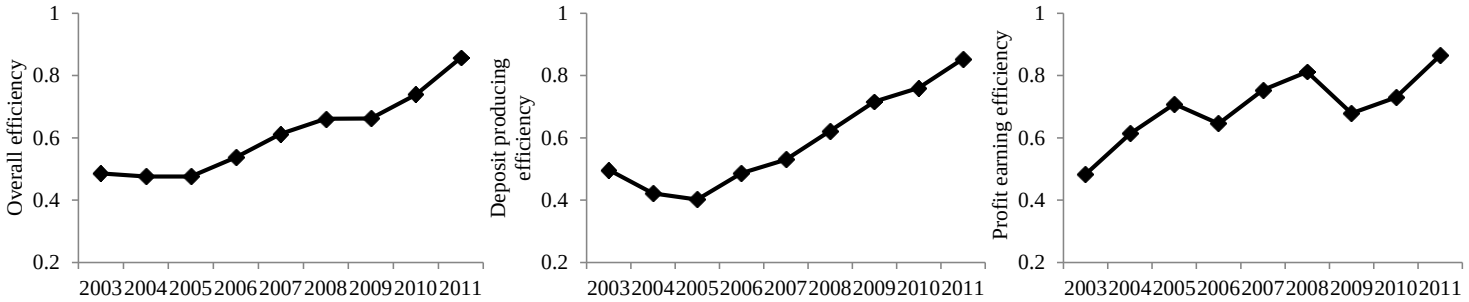

Fig 3 Average overall and sub-stage efficiency across the entire study period

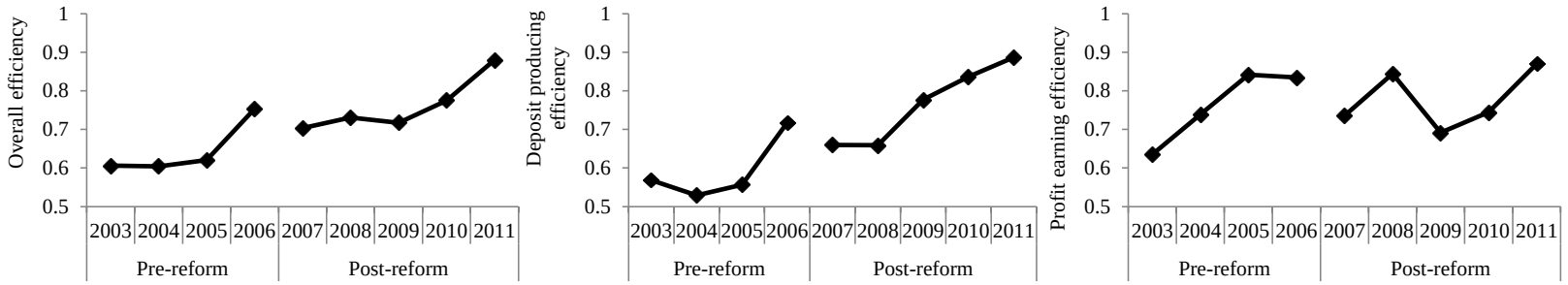

Fig 4 Average overall and sub-stage efficiency during the pre-reform and post-reform periods

Fig 5 Average overall and sub-stage efficiency under a 3-year window analysis

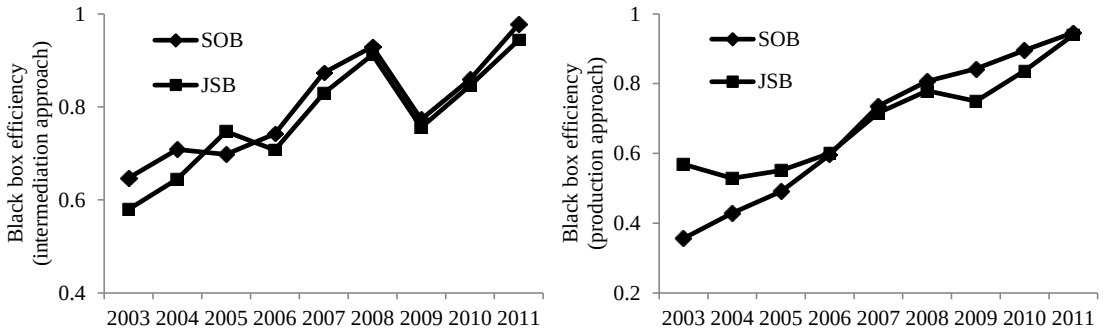

Fig 6 Average black box model efficiency (intermediate and production approaches) for SOBs and JSBs across the entire study period

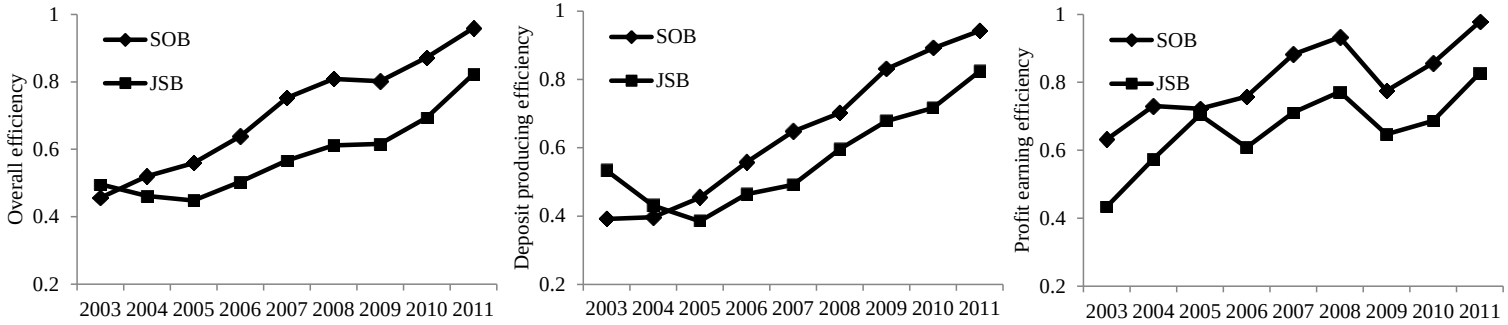

Fig 7 Average overall and sub-stage efficiency for SOBs and JSBs across the entire study period

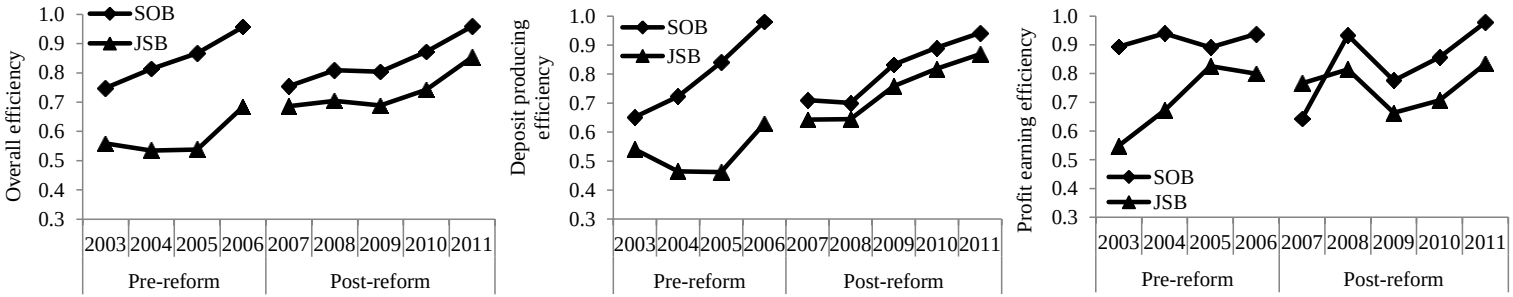

Fig 8 Average overall and sub-stage efficiency for SOBs and JSBs during the pre-reform and post-reform periods

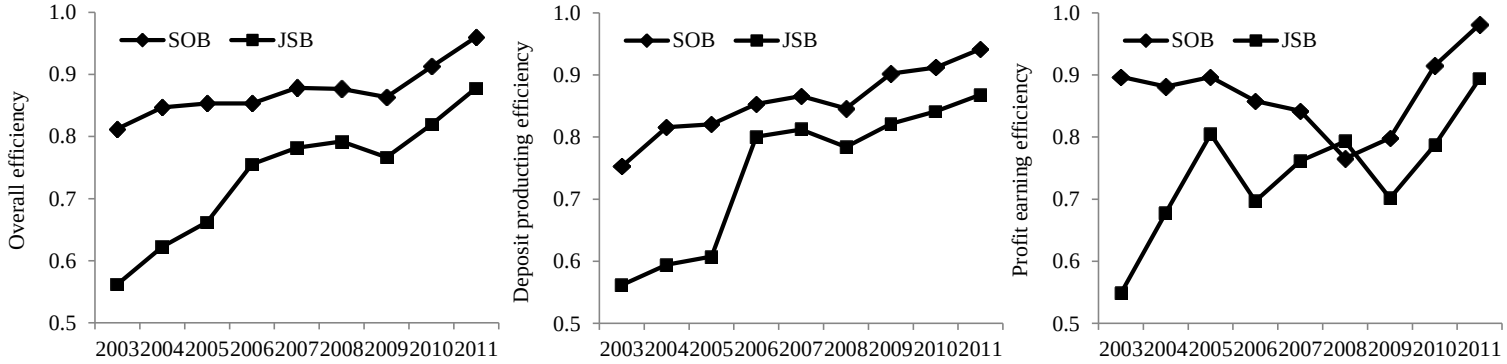

Fig 9 Average overall and sub-stage efficiency for SOBs and JSBs under a 3-year window analysis