Chen, Shiyi; Härdle, Wolfgang Karl; Wang, Li

Working Paper

Estimation and Determinants of Chinese Banks' Total Factor Efficiency: A New Vision Based on Unbalanced Development of Chinese Banks and Their Overall Risk

IRTG 1792 Discussion Paper, No. 2020-001

Provided in Cooperation with:
Humboldt University Berlin, International Research Training Group 1792 "High Dimensional Nonstationary Time Series"

Suggested Citation: Chen, Shiyi; Härdle, Wolfgang Karl; Wang, Li (2020) : Estimation and Determinants of Chinese Banks' Total Factor Efficiency: A New Vision Based on Unbalanced Development of Chinese Banks and Their Overall Risk, IRTG 1792 Discussion Paper, No. 2020-001, Humboldt-Universität zu Berlin, International Research Training Group 1792 "High Dimensional Nonstationary Time Series", Berlin

This Version is available at:
https://hdl.handle.net/10419/230807

IRTG 1792 Discussion Paper 2020-001

Estimation and Determinants of Chinese Banks' Total Factor Efficiency: A New Vision Based on Unbalanced Development of Chinese Banks and Their Overall Risk

Shiyi Chen [*]
Wolfgang K. Härdle [*2] [*3] [*4] [*5]
Li Wang [*6]

[*] Fudan University, China
[*2] Humboldt-Universität zu Berlin, Germany
[*3] Singapore Management University, Singapore
[*4] Charles University, Czech Republic
[*5] National JiaoTong University, Taiwan
[*6] East China Normal University, China

This research was supported by the Deutsche Forschungsgesellschaft through the International Research Training Group 1792 "High Dimensional Nonstationary Time Series".

http://irtg1792.hu-berlin.de
ISSN 2568-5619

Estimation and Determinants of Chinese Banks' Total Factor Efficiency: A New Vision Based on Unbalanced Development of Chinese Banks and Their Overall Risk.

Shiyi Chen [a], **Wolfgang K. Härdle**[b,c,d,e], **Li Wang**[f *]

a School of Economics, Fanhai International School of Finance, Fudan University, China
b Humboldt-Universität zu Berlin, Blockchain Research Center, IRTG1792, Untern den Linden 6, 10099 Berlin, Germany
c Sim Kee Boon Institute for Financial Economics, Singapore Management University, 81 Victoria Street, Singapore 188065, Singapore
d Department of Mathematics and Physics, Charles University, Prague, Ke Karlovu 2027/3, 12116 Praha 2, Czech Republic
e Department of Information Management and Finance, National JiaoTong University, Taiwan
f Faculty of Economics and Management, East China Normal University, China
Email: lwang@jjx.ecnu.edu.cn
*corresponding author

Abstract: The paper estimates banks' total factor efficiency (TFE) as well as TFE of each production factor by incorporating banks' overall risk endogenously into bank's production process as undesirable by-product in a Global-SMB Model. Our results show that, compared with a model incorporated with banks' overall risk, a model considering only on-balance-sheet risk may over-estimate the integrated TFE (TFIE) and under-estimate TFE volatility. Significant heterogeneities of bank TFIE and TFE of each production factor exist among banks of different types and regions, as a result of still prominent unbalanced development of Chinese commercial banks. Based on the estimated TFIE, the paper further investigates the determinants of bank efficiency, and finds that shadow banking, bank size, NPL ratio, loan to deposit ratio, fiscal surplus to GDP ratio and banking sector concentration are significant determinants of bank efficiency. Besides, a model with risk-weighted assets as undesirable outputs can better capture the impact of shadow banking involvement.

Key Words: Nonparametric Methods; Commercial Banks; Shadow Bank; Financial Risk

1. Introduction

During the past three decades, the Chinese banking sector has undergone strategic transformations in corporate governance, internal auditing functions and international development, with the joint efforts of banks and bank supervisory institutions. State-owned commercial banks (SOCBs) have transformed successfully from wholly state-owned commercial banks to shareholding companies by going public, recapitalizing and attracting strategic investors. Self-discipline and external supervisions are reinforced through the liberalization of both quantity and price as well as the introduction of competition from foreign banks. Cross-border activities and overseas development strategies of Chinese banks are also encouraged by the government in a prudent manner. On the whole, positive progresses have been made in the enhancement of the core competitiveness and performance of Chinese banks. Figure 1 depicts the change in nonperforming loan (NPL) ratio and provision coverage ratio of Chinese commercial banks between 2006 and 2012. As shown in the figure, all types of Chinese commercial banks including large commercial banks, joint-stock commercial banks, city commercial banks and rural commercial banks experienced a decreasing trend of NPL ratio, with an average NPL ratio dropping from 7.1% to 1%. At the same time, provision coverage ratio of the whole commercial banking system increased from 34.3% to 295.5%, more than seven times larger than that in 2006.

Though China has made a lot of achievements in enhancing the performance of its commercial banking sector, challenges which are posing a threat to the further development of banks especially the improvement of bank efficiency still exist, with some new characteristics:

First, unbalanced development among banks of different types or located in different regions becomes even more prominent nowadays. Large commercial banks are experiencing a much faster reform and development speed than those small and medium banks. As shown in Figure 1, NPL ratio decreased significantly for large commercial banks, with an annual decreasing rate of 14.6% to 1% by the end of 2012, while that of the small and medium banks, especially rural commercial

banks, decreased much slower. In 2008, NPL ratio of rural commercial banks exceeded the average NPL of the whole commercial banking system, becoming the banks with the highest NPL ratio in China until now. And even an increasing trend of NPL ratio for rural commercial banks was found from 2011 to 2012. The reasons for this unbalanced development among different types of banks are historical and institutional. Large commercial banks have long been regarded as the main pillar for the growth of the whole real economy, which enables them to get as many financial and material resources as possible from the government, such as the establishment of asset management companies (AMCs), capital injection with official international reserves or funds from issuing special treasury bonds and other policy supports. In contrast, small and medium banks have to self-digest their NPLs, and depend on their own shareholders and retaining profits for capital increase. The basic development strategy of 'reforming cities before rural areas' in financial system, totally different from the strategy of 'reforming rural areas before cities' in real economic system, is another reason for the dispersion of the development between city commercial banks and rural commercial banks. Besides, banks in different regions of China also show different extents of developments. The changes of the institutional environment of Chinese banks, caused by a number of market-oriented reforms, developed in a very unbalanced way across different provinces (Zhang et al., 2012). Limited number of bank branches, deposit and loans resources may restrict the performance enhancement of banks located in the middle and west of China.

Second, the development of shadow banking system in China catalyzes the expansion of banks' off-balance-sheet activities, resulting in a distortion of China's traditional credit expansion and underestimation of its commercial banks' overall risk. Different from the shadow banking system in developed countries which is mainly based on financial markets, Chinese shadow banking develops relying on those traditional commercial banks. Banks provide funds, liquidity and help selling the products for the shadow banking, and at the same time banks themselves transfer their on-balance sheet credits to off-balance sheet assets to escape supervisory regulations and get intermediate income. According to a report by the Chinese Orient Securities (Shao, 2013), the volumes of real economy-supported shadow banking (tier-1) and financial transaction supported shadow banking (tier-2) amounted respectively to 30.3 trillion (RMB) and 22.34 trillion (RMB) by the end of 2012, accounting for 45.03% and 33.20% of the total Chinese bank loans denominated in both domestic and foreign currency. Figure 2 describes the changes of the volume of Chinese shadow banking (tier-1) during the period 2002-2012. As shown in the figure, following a relatively slow growth of shadow banking before 2005, both shadow banking volume and the ratio of shadow banking to total bank loans experienced their first round of growth between 2005-2009, with shadow banking volume growing from 27.76 trillion (RMB) to 110.98 trillion (RMB) and the ratio of shadow banking volume to total bank loans growing from 13.41% to 26.08%. The ratio of shadow banking volume to aggregate financing to the real economy reached a peak of 32.64% in 2007 during this period. The second round growth of shadow banking system began in 2009, triggered by the strong credit demand and funding strains implemented by the policy authority (Hu and Mahendran, 2011). Larger increase in the shadow banking volume and the ratios of this volume to total bank loans and aggregate financing to the real economy were evident, with shadow banking volume growing from 110.98trillion (RMB) to 302.98 trillion (RMB) and the ratio of shadow banking volume to total bank loans growing from 26.08.41% to 45.03%.The ratio of shadow banking volume to aggregate financing to the real economy increased by 17.77%, reaching 42.14% by the end of 2012.

How will the change of Chinese commercial banks' overall risk, resulted from their involvement in shadow banking activities, impact the performance and efficiency of Chinese commercial banks nowadays? When this new characteristic is considered, will the evolution of efficiency differ among banks of different types or located in different areas? And what are the determinants of Chinese commercial banks' efficiency after accounting for their overall risk? Unfortunately, though more and more studies try to highlight the impact of risk on bank efficiency (Chiu et al., 2011; Chen, 2012; Saeed and Izzeldin, 2016), none of them, to the best of our knowledge, fully incorporate a bank's overall risk including off-balance sheet risk as an undesirable by-product of its asset production process into the measurement of bank efficiency. Most of the studies try to treat risk measures as control variables and analyze the impact of risk on bank efficiency after the estimation of efficiency (Sun and Chang, 2011; Hou et al., 2014) or include NPLs, which only capture a bank's on-balance sheet credit risk, as an undesirable by-product output arising from the production of loans. Besides, existing studies concerned with Chinese bank issues also have the drawback of limited data samples, which may lead to biased efficiency estimation. Rural commercial banks including those cooperative financial institutions, which have played a significant role in rural development, and a comparison between banks located in different regions of China are absent in all of the existing literature.

Thus, our paper contributes in the following ways: First, from a methodology perspective, we

dedicate to incorporate banks' overall risk, especially off-balance risk, endogenously into their asset production process as undesirable by-product for the estimation of banks' total factor efficiency (TFE). To highlight the importance of banks' overall risk, we also evaluate TFE with NPLs as undesirable outputs of bank production process. Second, our paper tries to overcome the drawback of limited data sample by investigating a unique sample of 171 Chinese banks, including 5 large commercial banks, 12 join-stock commercial banks, 103 city commercial banks and 51 rural commercial banks, which is the largest data sample until now as far as we know, making our results will be more convincing and meaningful; Third, We are also highlight the differences in total factor bank efficiency among different categories of banks and different regions at the same time. The further disaggregation of total factor efficiency helps us explore the source of Chinese banks efficiency for each kind of bank and each region.

The remainder of the paper is structured as follows. Section 2 summarizes the related literature regarding this topic. Section 3 describes the structure and development of Chinese banking system. Section 4 introduces our estimation methodology and regression model. Section 5 compares TFE among banks of different types or located in different regions of China, followed by TFE disaggregation and determinants analyses. Section 6 concludes.

2. Literature Review

Our paper builds on two strands of literature: i) literature concerned with the estimation methodology of bank efficiency; ii) literature with regard to the determinants of bank efficiency. We will first summarize these literature, and then highlights our contributions by identifying relevant research gaps in the literature.

2.1. Estimation Methodology of Bank Efficiency

Parametric techniques, such as the distribution-free approach and stochastic frontier approach (Duygun et al., 2013; Jiang et al., 2013; Tabak et al., 2013; Goddard et al., 2014), and nonparametric techniques, such as data envelopment analysis (Holod and Lewis, 2011; Halkos and Tzeremes, 2013; Saeed and Izzeldin, 2016) are the most commonly used methodologies for the estimation of bank efficiency. Compared with parametric techniques whose results heavily depend on how accurately the chosen functional form captures the true production relationship (Sun et al., 2013) and other nonparametric techniques, data envelopment analysis (DEA) has been regarded as a better and robust efficiency analysis tool since it uses actual data from evaluated units to construct the efficiency frontier without setting up a specific functional form, and at the same time allows for the existence of random errors (Yang and Liu, 2012). Besides, DEA-based procedures perform better than parametric methods in the estimation of an individual decision-making unit (individual bank in our case) productivity (Banker and Natarajan, 2008). The work of Chortareas et al. (2012), Chortareas et al. (2013), Barth et al. (2013), Harris et al. (2013) can all be recognized as representatives for the application of classical DEA in the estimation of bank efficiency. To perform more accurate efficiency evaluation, several modified DEA techniques have been exploited. Yang and Liu (2012) combine the network data envelopment analysis (NDEA) model which not only can do for modeling an organization but also for measuring the performance of its components, fuzzy approach, and multiple objective programming approach in the context of bank branch evaluation. Wu and Birge (2012) develop a serial-chain-merger data envelopment analysis (DEA) model to assess potential gains from the merger of different chain operations. Lin and Chiu (2013) integrate NDEA and independent component analysis (ICA) to evaluate the operational performance of the Taiwanese domestic banking sector. Chiu et al. (2013) apply Hybrid Meta-Frontier DEA approach which is first proposed by Tone (2004) and considers both radial variables and non-radial variables, taking into account the proportional and non-proportional changes in variables' characteristics, to evaluate the operational efficiency of banks in Taiwan. Wu et al. (2016) combine existing bi-level programing (BLP) methods and data envelopment analysis to develop a chain-merge BLP-DEA model in M&A performance evaluation.

However, none of these studies mentioned above have accounted for undesirable outputs, such as nonperforming loans (NPLs), when estimating the efficiency of banking sector. Just as Assaf et al. (2013) have pointed out, a bank that has high performance is not necessarily better than other banks if undesirable outputs are ignored in the performance evaluation, as it might achieve this at the expense of producing a high percentage of undesirable outputs. Not accounting for NPLs in estimating the frontier model might cause failures in crediting a bank for its effort to reduce undesirable outputs (Fernandez et al., 2002) and biased estimation results (Atkinson and Dorfman, 2005; Assaf et al., 2013). To the best of our knowledge, only a few researches incorporate undesirable outputs directly as a part of bank production process in recent years. Park and Weber (2006), following the work of Berg et al. (1992) which is the first to include the quality of assets

(i.e. loan losses) into the model, investigate the efficiency of Korean banks from 1992 to 2002 by using a directional technology distance function. They treat NPLs as an undesirable by-product output arising from the production of loans. Fukuyama and Weber (2008) examine the extent of Japanese banking inefficiency by modeling non-performing loans as a jointly produced undesirable by-product of the loan production process. Their estimation is based on the directional output distance function which is introduced by Chambers et al. (1996). More recently, Fujii et al. (2014) apply the weighted Russell directional distance model (WRDDM), which is a modification of traditional directional distance function model (TDDFM) and possesses the attractive advantages of easy computation and extension of incorporating the additional undesirable outputs into the programming problems, to measure productive inefficiency in Indian banking sector. Difference from the methodology of Fujii et al. (2014), Assaf et al. (2013) estimate the productivity and efficiency of Turkish banks from 2002 to 2010 by using a Bayesian stochastic frontier approach while accounting for nonperformance loans in the model.

Though the significance of the direct incorporation of undesirable outputs for evaluating bank efficiency has already been highlighted in a few studies, there are still several important gaps in the estimation of bank efficiency that need to be addressed:

First, most literature that integrate undesirable outputs in the production process of banking sector rely on directional distance function (DDF) methodology to measure the bank efficiency. However, this DDF approach assumes that the increase of desirable output and the decrease of undesirable output follow a similar proportion, which is too strict in the reality (Chen and Zhang, 2014). Besides, most of the efficiency measures in the literature are radial and angle, which make it very likely to overestimate efficiency when there are non-zero slacks in the constraints (Fukuyama and Weber, 2009). Thus, this paper will try to overcome the drawbacks of DDF by applying the non-radial, non-angle global slacks-based measure (GSBM) approach for the estimation of the actual banks' total factor efficiency in China. To be noted, though Fukuyama and Weber (2009) propose a directional slacks-based measure to evaluate the technical inefficiency of Japanese banks, they haven't accounted for undesirable outputs.

Second, until now loan loss (Berg et al., 1992) and nonperforming loans (Fujii et al., 2014) are the only undesirable outputs incorporated in the production process. As the impact of risk on bank efficiency gains more and more attention (Chiu et al., 2011; Chen, 2012; Saeed and Izzeldin, 2016), it is important to fully include endogenous risk into the measurement of bank efficiency. However, neither loan loss nor nonperforming loans, which mainly profile the credit risk resulted from banks' on-balance-sheet lending activity, can well capture the overall risk of banks, especially those off-balance-sheet risk exposure. In China, recent years have witnessed a significant surge in the off-balance activities of banks as a result of both strong credit demand and funding strains implemented by the policy authority (Hu and Mahendran, 2011). Shadowing banking and off-balance-sheet risk exposure is regarded as one of the main factors threatening the stability of the whole Chinese banking system. Thus, to well capture the impact of this off-balance risk on bank efficiency, this paper tries to incorporate a wider risk measurement, i.e. risk-weighted asset which is the sum of a bank's on-balance-sheet and off-balance-sheet asset weighted according to their risk, as an undesirable output for evaluating bank efficiency. To be noted, different from those literature which treat risk measures as control variables and analyze the impact of risk on bank efficiency after the estimation of efficiency(Sun and Chang, 2011; Hou et al., 2014), we directly model risk assets as a jointly produced undesirable by-product of the asset production process, and we are also the first paper to try to incorporate this wider risk measurement, which captures off-balance-sheet risk exposure, as an undesirable output into the model. Besides, a comparison is made between the estimated total factor efficiency accounting for nonperforming loans and the total factor efficiency accounting for risk weighted assets, to highlight the differences.

Third, though many studies have tried to evaluate the efficiency of Chinese banking sector, few of them accounts directly in their model for an undesirable output. Almost all of the studies are based on stochastic frontier approach (Sun et al., 2013; Yin et al., 2013) or DEA approach (Hou et al., 2014; Dong et al., 2014) without undesirable by-product, resulting in distorted estimations of the real efficiency of Chinese banking. To our knowledge, Wang and Zhu (2011a, 2011b) are the only persons in China who have incorporated undesirable output into the bank production process. However, their analysis considers only non-performing loans and covers only 27 commercial banks in China, far from the total number of banks with public information. Other studies concerned with Chinese bank issues also have the same drawbacks for their limited data samples. Most of them, such as Jiang et al. (2013), Fungáčová et al. (2013), Dong et al. (2014), use a sample comprising less than 80 Chinese commercial banks. Zhang et al. (2012) and Yin et al. (2013) estimate the bank efficiency based on a sample of 133 Chinese banks, which is the largest sample that has been used so far. Besides, rural commercial banks including those cooperative financial institutions, which have played a significant role in rural development, are

absent in all of the existing literature. This paper tries to overcome these drawbacks by investigating a unique sample of 171 Chinese banks, including 5 large commercial banks, 12 join-stock commercial banks, 103 city commercial banks and 51 rural commercial banks. Due to better data quality, our results will be more convincing and meaningful. We are also the first paper to highlight the differences in total factor bank efficiency among different categories of banks and different regions at the same time. The further disaggregation of total factor efficiency helps us explore the source of Chinese banks efficiency for each kind of bank and each region.

2.2 The Determinants of Bank Efficiency

The second strand of literature related to our paper investigates the determinants of bank efficiency. Hsiao et al. (2010) attribute the improved efficiency in post-reform period of Taiwan to the enhancement in banking and risk management practices. Yang and Liu (2012) support the positive support of banking privatization on managerial inefficiency of state-owned banks, while Goddard et al. (2014), after analyzing the cost efficiency for Latin American, find that the mean rank cost efficiency of privately-owned banks in Mexico declined faster than that of state-owned banks.

Besides bank characteristics, market competition is also identified as an important determinant of bank efficiency. Maudos and Guevara (2007) supports a negative relationship between market competition and bank efficiency, after examining the impact of market power in the loan and deposit markets on bank efficiency for 15 European countries over 1993–2002. Their results show the existence of a positive relationship between market power and cost X-efficiency. However, Hou et al. (2014) argue that the lower market power caused by intense market competition tend to improve technical efficiency, for banks are compelled to develop advanced technical experience and skills and they support their argument by analyzing 44 major Chinese commercial banks between 2007 and 2011. Different from Maudos and Guevara (2007) and Hou et al. (2014), Duygun et al. (2013) try to quantify the impact that the Schumpeterian competition mode, i.e. competition through the launch of new products, has on the cost and profit efficiency of the UK commercial banks and the results show that the competition intensity in the commercial banking sector does affect negatively the mean cost and profit efficiency in the sector but there is evidence that as competition intensity increases in the sector, commercial banks react by improving their cost and profit efficiency.

As for the policy environment, regulatory and supervisory policies are regarded as one of the most important determinant of bank efficiency. Gaganis and Pasiouras (2013), by using a large sample of nearly 4000 commercial banks operating in almost 80 countries, find that bank efficiency decreases as the number of the financial sectors that are supervised by the central bank increases and banks in those countries with greater unification of supervisory agencies also tend to be less profit efficient. However, Chortareas et al. (2012), Barth et al. (2013) argue that the impact of regulatory and supervisory policies on commercial bank efficiency depends on the concrete form of policies. Based on an un-balanced panel analysis of 4050 banks observations in 72 countries over the period 1999–2007, Barth et al. (2013) show that tighter restrictions on bank activities are negatively associated with bank efficiency, while greater capital regulation stringency is marginally and positively associated with bank efficiency. A strengthening of official supervisory power is positively associated with bank efficiency only in countries with independent supervisory authorities. Besides regulatory and supervisory policies, Harris et al. (2013) examines the impact of the Troubled Asset Relief Program (TARP) capital injections on the operational efficiency of American commercial banks and they find that banks receiving the capital injection from TARP tend to have lower operating efficiency as a result of the abated incentives of bank managers to adopt best practices that improve asset quality, and the moral hazard associated with bailouts. For more work about the determinants of bank efficiency, we can refer to Fu and Heffernan(2009), Fungáčová et al. (2013), Fujii et al. (2014).

Recent years also see an extensive literature dedicated to explain the evolution of Chinese bank efficiency. Zhang et al. (2012) show that the efficiency of Chinese city commercial banks is heavily influenced by the effectiveness of law enforcement in the region. Better legal environment, higher efficiency in the legal system, and stronger protection of intellectual property right are associated with a higher level of efficiency among these banks. Sun et al. (2013) investigate the effect of strategic investors on bank efficiency in the context of regional economic development. Their analysis shows a positive role of strategic investors in enhancing the efficiency of Chinese city commercial, and this positive effect is negatively correlated to the level of regional economic development. Yin et al. (2013) support the positive effect of WTO accession on bank efficiency. The largest banks with substantial state ownership have enjoyed a more prominent improvement in efficiency. Jiang et al. (2013) appraise the privatization of banks for its significant role in improving performance with respect to revenue inflow and efficiency gains in

the short-run or long-run (initial public offerings). However, as mentioned before, the estimated bank efficiency which is used for further analysis may be biased due to the drawbacks results from limited data sample or estimation methodology. Thus, it is pretty necessary to reanalyze the evolution of Chinese bank efficiency and their determinants based on improved data sample and methodology. Besides, to well illustrate the bank efficiency, the impact of the development of shadow banking on bank efficiency should also be checked.

3. Chinese Banking System: an Overview

The banking system in China is the largest and most complex among the countries presently in transition from central planning to market-based economies (Lin and Zhang, 2009). It has undergone a series of significant transformations since 1978. A good knowledge of the structure and development of Chinese banking system will help us better understand of the evolution and determinants of bank efficiency.

3.1 A Multi-Tier Banking System

By the end of 2012, the Chinese banking sector consists of 2 policy banks and China Development Bank (CDB), 5 large commercial banks, 12 joint-stock commercial banks, 144 city commercial banks, 337 rural commercial banks, 147 rural cooperative banks, 1927 rural credit cooperatives(RCCs), 1 postal savings bank, 4 banking assets management companies, 42 locally incorporated foreign banking institutions, 67 trust companies, 150 finance companies of corporate groups, 20 financial leasing companies, 5 money brokerage firms, 16 auto financing companies, 4 consumer finance companies, 800 village or township banks, 14 lending companies and 49 rural mutual cooperatives, where large commercial banks, joint-stock commercial banks, city commercial banks, rural commercial banks jointly constitute the whole Chinese commercial banking system. Figure 3 shows the market share of banking institutions in terms of assets from 2003 to 2012. As what we can learn from the figure, the total market share of large commercial banks witnessed a continuously decreasing trend, from 58.03% at the end of 2003 to 44.93% at the end of 2012. While the market shares of other three types of Chinese commercial banks all kept increasing over the period, with the share of joint-stock commercial banks increasing from 10.70% to 17.61%, the share of city commercial banks increasing from 5.29% to 9.24%, and the share of rural commercial banks increasing from 0.14% to 4.70%. The share of policy banks and the CDB changed little during this period, and the share of other banking institutions experienced a decreasing trend to 15.13% by the end of 2012. All the data are sourced from the annual reports of China Banking Regulatory Commission (CBRC).

Though homogeneous competition and business model is evident in Chinese commercial banks nowadays, different types of commercial banks still have different comparative advantages in sponsoring economic development. The Large commercial banks, including Agricultural Bank of China (ABC), Bank of China (BOC), China Construction Bank (CCB), Industrial and Commercial Bank of China (ICBC), Bank of Communications (BOCOM), which still rank in top five, have played a significant role in providing credit to state-owned enterprises (SOEs) and big projects, for their pretty large branch networks and asset values. While the geographical coverage and asset values are much smaller for other commercial banks, especially city commercial banks and rural commercial banks. Generally speaking, joint-stock commercial banks (JSCBs), which mainly provide loans to small SOEs and firms with partial private ownership including small and medium enterprises (SMEs), tend to expand their branches in the regions of origin or in those coastal areas with good economic perspectives, though they are also regarded as national banks in China (García-Herrero et al., 2006). The largest five joint-stock commercial banks in terms of asset values by the end of 2012 are Merchants Bank, Evergrowing Bank, China Minsheng Banking Corporation, Shanghai Pudong Development Bank and China Citic Bank. Different from large commercial banks and joint-stock commercial banks, city commercial banks and rural commercial banks typically aim at financing SMEs, especially those located in their own administrative regions, and supporting development policies of local governments. Some are even regarded as the “second finance” of local governments (Qian et al., 2011).

3.2 The Reform of Chinese Commercial Banking System

3.2.1 First Stage of the Reform (1978-1993)

Based on the work of García-Herrero et al. (2006), Berger et al. (2009), Lin and Zhang (2009), Chang et al. (2012), Sun et al. (2013), Liang et al. (2013), the reform of Chinese commercial banking system can be divided into three stages. In the first stage of financial reform, commercial

banking activities and foreign exchange transactions etc. were removed from the People's Bank of China (PBC), through the establishment of 4 wholly state-owned commercial banks (SOCBs or the 'Big Four'). Before 1979, Chinese financial system was a mono-bank system where PBC took charge of a series of issues such as deposit-attracting, commercial lending, monetary policy implementation, foreign reserve management and so on, with fairly low operating efficiency. To solve this multi-task status of PBC and improve the operation of banking system, three of the 'Big Four', Agricultural Bank of China (ABC), Bank of China (BOC), China Construction Bank (CCB), which specialized in fostering and supervising rural banking activities, carrying out foreign currency transactions and supporting the construction sectors respectively, were established in 1979. This specialization of operating kept until the end of 1985, one year after the last one of the 'Big Four' i.e. Industrial and Commercial Bank of China (ICBC) was established, and since then all the 'Big Four' members could enter any business field which was allowed by the PBC and compete with each other.

Rural credit cooperatives (RCCs) and urban credit cooperatives (UCCs), which were mainly under the control of local governments and aimed at financing small and medium enterprises (SMEs), were stablished during this stage as well to sponsor development of the areas with scarce resources. They attract deposits from small towns or rural areas.

3.2.2 Second Stage of the Reform (1994-2002)

Due to the soft-budget constraints for SOEs loans, weak credit culture (García-Herrero et al., 2006) and also the poor management (Sun et al., 2013), nonperforming loans (NPLs) increased significantly during this period in both the SOCBs and UCCs. To ameliorate this problem and improve the performance of commercial banks, a lot of efforts were made by the government:

Four asset management companies (AMCs), legally independent agencies with a very broad mandate, were created in 1998 for the cleaning-up of non-performing loans of the SOCBs. These AMCs not only took charge of the reconstruction of NPLs including converting them to equity, but also had the responsibility to pay for the NPLs they received. Besides, the Ministry of Finance injected 270 billion RMB, which was financed through the issue of 30-year government special bonds, into the SOCBs to improve the balance sheets of them.

For UCCs, the government tries to ameliorate their NPLs problem by consolidating all the UCCs, part of the RCCs and local financial institutions located in towns into newly formed joint-stock companies, namely city commercial banks, which inherited all NPLs from UCCs and at the same time got injections from local public funds (Sun et al., 2013). These cities commercial banks are not allowed to set up branches in any other area outside their own administrative regions until 2006.

Market practices began to be introduced during this period: The establishment of three policy banks, i.e. the Agricultural Development Bank of China (ADBC), China Development Bank (CDB), and the Export–Import Bank of China (Chexim) in 1994 enabled SOCBs to get rid of policy-lending activities and focus on only commercial business, making them to be more profit-oriented; SOCBs were also encouraged to manage their own assets and take more responsibility for their own lending decisions, through the reduction of reserve requirements and the removal of some credit quotas; Government interference in commercial lending was forbidden in 1999, at least in formal terms, and private capital was allowed to enter JSCBs and CCBs (García-Herrero et al., 2006).

3.2.3 Third Stage of the Reform (2003-Current)

This stage of the reform is mainly characterized by the establishment of China Banking Regulatory Commission (CBRC), ownership reform of SOCBs, development of initial public offerings(IPOs), foreign strategic attraction and so on.

In 2003, CBRC was established by the government, to take over the regulatory and supervisory functions of the banking sector from the PBC who was mainly responsible for monetary policies from then on. Its objectives include protecting consumers and depositors, maintaining the stability in the banking system, enhancing banks' competitiveness, encouraging competition, educating the public on the role of finance and eradicating financial crime. To this end, it focuses on the strength of financial institutions, capital adequacy issues, and the restructuring of the banking sector. At the same time, the CBRC, itself, is enhancing its transparency through the publication of individual bank data, including NPLs (García-Herrero et al., 2006).

Another important reform was the successful transformation of SOCBs from wholly state-owned banks to shareholding companies by going public and recapitalizing. A total amount of 37.5 billion (USD) capital was injected in to SOCBs in 2003 and 2005, with CCB and BOC which is the two best-performing banks then receiving 22.5 billion in 2003 and ICBC receiving 15

billion. The capital all collected from the official international reserves, by selling US government bonds. At the same time, CCB, the first bank in China to go public, was listed on Hong Kong Exchange for 8 billion (USD) in October 2005 and on Shanghai Stock Exchange for 7.6 billion (USD) in September 2007. BOC and ICBC raised 13.7 billion (USD) and 21.9 billion (USD) respectively in 2006 through the listing in both Hong Kong Exchange and Shanghai Stock Exchange. ABC was the last one in the 'Big Four' to go public. It made an initial public offering for 11.98 billion (USD) in Hong Kong Exchange and for 10.12 billion (USD) in Shanghai Stock Exchange in July 2010. Besides, BOCOM was also incorporated as the SOCBs by the CBRC in 2007 for its large asset value. Ever since then, the 'Big Four', together with BOCOM, were named as 'large commercial banks' in China.

The attraction of strategic investors is also encouraged by the government during this period, to improve the governance structure and management performance of Chinese banks. According to Ma (2007), the total declared foreign direct investment (FDI) in Chinese banks reached 16.5 billion (USD) by late 2005, accounting for approximately 15 percent of the banking sector's core capital. Moreover, in January 2006, Goldman Sachs Group Inc., Allianz AG, and American Express Co., signed an agreement to buy a total 10% stake of ICBC for $3.78 billion, and Goldman Sachs has been providing staff training, risk-management assistance and guidance on internal control and corporate governance (Berger et al., 2009).

3.3 New Characteristics of Chinese Commercial Banks in Recent Years

Recent years have witnessed a series of new characteristics of Chinese commercial banks: Unbalanced development among banks of different types or located in different regions becomes even more prominent; The development of shadow banking system in China catalyzes the expansion of banks' off-balance-sheet activities, resulting in a distortion of China's traditional credit expansion and underestimation of its commercial banks' overall risk. As the unbalanced development of Chinese banks is already introduced in detail in the first section of the paper, we here mainly introduce Chinese shadow banking and its relationship with traditional commercial banks to help us better understand the underlying risks especially those off-balance-sheet risks Chinese banks are now confronted with.

Generally, Chinese shadow banking system can be categorized into three kinds(Shao, 2013): The first kind, which is called real economy-supported shadow banking (tier-1), refers to the shadow banking instruments and activities providing financing for the real economy, such as bank acceptances, entrusted loans, letters of credit (L/Cs), financial leasing and other informal lending; The second kind, which is named as financial transaction-supported shadow banking (tier-2), refers to the shadow banking instruments and activities supporting financial transactions in capital markets, such as wealth management products (WMPs), public offering of fund, social insurance fund, insurance asset management and so on; The last kind refers to the shadow banking instruments and activities related to financial derivatives, which is called leverage-amplification shadow banking (tier-3), such as credit risk mitigation (CRM) and so on.

Here, we mainly introduced entrusted loans and WMPs, two of the most important forms of shadowing banking in China today. Entrusted loans are essentially inter-corporate lending in China, with lenders setting up all the terms with targeted borrowers (including size, maturity, yield, and collateral). Banks therefore act as intermediaries and trustees to legalize the process and charge 20-30bp as fee income. Banks may be confronted with risks for the high proportion borrowers from property sector as well as the weak credit profile of these borrowers (Hu and Mahendran, 2011). Different from entrusted loans, WMPs are investment management plans sold by banks (Hu and Mahendran, 2011). Usually banks collect short-term funds through the issuing of WMPs and invest them in long-term assets including bonds, stocks, bank loans and portfolios etc., which is quite similar to the operation model of SIV in developed countries. In 2012, 47.71% of the funds raised by WMPs were invested into bond and money market and 38.47% went into portfolio investments. While only 0.36% were invested into bank loans, after the implementation of strict restrictions on loan markets in 2010 (Shao, 2013).

Most of the shadow banking instruments and activities in China depend heavily on traditional commercial banks, obtaining liquidity supports and selling products through commercial banks, which leads to a surge in banks' off-balance activities and underestimation of banks' overall risk. Figure 4 shows the corporation model among commercial banks (CBs), securities companies (SCs) and trust companies (TCs) in the operating of WMPs. As shown in the figure, traditional commercial banks exert a key role in making investment and operating decisions, while securities companies and trust companies usually function as channels in case of WPMs.

4. Methodology

1. Estimation Methodology: Global SBM Approach

The paper estimates banks' TFE by incorporating banks' overall risk endogenously into bank's production process as undesirable by-product in a Global-SMB Model. Compared with existing methods in bank efficiency estimation, the method has the following advantages: (i) The model assumes a non-radial, non-angle and slack-based measure, while most of the efficiency measures such as DDF are radial and angle, which make it very likely to overestimate efficiency when there are non-zero slacks in the constraints (Fukuyama and Weber, 2009); (ii) The model incorporates the overall risk of banks, i.e. both on-balance-sheet and off-balance-sheet risk, as undesirable by-product into the estimation of TFE, while existing methods consider only on-balance-sheet risk which is measured by loan loss or nonperforming loans.

To compare with the models that consider only on-balance-sheet risk, we define two models: (i) Model 1 incorporates the overall risk of banks which is measured by risk-weighted assets as an undesirable output; (ii) Model 2 incorporates non-performing loans as an undesirable output. All the inputs and desirable outputs are the same for these two models. To be noted, as bank loans itself constitutes one of the most important parts of total assets, we haven't modeled both risk-weighted assets and non-performing loans as undesirable by-products of the same production process to avoid possible high correlation between these two variables.

Then we need to decide inputs and desirable outputs for estimation, production approach and intermediation approach are two methods which are widely used for the choice of input and desirable output variables. Compared with the production approach which is more appropriate for evaluating the efficiency of bank branches (Berger and Humphrey, 1997), the intermediation approach has been widely used for the estimation of bank efficiency, including the valuation of Chinese banks' performance (Fungáčová et al., 2013; Hou et al., 2014). It emphasizes the main function of the bank as a financial intermediary, collecting deposits to transform them with labor and capital etc. into loans and other outputs.

Based on intermediation approach, we include total deposit, equity, net value of fixed asset, numbers of employees, interest expense, administration expense and operating expense from which administration expense is subtracted as inputs. Any two of these input variables have no overlapped part. For desirable output, following Wang and Zhu (2011a, 2011b), we incorporate perform loans, equaling total loans minus nonperforming loans, and pre-tax net profit into the model.

The concrete model is defined as follows:

Assume there are n decision-making units (DMU) at time t. For each DMU, there are k inputs, l desirable outputs and m undesirable outputs. x, y, b, X, Y and B represent the column vector and matrix of inputs, desirable outputs and undesirable outputs, respectively. Here, the DMUs are 171 banks in China. $k = 7$ for total deposit, equity, net value of fixed asset, numbers of employees, interest expense, administration expense and operating expense, $l = 2$ for perform loans and pre-tax net profit, $m = 1$ for nonperforming loans in Model 1 and for risk-weighted assets in Model 2. The production set P could be defined as:

$$P = \{(x, y, b) \mid x \geq X\lambda, y \leq Y\lambda, b \geq B\lambda, \lambda \geq 0\} \tag{1}$$

The global SBM TFE for i-th DMU could be obtained by resolving the following fraction programming:

$$TFIE^t_{NPL}(x^t_i, y^t_i, b^t_i) = \min \frac{1 - (1/k)\sum_{k=1}^{k}(s^{x,-}_k / x^t_{k,i})}{1 + [1/(l+m)][\sum_{l=1}^{l} s^{y,+}_l / y^t_{l,i} + \sum_{m=1}^{m}(s^{b,-}_m / b^t_{m,i})]} \tag{2}$$

$$s.t. \quad x_i = X\lambda + s^{x,-}_i; \quad y_i = Y\lambda - s^{y,+}_i; \quad b_i = B\lambda + s^{b,-}_i$$

$$s^{x,-}_i \geq 0; \quad s^{y,+}_i \geq 0; \quad s^{b,-}_i \geq 0; \quad i'\lambda = 1; \quad \lambda \geq 0$$

where $TFIE$ presents the total factor integrated factor of the unit. $s^{x,-}_i$, $s^{y,+}_i$, $s^{b,-}_i$ represent the over-inputs, under-desirable outputs and over-undesirable outputs, respectively, referred to as the slack variables. λ is the intensity vector, the summation of its elements being 1 indicating the assumption of varying return to scale (VRS). The value of this score lies between 0 and 1, and the larger the value, the higher the efficiency of the unit is; if $TFIE_{NLP} = 1$, it reveals that the DMU

is efficient that is located on the production technique frontier.

By using the Charnes-Cooper transformation, the above nonlinear programming in Equation (2) could be transferred into the equivalent linear programming as shown below:

$$TFIE_{LP}^{t}(x_i^t, y_i^t, b_i^t) = \min\tau - (1/k)\sum_{k=1}^{k}(S_k^{x,-}/x_{k,i}^t)$$
$$s.t. \quad 1 = \tau + [1/(l+m)][\sum_{l=1}^{l}(S_l^{y,+}/y_{l,i}^t) + \sum_{m=1}^{m}(S_m^{b,-}/b_{m,i}^t)] \tag{3}$$
$$\tau x_i = X\Lambda + S_i^{x,-}; \quad \tau y_i = Y\Lambda - S_i^{y,+}; \quad \tau b_i = B\Lambda + S_i^{b,-}$$
$$S_i^{x,-}, S_i^{y,+}, S_i^{b,-} \geq 0; \quad i'\Lambda = \tau; \quad \Lambda \geq 0; \quad \tau > 0$$

If the optimal solutions of linear programming in Equation (3) are symbolized by $(TFIE_{LP}^{*}, S^{x,-,*}, S^{y,+,*}, S^{b,-,*}, \tau^{*}, \Lambda^{*})$, the optimal solutions of nonlinear programming in Equation (2) could be expressed accordingly as follows:

$$TFIE_{NLP}^{*} = TFIE_{LP}^{*}, \quad \lambda^{*} = \Lambda^{*}/\tau^{*}$$
$$s^{x,-,*} = S^{x,-,*}/\tau^{*}, \quad s^{y,+,*} = S^{y,+,*}/\tau^{*}, \quad s^{b,-,*} = S^{b,-,*}/\tau^{*} \tag{4}$$

The global SBM total-factor efficiency for each input and output in i-th DMU could be calculated as below:

$$TFDE_{i,t}^{input} = (x_{i,t}^{input} - s_{i,t}^{input})/x_{i,t}^{input}$$
$$TFDE_{i,t}^{undesirable\ output} = (b_{i,t}^{undesirable\ output} - s_{i,t}^{undesirable\ output})/b_{i,t}^{undesirable\ output} \tag{5}$$
$$TFDE_{i,t}^{desirable\ output} = y_{i,t}^{desirable\ output}/(y_{i,t}^{desirable\ output} + s_{i,t}^{undesirable\ output}) \quad (\ )$$

The value of $TFDE_{i,t}^{input}$, $TFDE_{i,t}^{undesirable\ output}$, $TFDE_{i,t}^{desirable\ output}$ also lies between 0 and 1, and the larger the value, the higher the efficiency of the unit is.

2. Empirical Model for the Determinants of TFIE

To further explore the determinants of TFIE of Chinese banks, especially the impact of the development of shadow banking on TFIE, we specify the regression model as follows based on existing literature:

$$TFIE_{i,t} = \delta_0 + \delta_1 SB_{t-1} + \vec{\delta}_2 \overrightarrow{CB}_{i,t-1} + \vec{\delta}_3 \overrightarrow{MC}_{t-1} + \delta_4 CON_{t-1} + \xi_{i,t} \tag{6}$$

$$\overrightarrow{CB}_{i,t-1} = (SIZE_{i,t-1}, OWN_{i,t-1}, NPLR_{i,t-1}, ROA_{i,t-1}, LTDR_{i,t-1}, CAR_{i,t-1}) \tag{7}$$

$$\overrightarrow{MC}_{t-1} = (GDPG_{t-1}, INF_{t-1}, FSTGR_{t-1}) \tag{8}$$

where:

(i) $TFIE_{i,t}$ is the total factor integrated efficiency of bank i for period t.

(ii) SB_{t-1} is the ratio of shadow banking volume to total bank loans in period $t-1$. According to the 'diverting effect' analyzed in the next section of the paper, a negative relationship between the development of shadow banking and banks' TFIE is predicted.

(iii) $\overrightarrow{CB}_{i,t-1}$ is a vector of bank-level variables which have been recognized to have significant effects on bank efficiency, including bank size $SIZE_{i,t-1}$, ownership structure $OWN_{i,t-1}$, NPL ratio $NPLR_{i,t-1}$, return on asset $ROA_{i,t-1}$, loan to deposit ratio $LTDR_{i,t-1}$ and capital adequacy ratio $CAR_{i,t-1}$. Bank size is measured as the log of banks' total assets. The ownership structure is measured by a dummy variable which takes the value of one if the bank is state-owned. NPL ratio is measured as the ratio of non-performing loans to total loans. Based on the existing work, the impacts of bank size and capital adequacy ratio on bank efficiency are ambiguous. On one hand, larger banks tend to have higher bank

efficiency for their scale economies in banking (Barth et al., 2013) or a specialized workforce (Hou et al., 2014). On the other hand, the concept of "too big to fail" may decrease managers' incentives for better performance, resulting in lower bank efficiency. Fukuyama and Weber (2009), by investigating Japanese Shinkin banks, find that an increase in bank size will increase bank inefficiency. Higher capital ratio contributes to alleviating agency problems between managers and shareholders, giving the latter greater incentives to monitor managers' performance and ensure that the bank is run efficiently (Chortareas et al., 2012). However, Yin et al. (2013) argue that a higher capital ratio may lead to lower efficiency as the cost of capital is more expensive than deposits. For ownership structure, since state-owned banks are more likely to be directed to support social goals such as creating employment opportunities (Megginson and Netter, 2001) or maximize politician's personal objectives (La Porta et al., 2002; Cornett et al., 2010), lower efficiency is predicted to exist among state-owned banks ceteris paribus. $OWN_{i,t-1}$ equals to one if government is the largest shareholder of a bank. Otherwise, a value of zero will be given to it. Return on asset is introduced here to capture the impact of profitability on bank efficiency. As pointed out by Chortareas et al. (2013), larger banking institutions with higher profitability ratios benefit substantially banks' efficiency levels. NPL ratio and loan to deposit ratio are incorporated in the regression model to reflect the influence of credit risk and liquidity risk on bank efficiency, based on the work of Hsiao et al. (2010), Chortareas et al. (2012, 2013). According to bad luck (BL) hypothesis, an increase in bank risk causes managers to operate less efficiently by incurring risk monitoring costs in their endeavor to preserve the quality of their asset portfolio (Saeed and Izzeldin, 2016). Thus, a negative relationship between NPL ratio (loan to deposit ratio) and bank efficiency is predicted here. To be noted, the positive effect of loan to deposit ratio on bank efficiency is also evident in some literature (Chortareas et al., 2013; Hou et al., 2014). As argued by Chortareas et al. (2013), banks with higher proportions of loans may increase the pressures on management to effectively deal with credit risk, thus improving the efficiency of the banking institutions.

(iv) $\overrightarrow{MC}_{t-1}$ is a vector of macro-level variables, including GDP growth rate $GDPG_{t-1}$, annual inflation rate INF_{t-1} and fiscal surplus to GDP ratio $FSTGR_{t-1}$. The impact of GDP growth rate on bank efficiency is uncertain. Lensink et al. (2007), Gaganis and Pasiouras (2013) support a positive relationship and argue that banks locate in more prosperous areas tend to have better access to new technology, while Chortareas et al. (2012) think that banks in expanding markets with higher GDP may be less efficient in controlling their costs. Inflation is expect to be negatively related to bank efficiency as the higher interest rate caused by higher inflation rate can raise the interest costs of banks and reduce efficiency in activities such as risk management and evaluation of credit information through greater uncertainty and risk (Saeed and Izzeldin, 2016). Fiscal surplus to GDP ratio is introduced here to reflect the impact of the implicit guarantee from Chinese governments on bank efficiency in the absence of deposit insurance. A negative effect is predicted here since the soft-budget problem is more severe among banks located in an administrative region whose governor has stronger implicit guarantee ability.

(v) CON_{t-1} represents the concentration of banking sector denoted by the Herfindahl-Hirschman index (HHI) which equals the sum of squared market shares according to bank loans. Let $MSL_{i,t}$ be the market share of bank i in the loan market, n be the total number of banks in the market. Then, CON_t can be defined as $CON_t = \sum_{i=1}^{n} MSL_{i,t}^2$. Actually, no consistent findings about the impact of market concentration on bank efficiency exist until now. Researchers, such as Chortareas et al. (2012), Barth et al. (2013) support a negative relationship and they think that more concentrated power gives bank managers less incentives to pursue better performance. While Pruteanu-Podpiera et al. (2008), Fungáčová et al. (2013) argue from the perspective of imperfect competition structure of banking markets that greater bank competition among banks may reduce the length of their customer relationships which are aimed at mitigating moral hazard problems, thus leading to lower bank efficiency.

(vi) $\xi_{i,t}$ is the error term.

(vii) $\delta_1, \delta_2, \delta_3, \delta_4$ are the slope coefficients or vectors of coefficient estimates.
It is possible that our results are affected by the endogenous problem: The change of bank efficiency may affect banks' performance in other indicators, and even the whole economy for its important role of providing finance to the real departments. To alleviate this problem, all the explanatory variables are lagged by one period, referring to Lu and Chen (2009) and Marques et al. (2013).

5. Data and Empirical Analysis

5.1. Data

Our sample consists of an unbalanced dataset of 171 Chinese commercial banks between 2004 and 2012. Regarding bank specialization, we categorize all of these banks into four groups: large commercial banks, joint-stock commercial banks, city commercial banks and rural commercial banks. As shown in Table 1, the sample incorporates all the 5 large commercial banks (making up 3.78% of the total number of observations), i.e. Industrial and Commercial Bank of China, Agricultural Bank of China, Bank of China, China Construction Bank and Bank of Communications, 12 joint-stock commercial banks (making up 8.66% of the total number of observations), i.e. China Citic Bank, China Everbright Bank, Huaxia Bank, China Guangfa Bank, Ping An Bank, China Merchants Bank etc., 103 city commercial banks (making up 64.51% of the total number of observations) and 51 rural commercial banks which includes rural cooperative financial institutions (making up 23.05% of the total number of observations).

Most of the accounting data on commercial banks are gathered by hand from the annual reports of each bank and the "Almanac of China's Finance and Banking". The remaining part of data is drawn from Wind financial database and Bankscope Database. For the missing values, we follow the method of Jiang and Chen (2012) to estimate them. Data on macro-economy are all sourced from the "China City Statistical Yearbook", the "China Statistical Yearbook" or the website of the People's Bank of China. Table 2 shows descriptive statistics of all the variables used for efficiency estimation, based on annual data for the periods 2004-2012. All variables, excluding those ratio ones, are inflation-adjusted to base-year 2005. As shown in the table, almost all of the variables used for TFE estimation are of pretty high standard deviation. For two key variables-risk asset and non-performance loans, the lowest values of them are respectively 38 million and zero in RMB, while the largest values of them amount to 7.61 trillion and 0.74 trillion in RMB respectively. For other variables, deposits, perform loans and equity have the largest standard deviation, and the means of these variables are respectively 0.25 trillion, 0.15 trillion and 0.02 trillion. The high standard deviations in the table indicate that it is significant to highlight heterogeneity in the estimated TFE of Chinese commercial banks.

5.2. TFE Analysis at the Group Level

Based on global SBM approach, we estimate the actual TFE for 171 Chinese commercial banks between 2004 and 2012. Estimation of TFIE is based on MATLAB. This sub-section is mainly concentrated on analyzing the evolution of estimated TFIE of different bank groups, i.e. large commercial banks, joint-stock commercial banks, city commercial banks and rural commercial banks, when different undesirable outputs are incorporated in bank production process. Model 1 with risk-weighted assets as undesirable by-product can well capture a bank's overall risk especially off-balance-sheet risk exposure, while Model 2 with NPLs as undesirable by-product like other studies mainly focus on the credit risk caused by a bank's on-balance-sheet lending activities.

Table 3 presents the changes of weighted-average (by assets) TFIE in both Model 1 and Model 2 from 2004 to 2012 by group. Considering the overall performance of TFIE for different types of banks during this period first, the estimated efficiency in Model 1 displays a totally different pattern from that in Model 2. Specifically, when we incorporate NPLs into the estimation of TFE like what traditional studies concerned with undesirable production outputs have done (i.e. Model 2), joint-stock commercial banks in China have the highest average TFIE, 0.890 over the whole period, and even in most of the years between 2004 and 2012 such as the years 2006-2008, 2010 and 2012, joint-stock commercial banks also rank first in terms of TFIE. City commercial banks and rural commercial banks have the poorest TFIE performance during the same period, with an average value of 0.791 and 0.816 respectively. However when we include risk-weighted assets as undesirable by-products (Model 1), joint-stock commercial banks only possess an average TFIE of 0.788 over the period, ranking behind large commercial banks (0.855) and even rural commercial banks (0.860). Years such as 2007, 2008 and 2011 even witness TFIEs below 0.7 for joint-stock

commercial banks. Rural commercial banks have the highest average TFIE (0.86) during the whole period, and city commercial banks rank last, with an average TFIE of 0.741. Large commercial banks have the second highest TFIE in both Model 1 and Model 2, with an average value of 0.855 and 0.867 respectively.

Actually joint-stock commercial banks are regarded by many researchers as banks with the best performance in China or at least with better performance than large commercial banks, which coincides with the results of Model 2, due to their advantage in cost control, technical application and better governance (See Chang et al., 2012; Fungáčová et al., 2013; Yin et al., 2013; Jiang et al., 2013). However, all these studies ignore the fact that advantages possessed by joint-stock commercial banks have also catalyzed their off-balance sheet activities in recent years through financial innovations, which may lead to biased efficiency evaluation. Hua Xia Bank, one of the joint-stock commercial banks in China, was even confronted with a high probability of default for its WMPs in 2012. In Model 2, when taking the overall risk of banks into account, the TFIE of joint-stock commercial is much lower than that in Model 1, showing that off-balance-sheet activities and higher risk taking may divert bank managers attention from mundane operational problems (Saeed and Izzeldin, 2016), leading to a decrease in a bank's integrated efficiency. In contrast, rural commercial banks still center on traditional lending activities nowadays due to its limited branches poor human capital and innovation ability etc., with the highest NPL ratios and lowest participation in off-balance-sheet activities in China. This explains why rural commercial banks tend to possess lower TFIE when we treat NPLs as undesirable by-product of bank production process. City commercial bank performed even much worse than rural commercial banks before 2007 when NPLs is considered, while after 2007 they experienced an increasingly improvement in IFIE performance due to a series reforms carried out by the governments, such as attracting foreign strategic investors, restructuring cities commercial banks and allowing them to extend outside their own administrative regions etc. The average TFIE of city commercial banks after 2007 is actually larger than rural commercial banks in Model 2, indicating that rural commercial banks are the worst performing commercial banks in terms of average TFIE after 2007 when NPL is considered.

We then analyze the evolution of TFIE for each type of commercial banks concretely. As shown in Table 3 and Figure 5-8, the average TFIE tend to get lower over the whole period for large commercial banks, joint-stock commercial banks and city commercial banks when risk-weighted assets are incorporated as undesirable outputs, while the average TFIE is higher for rural commercial banks in this case. Specifically, for large commercial banks, both TFIE estimated in Model 1 and Model 2 experienced a decreasing trend between 2005 and 2008, which is mainly due to the technical regression happened in this period caused by the change of macro-policies, credit polies and supervisory regulations (Cai and Guo, 2009; Ke and Feng, 2013). The frequent raising of required reserve rate and tight capital requirement of CBRC jointly impeded the growth of bank loans, making the growth rate of inputs greater than that of "good" outputs (Ke and Feng, 2013). The increase of TFIE for large commercial banks in 2009 in both models and only a slight drop of TFIE in the following year in Model 2 show better abilities for large commercial banks to deal with financial crisis. Chang et al. (2012) even find an increasing TFP for large commercial banks while decreasing TFP for joint commercial banks around the 2008 financial crisis. All these indicate that ownership reform, initial public offerings (IPOs) and capitalization etc. indeed have positive effects on the improvement of the performance of large commercial banks. Interestingly, the TFIE gap between Model 1 and Model 2 is more prominent for large commercial banks before 2008, which may be caused by the implementation of a series of regulations to monitor and refrain banks' off-balance-sheet activities after 2008. For example, banks are not allowed to use proceeds from WMPs to buy their own credit assets and at the same time they are required to put back onto their balance sheets the credit assets sold to trust companies through single-investor trust products (Hu and Mahendran, 2011). For joint-stock commercial banks, a steady increase in the TFIE was evident almost over the whole period, except for a drop from 0.935 by the end of 2008 to 0.876 by the end of 2009, when we incorporate NPLs in the production process. However, the estimated TFIEs tend to be more volatile during the whole period if risk-weighted assets are included in the model. Corresponding to the two rounds of significant growth of shadow banking shown in Figure 2, TFIE of joint-stock commercial banks also experienced two rounds of downward trends, with the first round reaching a bottom of 0.603 in 2007 and the second time reaching a bottom of 0.647 in 2011. For city commercial banks, TFIE experienced a drop in 2007 and 2008 as joint-stock commercial banks in Model 1 which may be attributed to their participation in off-balance-sheet activities and an increasing in overall risk taking, while in Model 2 TFIE still kept an increasing trend during this period. Besides, drop in TFIE estimated by Model 1 is also much larger for city commercial banks in 2010. Though the evolution of TFIE tend to be more volatile when risk-weighted assets are considered, an increasing trend of TFIE can be found in both models, which indicate that the restructuring policies, foreign strategic investors attraction and other reforms help

improve the TFIE of cities commercial banks in recent years. Also due to stricter regulation for off-balance sheet activity, the TFIE gap between Model 1 and Model 2 tend to be smaller for city commercial banks. For rural commercial banks, TFIE in Model 1 and Model 2 also behave totally different, the average TFIE is lower when consider NPLs as undesirable products of bank production process, and it reached the lowest level of 0.545 in 2009, mainly due to the deterioration of the loan quality and the increase of credit risk caused by 2008 financial crisis.

Thus, we conclude that, considering on-balance-sheet lending activities only may over-estimate the overall average TFIE and under-estimate TFIE volatility of large commercial banks, joint-stock commercial banks and city commercial banks, while a model incorporating risk-weighted average can well capture the lower efficiency of these banks during two important periods in China. The first is between 2006 and 2008 when off-balance-sheet activities and overall bank risk taking surge due to the prosperity of Chinese stock market and flooded market liquidity, and the second is between 2009 and 2012 when Chinese shadow banking system embraced its second round of growth due to the strong credit demand and funding strains implemented by the policy authority. In contrast, for rural commercial banks, it is appropriate to be concentrated on the quality of on-balance-sheet lending activities of rural commercial banks for the estimation of bank TFE for their limited participation in off-balance-sheet activities and still severe NPL problems in recent years. Actually the estimated TFIE with NPLs as undesirable by-products can well capture the negative shock to loan quality brought about by 2008 financial crisis for rural commercial banks.

5.3. TFE Analysis at the Regional Level

Table 4 reports the changes of weighted-average (by assets) TFIE in both Model 1 and Model 2 from 2004 to 2012 by region. Considering the overall performance of TFIE for banks located in different regions during the whole period first, both models show that banks in the east of China have the highest average TFIE, with a value of 0.835 in Model 1 and a value of 0.868 in Model 2. Banks in the middle of China rank second in terms of TFIE performance in both models as well, with a value of 0.716 in Model 1 and a value of 0.734 in Model 2. Banks in the west of China have the poorest TFIE performance in these 2 models, but the gap between banks in the west of China and banks in the middle of China is not as large as that between banks in the middle of China and banks in the east of China. For TFIE in each year between 2004 and 2012, banks in eastern China always possess the highest TFIE (except 2008) no matter which undesirable output is included in the production process. And it is also more common for Banks in the middle of China to experience higher TFIE than banks in the west of China during the period. The above heterogeneity in TFIE performance among banks of different regions, especially between banks in eastern and non-eastern region, is closely associated with the unbalanced regional development of Chinese commercial banks. Eastern areas which incorporate many fast developing cities such as Shanghai, Beijing and Guangzhou etc., provide commercial banks with abundant financial resources (like deposits, loans, financial networks), favorable economic environment and brilliant employees, leading to better governance and high efficiency of banks located in these areas. Actually all of the headquarters of large commercial banks and joint-stock commercial banks lie in the east of China today.

Besides, we also compare the evolutions of TFIE in Model 1 and Model 2 for banks in each region. As shown in Table 4 and Figure 10-13, the average TFIE over the whole period in Model 1 is lower than that in Model 2 in all regions of China, showing that considering only on-balance-sheet lending activities of banks may over-estimate the average bank TFIE in each region. Specifically, for banks in the east of China (Figure 9), the evolution of TFIE follows a trend similar to that of large commercial banks, but with larger gap in TFIE between Model 1 and Model 2. For example, years such as 2007, 2008 and 2011 experienced a gap of 0.115, 0.076 and 0.092 respectively for banks in eastern China, while that for large commercial banks is 0.072, 0.029 and 0.031 accordingly. This may be due to the fact that a lot of joint-stock commercial banks which are also enthusiastic about financial innovation and off-balance sheet activities still develop their business in the region of origin or the fast-growing coastal area, though they are allowed to operate at the national level (García-Herrero et al., 2006). For banks in the middle of China (Figure 10), TFIE estimated by Model 1 experienced an increasing trend to 0.782 between 2005 and 2008, then fell to 0.704 between 2009 and 2010, and rose again to 0.840 between 2011 and 2012, while TFIE estimated by Model 2 experienced an increasing trend before 2011, with two slightly drop in 2007 (by 0.015) and 2009 (by 0.030) and fell heavily to 0.604 between 2011 and 2012. The absence of a decreasing trend between 2005 and 2008 when risk-weighted assets are incorporated in the model can be mainly attributed to the sample characteristics that 92.16% of the rural commercial banks, which are still confined to traditional on-balance-sheet lending activities, in the sample locate in the middle of China, making the negative effect of banks' overall

risk on TFIE not so significant during this period. Besides, with an increase in the NPL ratio of rural commercial banks, estimated TFIEs which include NPLs as undesirable outputs dropped heavily between 2011 and 2012. For banks in the west of China (Figure 11), the estimated TFIE in Model 1 is higher than that in Model 2 before 2006. However, as the development of Chinese shadow banking and the improvement of local banks' loan quality in recent year, TFIEs accounting for overall risk of banks were lower that accounting for nonperformance loans in most of the years after 2006. TFIE in Model 1 increased from 0.623 to 0.752 between 2004 and 2007, then dropped to 0.667 in 2008, but rose again steadily to 0.789 by the end of 2012 with only a small drop by 0.015 in 2010, while TFIE in Model 2 increased from 0.563 to 0.781 between 2004 and 2008, then dropped to 0.718 between 2009 and 2010, but increased to 0.847 by the end of 2012. The drop of TFIE in 2009 and 2010 when NPLs are treated as undesirable by-products is mainly due to the deterioration of borrower's balance sheet and bank loan quality resulted from 2008 financial crisis. Though the evolution of TFIE is different when we consider different by-products in the model, an overall increasing trend is evident no matter which undesirable output is chosen for banks in the middle and west of China, showing an improvement of the overall bank TFIE performance in non-eastern China. Besides, we should also pay close attention to the unbalance regional development of banks between eastern and non-eastern China, and also to the high volatility of TFIE in these regions, especially when overall risk of banks is considered.

5.4. TFE Disaggregation

5.4.1 TFE Disaggregation Analysis by Group

To further explore the individual drivers as well as impediments behind bank TFE, we also estimate the TFE of each input and output. Table 5 and Table 6 respectively reports the weighted-average (by asset) TFE of each input and output when risk-weighted assets and NPLs are incorporated as undesirable by-products of bank production process. Though different input and output factors display different TFE evolution patterns, both models generate a similar ranking in average TFE among all the input and output factors during the whole sample period. The top 3 factors driving the growth of TFE for all banks in the sample are performing loans, equity and net profits no matter which output is regarded as undesirable output. In the last 5 driving factors, four of them are the same, including employee, fix asset, operating expense and administration expense. The ranking shows that as a whole the low performance of Chinese commercial banks in allocating human and fix asset resources, controlling operating costs impede the efficiency improvement of their integrated efficiency. As Wang and Zhu (2011a) have pointed out, over-organization and resource wasting are still evident in China. Besides, considering the ranking in average TFE over the whole period among all the input and output factors by group, employee, fix asset, operating expense and administration expense also rank last for each group in both Model 1 and Model 2. Interestingly, operating expense is the second least efficient factor for large commercial banks and joint-stock commercial banks if risk-weighted assets are considered as undesirable outputs, while it has a higher ranking in TFE if we include NPL as undesirable by-product. The worse TFE performance of operating expense when risk-weighted asset is incorporated in the model shows that off-balance-sheet activities and higher overall risk taking of banks may divert bank managers' attention from mundane operational problems (Saeed and Izzeldin, 2016). Joint-stock commercial banks, which are better at financial innovation, have the lowest TFE of risk-weighted assets (0.806) and operating expense (0.778) among all kinds of banks when risk-weighted assets are included into the model, while they possess the best TFE performance of NPLs (0.952) and operating expense (0.903) when NPLs are considered, also supporting the 'diverting effect' of banks' overall risk.

For the evolution of each factor's TFE, most TFEs of large commercial banks, joint-stock commercial banks and rural commercial banks experienced lower TFE between 2007 and 2009 than the years between 2004 and 2006, when risk-weighted assets are treated as undesirable outputs. Though an increase of TFE for these factors was evident between 2010 and 2012 in this case, the increment was still pretty limited for factors with poor ranking in efficiency, such as employee, fix asset, administration expense, operating expense, interest expense and risk-weighted assets, and some even kept a decreasing trend during this period. Specifically, taking joint-stock commercial banks as an example, the average TFE of operating expenses fell from 0.858 between 2004 and 2006 to 0.702 between 2007 and 2009, then rose little to only 0.778 between 2010-2012. Besides, the average TFE of risk-weighted assets also fell from 0.914 between 2004 and 2006 to 0.725 between 2007 and 2009, and then rose to 0.779 which is far less than 0.914 between 2010 and 2012. This characteristic of the changes in TFE of input and output factors is closely related to the development of financial innovation ability and increase in off-balance sheet exposure. The over-heated macro-economy, flooded liquidity in stock market, tight

monetary policy and less regulations for off-balance-sheet business before the first half of 2008 provide a good environment for financial innovation and shadow banking activities, leading to higher overall bank risk and poorer operating efficiency. Though government authorities have tried their best to monitor and improve stability of Chinese banking system after 2008 through the implementation of a series regulation items, the improvement of TFE for factors with poor ranking in efficiency is still quite limited. In contrast, a decreasing trend of TFE between 2007 and 2009 is absent for most of factors of joint-stock commercial banks, city commercial banks and rural commercial banks when NPLs are incorporated as undesirable outputs. In this case, TFE for most input and output factors experienced a decreasing trend between 2010 and 2012, which may be caused by the deterioration of both banks' and borrowers' balance-sheets after 2008 financial crisis. Banks need to make more effort or use more labor and operating resource to get their loan back. To be noted, for large commercial banks, most factor experienced a decreasing trend between 2007 and 2009, which is mainly due the technical regression of large commercial banks (Cai and Guo, 2009; Ke and Feng, 2013) caused by the change of macro-policies, credit polies and supervisory regulations.

2. TFE Disaggregation Analysis by Region

Table 7 and Table 8 respectively reports the weighted-average (by asset) TFE of each input and output by region using risk-weighted assets and NPLs as undesirable by-products of bank production process respectively. Employee, fix asset, operating expense and administration expense are included in the last 5 driving factors for banks' whole TFE in every region of China, and this result is robust to the choice of undesirable outputs. Besides, we can also get other results which are also evident in both models. TFEs of employee are the lowest in both models as well as in each region. TFEs of fix assets are the second lowest for banks in the east of China, while it is higher than TFEs of administration and operating expenses for banks located in the middle and west of China. This result is reasonable. Bigger banks such as large commercial banks, which are confronted with serious problems like over-expansion in branches and labors today mainly set their headquarters or develop their business in the more developed east of China, resulting in poorer performance of fix assets for banks in these areas. While banks in the middle and east of China, mainly local commercial banks and smaller branches of large commercial banks, are faced with problems such as the shortage of talent managers and financial resources, poor governance and high operating cost etc., making operating cost inefficiency a more severe problem than fixed asset inefficiency.

We then focus on the differences in TFEs of input and output factors among different regions when different undesirable by-products are included in the model. Considering the average TFE over the whole sample period firstly, operating expense is the third least efficient factor for banks located in the east of China if risk-weighted assets are considered as undesirable outputs, while it has a higher ranking in TFE if NPLs are incorporated in the model. The worse TFE performance of operating expense for banks in the east of China when risk-weighted asset is incorporated in the production process can be also attributed to the unbalanced distribution of large commercial banks and joint-stock commercial banks and the "diverting effect" of banks' overall risk. Moreover, for the evolution of each factor's TFE, most production factors of banks in eastern China experienced lower TFE between 2007 and 2009 compared with that between 2004 and 2006, and possessed a little higher TFE between 2010 and 2012 in both models, while most factors of banks in the middle and west of China experienced totally different or even opposite TFE evolution paths. These results correspond with the TFE evolution characteristics of different kinds of banks.

2. Determinants of Chinese Banks' TFIE

Table 9 and Table 10 presents the regression results of our empirical specification using TFIE estimated by Model 1 and Model 2 respectively. STATA was used to run the regression models. Regression (6) reports fixed-effect estimation results with all control variables in equation (6). However, one may argue that our regression results may change with the choice of independent variables. To show our results are robust to the choice of independent variables, we also report results with different variables, which are shown in Regression (1) to (5) in Table 9 and Table 10. As shown in the tables, our results are robust to the choice of variables.

Bank size is positively associated with TFIE, consist with the findings of Hou et al. (2014) whose work also supports the positive effect of banks size in Chinese commercial banking sector. Larger banks in China are more conducive to efficient bank operation due to their scale economies in banking (Barth et al., 2013) or a specialized workforce (Hou et al., 2014). Bank credit and liquidity risks, denoted by NPL ratio and loan to deposit ratio respectively, impose negative impacts on TFIE of Chinese commercial banks, which suggest that banks with higher loan quality

and liquidity may have higher efficiency since managers can spend less monitoring costs in their endeavor to preserve the quality of their assets or to take precautions against liquidity risk. Government implicit guarantee ability, represented by fiscal surplus to GDP ratio, is also negatively related to bank TFIE, indicating that parachutes from government may intensify soft-budget problems, resulting in poorer bank performance. In many prefectures and counties of China, local governments have direct bank control or personnel appointment rights, facilitating financial resources grabbing and yardstick competition among local governments. Some city commercial banks are even regarded as the "second finance" of local governments (Qian et al., 2011), providing strong incentives for local governments to bail out a local bank confronted with default risks. Banks located in a region with better government financial status are usually more likely to be successfully rescued in case of failure and thus care less about efficient operation. Higher market concentration is related with lower TFIE, consistent with the argument of Barth, Lin et al. (2013) that lower competition caused by more concentrated power decreases the incentive for bank managers to pursue better performance. Besides, for other explanatory variables such as government-ownership, capital adequacy ratio and GDP growth rate etc., though the signs of their coefficients are consistent with our prediction and existing literature, a significant relationship between any one of these variables and bank TFIE fails to exist in China. All these results are quite robust to the choice of undesirable outputs for the estimation of TFIE as well as the choice of regression variables.

For the impact of the development of shadowing banking on bank TFIE when we incorporate different undesirable outputs to estimate the efficiency. As shown in Table 9 and Table 10, a one percent increase in the ratio of shadow banking volume to total bank loans tends to decrease bank TFIE by a larger extent when risk-weighted assets are included in the production process as undesirable by-products. And the impact of shadow banking development on bank efficiency is more significant and robust in this case. Thus, we can conclude that, though a decreasing trend of NPL ratio, together with progresses in liquidity management techniques and increasingly intensified market competition, contribute to the improvement of bank efficiency in recent years, the increasing participation in shadow banking activities and off-balance sheet exposure poses a new threat to the enhancement of the performance of Chinese commercial banks. Off-balance-sheet activities and higher overall risk taking of banks may divert bank managers' attention from mundane operational problems (Saeed and Izzeldin, 2016). It is important to highlight this off-balance-sheet exposure and incorporated this into the estimation of bank efficiency. Empirical results show that a model with risk-weighted assets as undesirable outputs can better capture the impact of shadow banking involvement, while at the same time reflect other significant determinants predicted by other models.

2. Conclusion

The paper dedicates to estimate banks' TFE as well as TFE of each production factor by incorporating banks' overall risk endogenously into bank's production process as undesirable by-product in a Global-SMB Model. The estimation results show that, compared with a model incorporating bank's overall risk, a model considering only on-balance-sheet risk may over-estimate the overall average TFIE and under-estimate TFE volatility of commercial banks except rural commercial banks. Significant heterogeneities of bank TFIE and TFE of each production factor exist among banks of different types and regions, as a result of still prominent unbalanced development of Chinese commercial banks. Banks in the east of China have the highest average TFIE while banks in the west of China take the poorest TFIE performance during the sample period no matter which undesirable output is incorporated.

Moreover, based on the estimated TFIE, the paper also investigates the determinants of Chinese bank efficiency. Bank size is positively associated with TFIE. Larger banks in China are more conducive to efficient bank operation due to their scale economies in banking or a specialized workforce. Bank credit and liquidity risks have negative impacts on TFIE, suggesting that banks with higher loan quality and liquidity may have higher efficiency since managers can spend less monitoring costs in their endeavor to preserve the quality of their assets or to take precautions against liquidity risk. Government implicit guarantee ability is also negatively related to bank TFIE, indicating that parachutes from government may intensify soft-budget problems, resulting in poorer bank performance. The development of shadowing banking has a negative impact on banks' TFIE, indicating that the increasing participation in shadow banking activities and off-balance sheet exposure poses a new threat to the enhancement of the performance of Chinese commercial banks.

The results in our paper have several implications for policy: First, improving bank efficiency cannot be limited to bank management and operation reform. Bankers also need to pay attention to

the negative effect of bank risk on bank efficiency. The improvement of risk regulatory rules may also help increase bank efficiency. Besides, as significant heterogeneities exist among banks of different types and regions, regulatory rules need also consider these heterogeneities. Second, the establishment of explicit deposit insurance system is of great importance in improving bank efficiency as the existence of soft-budget problems which caused by implicit government guarantee. Third, paying closely attention to the over-organization and resource misallocation problems may help improve the efficiency of production inputs such as labor, fixed assets and operating expenses.

Acknowledgements
Shiyi Chen thanks the supports from National Science Fund for Distinguished Young Scholars (71525006), Cheung Kong Scholars Programme and Shanghai Leading Talent Project. Wolfgang K. Härdle thanks the supports from Deutsche Forschungsgesellschaft through the International Research Training Group 1792 "High Dimensional Nonstationary Time Series", Czech Science Foundation(19-28231X) and the Taiwan YuShan Scholarship. Li Wang thanks the supports from National Natural Science Foundation (71603056), Humanities and Social Sciences Projects of Ministry of Education (16YJC790093), Shanghai Philosophy and Social Science Planning Project (2019BJB006) and Fundamental Research Funds for the Central Universities (2017ECNU-HLYT015). The authors bear all the responsibility for the article.

Literature

Assaf, A. G., R. Matousek, and E. G. Tsionas, 2013. "Turkish Bank Efficiency: Bayesian Estimation with Undesirable Outputs" *Journal of Banking and Finance* 37, 506-517.

Atkinson, E., and J. H. Dorfman, 2005. "Bayesian Measurement of Productivity and Efficiency in the Presence of Undesirable Outputs: Crediting Electric Utilities for Reducing Air Pollution" *Journal of Econometrics* 126, 445-468.

Banker, R. D., and R. Natarajan, 2008. "Evaluating Contextual Variables Affecting Productivity Using Data Envelopment Analysis" *Operations Research* 56, 48-58.

Barth, J. R., C. Lin, Y. Ma, J. Seade, and F. M. Song, 2013. "Do Bank Regulation, Supervision and Monitoring Enhance or Impede Bank Efficiency" *Journal of Banking and Finance* 37, 2879-2892.

Berg, S. A., F. R. Forsund, and E. S. Jansen, 1992. "Malmquist Indices of Productivity Growth during the Deregulation of Norwegian Banking, 1980-89" *Scandinavian Journal of Economics* 94, 211-228.

Berger, A. N., and D. B. Humphrey, 1997. "Efficiency of Financial Institutions: International Survey and Directions for Future Research" *European Journal of Operational Research* 98, 175-212.

Berger, A. N., I. Hasan, and M. Zhou, 2009. "Bank Ownership and Efficiency in China: What will Happen in the World's Largest Nation?" *Journal of Banking and Finance* 33, 113-130.

Cai, Y. Z., and M. J. Guo, 2009. "Empirical Study on Total Factor Productivity of China's Listed Commercial Banks" *Economic Research Journal (China)* 9, 52-65.

Chambers, R.G., Y. Chung, and R. Färe, 1996. "Benefit and Distance Functions" *Journal of Economic Theory* 70(2), 407-419.

Chang, T. P., J. L. Hu, R. Y. Chou, and L. Sun, 2012. "The Sources of Bank Productivity Growth in China during 2002-2009: A Disaggregation View" *Journal of Banking and Finance* 36, 1997-2006.

Chen K., 2012. "Incorporating Risk Input into the Analysis of Bank Productivity: Application to Taiwanese Banking Industry" *Journal of Banking and Finance* 36, 1911-1927.

Chen, S. Y., and S. J. Zhang, 2014. "Large-Scale Land Use for Construction and Energy Consumption after the New Millennium with Their Impact on Total-Factor Efficiency Change in

China's Regional Economy" *Energies*, 7,1986-2003.

Chiu, Y. H., Y. C. Chen, and X. J. Bai, 2011. "Efficiency and Risk in Taiwan Banking: SBM Super-DEA Estimation" *Applied Economics* 43(5), 587-602.

Chiu, Y., Z. Luo, Y. Chen, Z. Wang, and M. Tsai, 2013. "A Comparison of Operating Performance Management between Taiwan Banks and Foreign Banks Based on the Meta-Hybrid DEA Model" *Economic Modelling* 33, 433-439.

Chortareas, G., C. Girardone, and A. Ventouri, 2012. "Bank Supervision, Regulation, and Efficiency: Evidence from the European Union" *Journal of Financial Stability* 8, 292-302.

Chortareas, G., C. Girardone, and A. Ventouri, 2013. "Financial Freedom and Bank Efficiency: Evidence from the European Union" *Journal of Banking and Finance* 37, 1223-1231.

Cornett, M. M., L. Guo, S. Khaksari, and H. Tehranian, 2010. "Performance Differences in Privately-Owned versus State-Owned Banks: An International Comparison" *Journal of Financial Intermediation* 19, 74-94.

Dong, Y., R. Hamilton, and M. Tippett, 2014. "Cost Efficiency of the Chinese Banking Sector: A Comparison of Stochastic Frontier Analysis and Data Envelopment Analysis" *Economic Modelling* 36, 298-308.

Duygun, M., V. Sena, and M. Shaban, 2013. "Schumpeterian Competition and Efficiency among Commercial Banks" *Journal of Banking and Finance* 37, 5176-5185.

Fernandez, C., G. Koop, and M. Steel, 2002. "Multiple-Output production with Undesirable Outputs: An Application to Nitrogen Surplus in Agriculture" *Journal of Banking and Finance* 34, 127-138.

Fu, X., and S. Heffernan, 2009. "The Effects of Reform on China's Banking Structure and Performance" *Journal of Banking and Finance* 33, 39-52.

Fukuyama, H., and W. L. Weber, 2008. "Japanese Banking Inefficiency and Shadow Pricing" *Mathematical and Computer Modelling* 71, 1854-1867.

Fukuyama, H., and W. L. Weber, 2009. "A Directional Slacks-Based Measure of Technical Inefficiency" *Socio-Economic Planning Sciences* 43, 274-287.

Fungáčová, Z., P. Pessarossi, and L. Weill, 2013. "Is Bank Competition Detrimental to Efficiency? Evidence from China" *China Economic Review* 27, 121-134.

Fujii, H., S. Managi, and R. Matousek, 2014. "Indian Bank Efficiency and Productivity Changes with Undesirable Outputs: A Disadvantage Approach" *Journal of Banking and Finance* 38, 41-50.

Gaganis, C., and F. Pasiouras, 2013. "Financial Supervision Regimes and Bank Efficiency: International Evidence" *Journal of Banking and Finance* 37, 5463-5475.

García-Herrero, A., S. Gavilá, and D. Santabárbara, 2006. "China's Banking Reform: An Assessment of its Evolution and Possible Impact" *Economic Studies* 52, 304-363.

Goddard, J., P. Molyneux, and J. Williams, 2014. "Dealing with Cross-Firm Heterogeneity in Bank Efficiency Estimates: Some Evidence from Latin America" *Journal of Banking and Finance* 40, 130-142.

Halkos, G. E., and N. G. Tzeremes, 2013. "Estimating the Degree of Operating Efficiency Gains from A Potential Bank Merger and Acquisition: A DEA Bootstrapped Approach" *Journal of Banking and Finance* 37, 1658-1668.

Harris, O., D. Huerta, and T. Ngo, 2013. "The Impact of TARP on Bank Efficiency" Journal of *International Financial Markets, Institutions and Money* 24, 85-104.

Holod, D., and H. F. Lewis, 2011. "Resolving the Deposit Dilemma: A New DEA Bank Efficiency

Model" *Journal of Banking and Finance* 35, 2801-2810.

Hou, X., Q. Wang, and Q. Zhang, 2014. "Market Structure, Risk Taking and the Efficiency of Chinese Commercial Banks" *Emerging Markets Review* 20, 75-88.

Hsiao, H., H. Chang, A. M. Cianci, and L. Huang, 2010. "First Financial Restructuring and Operating Efficiency: Evidence from Taiwanese Commercial Banks" *Journal of Banking and Finance* 34, 1461-1471.

Hu, Y., and D. Mahendran, 2011. "China Banks: Shadow Banking Conundrum" *Hongkong and Shanghai Banking Corporation Limited (HSBC)*, *Global Research*, *19th October*. http://www.doc88.com/p-2512405381640.html

Jiang, S. X., and Y. C. Chen, 2012. "Monetary Policy, Bank Capital and Risk-Taking" *Journal of Financial Research (China)* 4, 1-16.

Jiang, C., S. Yao, and G. Feng, 2013. "Bank Ownership, Privatization and Performance: Evidence from A Transition Country" *Journal of Banking and Finance* 37, 3364-3372.

Ke, K. L., and Z. X. Feng, 2013. "The Growth and Convergence of Chinese Commercial Banks' Total Factor Productivity" *Journal of Financial Research (China)* 6, 146-159.

La Porta, R., F. López de Silanes, and A. Shleifer, 2002. "Government Ownership of Banks" *Journal of Finance* 57, 265-301.

Lensink, R., A. Meesters, and I. Naaborg, 2007. "Bank Efficiency and Foreign Ownership: Do Good Institutions Matter?" *Journal of Banking and Finance* 32, 834-844.

Liang, Q., P. Xu, and P. Jiraporn, 2013. "Board Characteristics and Chinese Bank Performance" *Journal of Banking and Finance* 37, 2953-2968.

Lin, T., and S. Chiu, 2013. "Using Independent Component Analysis and Network DEA to Improve Bank Performance Evaluation" *Economic Modelling* 32, 608-616.

Lin, X., and Y. Zhang, 2009. "Bank Ownership Reform and Bank Performance in China" *Journal of Banking and Finance* 33, 20-29.

Lu, M., and Z. Chen. 2009. "Fragmented Growth: Why Economic Opening May Worsen Domestic Market Segmentation ?" *Economic Research Journal* (China) 3, 42-52.

Ma, G. 2007. " Who pays China's bank restructuring bill?" *Asian Economic Papers* 6(1), 46-71.

Marques, L. B., R. Correa, and H. Sapriza, 2013. "International Evidence on Government Support and Risk Taking in the Banking Sector" *Federal Reserve Board (FRB) International Finance*, *Discussion Paper No.1086.* https://ssrn.com/abstract=2328705

Maudos, J., and J. F. Guevara, 2007. "The Cost of Market Power in Banking: Social Welfare Loss VS. Cost Inefficiency" *Journal of Banking and Finance* 31, 2103-2125.

Megginson, W. L., and J. M. Netter, 2001. "From State to Market: A Survey of Empirical Studies" *Journal of Economic Literature* 39, 321-389.

Park, K., and W. Weber, 2006. "A Note on Efficiency and Productivity Growth in the Korean Banking Industry, 1992-2002" *Journal of Banking and Finance* 30, 2371-2386.

Pruteanu-Podpiera, A., L. Weill, and F. Schobert, 2008. "Banking Competition and Efficiency: A Micro-Data Analysis on the Czech Banking Industry" *Comparative Economic Studies*, 50, 253-273.

Qian, X. H., T. Q. Cao, and W. A. Li, 2011. "Promotion Pressure, Officials' Tenure and Lending Behavior of the City Commercial Banks" *Economic Research Journal (China)* 12, 72-85.

Saeed, M., and M. Izzeldin, 2016. "Examining the Relationship between Default Risk and

Efficiency in Islamic and Conventional Banks" *Journal of Economic Behavior and Organization* 132, 127-154.

Shao, Y., 2013. "Shadow Banking: International Prospect and Chinese Case (Second Part)" *Financial Development Review (China) 8*, 48-84.

Sun, J. J., K. Harimaya, and N. Yamori, 2013. "Regional Economic Development, Strategic Investors, and Efficiency of Chinese City Commercial Banks" *Journal of Banking and Finance* 37, 1602-1611.

Sun, L., and T. Chang, 2011. "A Comprehensive Analysis of the Effects of Risk Measures on Bank Efficiency: Evidence from Emerging Asian Countries" *Journal of Banking and Finance* 35, 1727-1735.

Tabak, B. M., R. B. Miranda, and D. M. Fazio, 2013. "A Geographically Weighted Approach to Measuring Efficiency in Panel Data: The Case of US Saving Banks" *Journal of Banking and Finance* 37, 3747-3756.

Tone, K., 2004. "A Hybrid Measure of Efficiency in DEA" *National Graduate Institute for Policy Studies(GRIPS)*, *Research Report Series*. https://www.researchgate.net/publication/288870547_A_hybrid_measure_of_efficiency_in_DEA

Wang, B., and N. Zhu, 2011a. "Bank Efficiency and Total Factor Productivity Growth for the Listing Banks in China under the Constraint of Non-performing Loans" *Journal of Financial Research (China)* 1, 110-130.

Wang, B., and N. Zhu, 2011b. "Total Factor Productivity Growth in China Banking Industry under the Constraint of Non-performing Loans" *Economic Research Journal (China)* 5, 32-45,73.

Wu, D. D., and J. R. Birge, 2012. "Serial Chain Merger Evaluation Model and Application to Mortgage Banking" *Decision Sciences* 43(1), 5-36.

Wu, D. D., C. Luo, H. Wang, and J. R. Birge, 2016. "Bi-level Programming Merger Evaluation and Application to Banking Operations" *Production and Operations Management* 25(3), 498-515.

Yang, C., and H. Liu, 2012. "Managerial Efficiency in Taiwan Bank Branches: A Network EDA" *Economic Modelling* 29, 450-461.

Yin, H., J. Yang, and J. Mehran, 2013. "An Empirical Study of Bank Efficiency in China after WTO Accession" *Global Finance Journal* 24, 153-170.

Zhang, J., P. Wang, and B. Qu, 2012. "Bank Risk Taking, Efficiency, and Law Enforcement: Evidence from Chinese City Commercial Banks" *China Economic Review* 23, 284-295.

IRTG 1792 Discussion Paper Series 2020

For a complete list of Discussion Papers published, please visit http://irtg1792.hu-berlin.de.

001 "Estimation and Determinants of Chinese Banks' Total Factor Efficiency: A New Vision Based on Unbalanced Development of Chinese Banks and Their Overall Risk" by Shiyi Chen, Wolfgang K. Härdle, Li Wang, January 2020.

IRTG 1792, Spandauer Strasse 1, D-10178 Berlin
http://irtg1792.hu-berlin.de

This research was supported by the Deutsche Forschungsgemeinschaft through the IRTG 1792.