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PERFORMANCE ANALYTICS WITH DEA:
BASIC CONCEPTS AND METHODS
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ASSESSING THE EFFICIENCY PROFILES OF
CHINESE BANKS USING DEA: SURVEY,
CLASSIFICATION, AND CRITICAL ANALYSIS

GROUP TWO

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ABSTRACT

This survey article aims to provide an overview of the field's research on Chinese banks' efficiency profiles, particularly on Data Envelopment Analysis (DEA) studies. Using a literature review, we analyse 50 AJG-rated papers published between 1993 and 2023 from the perspective of research questions, contributions, methodologies, models, variables, and data. After that, we conduct a critical analysis to point out methodological gaps and shortcomings and report mixed findings. Future research directions based on DEA analysis of Chinese banks could be expanding dynamic network analysis to understand temporal dynamics better, integrating all six assessment perspectives for a holistic view, employing multiple efficiency measurements for comprehensive inefficiency insights and utilising a 3-stage DEA model to account for heterogeneous operating environments, improving accuracy in identifying inefficiency causes.

Keywords: Data Envelopment Analysis (DEA), Chinese banks, literature surveys, critical analysis, efficiency

1. **Introduction**

Data envelopment analysis has been playing a key role in identifying the optimal structure for bolstering efficiency in the bank sectors. This methodology is very suitable for a country that is experiencing the restructuration in financial industry, such as China. An *et al*., (2015) highlighted the growing number of foreign banks in Chinese industry has heightened the competitive pressure for Chinese banks. Hence, the Chinese banks are experiencing a restructuring process to find which sectors and factors are influencing their efficiency to meet the burgeoning modernizing economy needs. This paper uses Data envelopment analysis (DEA) to examine the profiles of commercial banks in China during the pivotal period. This study examines various DEA methodologies to classify Chinese banks' performance within some context including, technology, regulation, and global financial crisis. In the subsequent, this paper highlights essential strategies for Chinese banks in navigating the internal and international economic pressure.

In literature survey, it is divided into five parts of explanatory of assessing the efficiency profiles of Chinese banks using DEA. Starting from the research problem, mostly it consists of research questions across studies like Xiaogang Chen *et al*. (2005) on financial deregulation and Matthews (2013) on risk management practices, alongside Xiaohong Liu *et al*. (2020)'s examination of operational technology heterogeneity, highlight the sector's nuanced challenges. These studies underscore the banking sector's complex adaptation to regulatory, technological, and economic shifts, emphasizing the vital role of strategic adaptability within Chinese banks. Building upon those research problems as foundation in this paper, main contributions (Appendix B) further elucidate the methodological advancements in DEA applications and its effect. Xiaogang Chen *et al*. (2005) and Matthews (2013) delve into the impacts of deregulation and risk management on banking efficiency, highlighting the evolving nature of DEA methodologies. These advancements are instrumental in capturing the nuanced effects of diverse factors affecting banking efficiency, from regulatory changes to technological innovations. The main contributions from these studies not only reinforce the adaptability and depth of DEA as a tool for efficiency analysis but also bridge the initial exploration of research problems with concrete methodological approaches. This connection illustrates how DEA's adaptability is pivotal in providing strategic insights for operational improvements, making it an indispensable tool for navigating the sector's challenges and fostering strategic adaptability within Chinese banks. Then, on Appendix F provides a comprehensive summary of Decision-Making Units (DMUs) across different periods, highlighting the variousity and scope of the sample sizes and data sources utilized in these studies. The extensive range, from small-scale analyses of individual banks to expansive surveys covering multiple banking institutions across various countries, reflects the broad applicability and adaptability of DEA methodologies. Appendix B not only complements the methodological discussions in Appendix B but also enriches the narrative by providing a tangible context to the empirical investigations, offering a bird's eye view of the sector's evolving dynamics.

On certain conditions, various DEA models are applied, from traditional CCR and BCC to more specialized SBM and Network DEA models, used by researchers like Dong *et al*. (2014) and Xiao Shi *et al*. (2023). This methodological diversity highlights DEA's utility in navigating banks towards efficiency optimization amidst evolving market and regulatory conditions. This methodological diversity highlights DEA's utility in navigating banks towards efficiency optimization amidst evolving market and regulatory conditions. Inputs and outputs in DEA analysis on Appendix D reveal the sector's multifaceted nature through the variety of inputs and outputs considered for efficiency assessment. This diversity reflects the broad objectives of efficiency evaluations, from core banking functions to wider financial performance metrics, underlining DEA's comprehensive capacity to capture banking operations' essence. Response and Explanatory Variables in Second-Stage Analyses

Appendix E concentrate on efficiency drivers, with studies like those by Dong *et al*. (2014) and Wilson and Zhao (2023) employing regression analyses to discern the impact of external factors on efficiency scores. This inquiry is crucial for identifying strategic actions banks can undertake to address competitive and regulatory challenges. Then, the forthcoming sections are organized as follows: literature survey analysis which reviews existing literature related to use of DEA methodology to assess the efficiency profiles of Chinese banks, critical analysis which talks about the examination of the existing literature, identifying the methodological limitations, discrepancies, and areas where further research is needed, and conclusion to conclude all the components from the papers. Overall, the provided text outlines a structured and comprehensive academic paper on the efficiency profiles of Chinese banks using DEA.

2. Literature Survey Analysis

2.1. Research Questions and Contributions

First of all, in dynamic condition of commercial Chinese bank, each paper has different characteristic and problem. pivotal question of how deregulation and bank size have sculpted the operational efficiency of China's major banks, as examined by Chen, Skully, and Brown (2005). Their quest for understanding is shared by Wang *et al*. (2014), who delve into the evolution of efficiency over time. These papers foundational works are set the stage for comprehending the reference point used to calculate the efficiency of the sector. Another research problem is discussing the strategic management of risks and assets. Matthews (2013) and Du, Worthington, and Zelenyuk (2018) discuss the critical role that risk management practices and asset diversification play in shaping income efficiency and the overall financial health of banks.

The narrative then shifts to the operational research problem that are faced by the commercial banks in China, discussed by Liu, Yang, and Wu (2020) and Shi, Wang, and Emrouznejad (2023). These papers are exploring the implications of technological heterogeneity and the management of undesirable outputs. These studies highlight the sector's efforts to adapt to technological advancements and manage the complex modern bank operational system. Additionally, Wilson and Zhao (2023) providing insights into the banks' resilience and strategic responses during periods of economic uncertainty. These papers collectively underscore the Chinese banking sector's journey towards improved efficiency, emphasizing the strategic imperatives necessitated by an increasingly competitive global banking environment. Through a mix of methodologies, including Data Envelopment Analysis (DEA), these studies offer a nuanced understanding of the factors that shape the efficiency and operational strategies of Chinese commercial banks, marking significant contributions to the literature on banking efficiency and management.

To sum up, the narrative of the article papers not only highlights the Chinese banking sector's journey towards efficiency but also underscores the strategic imperatives required to thrive in an ever-competitive global environment. Additionally, the contributions of these studies can be categorized into two main areas, firstly exploration of specific factors' influence on bank efficiency, and secondly, the introduction of methodological innovations, as mentioned below:

a. Exploring Specific Factors' Influence on Bank Efficiency

When exploring specific factors' influence on bank efficiency, some research focus on internal factors like internal management and risk control, such as by Matthews (2013) and Yu *et al*. (2019), explored how risk management practices and credit risk impact banks' income and operational efficiencies. The paper written by Asmild and Matthews (2012) applied multi-directional efficiency analysis (MEA) to

investigate not only the levels of efficiency in Chinese banks but also the patterns of inefficiencies across different types of banks. And Xiaohong Liu *et al.* (2020), examined the effects of ownership structures (e.g., state-owned vs. joint-stock banks) and market power on bank efficiency.

As for external factors, economic environment had attracted much attention. Papers like Wilson and Zhao (2023) and Rasoul Rezvanian *et al.* (2010), etc. analysed how external factors such as global financial crises, economic stimulus plans, WTO accession and banking reforms (Rasoul Rezvanian, Rima Truk Ariss, Sayed M. Mehdian, (2010)), and regulatory changes affect bank efficiency.

b. Methodological Innovations

Apart from papers aiming at digging into factors to find directions for improvement, some papers creatively announced methodological innovations. Some focusing on refining current DEA models to more accurately evaluate bank efficiency when dealing with certain types of factors, for instance, the paper by Xiao Shi, Libo Wang, Ali Emrouznejad (2023) integrated undesirable outputs using a by-production framework. Xie *et al.* (2022) developed a multi-period leader-follower DEA model that incorporates undesirable outputs, providing a more accurate efficiency evaluation of commercial banks. Additionally, Hirofumi Fukuyama, Roman Matousek (2017) developed a bank network revenue function which considers the impact of NPLs (non-performing loans) on bank production.

We can notice that more papers focused on methodological innovations rather than applying DEA and identify targets for improvement. This trend reflects scholars' passion for the refinement of current methodology, indicates some DEA models might lack adaptability in certain circumstances.

2.2. Methodologies and Models

In this study, we focus on the DEA method. Although there is another method commonly used to evaluate the relative efficiency of various banks, that is stochastic frontier analysis (SFA) which is a parametric approach. Analysis using the DEA method can be conducted in various stages as mentioned by Iddouch, El Badraoui, and Ouenniche (2023), namely single-stage DEA analysis, two-stage DEA analysis, and three-stage DEA analysis. Single-stage analysis aims to derive efficiency profile estimates from the DMUs measured using a specific DEA model. These efficiency estimates can include overall technical efficiency, pure technical efficiency, scale efficiency, cost efficiency, revenue efficiency, profit efficiency, and allocative efficiency. Two-stage analysis is performed to analyze the determinants or drivers of efficiency using various regression methods such as pooled or panel regression, Tobit regression, and Seemingly Unrelated Regression. Then, the three-stage analysis aims to ensure fair benchmarking in the presence of non-homogeneous operating environments by purging environmental bias from the variables used in the model.

It was found that the majority of studies used single-stage DEA analysis, including studies conducted by Dong *et al.* (2014), Matthews (2013), Asmild and Matthews (2012), and Yu *et al.* (2019). Then, around one third of the studies used two-stage DEA analysis such as those conducted by Xie *et al.* (2022), Mohamed Ariff and Luc Can (2008), Fukuyama and Tan (2022), and Wu *et al.* (2023). It can also be concluded that the Tobit Regression and ordinary least squares method are popular in determining drivers of efficiency. From the many papers reviewed in this study, we did not find any research that used three-stage analysis.

In terms of the model types, DEA can be grouped into static black box models, dynamic black box models, static network models, and dynamic network models. Most authors use static black box models such as static CCR and BCC models. There are also many who use static network models such as those done by Matthews (2013), Fukuyama and Tan (2022), and Wu *et al.* (2023). This may

be due to the fact that banks operate in multiple stages, i.e. deposit generating stage and deposit utilizing stage (An *et al*., 2015). Furthermore, there are a few studies that use dynamic network models such as those done by Zhou (2019), which calculate efficiency estimates over multiple periods and consider carryovers from year to year.

2.3. Variables

The examination of efficiency evaluation in the first stage of Data envelopment analysis within the context of Chinese Banks, highlights a nuanced diversification in the selection of assessment perspectives. Predominantly, the literature gravitates towards three approaches: the Intermediation Approach (IA), the Profit-Oriented Approach (POA) and the Production Approach. The studies such as those by Xiaogang Chen *et al*. (2005), reflect a focus on the traditional role of financial institutions as intermediaries between savers and borrowers. Inputs typically include various categories of expenses, while outputs show loans, deposits, and non-interest income. On the other hand, the POA, represented by works like Matthews (2013) and Xiao Shi *et al*. (2023), underscores the significance of profitability, with operational costs and interest costs as inputs and a combination of interest and non-interest income as outputs. This distinction in approaches underscores the evolving nature of efficiency analysis within the banking sector, where the emphasis shifts based on the underlying financial model and the strategic objectives of the institutions under review. Furthermore, the studies by Fukuyama *et al*. (2023) and Necmi and Hiroshi (2010), exhibit the Production Approach (PA) as another type of perspective. This approach focuses on the production processes of banking services, considering inputs such as labor and physical capital and outputs like the volume of processed transactions or services rendered, highlighting an operational view of bank efficiency.

The second-stage DEA study provides a comprehensive examination of many variables connected to the efficiency estimates of Chinese banks. These variables are studied using a behavioral perspective and are classified into two unique categories: contextual/environmental and event-related. The variables included in Appendix E are carefully documented and serve as the explanatory factors that influence the complex operational environment of banks, affecting both efficiency and inefficiency results.

The contextual/environmental perspective includes macroeconomic data such as GDP growth rate, broad money supply, and policy uncertainty index. These components represent the economic conditions in which banks operate. Regulatory factors, such as capital adequacy ratios and interest rate liberalization indices, act as indicators for the regulatory environment in which banks function, revealing systemic limitations and the level of economic governance. The Herfindahl-Hirschman Index and different ownership structures reflect the competitive environment and internal governance, providing an overview of the strategic landscape in the banking sector.

On the other hand, the event-related perspective focuses specifically on internal factors that influence banks, such as their size and profitability. These factors indicate how well the bank operates and the advantages of being large. The perspective also considers risk-related variables including credit and liquidity issues. These characteristics work as a means of assessing the banks' current operational environment and their ability to quickly adapt to internal and external disruptions. Rezvanian, Truk Ariss, and Mehdian (2010) demonstrate that a combination of internal control factors, such as ownership type and concentration, and external influences, such as regulatory quality and economic development, have a significant role in determining efficiency. Their work presents a detailed and intricate analysis of the factors that contribute to efficiency.

Wu *et al*. (2023) established a direct connection between bank efficiency estimates and external economic and regulatory issues, emphasizing that efficiency is a multifaceted process driven by wider policy frameworks and market dynamics. Meanwhile, Fukuyama and Tan (2022) investigate the impact of demographic financial risks and corporate social responsibility on inefficiency estimates. They examine how bank policies directly affect various geographical landscapes and their socio-economic involvement.

By combining various viewpoints, Appendix E provides a thorough representation of the factors influencing the effectiveness of Chinese banks. The behavioral perspective emphasizes the importance of considering both the strong structural features of banks and the ever-changing economic and regulatory environments in which they operate. The inclusion of both perspectives not only enhances our comprehension of bank efficiency but also underscores the interconnected relationship between external forces and internal bank policy. Therefore, the DEA scores are not just numbers, but rather indications of the intricate relationship between the banks' strategic choices and their ability to adapt to the environment. These ratings provide useful insights for improving bank performance through a strategic approach.

2.4. Data

The following provides insights from Appendix F which consists of the number of DMUs used, period of analysis, sample sizes, and the sources of the data used in each paper.

DMUs Classification:

Appendix F offers a comprehensive summary of research carried out on Chinese banks, in which the DMUs can be classified according to the type of banks and their ownership arrangements as follows:

1. State-Owned Banks, research frequently incorporates major state-owned banks due to their substantial influence in China's banking industry.
2. Joint-stock banks, which are often studied due to their increasing significance.
3. City commercial banks, many studies concentrate on commercial banks, highlighting the sector's dynamic nature and its significance in the Chinese economy.
4. Regional banks, some studies focus on regional banks, emphasizing the interest in localized banking performance.
5. National banks, some papers concentrate on national banks, highlighting a particular interest in assessing the banking firm efficiency estimate within national context.
6. Foreign banks, some publications mention the presence of foreign banks in China, highlighting the global dimension of the Chinese banking sector.

Analysis Periods:

The analysis periods tend to involve multi-year investigations, frequently lasting over a decade. This longitudinal method is beneficial for monitoring patterns and alterations in the efficiency and performance of the banking industry. The investigation spans from 1993 to 2021, with periods starting from 1-year to 19-year period demonstrating a sustained interest in the financial operations of Chinese banking institutions.

Sample Sizes and Observations:

The sample sizes range widely, from tens of samples to 4,053 samples, showing a diverse range of study objectives, with certain research concentrating on a detailed examination of a limited number of

banks, while others adopt a more comprehensive strategy. This variety demonstrates the wide range of approaches and research questions discussed in the literature.

Data Sources:

The studies primarily rely on data from reputable databases like BankScope, Wind Database, and Fitch Connect, guaranteeing a high level of credibility and consistency in the research. Some studies have used individual bank reports, interviews, and internal records, which can offer distinctive perspectives but may present difficulties in terms of standardizing and verifying data.

Studying Chinese banks through these analyses provides a comprehensive perspective on the industry. There is a focus on state-owned and commercial banks, but there is also a notable interest in exploring the wider banking sector, which includes regional, joint-stock, and foreign banks. Relying on credible data sources and doing thorough analysis over extended periods establish a solid basis for reliable conclusions. It is important to consider the differences in sample sizes and the types of banks included in this research when analysing the results and making comparisons between different papers.

3. Critical Analysis

3.1. Methodological Gaps

Based on our knowledge and understanding of Data Envelopment Analysis (DEA), we have conducted a survey and analysis of empirical literature on the efficiency characteristics of Chinese banks using the DEA method. We identified several methodological gaps and shortcomings, which can be summarized as follows:

The first gap is the lack of dynamic network analysis, with only about 30% of the literature considering the temporal dynamics present in the real world. Moreover, these studies are mostly concentrated after the year 2020, such as Wu *et al.* (2023). Earlier literature, with the exception of Matthews (2013) among others, tends not to use a dynamic framework. This may lead to inaccurate identification by DEA of factors causing inefficiency in banks that are influenced by time.

The second gap is the absence of consideration for all or most of the six types of assessment perspectives. Only a portion of the literature employs a hybrid or integrated approach to combine at most two assessment perspectives, such as Tan, Wänke, Antunes, Emrouznejad (2024), who adopted a combined assessment perspective of the production approach and intermediation approach. These methods are used to estimate the efficiency characteristics of banks. The lack of coverage of perspectives makes it difficult for current DEA research on Chinese banks to meet the information needs of different stakeholders.

The third gap is that no study has examined multiple efficiency measurements (i.e., overall technical efficiency, pure technical efficiency, scale efficiency, cost efficiency, profit efficiency, revenue efficiency, and allocative efficiency) to provide a comprehensive idea of the reasons behind the inefficiency of Chinese banks to all stakeholders, such as shareholders, policymakers, etc. Most of them, for example, Kai *et al.* (2018) and James *et al.* (2013) only used profit efficiency and overall technical efficiency, respectively. Only a few of them like the one written by Fukuyama, *et al.* (2021) used multiple efficiency measurements including allocative efficiency and technical efficiency.

The fourth gap is the absence of literature using a 3-stage DEA model to exclude the effect of their heterogeneous operating environments. This may lead to environmental biases causing inaccurate identification of the causes of inefficiency in banks.

3.2. Shortcomings

As for the shortcomings, the results of our literature survey regarding DEA analysis in Chinese banking found that none of the papers utilized three-stage DEA analysis to address environmental bias. Three-stage analysis in DEA, if conducted, would eliminate environmental bias by purging the environmental effects from the efficiency estimates. This is quite unfortunate because even though the research scope is limited to one country, there are various environmental variables that could lead to bias, such as geographic location and market structure. This is also evidenced by Fukuyama and Tan (2022), who found that differences in geographic location affect the efficiency of Chinese banks.

Most of the studies ignore the significant diversity among Chinese banks, often directly comparing efficiency estimates across different types of banks without addressing the banks heterogeneity. For instance, research by An *et al*. (2015) and Chen, Skully, and Brown (2005) which studied efficiencies of state-owned, joint-stock, and city commercial banks while ignoring the banks heterogeneity. Nevertheless, some studies like those by Liu *et al*. (2020) and Cho and Chen (2021), utilize meta-frontier DEA analysis to categorize Chinese banks into groups based on bank types. This approach improves the objectivity of efficiency estimates by acknowledging the diverse characteristics of each bank types.

The variables selected for a DEA model are influenced by research goals and perspectives. The production approach guides the researcher to assess a bank's ability to generate products like loans and deposits, while the profit-oriented focuses on income generation for stakeholders. Some studies, like those by Asmild and Matthews (2012) and Xie *et al*. (2022), do not specify their approach or assessment perspective when forming the DEA model. However, many researchers, such as An *et al*. (2015) and Chen, Skully, and Brown (2005), determine their approach beforehand. This ensures more interpretable relative performance estimates among DMUs. However, some use input-output variables that are not aligned with their defined assessment perspective. For example, incorporating income variables as output variables in the analysis with the intermediation approach done by Chen, Skully, and Brown (2005), even though income variables are generally used in the profit-oriented approach, thus making the focus blurry. Additionally, some papers lack detailed variable definitions, as observed in Dong *et al*. (2016) by not defining capital, which could refer to various meaning including equity capital or debt capital.

Then, it can also be seen in Appendix C and Appendix E that substantial number of studies conducted two-stage DEA analysis to determine significant drivers of the efficiency estimates from the DEA model used. At this matter, there are authors who select efficiency driver variables which have already been used in the DEA model for efficiency score estimation. For instance, Xie *et al*. (2022) used non-performing loans (NPL) as both the drivers of efficiency and the output variable of the model.

In addition to that, there are several studies that do not use control variables in their second-stage analysis. Xie *et al*. (2022), Chen, Skully, and Brown (2005), and An *et al*. (2015) did not use any control variables in their second-stage analysis. However, many use control variables in their second-stage analysis as well, such as Liu *et al*. (2020), Dong, Hamilton, and Tippett (2014), and Du, Worthington, and Zelenyuk (2018) who use control variables such as asset scale, deposit to loan ratio, and interest margin. The use of control is crucial as it serves to counteract the impact of the inherent

attributes of both internal and external bank environments on the main factors of efficiency (Iddouch, El Badraoui, and Ouenniche, 2023).

Furthermore, another concern in determining efficiency drivers is the presence of endogeneity between efficiency drivers and efficiency value estimates. The endogeneity problem arises due to the mutual causality between independent variables and the dependent variable in a model (Cho and Chen, 2021). Some studies completely overlook this issue by not addressing related measures such as endogeneity tests and appropriate regression methods like seemingly unrelated regression and system GMM estimator. However, there are some studies that address endogeneity by using the system GMM estimator, as done by Cho and Chen (2021). Additionally, Tan *et al*. (2021) also revealed the presence of endogeneity between efficiency estimates and market competition.

Last but not least, among the shortcomings, many studies ignore statistical tests to check the statistical significance of differences. For instance, Luo and Yao (2010) and An *et al*. (2015) did not use statistical tests to state differences in efficiency estimates of different bank types. However, fortunately, many others use statistical tests, such as Dong *et al*. (2016) using the Wilcoxon-Mann-Whitney test to check the statistical significance of efficiency estimate differences between bank types and period of analysis, and Liu *et al*. (2020) who use the Kruskal-Wallis test to test the significance of efficiency differences between SOB, JSB, and CCB.

3.3. Mixed Findings

There have been numerous academic studies conducted on the efficiency of Chinese banks, resulting in varying interpretations and conclusions. Xu and Zhou (2020) contend that State-Owned Commercial Banks (SOCBs) perform well, but they note minor fluctuations in efficiency levels. Antunes *et al*. (2022) also place SOCBs at the top in terms of efficiency among all bank types. Zhou *et al*. (2019) agree with this conclusion, suggesting that these banks have robust operational practices. However, Fukuyama, Tsionas, and Tan (2023) have observed inefficiency and significant volatility among SOCBs, contradicting the common assumption of their operational superiority.

City Commercial Banks (CCBs) face a troubling outlook as Xu and Zhou (2020) highlight their declining efficiency, a view shared by Liu, Yang, and Wu (2020), who point to a decrease in deposit efficiency. These reports raise concerns about CCBs' ability to retain traditional banking operations in the face of real estate market pressures and the rise of fintech, which are siphoning traditional deposit streams.

Wang *et al*. (2014) criticize traditional DEA models for overestimating bank efficiency, advocating for a two-stage DEA model that might better capture the intricacies of banking operations. This criticism is echoed by Antunes *et al*. (2022) and Du, Worthington, and Zelenyuk (2018), who call for more accurate and diverse methodologies to assess efficiency, reflecting a broader call in the academic community for improved evaluation tools.

The efficiency of Foreign Banks (FBs) is viewed through diverse lenses. Dong *et al*. (2016) and Fukuyama and Tan (2022) commend FBs for their cost efficiency, potentially pointing to effective management and cost-minimization strategies. Contrary to this, Antunes *et al*. (2022) detect considerable efficiency volatility in FBs, indicating that these banks, while adept at managing costs, may struggle with the uncertainties of the Chinese market.

The efficiency of Rural Banks (RBs) is a matter of debate among experts. According to Wang and Chen (2024), RBs are highly efficient due to their specialised knowledge of rural markets and customer needs. However, Antunes *et al*. (2022) disagree with this claim and rank RBs as the least

efficient group. They suggest that this could be due to challenges such as limited resources and less sophisticated operational structures typical in rural banking environments.

Conflicting reports on the performance of various bank types further complicate the landscape of banking efficiency. For instance, the high inefficiency and volatility reported by Fukuyama, Tsionas, and Tan (2023) in SOCBs stand in opposition to other reports of their efficiency. Similarly, while Wang and Chen (2024) praise the efficiency of RBs, Antunes *et al.* (2022) categorise them as the least efficient. These divergent findings reflect the complexity of the banking efficiency landscape in China and suggest that while certain bank types, such as SOCBs and FBs, may excel in specific efficiency aspects, their overall performance is subject to a range of factors, including market dynamics, regulatory impacts, and the precision of the methodological tools employed in their evaluation.

4. Conclusion

This literature survey and critical analysis assesses the efficiency of the profiles of Banks in China using Data Envelopment Analysis. Initially, the process starts by classifying the research problem and contribution, classifying the framework inside stages in the DEA process, classifying the variables for specification in Data Envelopment Analysis, and classifying the approach, inputs and outputs. During the literature review, we found some extensions in terms of using some methodologies, such as CCR and BCC. Then, various period analyses, from 1993 until 2018, make this literature review more impactful in identifying the market dynamics and competition, especially in China. In addition, having a variety of periods of analysis enables us to compare the efficiency of the bank's performance and analyse which methodologies are more effective in specific conditions. Our findings reveal significant methodological gaps and shortcomings. Key issues include a need for dynamic network analysis, insufficient coverage of assessment perspectives, and limited exploration of multiple efficiency measurements. Also, there needs to be a three-stage DEA model to address environmental biases. Most studies overlook the diversity among banks and the selection of variables, which skews efficiency estimates. Endogeneity and the absence of statistical tests for significance further complicate the analysis. Additionally, conflicting reports on bank types' efficiency emphasise the need for a nuanced approach. A more comprehensive approach will refine accuracy, provide a deeper understanding of operational strengths and weaknesses, and inform policy decisions for a more robust banking sector in China.

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APPENDIX

Appendix A: Summary of research problems and/or questions.

Reference	Research Problem(s) / Question(s)
Chen, Skully and Brown (2005)	The paper investigates how the efficiency of major Chinese banks evolved, particularly after the financial deregulation in 1995. It aims to determine if deregulation led to improved efficiency and whether bank size influences efficiency levels
Matthews (2013)	How risk management practices influence the income efficiency of Chinese banks.
Liu, Yang, Wu (2020)	Evaluating performance of Chinese commercial banks using DEA, considering operational technology heterogeneity, measuring the degree of this heterogeneity, targeting intermediate variables of banks, and representing weak disposability of undesirable outputs
Wilson and Zhao (2023)	How did the performance of Chinese commercial banks change before, during, and after the 2007–2008 global financial crisis, and in response to China's stimulus plan between 2008 and 2010?
Shi, Wang, Emrouznejad (2023)	performance evaluation of Chinese commercial banks, considering the impact of bad/undesirable outputs. It proposes an improved slacks-based DEA model within a by-production framework
Asmild and Matthews (2012)	Efficiency patterns in Chinese banks, particularly differentiating between State Owned Banks (SOBs) and Joint Stock Banks (JSBs), using Multi-directional Efficiency Analysis (MEA)
Du, Worthington and Zelenyuk (2018)	The study investigates the impact of earning asset diversification on Chinese bank efficiency from 2006 to 2011, adapting a two-stage DEA approach to a panel data setting.
Dong *et al.* (2014)	investigates the cost efficiency of Chinese banks from 1994 to 2007, comparing stochastic frontier analysis (SFA) and data envelopment analysis (DEA).
Barth *et al.* (2013)	Examines the impact of bank regulation, supervision, and monitoring on bank efficiency. Investigates the effects of different regulatory and supervisory frameworks on the operational efficiency of banks.
Xie *et al.* (2022)	Operational efficiency of China's listed commercial banks using a novel approach that accounts for undesirable outputs in efficiency evaluation
Ariff and Can (2008)	Investigates cost and profit efficiency in Chinese banks, considering ownership, size, risk profile, profitability, and environmental changes using non-parametric methods.
Fukuyama and Tan (2022)	Efficiency of Chinese banks, focusing on input, output, and stability efficiencies using a three-stage network DEA model. The paper also examines the impact of market power and loan loss provisions on bank efficiency.
Liu *et al.* (2020)	Investigates the influence of changes in ownership structure on the efficiency of Chinese commercial banks, focusing on deposit and loan efficiencies.
Yu *et al.* (2019)	Estimating the operational efficiencies of Chinese banks, considering credit risk. It aims to optimize operational and interest income, and non-performing loan amounts
Cho, Chen (2021)	The study examines the impact of financial technology (Fintech) on the cost efficiency and productivity of China's banking industry.
Zhu, Li and Liang (2018)	Improving the efficiency measurement of Chinese commercial banks using a two-stage Slack-Based Measure (SBM) model with a leader-follower structure.
Rezvanian, Ariss, Mehdian, (2010)	Examines cost efficiency, technological progress, and productivity growth in Chinese banking, focusing on the period before and after China's WTO accession. Investigates how these factors are influenced by WTO accession and banking sector reforms.
Wu *et al.* (2023)	Investigates how interest rate liberalization impacts the efficiency of Chinese commercial banks.

Necmi K. Avkiran (2011)	Investigating to what extent bank DEA super-efficiency estimates are associated with key financial ratios to help selecting financial ratio benchmarks objectively.
Tan *et al*. (2024)	Investigating the performance in the banking industry, research on Chinese banking efciency is rather focused on discussing rankings to the detriment of unveiling its productive structure in light of banking competition
An, Chen, Liang & Wu (2015)	measure the efficiency of Chinese commercial banks, considering undesirable outputs within a two-stage operational process
Fukuyamaa, Tan (2022)	evaluating bank efficiency including strategic disposability and undesirable outputs in Chinese banks
Fukuyama, Matousek (2017)	It focuses on evaluating network revenue performance and behavioral differences between types of regional banks in Japan, particularly how banks can adjust inputs/outputs to maximize revenue and the optimal level of non-performing loans (NPLs)
Matthews and Xiao (2020)	it aims to measure cost inefficiency of Chinese banks using the familiar non-parametric method of Data-Envelopment-Analysis (DEA) by bootstrapping methods to provide estimates that lend themselves to statistical inference. it decomposes the measure of cost inefficiency into its constituent parts of technical inefficiency and allocative inefficiency the bootstrap estimates of inefficiency are used to test various hypotheses regarding Hthe levels, trends and convergence in technical inefficiency and allocative inefficiency
Fukuyama, Tsionas, Tan (2023)	The study aims to contribute to the fields of empirical banking and operational research in banking by proposing a two-staged dynamic Data Envelopment Analysis (DEA) model. This model specifically considers the role of loan loss reserves in the banking production process, treating them as a carryover variable.
Avkiran and Morita (2010)	To capture the interactions among different perceptions on a common set of performance measures
Xu and Zhou (2020)	The purpose of this paper is to evaluate Chinese commercial banks efficiency based on different non-performing loans in the process.
Matthews, *et al*. (2010)	To examine the productivity growth of the nationwide banks of China and a sample of city commercial, banks for the ten years to 2007
Hou, *et al*. (2014)	investigate the impact of market structure and risk taking on the efficiency of Chinese commercial banks
Fukuyama, *et al*. (2021)	This paper focuses on the use of loan loss reserves (LLRs) in the banking production process and considers it as a variable with a dual role.
Fukuyama, *et al*. (2021)	Is corporate social responsibility (CSR) good for efficiency in the Chinese banking industry?
Dong *et al*. (2016)	To examine the cost and profit efficiency of four types of Chinese commercial banks over the period from 2002 to 2013.
Luo *et al*. (2011)	To evaluate the effectiveness of stock listing on Chinese commercial banks' efficiency using two different frontier approaches.
Antunes *et al*. (2022)	To evaluate the efficiency of 39 Chinese commercial banks over the period 2010–2018. Also, in the second stage, investigates the inter-relationships between efficiency and some bank-specific variables (i.e. bank profitability, bank size, expenses management, traditional business and non-traditional business) under the Robust Endogenous Neural Network Analysis.
Bingquan *et al*. (2019)	To address the relationship of Chinese urban commercial banks' output loans around neighbouring regions and include the effect of the regional market environment on bank performance.
Luo *et al*. (2010)	The most significant reform before the crisis was ownership diversification, aiming to improve corporate governance and efficiency. This article will study whether this reform has really improved bank efficiency.
Wang *et al*. (2014)	evaluate the level of efficiency of the Chinese commercial banking system and identify the sources of inefficiency\ How has the efficiency of the Chinese commercial banking system changed over time\ What are the implications of the

	findings for the improvement of the Chinese commercial banking system
Fukuyama, Tsionas, and Tan (2023)	addresses the development and application of a dynamic network data envelopment analysis model to evaluate the relative efficiency of DMUs within the Chinese banking industry, considering the sequential structure, behavioral-causal analysis, and the impact of different types of risk on bank profitability.
Zhou, X.,(2019)	addressed in the is the evaluation of banking system efficiency in the presence of uncertainty using a multi-period three-stage DEA model \ to address the challenge of evaluating the efficiency of banking systems while considering uncertainty, which is a critical issue in the banking industry
Boussemart, J.P. (2019)	investigates the concept of credit risk (in)efficiency and proposes a method to measure it jointly with the productive (in)efficiency of banks using a nonparametric Data Envelopment Analysis (DEA) model.
Luo, Bi, Liang (2012)	concerns selecting appropriate input and output indicators for DEA efficiency evaluation. It aims to address problems such as selection tools, correlation analysis, and classification of input versus output status
Antunes (2024)	estimates the cost efficiency of Chinese banks using an innovative Data Envelopment Analysis (DEA) model. Additionally, it explores the interrelationships between efficiency and other bank-specific variables using a Stochastic Structural Relationship Programming (SSRP) Model based on neural networks
Li (2019)	extends the model proposed by Salo and Punkka (2011) to more common and practical applications that consider the two-stage production structure, and it calculates each Decision Making Unit's (DMU) ranking interval for the overall system as well as for each subsystem/sub-stage
Huang *et al.* (2017)	The study seeks to understand how to measure the efficiency of Chinese commercial banks within a stochastic multistage production framework. It proposes a network data envelopment analysis (DEA) that characterizes the multistage network production processes and estimates the fractions of shared inputs used by each production stage
Shabani, and Shirazi (2023)	development of a comprehensive network DEA model for the performance evaluation of commercial bank branches in dynamic competitive conditions, providing valuable insights for commercial banks to enhance their operational efficiency and overall performance in a dynamic and competitive environment
Lin, Lee and Chiu, T. (2009)	to objectively measure the operating efficiency of the bank's branches, providing an impartial and rational assessment of their performance. This could help in better resource configuration, meeting corporate operation objectives, and improving management decisions
Zhang and Wang (2014)	The study examines whether reforms have improved the productivity efficiency of Chinese banks during their expansion post-reform era.
Wang and Chen, (2024)	Evaluating the operational performance of Chinese commercial banks with a focus on understanding the impact of time lag effects on efficiency assessments
Chen, Matousek and Wanke (2018)	Explores Chinese bank efficiency during the global financial crisis. It employs a two-stage approach integrating satisficing Data Envelopment Analysis (DEA) under a stochastic environment and Support Vector Machine regression to differentiate between high/low efficiency banks within specific performance thresholds.

Appendix B: Summary of the main contribution(s) of the paper.

Reference	Main Contribution(s) of the Paper
Chen, Skully and Brown (2005)	the application of DEA for analysing bank efficiency in China's unique context, and an assessment of the impact of financial deregulation on banking efficiency
Matthews (2013)	Integration of risk management metrics into a Network DEA framework to evaluate the impact of risk management on bank income efficiency.
Liu, Yang, Wu (2020)	Integration of the meta-frontier technique into DEA for assessing bank performance with technological heterogeneity, targeting intermediate outputs, and accounting for differences in operational technology among banks.
Wilson and Zhao (2023)	Understanding the impact of the global financial crisis and subsequent stimulus on Chinese banks' efficiency and productivity.
Shi, Wang, Emrouznejad (2023)	the development of an improved slacks-based DEA model that integrates undesirable outputs using a by-production framework. This model provides a more accurate assessment of bank efficiency
Asmild and Matthews (2012)	Applying multi-directional efficiency analysis (MEA) to investigate not only the levels of efficiency in Chinese banks but also the patterns of inefficiencies across different types of banks
Du, Worthington and Zelenyuk (2018)	Development of a dynamic version of the two-stage DEA approach with truncated regression and double-bootstrapping, applied to Chinese banking data, examining the impact of asset portfolio diversification on bank efficiency.
Dong *et al.* (2014)	Efficiency analysis in Chinese banking by comparing SFA and DEA methods. It assesses the consistency of efficiency scores between these approaches and provides insights into the most suitable methods for banking efficiency analysis.
Barth *et al.* (2013)	Provides empirical evidence on the relationship between bank efficiency and various aspects of bank regulation, supervision, and monitoring. Highlights how different regulatory environments affect bank operations.
Xie *et al.* (2022)	Development and application of a multi-period leader-follower DEA model that incorporates undesirable outputs, providing a more accurate efficiency evaluation of commercial banks.
Ariff and Can (2008)	Introduces a non-parametric approach to analyze both cost and profit efficiency in Chinese banks and examines the influence of key factors on these efficiencies.
Fukuyama and Tan (2022)	Development of a three-stage network DEA model to separately evaluate input, output, and stability efficiencies of banks, incorporating market power and loan loss provisions into the analysis
Liu *et al.* (2020)	Provides an in-depth analysis of how ownership structure impacts the efficiency of bank deposits and loans using a two-stage meta-frontier DEA network model.
Yu *et al.* (2019)	DEA framework for analysing potential income gains in banks, emphasizing technical improvements in credit and loan provision reduction
Cho, Chen (2021)	The paper's main contribution is the application of the metafrontier cost Malmquist productivity index to analyze the impact of Fintech on the banking industry's productivity and efficiency.
Zhu, Li and Liang (2018)	A modified two-stage SBM model that incorporates a leader-follower structure, providing a more realistic efficiency assessment for banks
Rezvanian, Ariss, Mehdian, (2010)	The paper offers new insights into the efficiency and productivity of Chinese banks, with a particular focus on the effects of WTO accession and banking reforms. Utilizes a comprehensive methodology to assess changes over time.
Wu *et al.* (2023)	Introduces a two-stage network DEA approach to evaluate bank efficiency in the context of interest rate liberalization, offering novel insights into the varying effects of liberalization on different stages of banking operations
Necmi K. Avkiran (2011)	post-tax profits to average total assets, and return on average equity show a strong relationship with efficiency estimates. This finding raises the potential to use efficiency estimates to predict certain key financial ratios' future value

	DEA can Help to guide the governments on deregulation and market structure DEA can help market analysts in pricing decisions DEA can Improve managerial performance by separating the best from the worst performers
Tan et al. (2024)	The main contribution is the development of a two-stage network production process to evaluate the efficiency of Chinese commercial banks and an integrated MLP-HMM model to examine endogeneity among banking competition, contextual variables, and efficiency levels
An, Chen, Liang & Wu (2015)	To determine efficiency statuses of these bank in order to minimize the slacks in input and output Gives a suggestion for the managers to pay more attention to the relatively low efficient deposit-generating stage and should improve their ability to absorb more deposits by applying more attractive policies very useful for the banks to reduce the gap between their intermediate measures set in two stages. That is, the results can provide a good alternative for well coordinating the activities of the two stages in order to reduce resource waste
Fukuyama, Tan (2022)	The current study significantly contributes to the empirical banking and operational research literature by filling in these significant gaps
Fukuyama, Matousek (2017)	paper's major contribution is the development of a bank network revenue function which considers the impact of NPLs on bank production and a two-stage network model that includes these NPLs.
Matthews and Xiao (2020)	giving a suggestion that state-owned banks are more constrained by social and political objectives in their downsizing strategy than JSCBs
Fukuyama, Tsionas, Tan (2023)	contributes to the subject area of empirical banking and operational research in banking by proposing a two-stage dynamicDEA model that considers the desirability of loan loss reserves in the banking production process with a carryover role.
Avkiran and Morita (2010)	The findings help the management to collaborate with amenable shareholders to shape the perceptions held by the recalcitrant regulators
Xu and Zhou (2020)	It gives an influence combining ARs restrictions with a two-stage DEA model for considering the different undesirable outputs. Firstly, the classification of undesirable outputs (non-performing loans) in banking system was introduced due to its risk level, which means that the impact on the banking operation system is different. Secondly, based on the particularity of banking operation system and the applicability of AR restrictions, the additive two-stage AR-DEA model was unitized to evaluate the DMU efficiency
Matthews, et al. (2010)	To examine the productivity growth of the nationwide banks of China and a sample of city commercial, banks for the ten years to 2007
Hou, et al. (2014)	investigate the impact of market structure and risk taking on the efficiency of Chinese commercial banks
Fukuyama, et al. (2021)	This paper focuses on the use of loan loss reserves (LLRs) in the banking production process and considers it as a variable with a dual role.
Fukuyama, et al. (2021)	Is corporate social responsibility (CSR) good for efficiency in the Chinese banking industry?
Dong et al. (2016)	To examine the cost and profit efficiency of four types of Chinese commercial banks over the period from 2002 to 2013.
Luo et al. (2011)	To evaluate the effectiveness of stock listing on Chinese commercial banks' efficiency using two different frontier approaches.
Antunes et al. (2022)	To evaluate the efficiency of 39 Chinese commercial banks over the period 2010–2018. Also, in the second stage, investigates the inter-relationships between efficiency and some bank-specific variables (i.e. bank profitability, bank size, expenses management, traditional business and non-traditional business) under the Robust Endogenous Neural Network Analysis.
Bingquan et al. (2019)	To address the relationship of Chinese urban commercial banks' output loans around neighbouring regions and include the effect of the regional market

	environment on bank performance.
Luo *et al*. (2010)	bank efficiency increased by almost 5% after listing. Despite the fact that Joint Equity Banks (JEBs) still perform better than SOBs, the latter manage to catch up and reduce the efficiency gap with the former during the past few years. This in part explains why the Chinese banking system has been less affected by the current world financial crisis than their western counterparts, leading to an important conclusion that SOB reforms in China over the past 10 years have produced remarkable results.
Wang *et al*. (2014)	This study is the first to use a two-stage strategy to evaluate the efficiency implications of ownership type in the Chinese banks. The two-stage DEA model developed in this research expands the literature on banking efficiency evaluation and inefficiency identification, provides accurate and current information on the efficiency of the Chinese bank industry, guiding the development and implementation of policies for future industry growth.
Fukuyama, Tsionas, and Tan (2023)	the development and application of a novel dynamic network data envelopment analysis model that integrates sequential structure, behavioral-causal analysis, and dynamic characteristics to evaluate the relative efficiency of DMUs within the Chinese banking industry. This contributes to the advancement of research in the field of performance evaluation and management within the banking industry, addressing inefficiency and risk assessment through advanced analytical techniques.
Zhou, X.,(2019)	the development of a comprehensive network DEA model for the performance evaluation of commercial bank branches in dynamic competitive conditions, providing valuable insights for commercial banks to enhance their operational efficiency and overall performance in a dynamic and competitive environment
Boussemart, J.P. (2019)	This paper uses a network DEA modelling framework that separates performance into economic and credit risk efficiencies. The approach allows for the separate measurement of economic efficiency, derived from the production of good outputs, and credit risk management efficiency, related to the minimization of non-performing loans
Luo, Bi, Liang (2012)	a new method for choosing DEA variables based on the concept of cash value added (CVA). This method is proposed to be more objective, providing managers and researchers with relevant variables and exact status designations, and the data can be easily obtained from balance sheets and cash flow statements
Antunes (2024)	firstly, it introduces a new DEA model that accounts for time-series data when computing cost efficiency and allows for cost-saving and comparative analysis. Secondly, it proposes a SSRP Model to analyze non-linear relationships between efficiency and various bank-specific variables, enhancing the accuracy of results
Li (2019)	Develops a method to obtain ranking intervals for classic two-stage production systems. This method considers the internal structure of a bank and divides the production process into two subsystems, allowing for a more nuanced analysis of efficiency
Huang *et al*. (2017)	The paper's primary contribution is the establishment of an economic model that leads to the network stochastic frontier analysis (SFA) framework, capable of characterizing multistage network production processes and providing more accurate efficiency measurements by considering the specific sources of inefficiency in multistage production processes within banks
Shabani, and Shirazi (2023)	development of a comprehensive network DEA model for the performance evaluation of commercial bank branches in dynamic competitive conditions, providing valuable insights for commercial banks to enhance their operational efficiency and overall performance in a dynamic and competitive environment
Lin, Lee and Chiu, T. (2009)	to objectively measure the operating efficiency of the bank's branches, providing an impartial and rational assessment of their performance. This could help in better resource configuration, meeting corporate operation objectives, and improving

	management decisions
Zhang and Wang (2014)	Introduces a comprehensive analysis of efficiency using DEA, assessing technical, pure technical, and scale efficiencies, and explores the impact of ownership structure.
Wang and Chen, (2024)	The development of a dynamic three-stage time-lag range directional measure (RDM) cross-efficiency model that simultaneously considers three types of time-lag elements (fixed assets, deposits, and NPLs) to assess bank operational performance more accurately.
Chen, Matousek and Wanke (2018)	Innovative application of a satisficing DEA model in a stochastic setting to compute efficiency levels and using machine learning to examine efficiency determinants across performance thresholds.

Appendix C: Summary of models used within DEA Analyses for assessing the efficiency of DMUs

Reference	First Stage Model	Second Stage Model	Third Stage Model
Dong et al., (2014)	SFA, CCR Model BCC Model	n/a	n/a
Chen, Skully and Brown (2005)	CCR model	n/a	n/a
Matthews (2013)	Network DEA Model	n/a	n/a
Liu, Yang, Wu (2020)	Meta-frontier DDF model	n/a	n/a
Wilson and Zhao (2023)	FDH Model	n/a	n/a
Shi, Wang, Emrouznejad (2023)	SBM Model	n/a	n/a
Asmild and Matthews (2012)	Multi-directional SBM	n/a	n/a
Du, Worthington and Zelenyuk (2018)	BCC and CCR model	Truncated regression and double bootstrapping	n/a
Barth et al. (2013)	BCC model	Truncated regression	n/a
Xie et al. (2022)	VRS DDF Model	OLS Panel Regression	n/a
Ariff and Can (2008)	BCC model	Tobit Regression	n/a
Fukuyama and Tan (2022)	Three-stage Network DEA Model	Tobit Regression	n/a
Liu et al. (2020)	Meta-Frontier radial DDF Network Model	Multiple regression	n/a
Yu et al. (2019)	CCR Model	n/a	n/a
Cho, Chen (2021)	BCC model	System-GMM	n/a
Zhu, Li and Liang (2018)	Two-stage Network SBM Model	n/a	n/a
Rezvanian, Ariss, Mehdian, (2010)	BCC model	Tobit Regression	n/a
Wu et al. (2023)	Two-stage Network SBM Model	Tobit Regression	n/a
Necmi K. Avkiran (2011)	Core profitability model – SBM, Expanded profitability model – SBM, Financial Ratio Model - SBM	Statistical Test: Simple Regression	
Tan et al. (2024)	GMSS – DEA Model	OLS Regression Model	n/a
An, Chen, Liang & Wu (2015)	SBM (Deposit Generation Stage and Deposit utilizing stage)	n/a	n/a
Fukuyama, Tan (2022)	SBM Model, DDF Model	n/a	n/a
Fukuyama, Matousek (2017)	Two-stage Network DEA Model for bank analysis	regression	- n/a
Matthews and Xiao (2020)	CCR-DEA Model	n/a	n/a
Fukuyama, Tsionas, Tan (2023)	Dynamic Network Bank	Truncuted Regression and Tobit Regression	n/a
Avkiran and Morita (2010)	Non-radial DEA Model Range-adjusted Measure (RAM) and Super-	n/a	n/a

	efficiency Range-adjusted Measure (SRAM)		
Xu and Zhou (2020)	BCC Model (Assurance Region (AR) Model)	Multiple Regression	n/a
Matthews, *et al*. (2010)	Polyhedral cone-ratio DEA model	n/a	n/a
Hou, *et al*. (2014)	CCR	Tobit	n/a
Fukuyama, *et al*. (2021)	Network SBI models	Regression analysis	n/a
Fukuyama, *et al*. (2021)	BCC Model	Bootstrapped truncated regression & Ordinary least square regression	n/a
Dong *et al*. (2016)	SFA	n/a	n/a
Luo *et al*. (2011)	CCR-CRS & BCC-VRS	n/a	n/a
Antunes *et al*. (2022)	SBM	Robust Endogenous Neural Network Analysis	n/a
Bingquan *et al*. (2019)	Spatial Durbin production frontier model	n/a	n/a
Luo *et al*. (2010)	CCR & BCC	n/a	n/a
Wang *et al*. (2014)	Two-stage Network DEA	n\a	n\a
Fukuyama, Tsionas, and Tan (2023)	The two stage DNDEA model	n\a	n\a
Zhou, X.,(2019)	Multi-period three-stage Dynamic Network DEA model	n\a	n\a
Boussemart, J.P. (2019)	Network DDF DEA model	n\a	n\a
Luo, Bi, Liang (2012)	CVA model	n\a	n\a
Li (2019)	Two-stage DEA Model, Two-stage production system	n\a	n\a
Huang *et al*. (2017)	Network SFA model	n\a	n\a
Antunes (2024)	Network DEA Model	n\a	n\a
Shabani, and Shirazi (2023)	Dynamic network DEA model	n\a	n\a
Lin, Lee and Chiu, T. (2009)	BBC model, CCR model	n\a	n\a
Zhang and Wang (2014)	CCR and BCC Models	Tobit Regression	n/a
Wang and Chen, (2024)	Dynamic network DDF	n/a	n/a
Chen, Matousek and Wanke (2018)	CCR and BCC Models	n/a	n/a

Appendix D: Summary of Inputs & Outputs and their measures used in assessing the efficiency of DMUs and the perspective, also referred to as approach, from which the analysis is performed.

Reference	Assessment Perspective	Inputs	Outputs
Chen, Skully and Brown (2005)	Intermediation approach	interest expenses, non-interest expenses (including labor costs), price of deposits (interest paid on deposits divided by total deposits), and price of physical capital (approximated by non-interest expenses divided by fixed assets)	loans, deposits, and non-interest income
Matthews (2013)	Profit Oriented Approach	Operational costs, fixed assets, and deposits	Net-interest income and non-interest income
Liu, Yang, Wu (2020)	Intermediation approach	Fixed assets, labor, and operating expenses	Loans, business income, non-performing loan ratio, and deposits (as intermediate variables)
Wilson and Zhao (2023)	Intermediation Approach	Total funding, labor services, Fixed asset	Consumer loan, real estate loans, business and other loans, securities, off-balance sheet items
Shi, Wang, Emrouznejad (2023)	Profit-Oriented approach	Interest costs, operating costs	Interest income, non-interest income, non-performing loans
Asmild and Matthews (2012)	Profit Oriented Approach	Labor, fixed assets, total deposits, non-performing loans	Net-interest income, non-interest income
Du, Worthington and Zelenyuk (2018)	Profit-Oriented approach	Interest expenses, labor costs, other operating expenses	Net interest income, net fees and commissions, other operating income
Dong et al., (2014)	Intermediation Approach	Total borrowed funds, physical capital, and labor	Total loans, other earning assets, and non-interest income.
Barth et al. (2013)	Intermediation approach	Inputs include total deposits, labor (personnel expenses), physical capital (fixed assets), and loan loss provisions.	Outputs consist of total loans and other earning assets, and other operating income.
Xie et al. (2022)	Intermediation Approach	Labor force, fixed assets, operating costs	Interest income, non-interest income, performing loans, non-performing loans (undesirable output)
Ariff and Can (2008)	Profit-Oriented Approach	Loanable funds, Number of employees, Physical capital	Loans, Investments
Fukuyama and Tan (2022)	Profit Oriented Approach	Labor, capital, fixed assets, expenses	Interest income, non-interest income
Liu et al. (2020)	Intermediation approach	Fixed assets, labor, operating expenses	Loan, Interest Income, and Non-performing loan ratio
Yu et al. (2019)	Profit Oriented Approach	Capital stock, employed labor, deposit	Interest income, operational income, non-performing loan
Cho, Chen (2021)	Intermediation	Labor cost, total deposits, total	Total loans, total earning

		money market funding, other funding, Business and management expenses	assets, Fee income plus comission income
Zhu, Li and Liang (2018)	Intermediation Approach	Fixed asset, operational cost, staff wages, reserve	Net increase in bank advances (loan and credit) to customers, return on investment
Rezvanian, Ariss, Mehdian, (2010)	Intermediation Approach	Borrowed funds, labor and fixed asstes	Net loans, deposits, other earning assets
Wu *et al.* (2023)	Intermediation Approach	Fixed asset, employed labor	Loans, securities investment, non-performing loan
Necmi K. Avkiran (2011)	Intermediation approach	Interest expense on customer deposits Other interest expense Personnel expenses Other operating expenses	Interest income on loans Other interest income Net fees and commissions Other operating income
Tan *et al.* (2024)	Production approach and intermediation approach	Production approach(Expenses, number of employees, overhead costs, and equity capital), Intermediation approach efficiency(non interest expenses, interest expenses, and loan loss provision)	Production approach(fixed assets, liquid assets, total assets), Intermediation approach efficiency(Interest income, non interest income, net income, gross revenue)
An, Chen, Liang & Wu (2015)	Production approach	Slack-based measure model-Deposit Generation Stage (Number of labors, Equity capital, Net-value fixed assets) Slack-based measure model-Deposit utilizing stage(deposits)	Slack-based measure model-Deposit Generation Stage (Deposits) Slack-based measure model- Deposit utilizing stage(loans and securities investments)
Fukuyama, Tan (2022)	Integrated Approach (Production Approach and Intermediation Approach)	Production approach(labour cost and other operating costs) , Intermediation approach (labor, fixed assets, and deposits)	Production approach (Innovation efficiency), Intermediation approach(securities and loans)
Fukuyama, Matousek (2017)	Production approach	Labor Capital Operational resources	Financial products and services Accumulated deposits Processed application
Matthews and Xiao (2020)	Hybrid approach (Intermediation Approach and Asset Approach)	Liabilities	Total performing loans Total earning assets Bad loans
Fukuyama, Tsionas, Tan (2023)	Production approach	Labor Capital Equity of the current year Non-performing loans	Deposits Raised funds
Avkiran and Morita (2010)	Production Approach	Shareholders Customers Management Employees	loans

			regulators
Xu and Zhou (2020)	Production Approach	Total assets Labor Operating expenses	Deposits
Matthews, *et al.* (2010)	Hybrid between the intermediation and production approaches (Intermediation Approach & Production Approach)	IA: Deposits (RDEP), overheads (ROHD), fixed assets (RFA)	IA: Loans (RLOAN), PA: other earning assets (ROEA), RFEE (net fee income)
Hou, *et al.* (2014)	Intermediation Approach	total deposits ( ), fixed assets ( ), number of employees ( ),	total net loan ( ), other earning assets ( ),
Fukuyama, *et al.* (2021)	Production Approach	Personnel expenses Equity capital, Fixed assets	Loan loss reserves (LLRs)
Fukuyama, *et al.* (2021)	Profit-oriented Approach	number of employees, fixed assets, deposit	interest income, non-interest income
Dong *et al.* (2016)	Intermediation Approach	Price of total borrowed funds (w1) (ratio of total interest expenses to total borrowed funds) Price of physical capital (w2), also known as the flow factor price for capital (measured by the ratio of other operating expenses to fixed assets) Price of labor (w3) (using the ratio of personnel expenses to the number of employees as a proxy) Total equity capital (z) (as a quasi-fixed input)	Total loans (y1) Other earning assets (y2) Non-interest income (y3)
Luo *et al.* (2011)	Intermediation Approach	Number of employees, Fixed assets, Deposits	Total loans, Other earning assets
Antunes *et al.* (2022)	Intermediation Approach	fixed assets, total deposits, and personnel expenses	total securities and total loans
Bingquan *et al.* (2019)	Intermediation Approach	deposits, labour and fixed assets	loans
Luo *et al.* (2010)	Intermediation Approach	Number of employees, fixed assets, and deposits (estimated due to missing data)	Total loans (TLs) and other earning assets.
Wang *et al.* (2014)	Intermediation Approach	Fixed assets, Labors	Non-interest incomes, Interest incomes, Non-performing loans
Fukuyama, Tsionas, and Tan (2023)	Profit oriented approach	Fixed asset, labor, deposits	Income, equity capital
Zhou, X.,(2019)	Intermediation Approach	Employee's salaries\ fixed assets	Net interest incomes\ non performing loans
Boussemart, J.P. (2019)	Intermediation Approach	Interest expenses (IE), non-interest expenses (NIE).	interest income (II), non-interest income (NII)), bad

			outputs (non-performing loans (NPL) Good loans (GL) are considered a desirable output, while non-performing loans (NPL) are treated as an undesirable output.(ask)
Luo, Bi, Liang (2012)	Intermediation Approach	cash and balances with central banks, deposits and placements with banks, investments, loans and advances to customers, financial assets held for trading, and other assets	customer deposits and stockholders' equity
Antunes (2024)	Intermediation Approach	fixed assets, total deposits, and personnel expenses	total securities and gross loans (the paper mention variables for second model)
Li (2019)	Intermediation Approach	Fixed assets, Labours	interest income \non-income interest
Huang *et al.* (2017)	Intermediation Approach	labor and capital	loans, investments, and non-interest income
Shabani, P. and Akbarpour Shirazi, M., (2023)	Profit oriented approach	Fixed asset, number of employees	Interest income, non-interest income, non-performing loans
Lin, Lee and Chiu, T. (2009	Intermediation Approach	the number of staff, interest expense, deposit operating amount (including check deposit, current deposit, foreign exchange current deposit, current savings deposit, current treasury bond deposit, time deposit), and current deposit operating amount	loan operating amount, interest revenue, operating revenue and earning
Zhang and Wang (2014)	Intermediation approach	Labor, Fixed asset, deposits, non-interest expense	Loan, securities, trading activities, non-interest income
Wang and Chen, (2024)	Intermediation approach	Labor, interest cost, operational cost, fixed assets.	Total loan, and total investment
Chen, Matousek and Wanke (2018)	Intermediation approach	Loan reserve, equity, impaired loan, operational cost, labor, number of branches, depreciation	Total asset, fixed assets, gross loans, total securities, deposits, profit, net interest income, non interest operating income

Appendix E: Summary of response and explanatory variables used in the second-stage analysis of two-stage analyses and the perspective that shapes the choice of the explanatory variables.

Reference	Behavioural Perspective	Response/dependent variable	Explanatory variables / drivers
Du, Worthington and Zelenyuk (2018)	Asset diversification on profit efficiency	Profit Efficiency	Other Earning Asset over Loans (OEL/L), Other Earning Assets over Total Earning Assest (OEA/TA)
Barth et al. (2013)	The effect of internal factors influence the bank efficiency	Technical efficiency	Activity restrictiveness, overall capital stringency, Herfindial Index (HHI), government ownership of banks, bank size, bank equity, Country GDP and Inflation
Xie et al. (2022)	External economic environment and internal bank factors	Efficiency value: input-output ratio	Broad money supply, NPL ratio, capital adequacy ratio, leverage ratio, loan-to-deposit ratio, GDP growth rate, policy uncertainty index, central parity of currency exchange, international short-term capital inflow
Ariff and Can (2008)	The effect of internal and external factors influence the cost and profit efficiencies	Cost and Profit Efficiency	Ownership structure SOCB, Ownership structure JSCB, bank size, credit risk, asset quality, capital risk, liquidity risk
Fukuyama and Tan (2022)	Demographical financial risk and CSR	Input inefficiency, stability inefficiency, output inefficiency	NPL Ratio from western area, NPL Ratio from middle area, NPL Ratio from eastern area, loan to SME, donations, balance of green credit
Liu, Yang, Wu (2020)	ownership structure on the deposit and loan efficiencies of banks	Profit and Cost Efficiency	Ownership nature, Ownership concentration, Ownership liquidity, Control variable
Rezvanian, Ariss, Mehdian, (2010)	investigate cost efficiency determinants of Chinese banks	Cost efficiency	Profitability, capitalization, bank size, Foreign, Big Four, Regulatory Quality and Economic Development
Wu et al. (2023)	External economic and regulatory factor	Efficiency value	Interest rate liberalization index, consumer price index, market risk
Avkiran (2011)	investigates whether DEA super-efficiency estimates align with financial performance indicators	Efficiency value	PTP/ATA (post-tax profits to average total assets)
Tan, Wänke, Antunes, Emrouznejad (2024)	External real-world behaviours and decisions	Efficiency scores	Efficiency Value, relationship competition value
Fukuyama and Matousek (2017)	bank performance evaluation from a network perspective,	Efficiency scores	Loans and mortgages Investment products Individual financial advisory

	incorporating non-performing loans into the efficiency measurement		services Exclusive banking products Non-performing loans Operational losses Compliance issues
Fukuyama, Tsionas, Tan (2023)	Internal bank which has different sizes and market segment	Inefficiency: Technical inefficiency, allocative inefficiency	Agriculture sector Wholesale sector Water conservancy, environment and public facitilities sector Financial services sector
Xu and Zhou (2020)	assessing the efficiency of financial supply chains in Chinese commercial banks	overall stage efficiency	internet finance (ln DFII), loan quality (ln DARit), return on equity (ROEit), balance loan ratio (BLRit), gross domestic product (GDPt), consumer price index (CPIt), and different types of banks (TYPEi)
Hou, *et al.* (2014)	market structure, bank risk	technical efficiency	Herfindahl-Hirschman Index in deposits; the ratio of equity to total assets , the ratio of loan loss provisions to total loans , the ratio between total loans and deposits
Fukuyama, *et al.* (2021)	the risk from the perspective related to banks' ability to withstand the potential negative shocks	direct technical efficiency	LLRs (loan loss reserves) and total loans
Fukuyama, *et al.* (2021)	the impact of CSR on bank efficiency	Indirect technical efficiency, Technical efficiency, Indirect allocative efficiency	Donations (reflecting social contribution), Balance of green credit (reflecting environmental responsibility), Loans to Small and Medium-sized enterprises (SMEs)
Antunes *et al.* (2022)	Bank profitability, bank size, expenses management, traditional business and non-traditional business	Technical efficiency	bank size (natural logarithm of total assets), bank profitability (return on assets), expense management (the sum of total interest expenses and non-interest expenses over total assets); traditional bank business (the ratio of interest income to total assets); and non-traditional bank business (the ratio of non-interest operating income to total assets).
Jorge Antunes(2024)	efficiency scores	Efficiency scores	bank size (natural logarithm of total assets), bank profitability (return on assets), expense

			management (the sum of total interest expenses and non-interest expenses over total assets), traditional bank business (the ratio of interest income to total assets), and non-traditional bank business (the ratio of non-interest operating income to total assets)
Tina Zhang and Wang (2014)	Impact of bank ownership to technical efficiency	Bank technical efficiency	Bank ownership (state or foreign), leverage, bank size

Appendix F: Summary of Number of DMUs, Period of Analysis, Sample size, and Source(s) of Data

Reference	Number of DMUs & their country(ies)	Period of analysis	Sample Size	Source of Data
Chen, Skully and Brown (2005)	43 Chinese banks, including state-owned, regional joint-equity, and investment banks	1993–2000	43	BankScope, which aggregates comprehensive financial information on banks globally
Matthews (2013)	18 Chinese banks	2007-2008	36	Chinese banks, interviews
Liu, Yang, Wu (2020)	28 Chinese Commercial Banks	2013–2017	140	Wind Database
Wilson and Zhao (2023)	124 Chinese banks (incl. 32 foreign banks)	2007-2014	992	BankScope
Shi, Wang, Emrouznejad (2023)	36 Chinese Commercial Banks	2016-2021	216	Data extracted from banks' annual reports and the Wind Database
Asmild and Matthews (2012)	14 Chinese banks	1997-2008	168	Bankscope, individual bank reports
Du, Worthington and Zelenyuk (2018)	140 chinese commercial banks	2006-2011	840	BankScope
Dong *et al.*, (2014)	41 Chinese banks	1994-2007	397	Almanac of China's Finance and Banking, BankScope, and other financial reports
Barth *et al.* (2013)	4053 banks in 72 countries	1999-2007	8115	BankScope
Xie *et al.* (2022)	16 listed Chinese commercial banks	2009-2018	160	Wind database, annual reports
Ariff and Can (2008)	28 Chinese banks	1995-2004	230	Bankscope
Fukuyama and Tan (2022)	72 Chinese banks	2007-2017	792	*Information not available*
Liu *et al.* (2020)	71 Chinese commercial banks	2011-2015	355	Bank annual reports and the Yearly Statistics Book of China's Finance
Yu *et al.* (2019)	25 Chinese listed banks	2012-2016	125	Individual bank annual reports
Cho, Chen (2021)	34 chinese banks	2011-2017	238	Orbis Bank Database
Zhu, Li and Liang (2018)	8 Chinese commercial banks	2012	8	Individual bank websites and reports
Rezvanian, Ariss, Mehdian, (2010)	62 Chinese Banks	1998-2006	349	Bankscope
Wu *et al.* (2023)	27 Chinese	2006-2020	405	Bankfocus,

	commercial banks			individual bank annual reports,
Necmi K. Avkiran (2011)	51 commercial bank (SOCB group, JSCB group, CiCB group LIFB group) and 1 country (China)	2007 - 2008	102	From OSIRIS, DataStream for Bank Annual reports for fiscal years ending in December 2007 and 2008 for twenty-one publicly listed Chinese commercial banks
Tan *et al.* (2024)	27 DMUs and Commercial banks in China	2007 to 2017	297	Fitch Connect and Annual Financial Statesment
An, Chen, Liang & Wu (2015)	16 (Chinese commercial banks, covering different types like state-owned, joint-stock, and city commercial banks) and China	2008 - 2012	80	Annual reports, banking association data, and national credit system data
Fukuyama, Tan (2022)	71 (banks which are concerned t five types of performance, consisting of innovation, two kinds of stability, profitability and CSR) and China	2011-2019	639	Collecting balanced panel dataset
Fukuyama, Matousek (2017)	72 Regional Japanese Bank I and II	September 2000 – march 2013	1008	Japanese regional bank report
Matthews and Xiao (2020)	14 Chinese bank	1997 - 2016	280	Fitch/Bankscope, and individual annual reports of banks
Fukuyama, Tsionas, Tan (2023)	25 Banks	2013 - 2020	500	Financial statement
Avkiran and Morita (2010)	20 listed Chinese banks	Ending December 2007	20	OSIRIS Datastream
Xu and Zhou (2020)	26 chinese commercial banks	2013 - 2017	130	Wind database and the year book of each bank
Matthews, *et al.* (2010)	5 state-owned or state-controlled commercial banks (SOCB), 9 joint-stock commercial banks (JSCB) and 47 city commercial banks (CCB)	1997-2007	314	Fitch/Bankscope
Hou, *et al.* (2014)	44 major Chinese commercial banks	2007-2011	220	BankScope database

Fukuyama, *et al.* (2021)	43 Chinese banks	2010–2019	430	Not given
Fukuyama, *et al.* (2021)	72 Chinese commercial banks	2007–2017	792	Fitch Connect
Dong *et al.* (2016)	142 Chinese banks	2002-2013	1704	BankScope
Luo *et al.* (2011)	14 listed Chinese commercial banks	1999–2008	140	Thompson's Bankscope
Antunes *et al.* (2022)	39 Chinese commercial banks	2010–2018	351	Fitchconnect
Bingquan *et al.* (2019)	65 Chinese urban commercial banks	2013–2017	325	Orbis Bank Focus
Luo *et al.* (2010)	14 Chinese listed commercial banks	1999-2008	140	Bankscope
Wang *et al.* (2014)	16 Chinese banks divided into two groups of 4 SOBs and 12 JSBs	2003-2011	144	Fitch–Thompson Bankscope, official sources of bank annual reports, and the Yearly Statistics Book of China's Finance
Fukuyama, Tsionas, and Tan (2023)	43 banks with 5 different ownership types: state-owned, joint-stock, city, rural and foreign banks	2010-2018	387	the Fitch Connect database
Zhou, X.,(2019)	16 Chinese listed commercial banks	2014-2016	48	From WIND
Boussemart, J.P. (2019)	30 Chinese commercial banks	2005-2012	240	the Bankscope database, with variables expressed in Chinese yuan with 2004 as the base year (CNY 2004)
Luo, Bi, Liang (2012)	14 Chinese commercial banks	2008	14	the annual reports of the 14 Chinese commercial banks
Antunes (2024)	39 commercial banks	2010-2018	351	The Fithconnect database
Li (2019)	16 stock-listed commercial banks in China	Not mentioned	Not Mentioned	from Bank-scope resource package produced by Bureau Van Dijk (BVD), Yearly Statistics Book of China's Finance and the annual reports of the banks.
Huang *et al.* (2017)	172 Chinese commercial banks	2002-2015	2408	compiled from unconsolidated financial statements

				of BankScope, which is Fitch's International Bank Database.
Shabani, P. and Akbarpour Shirazi, M., (2023)	38 branches of an Iranian commercial banks	2016-2020	190	Not specified.
Lin, Lee and Chiu, T. (2009	117	2006	117	the internal operation management statistic form
Zhang and Wang (2014)	16 Chinese commercial banks	2006-2011	96	Bankscope
Wang and Chen, (2024)	39 Chinese commercial banks	2017-2021	195	China Banking and Insurance Regulatory Commission for performance analysis.
Chen, Matousek and Wanke (2018)	127 Chinese banks	2008-2011	508	Individual bank annual reports