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POTENTIAL STRUCTURAL EFFICIENCY OF CHINESE COMMERCIAL BANKS

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Abstract. Given that structural efficiency serves as a significant instrument, this paper applies a novel approach to measure structural efficiency levels within Chinese banks from the perspective of potential improvement. To further investigate the patterns of structural efficiency, the overall structural efficiency is disaggregated into a series of variable-specific structural efficiencies. It reveals that fixed assets and non-interest incomes constitute the primary sources of structural inefficiency during the study period. Furthermore, the structural efficiencies of small-medium commercial banks surpass those of large state-owned commercial banks, although the efficiency gap between the two types of banks has narrowed. Based on the variable-specific structural efficiencies, this paper further explores the structural efficiency patterns within the Chinese banking sector.

Keywords: structural efficiency, multi-directional efficiency analysis, potential improvement, overall efficiency, variable-specific efficiency, Chinese banking.

JEL Classification: C61, D24, G21.

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1. Introduction

In recent decades, the Chinese banking sector has played a pivotal role in driving China's economic growth substantially. Following the full liberalization of China's financial market in 2006, individual Chinese commercial banks have enhanced their managerial capabilities and competitiveness through financial restructuring, recapitalization, and other measures. Notably, a substantial body of studies examining the technical performance of Chinese banks has been published in scientific journals (e.g., Asmild & Matthews, 2012; Boussemart et al., 2019; Zhu et al., 2025). However, studies investigating structural performance, particularly within the Chinese banking sector, remain insufficient. Unlike technical performance, which is widely used to assess the managerial efficiency of individual banks, structural performance pertains to the efficiency of resource allocation between banks. Furthermore, in alignment with the ongoing financial structural reform within the Chinese banking sector, this paper aims to evaluate the structural performance of Chinese banking and identify the best and worst performers.

It is widely acknowledged that efficiency serves as a favorable alternative instrument for performance evaluation, with Data Envelopment Analysis (DEA) constituting a widely used nonparametric approach for measuring efficiency. Farrell (1957) introduced the concepts of

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technical efficiency and structural efficiency, where the former pertains to "...producing maximum output from a given set of inputs", whereas the latter "...measures the extent to which an industry keeps up with the performance of its own best firms". Within the literature examining efficiency evaluation in the Chinese banking sector, numerous studies have used DEA to measure technical efficiency, which concerns the management capability of individual banks. A general finding indicates that small-medium commercial banks outperformed large state-owned commercial banks (e.g., Zhu et al., 2015), while recent studies imply that the technical efficiency gap between the two types of banks has been narrowing (e.g., Asmild & Matthews, 2012; Boussemart et al., 2019). In summary, the improvement of technical efficiency within individual Chinese banks has produced significant outcomes. However, financial structural imbalance has recently emerged as a new challenge for the Chinese banking sector, manifesting as misallocation of financial resources (Wu, 2018; Song & Xiong, 2018; Chen et al., 2020). A substantial body of studies has investigated banking performance from the perspective of the operational structure of individual institutions, drawing upon various structural theories such as the Modigliani-Miller theorem and the Markowitz theory. For instance, Oanh et al. (2023) explored the impact of capital structure on banking performance. Additionally, considering diverse micro-market structures, Duong et al. (2023) examined the effects of bank funding diversity and bank lending on net interest margins. Nevertheless, to the best of our knowledge, limited studies have investigated the structural efficiency of the banking system and focused on the degree of resource allocation. Consequently, moving beyond conventional structural theories centered on the internal structure of individual banks, this paper endeavors to assess the structural efficiency of the Chinese banking sector based upon Farrell (1957).

In addition to the structural efficiency framework, this paper extends the analysis in two significant directions. First, concerning the evaluation of structural efficiency within the Chinese banking sector, this paper suggests the consideration of potential improvement rather than past production as the benchmark. It more accurately measures the structural efficiency and fully exploits its developmental potential. Second, this paper seeks to derive variable-specific structural efficiency measures. These measures facilitate the exploration of structural efficiency sources across each input and output. While nonradial measures, such as the Russell index and slack-based measures, can disaggregate overall efficiency, they require the specification of an objective function involving an arbitrary aggregation of the variable-specific efficiency scores (Asmild et al., 2016).

Methodologically, this paper suggests a structural efficiency index to measure structural efficiency within the Chinese banking sector. Although Zhu et al. (2019a) introduced a conventional DEA-based marginal efficiency contribution index, it fails to adequately assess potential improvements and variable-specific structural efficiency. Consequently, this paper incorporates a Multi-directional Efficiency Analysis (MEA) into the structural efficiency index. The MEA endogenously determines an optimal direction vector for each input and output, thereby enabling the measurement of potential improvements specific to each variable. Furthermore, the structural efficiency index provides the expected structural efficiency value for each bank, rather than solely for the entire banking sector. Notably, the novel MEA-based structural efficiency index enables the examination of both levels and patterns of potential structural efficiencies across the Chinese banking sector.

The remainder of this paper is arranged as follows. First, a brief literature review is provided. Secondly, an overview of the Chinese banking sector is provided and a series of hypotheses are put forward. Then the methodology is outlined. Subsequently, the data used are presented, followed by empirical results and discussions. The concluding remark is presented in the last section.

2. A brief literature review

2.1. Definition and measures of structural efficiency

Within the domain of financial structure theories, the contributions of Modigliani and Miller (1958) and Markowitz (1952) are widely acknowledged as foundational principles. The former posits that in a perfect market, capital structure exerts no effect on the market value of firms. However, in the extended version, capital structure can influence operational efficiency. It provides a valuable analytical framework for subsequent research. The latter offers an essential framework for understanding structural efficiency. Specifically, it suggests that an industry diversified by firms with varying business strategies may achieve higher efficiency than a single firm. It aids in explaining why industries with diverse structures exhibit greater efficiency, even when individual firms exhibit lower efficiency.

Farrell (1957) introduced the concept of structural efficiency from the perspective of production efficiency. Structural efficiency is measured by the weighted average of individual firms' efficiency scores, and the weights are determined by the outputs. In this regard, Førsund and Hjalmarsson (1979) argued that using outputs to assign weights is difficult to understand in economics, so they suggested using average firms to calculate the efficiency of an industry. However, Ylvinger (2000) criticized the research of Førsund and Hjalmarsson (1979) because industrial structural efficiency based on average firms would generate a series of doubtful conclusions. For this reason, Ylvinger (2000) followed Farrell (1957) and used linear programming to construct a DEA-based structural efficiency model based on the relative weighted average. However, Leleu and Briec (2009) argued that any form, especially with endogenous weighted averages, should be questioned. Subsequently, Li and Cheng (2007) tried to use the shadow price to systematically solve the "structural efficiency puzzles". However, Fang and Li (2013) found that the shadow price model by Li and Cheng (2007) does not always have a unique optimal solution. In terms of the puzzles by Li and Cheng (2007), Karagiannis (2015) explained the difference between technical efficiency and scale efficiency by analyzing the covariance and found that the reallocative efficiency plays a critical role. From the perspective of marginal efficiency contribution, Zhu et al. (2019a) constructed an average efficiency contribution index and an average contribution index to evaluate expected structural efficiency, thus testing the contribution of individual firms to industrial efficiency. Zelenyuk and Panchenko (2024) extended aggregation theory for structural efficiency measures using the directional distance function, permitting varying directions for both individual and aggregate measures. Begen et al. (2024) introduced an innovative algebraic representation for the industrial structural output set, facilitating the derivation and decomposition of group efficiency measures.

2.2. Multi-directional efficiency analysis

The MEA, based on axiomatic bargaining theory analogous to the Kalai-Smorodinsky solution, presents an alternative approach for efficiency measurement. Axiomatic bargaining theory rests upon principles such as Pareto efficiency and symmetry, ensuring a fair resource allocation within the bargaining framework. Within the MEA, these axioms direct the allocation strategies for each firm, thereby reflecting both potential improvements and positioning relative to the technological frontier. Diverging from conventional DEA-based efficiency analysis, the MEA provides not only an endogenous direction vector instead of an exogenous one, but also delivers variable-specific efficiency scores. Building upon the concept of "potential improvement" introduced by Bogetoft and Hougaard (1999), Asmild et al. (2003) developed the MEA, whereby potential improvement is derived from each firm's local production objective and the overarching structure of the dominating set.

The MEA has been extensively applied across various fields, including the banking sector. Asmild and Matthews (2012) applied the MEA to evaluate the technical efficiency of Chinese commercial banks, performing a disaggregation of overall efficiency into variable-specific efficiencies. Zhu et al. (2019b) applied the endogenous direction vector derived from MEA to define different risk preferences and subsequently measure the technical efficiency of Chinese commercial banks. Yang (2023) developed a network MEA model to examine the internal structure of the banking system. Xu et al. (2024) assessed the financial efficiency of microfinance institutions using the MEA and examined potential influencing factors related to macroeconomics and institutional frameworks.

2.3. Comments

Although several studies have examined structural efficiency and banking efficiency evaluation using the MEA, respectively, we have identified significant research gaps between previous and current studies.

- Much of the existing literature has addressed structural efficiency primarily from a theoretical perspective, focusing on model construction and modification, while practical applications, particularly within the banking sector, have received limited attention. Zhu et al. (2020) applied a DEA-based structural efficiency approach to evaluate the Chinese banking sector comprehensively, without incorporating the potential improvement and examining variable-specific efficiency.
- A substantial body of literature investigates banking efficiency, and several papers have used the MEA, but most of the literature above has focused on technical efficiency, rather than structural efficiency.
- The MEA-based variable-specific structural efficiency is introduced in this paper. Several papers have considered variable-specific technical efficiency of banks, but to the best of our knowledge, few papers have taken the variable-specific form into the MEA-based structural efficiency.

3. Overview of the Chinese banking sector

A rich body of studies has guided the development of the Chinese banking sector, where the technical efficiency of the Chinese banking sector as a focus generally shows an upward trend, whereas the structural efficiency is insufficiently studied. Although remarkable achievements have been made in individual banks in China, due to an imbalance in Chinese banking, such as overcapacity and accumulated risks, improving the Chinese banking structure has become a new challenge. Here, we highlight profound details in the Chinese banking sector and advance a series of empirical hypotheses as follows.

3.1. Hypothesis 1: there are differences between structural efficiency and technical efficiency in the Chinese banking sector

The high-quality development of China's economy requires the effective improvement of resource allocation associated with financial structure optimization. At present, many scholars have conducted a large number of studies on the technical efficiency of the Chinese banking sector and have found that the technical efficiency of the Chinese banking sector has been at a high level. This enhancement is attributable to factors such as enhanced corporate governance structures, the adoption of state-of-the-art technologies, and accelerated digital transformation initiatives. In contrast to technical efficiency, structural efficiency primarily concerns resource reallocation among individual banks. The Chinese banking sector exhibits significant structural deficiencies, including irrational credit structure (Wei et al., 2016) and homogeneous financial products (Zhu et al., 2019b). These adverse effects have undermined the structural efficiency of the Chinese banking sector. As mentioned above, the emphasis on individual bank profitability and the neglect of resource allocation optimization within the banking sector may result in a substantial disparity between structural efficiency and technical efficiency in the Chinese banking sector.

3.2. Hypothesis 2: fixed assets and non-interest incomes are major sources affecting structural efficiency of the Chinese banking sector

China's economic transformation since the 1980s, characterized by low-risk costs and compulsory credit spreads, rendered scale expansion – particularly through increased fixed assets – the primary mechanism for Chinese banks to secure substantial interest incomes (Zhu et al., 2019b). However, sustained reliance on scale expansion diminished incentives for financial product innovation within these institutions. Consequently, non-interest incomes remained undervalued before the 2010s, constituting a smaller proportion of the profits of Chinese banks. As interest rate liberalization advances, the net interest margin for traditional commercial banking operations faces progressive compression. This trend significantly constrains banks' profitability prospects while simultaneously compelling the banking sector to increasingly regard non-interest business as a strategic avenue for enhancing returns (Lee et al., 2021; Antunes et al., 2024). Owing to the diversification of non-interest financial products, such income streams are progressively becoming an essential imperative for banks pursuing stable and sustainable long-term growth.

3.3. Hypothesis 3: The Small-Medium Commercial Banks (SMCBs) have more structural efficiency than the Large State-Owned Commercial Banks (LSCBs) in both levels and patterns

Owing to broader financing channels and potential political advantages, LSCBs typically benefit from reduced interest and non-interest costs; consequently, their operational expense ratio is comparatively lower than that of SMCBs. Furthermore, thus far, the majority of non-interest incomes within the Chinese banking sector have derived from basic intermediary activities, such as service charges and net commission incomes, rather than high-tech intermediary businesses, including equity investment and personal finance. Hence, LSCBs can leverage their larger operational scale to generate greater profits relative to SMCBs, yet they possess diminished incentive to enhance their operational structure.

Additionally, non-performing loans constitute a matter of significant concern within financial structural reform in China. Corresponding to China's economic transformation, the volume of non-performing loans has increased rapidly since the 1980s, wherein government appropriations were supplanted by bank lending, particularly within LSCBs. Substantial non-performing loans adversely affect banking operational security and diminish the profitability and liquidity of banking assets, thereby substantially impairing the competitiveness of the Chinese banking sector. Benefiting from the state-owned bank reforms initiated in 2003, the volume of non-performing loans has declined markedly. Based solely on the volume of non-performing loans, both LSCBs and SMCBs demonstrate commendable performance. However, the mechanisms underpinning the reduction of non-performing loans differ between the two types of banks. LSCBs have reduced substantial volumes of non-performing loans primarily through governmental policy interventions, rendering their motivation partially exogenous and policy-oriented (Sun & Liu, 2023). Conversely, as market-oriented institutions lacking specific political advantages, SMCBs exhibit an endogenous motivation to reduce non-performing loans and refine their banking structure. Accordingly, SMCBs surpass LSCBs in structural efficiency concerning non-performing loans. Furthermore, driven by the advancement of financial structural reform in China, both LSCBs and SMCBs have enhanced their banking structures to varying extents.

4. Methodology

This paper employs the MEA-based structural efficiency index to evaluate structural efficiency, incorporating the MEA that accounts for potential improvement. This section outlines the measures of potential improvement in efficiency, the aggregation of firms, and the computation of the structural efficiency index.

4.1. Production technology and efficiency measures

Consider a set S of s banks, with each bank using N inputs $x=(x_1,\dots,x_N)\in R_+^n$ to produce M outputs $y=(y_1,\dots,y_M)\in R_+^M$, and the technology is defined as T = {(x, y)|x can produce y}. The corresponding input and output sets satisfy the assumption of compact set, and strong disposability of both inputs and outputs. The nonparametric representation is given as Eq. (1), where the λ_s is the intensity variable, and the sole condition $\lambda_s \ge 0$ indicates constant return to scale (CRS).

$$T=\{(x,y)\,|\sum_{s=1}^{S}\lambda_s x_{sn}\le x_{s'n},\sum_{s=1}^{S}\lambda_s y_{sm}\ge y_{s'm},\lambda_s\ge 0, n=1,\dots,N, m=1,\dots,M\}. \quad (1)$$

Considering how to measure the efficiency score e (·) of each bank, it is suggested to use the MEA, which is based on the location of the specific production target as well as the shape of its global dominant set, instead of conventional DEA models. In Eq. (2), with the exception of the n-th input in the set N, where $n\in N$, the rest, including (N–1) inputs $x_{s(-n)}$, removing the n-th, and M outputs y_{sm} are fixed. It is also interpretable in Eq. (3) for the m-th output.

$$x_{s'n}^{*}=Min\left\{\theta_{s'n}\left|\begin{array}{l}\sum_{s=1}^{S}\lambda_s x_{sn}\le\theta_{s'n},\ n=1,\dots,N;\ \sum_{s=1}^{S}\lambda_s x_{s(-n)}\le x_{s'(-n)},\ -n=N\setminus\{n\}\\ \sum_{s=1}^{S}\lambda_s y_{sm}\ge y_{s'm},\ m=1,\dots,M;\ \lambda_s\ge 0,\ s=1,\dots,S\end{array}\right.\right\}; \quad (2)$$

$$y_{s'm}^{*}=Max\left\{\psi_{s'm}\left|\begin{array}{l}\sum_{s=1}^{S}\lambda_s x_{sn}\le x_{s'n}, n=1,\dots,N;\ \sum_{s=1}^{S}\lambda_s y_{sm}\ge\psi_{s'm}, m=1,\dots,M\\ \sum_{s=1}^{S}\lambda_s y_{sm}\ge y_{s'(-m)}, -m=M\setminus\{m\};\ \lambda_s\ge 0, s=1,\dots,S\end{array}\right.\right\}. \quad (3)$$

The idea points $(\theta_{s1},...,\theta_{sn},\psi_{s1},...,\psi_{sm})$ are obtained in Eqs. (2)–(3). Through the maximizations of potential input contraction and potential output expansion, the direction vector $(g_{x_{sn}}^{MEA}, g_{y_{sm}}^{MEA}) = (x_{s1}-\theta_{s1},...,x_{sn}-\theta_{sn},\psi_{s1}-y_{s1},...,\psi_{sm}-y_{sm})$, which thinks of efficiency improvements as a bargaining process for each input and output is obtained endogenously and inserted into the Directional Distance Function (DDF) as Eq. (4).

$$DDF = Max\left\{\beta_{s'}\left|\begin{array}{l}\sum_{s=1}^{S}\lambda_s x_{sn} \le x_{s'n} - \beta_{s'} g_{x_{s'n}}^{MEA},\ n=1,...,N;\\ \sum_{s=1}^{S}\lambda_s y_{sm} \ge y_{s'm} + \beta_{s'} g_{y_{s'm}}^{MEA},\ m=1,...,M\\ \lambda_s \ge 0,\ s=1,...,S\end{array}\right.\right\}. \tag{4}$$

Combining the potential improvement direction vector (g_x^{MEA}, g_y^{MEA}) and benchmark β_s, the $\beta_s g_{x_{sn}}^{MEA}$ and $\beta_s g_{y_{sm}}^{MEA}$ are the potential improvements of each input and output, respectively. It is straightforward to interpret the individual variable-specific efficiency score of input e_{xsn} and output e_{ysm} in Eqs. (5)–(6) respectively.

$$e_{xsn} = \frac{x_{sn} - \beta_s g_{x_{sn}}^{MEA}}{x_{sn}} = \frac{x_{sn} - \beta_s (x_{sn} - \theta_{sn})}{x_{sn}}; \tag{5}$$

$$e_{ysm} = \frac{y_{sm}}{y_{sm} + \beta_s g_{y_{sm}}^{MEA}} = \frac{y_{sm}}{y_{sm} + \beta_s(\psi_{sm} - y_{sm})}. \tag{6}$$

With respect to the overall efficiency score, Asmild and Matthews (2012) suggested using a Slack-Based Measure (SBM) model as Eq. (7), which has desirable properties with straightforward interpretation as a product of the mean relative efficiency on the inputs and the mean relative efficiency on the outputs.

$$e_s = \frac{1 - \frac{1}{N}\sum_{n=1}^{N}\frac{\beta_s(x_{sn}-\theta_{sn})}{x_{sn}}}{1 + \frac{1}{M}\sum_{m=1}^{M}\frac{\beta_s(\psi_{sm}-y_{sm})}{y_{sm}}}. \tag{7}$$

4.2. Aggregate technology and contribution to structural efficiency

Regarding the evaluation of the structural efficiency of the Chinese banking sector, we suggest applying a structural efficiency index. The fundamental idea behind the structural efficiency index is reminiscent of a central idea in the economics of fair division. When a group of agents distributes the benefits of cooperation among themselves, the method of the renowned Shapley value is to divide the proceeds based on the expected marginal benefit of adding a given agent to all possible coalitions of the other agents in the group (Shapley, 1953).

On the basis of the production technology above, we merge any possible set $S' \subseteq S$ as a subset by the sum of individual inputs and outputs $\left(\sum_{s=1}^{S'} x_s, \sum_{s=1}^{S'} y_s\right)$ to construct a new technology frontier. An essential requirement is that each bank can enter the merged bank(s) only once. Finally, there are a total of $(2^S–1)$ potential merged banks that exist without an empty set.

Based on the new technology frontier, we can measure the structural efficiency index in Eq. (8). The I_i^S implies the bank i merging any possible nonempty group without itself. We can calculate both $e(S')$ and $e(S'\backslash\{i\})$ using Eqs. (5)–(7), and the difference between the two efficiency scores is the marginal efficiency contribution of bank i to the group S'. Totally, there are $(2^{S'-1}–1)$ types of combinations, and the I_i^S is the average of all marginal efficiency contributions.

It is straightforward to interpret that, if the $I_i^S>1$, the bank i contributes positive structural efficiency to group S'; if the $I_i^S<1$, the bank i contributes negative structural efficiency to group S'; and if the $I_i^S=1$, the bank i contributes no structural efficiency to group S'.

$$I_i^S = \frac{1}{2^{S'-1}-1} \sum_{\substack{S' \subseteq S\backslash\{i\} \\ S' \neq \varnothing}} \frac{e(S')}{e(S'\backslash\{i\})}. \tag{8}$$

5. Data

In terms of bank type, there are typically four Large State-Owned Commercial Banks (LSCBs), commonly referred to as the Big Four, and Small-Medium Commercial Banks (SMCBs), including joint stock commercial banks and local banks in the Chinese banking sector. Comparing the two types of banks, the LSCBs exhibit advantages in a larger operation scale with thousands of branches at home and abroad, and wider financing channels with lower costs, and have benefited from potential governmental guarantees to a certain extent. In contrast, SMCBs have depended on market-oriented management mechanisms with efficient decision-making and flexible operations to obtain profits. Therefore, we choose 16 major Chinese commercial banks as samples, including 4 LSCBs and 12 SMCBs.

We select the study period from 2013 to 2019. The Capital Management Measures for Commercial Banks issued by the China Banking Regulatory Commission came into effect in 2013, which implies that the Chinese banking sector strengthened its integration into the international financial regulatory system with capital regulation updated. Afterwards, the traditional development model of commercial banks relying on loan expansion has been changed. At the end of 2019, the COVID-19 pandemic broke out. On the one hand, the banking business system was severely damaged, and the supply and demand of credit declined. On the other hand, it was affected by the impact of the COVID-19 pandemic on the real economy, which reduced fees and benefits for banks. In order to reduce confusion among various impacts of external policies, particularly in the COVID-19 pandemic, on the structural efficiency of the banking sector, the study period ends in 2019.

The selection of input and output variables has been an ongoing topic in banking efficiency literature. Because neither the production approach nor the intermediation approach can fully capture the dual roles of the financial sector, we comprehensively consider both approaches to select variables. Commonly, labor (*LA*), fixed assets (*FA*), and deposits (*DEP*) are treated as inputs. Meanwhile, following the suggestions of Asmild and Matthews (2012), the non-performing loans (*NPL*), interpreted as a necessary cost of the output production, are taken into account as an input variable as well. Moreover, interest income (*II*) and non-interest income (*NII*) are outputs. Data is primarily sourced from the BankFocus database, with limited missing values supplemented manually from Chinese banks' annual reports.

Table 1. Descriptive statistics (unit: million CNY) (source: Bankfocus database)

Variable	2013		2016		2019	
	Mean	SD	Mean	SD	Mean	SD
LA (LSCB)	409 533	70 185	420 268	76 558	412 465	66 993
LA (SMCB)	39 347	26 928	45 415	25 081	48 181	25 855
FA (LSCB)	152 463	12 488	192 468	38 888	21 3581	62 856
FA (SMCB)	14 560	15 004	26 556	30 540	38 140	46 051
DEP (LSCB)	13 468 624	1 669 276	17 455 336	1 863 480	21 532 507	2 693 583
DEP (SMCB)	2 345 839	1 410 804	3 423 358	1 976 842	3 965 988	2 164 087
NPL (LSCB)	85001	8580	191 832	37 385	204 526	27 844
NPL (SMCB)	11753	9256	32 664	21 009	44 121	25 404
II (LSCB)	373 167	66 398	398 449	69 040	494 682	95 603
II (SMCB)	62 201	38 074	79 769	41 708	93 432	47 588
NII (LSCB)	4 602 775	688 456	6 463 301	862 312	8 465 641	1 171 292
NII (SMCB)	988 326	531 845	1 866 400	1 013 450	1 920 852	998 864

Note: SD – standard deviation.

The descriptive statistics for the variables from 2013 to 2019 are presented in Table 1. Generally, LSCBs maintain their dominant position by leveraging their scale advantages, while SMCBs catch up through rapid expansion. Moreover, *NII* has exceeded *II* as the primary driver of profitability for both types of banks. Meanwhile, *NPL* has highlighted substantial risks within the Chinese banking sector.

6. Results

6.1. Hypothesis 1: there are differences between structural efficiency and technical efficiency in the Chinese banking sector

The paper first examines whether a significant difference exists between technical efficiency and structural efficiency within the Chinese banking sector. Because different models based on different foundations are used to measure structural efficiency and technical efficiency, respectively, their scores are not directly comparable. Consequently, a one-tailed Spearman rank correlation test is used to investigate their correlations. Structural efficiency scores derive from both the structural efficiency index and the MEA specified in Eqs. (2)–(8), whereas technical efficiency scores are calculated solely using the MEA defined in Eqs. (2)–(7). Table 2 shows that all results are significant at the 1% level, and the correlations are not high enough, particularly for the SMCBs. This finding indicates a significant difference between the structural efficiency and technical efficiency, and further, it shows that it is necessary to study the structural efficiency of the Chinese banking sector.

Table 2. Spearman ranking correlation test for structural and technical efficiencies

Type	Overall	LA	FA	DEP	NPL	II	NII
All	0.824***	0.781***	0.676***	0.584***	0.726***	0.570***	0.801***
LSCB	0.833***	0.829***	0.914***	0.868***	0.533***	0.857***	0.835***
SMCB	0.651***	0.485***	0.509***	0.584***	0.703***	0.591***	0.541***

Note: *** implies significance at the 1% level.

In recent years, owing to a series of operational mechanism reforms within Chinese banking, the technical efficiency of the Chinese banking sector has risen. Distinct from conventional banking activities, the Chinese banking sector has developed numerous composite emerging businesses and robust risk management systems, thereby enhancing its capacity to furnish customers with diversified financial services. To augment technical efficiency, Chinese banks have streamlined management hierarchies, intensified investments in financial technology infrastructure, and actively embraced and promoted the application of advanced technologies, including big data, cloud computing, artificial intelligence, and blockchain. Although financial technology may induce greater volatility in profitability, it undoubtedly occupies a pivotal position in bank operations and management for enhancing the technical efficiency of Chinese banks (Xu & Zhou, 2020; Fu & Liu, 2023). Lee et al. (2021) further established that financial technology not only improves bank cost efficiency but also advances technological capabilities within the Chinese banking sector. Contrasting with the rapid growth in technical efficiency at the individual bank level, the structural efficiency of the Chinese banking sector exhibits significant potential for enhancement. Generally, influenced by economic development, the financial market environment, and other factors, the homogeneity of Chinese banks' business models remains pronounced, and a pattern of differentiated and personalized services is not yet established (He & Wei, 2023).

6.2. Hypothesis 2: the FA is a major source of structural (in)efficiency during the earlier period, while the NII is during the later period

Combining Eqs. (5)–(7), which are beneficial for obtaining overall and variable-specific potential improvements, and Eq. (8), which serves as the structural efficiency index, can be used to investigate the patterns of efficiencies. Figure 1 illustrates the changes in overall and variable-specific structural efficiencies in the Chinese banking sector during the period 2013–2019. As is evident from the dotted line representing a linear trend of overall structural efficiency, a slight downward trend is observed. To identify the primary sources of structural inefficiency in the Chinese banking sector, the overall structural efficiency is disaggregated into variable-specific structural efficiencies.

Figure 1 shows that the structural efficiency of the *FA* was smaller during the earlier period (2013–2015), while the *NII* performed poorly during the later period (2015–2019).

During the earlier period (2013–2015), the *FA* constituted the primary factor underlying the lower structural efficiency within the Chinese banking sector. There is an obvious scale gap between different types of banks. In the earlier period, aggressive scale expansion served as the principal strategy for large banks pursuing market share and operational profitability. However, following the 2010s, extensive scale expansion unaccompanied by transformations in business philosophy or enhancements in operational efficiency precipitated diminishing economies of scale and structural imbalances within bank operations (Zhu et al., 2019b). To mitigate structural risks stemming from significant size differentials, the market share of large

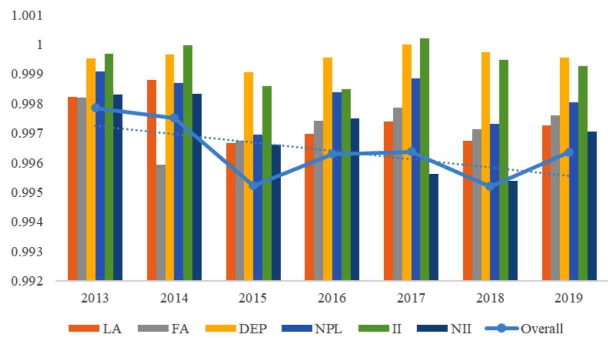

Figure 1. Changes in overall and variable-specific structural efficiencies

banks gradually contracted, whereas that of smaller banks expanded rapidly.

Concurrent with the reduction in scale-related benefits, the Chinese banking sector has continued to accelerate its business model transformation, particularly concerning the *NII*. Although the *NII* exhibited rapid growth during the later period (2015–2019), its structural efficiency remained suboptimal. Indeed, comprehensive optimization encompassing customer structure, business composition, asset-liability structure, and income streams has dispersed and reduced risks associated with previously monolithic operational structures. Competitiveness has been enhanced through improved comprehensive service capabilities. Nevertheless, fee and commission-based incomes have persistently dominated *NII*, commanding an absolute advantage. This dominance has strategically incentivized a focus on consolidating traditional businesses such as payment and settlement, agency services, bank cards, guarantees, and commitments. Consequently, insufficient development characterizes emerging business lines like investment banking, custody, and trusteeship. This result aligns with the findings of Fukuyama and Tan (2022) and represents a key driver of homogeneity within the banking operational structure.

6.3. Hypothesis 3: SMCBs have more structural efficiency than LSCBs in both levels and patterns

The MEA-based structural efficiency index enables the examination of both the levels and patterns of overall and variable-specific structural efficiencies across different types of banks. Figure 2 clearly illustrates that the overall structural efficiency of SMCBs exceeds that of LSCBs, although the gap is limited. Furthermore, the overall structural efficiency of SMCBs demonstrates relative stability, exhibiting a slight change throughout the study period. Conversely, the structural efficiency of LSCBs displays substantial fluctuations, characterized particularly by a significant decline between 2014 and 2015, followed by a gradual recovery. A primary explanation for this observed trend is that the operational structure of SMCBs exhibits greater adaptability to market mechanisms, whereas that of LSCBs remains more aligned with policy objectives, despite undergoing reforms leading to public listing.

Investigating the impacts of variable-specific structural efficiency on overall efficiency in Figure 3, intuitively, during the study period, SMCBs outperformed LSCBs in *LA*, *FA*, and *NII*, whereas the structural efficiency gaps alternated between LSCBs and SMCBs for *DEP*, *NPL*, and *II*. This finding is intuitive because SMCBs possess a moderate or potential operational scale (in *LA* and *FA*) and a more active financial innovation capability (in *NII*), resulting in

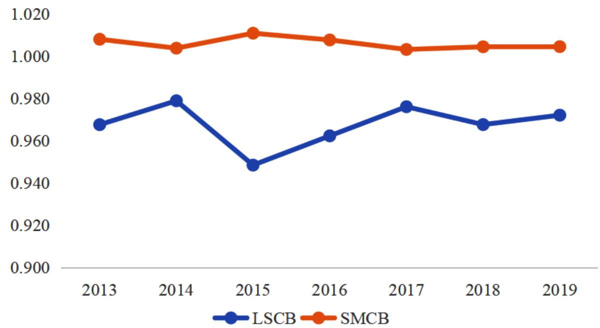

Figure 2. Overall structural efficiencies of LSCBs and SMCBs

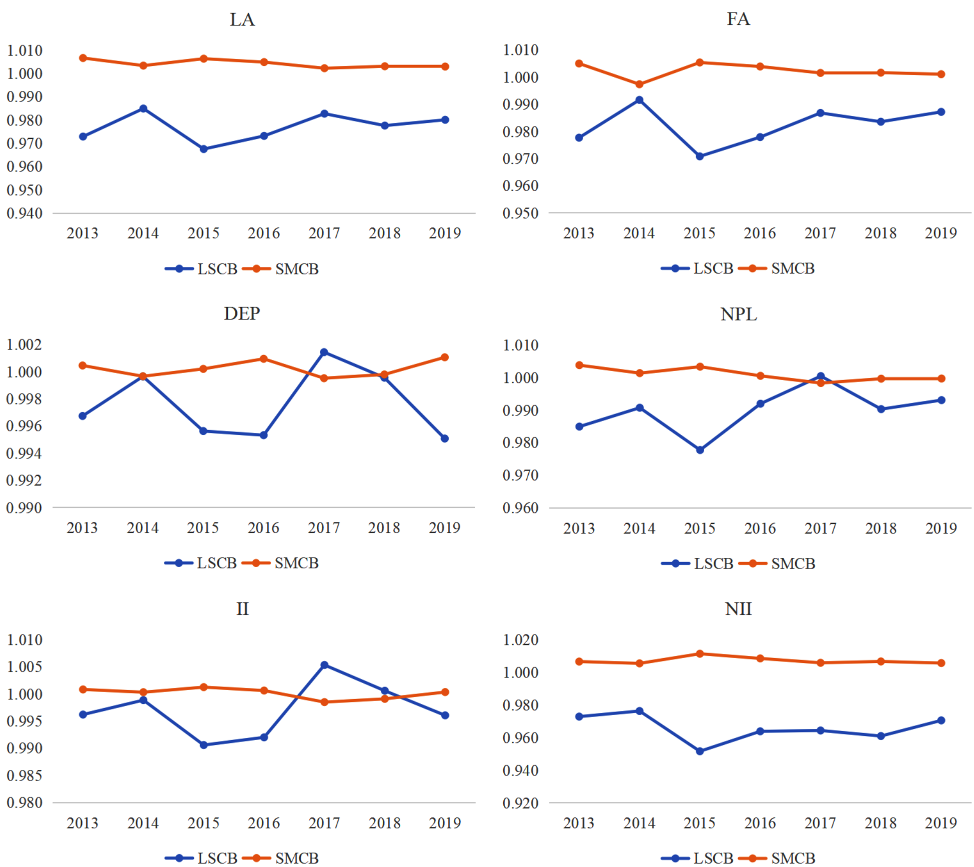

Figure 3. Variable-specific structural efficiencies of LSCBs and SMCBs

superior structural efficiency relative to LSCBs in these aspects. For *DEP*, *NPL*, and *II*, due to high homogeneity in typical businesses across both SMCBs and LSCBs, the structural efficiency gap is narrower.

Furthermore, to determine whether the structural efficiency gap between LSCBs and SMCBs is statistically significant, a one-tailed Mann-Whitney U test is employed as presented in Table 3.

Table 3. Results of the one-tailed Mann-Whitney U test

Variable	Type	P value
LA	SMCBs > LSCBs	<0.001
FA	SMCBs > LSCBs	<0.001
DEP	SMCBs > LSCBs	0.017
NPL	SMCBs > LSCBs	<0.001
II	SMCBs > LSCBs	0.071
NII	SMCBs > LSCBs	<0.001
Overall	SMCBs > LSCBs	<0.001

As seen in *LA*, *FA*, *DEP*, *NPL*, *NII*, and *overall*, SMCBs surpass LSCBs with statistically significant differences, where all p values are less than 1%. With regard to the *II*, its statistical significance level (P value) is 7.1%, higher than that of other variables, but below the 10% level. For *LA* and *FA*, LSCBs have redundant personnel and branches, and the structural efficiencies of *LA* and *FA* are significantly lower than those of SMCBs. Since 2015, the structural efficiencies of the *LA* and *FA* have improved to some extent, but there is still a large gap between them. For *NPL*, SMCBs retain higher structural efficiency, while LSCBs fluctuate during the study period. In terms of *NII*, SMCBs have maintained high efficiency, which shows that SMCBs have made continuous progress and development in various financial services over the years. At the same time, SMCBs and LSCBs gradually separated in *NII*.

Figure 4 illustrates that the overall structural efficiency of SMCBs exceeds that of LSCBs during the study period. However, linear trend approximation suggests a fluctuating yet generally narrowing structural efficiency gap between SMCBs and LSCBs, particularly evident after 2015.

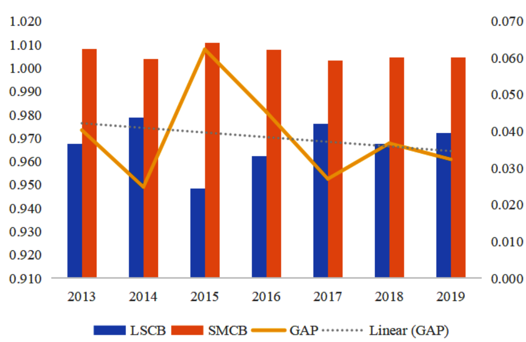

Figure 4. Gap in overall structural efficiencies between LSCBs and SMCBs

Figure 5 illustrates that the decline in overall structural efficiency stems from reductions in all variable-specific structural efficiencies. Each variable-specific SMCB consistently maintains elevated structural efficiency levels, whereas LSCBs exhibit substantial volatility. Analysis of linear trends reveals declining structural efficiency across all variable-specific structural efficiencies to varying degrees, except for *NII*, which demonstrates a marginally widening disparity. Specifically, LSCBs display significantly lower structural efficiencies than SMCBs concerning *LA* and *FA*, attributable to their extensive operational scale; however, this efficiency gap is narrowing. Regarding the *DEP*, a banking sector characterized by high homogeneity, the structural efficiency gap between LSCBs and SMCBs remains small. Owing to vigilant *NPL* management approaches adopted by all banks, the structural efficiency gap between LSCBs and SMCBs has markedly diminished. Concerning the *II*, SMCBs exhibit significantly higher structural efficiency than LSCBs, which experience considerable volatility influenced by national policies and the profitability of large state-owned enterprises. Conversely, the *NII* exhibits a widening structural efficiency gap, diverging from other variables; this stems from heterogeneous strategic motivations and distinct financial service mechanisms between LSCBs and SMCBs.

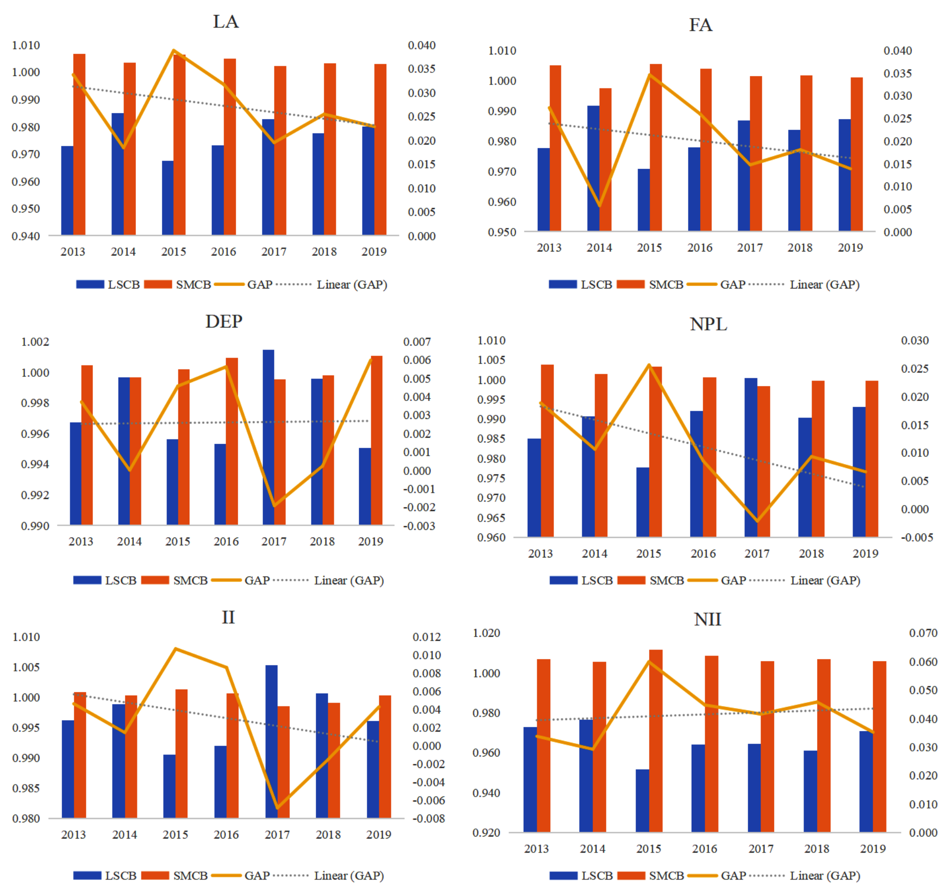

Figure 5. Gaps in variable-specific structural efficiencies between LSCBs and SMCBs

6.4. Discussion

The MEA-based structural efficiency index offers a novel approach to assess the potential improvement in the structure of the Chinese banking sector. For comparison, it is evident that employing conventional DEA models would only evaluate technical efficiency, which pertains to the managerial level of individual banks, while neglecting structural efficiency, which pertains to resource allocation among banks. Additionally, it is observed that using the DEA-based structural efficiency index would yield results for the levels of structural efficiency for Hypothesis 1 and parts of Hypothesis 3, but not for Hypothesis 2 and the remainder of Hypothesis 3 regarding patterns of structural efficiencies. Given the advantage of MEA in providing variable-specific forms for efficiency patterns, the MEA and the structural efficiency index are combined to test all hypotheses presented in this paper. Moreover, in contrast to Zhu et al. (2020), who found that LSCBs outperformed SMCBs in structural efficiency, this paper presents an opposing result, as the MEA accounts for potential improvements rather than past production (Asmild et al., 2003).

During the early stage of study, *FA* significantly influences structural efficiency within the Chinese banking sector, due to the Matthew effect. This effect suggests that larger and more profitable banks tend to expand their scale, thereby capturing more market share and creating a substantial disparity in bank size. Consequently, this leads to an imbalance in resource allocation. However, as the banking system evolves and technological advancements such as fintech and inclusive finance progress, the efficiency of resource circulation among various types of banks and the overall risk resilience of the Chinese banking sector have seen improvements. As a result, the impact of *FA* on structural efficiency has diminished (Zhu et al., 2019b). Moreover, enhancing the structural efficiency of *NII* can stabilize the overall profitability of banks, thereby increasing the robustness of their operations and reducing systemic risks. This contributes to increasing revenue and promoting stability. Nevertheless, there exists an asymmetry in the supervision of commercial banks and financial innovation by regulatory and policy bodies. *NII* businesses, particularly those involving risky financial activities, can, to some extent, undermine the effectiveness of monetary policy and accumulate risks, thus elevating systemic financial risks. Therefore, on one hand, the high degree of homogeneity in banking services is an urgent issue that needs to be addressed in the optimization of the banking business structure. On the other hand, policymakers should differentiate the supervision of various *NII* businesses when overseeing banks' *NII* activities. They should implement timely and appropriate regulatory measures to ensure that commercial banks can leverage the positive aspects of financial innovation without exacerbating systemic financial risks. It will further enhance the structural efficiency of banks.

Given the significant differences between structural efficiency and technical efficiency, banks should focus on improving their structural efficiency in tandem with their ongoing efforts to enhance technical efficiency. This can be achieved by optimizing the allocation of industrial resources and addressing the primary sources of structural inefficiency identified in this study, namely, *FA* in earlier periods and *NII* in later periods. By aligning their strategies with the evolving banking system and economic transformation, banks can mitigate these inefficiencies and enhance overall structural efficiency.

Investigation of two types of banks reveals that SMCBs exhibit superior structural efficiency relative to LSCBs, though this performance differential diminishes throughout the study period. Empirical evidence further demonstrates that SMCBs surpass LSCBs in structural efficiency patterns (Xie et al., 2022). LSCBs operate under concomitant political and social imperatives, including support for vulnerable state-owned enterprises, implementation of national financial development policies, and establishment of regional branch networks. Zhou et al. (2019) documented that LSCBs demonstrate a propensity for excessive investment in human and physical capital. Consequently, LSCBs should enhance operational agility and market responsiveness by emulating SMCB structural frameworks. Adopting more market-oriented operational paradigms could enable LSCBs to improve structural efficiency and reduce the performance gap with SMCBs. The structural efficiency limitations of LSCBs stem not necessarily from managerial deficiencies, but from a rational decision-making framework prioritizing non-pecuniary objectives despite sufficient resource mobilization capabilities. This operational orientation results in diminished structural adjustment sensitivity among LSCBs. Conversely, SMCBs maintain a stronger focus on profit maximization and exhibit more vigorous market competition. Historically, LSCBs were encumbered by policy mandates, maintenance of unprofitable industries, and employment objectives inconsistent with efficiency optimization. Recent strategic reforms within LSCBs have enhanced structural efficiency in *FA* and *NII*, progressively narrowing the structural efficiency gap with SMCBs. Identification of additional inefficiency sources and exploration of remedial measures could yield valuable insights for policymaking and practice. Implementation of ongoing monitoring mechanisms for structural efficiency remains imperative to ensure resilience and competitiveness within the Chinese banking sector amid persistent economic and financial challenges.

6.5. Robustness test

Given the inherent sensitivity of DEA-based approaches, such as MEA, this paper adopts the sensitivity analysis framework proposed by Nasrabadi et al. (2022) to assess the robustness of the findings. This framework measures how results change in response to variations in input or output variables. Specifically, two scenarios are examined: a 10% perturbation in inputs and a 10% perturbation in outputs. Table 4 displays the overall and variable-specific structural efficiency results for all banks, LSCBs, and SMCBs, derived from the Spearman rank correlation test under a 10% input variation. The results indicate statistically significant consistency despite the changes in inputs, thereby supporting the robustness of the findings. Similarly, consistent results are observed under a 10% output variation.

Table 4. Spearman ranking correlation test in the scenario with a perturbation of inputs

Type	Overall	LA	FA	DEP	NPL	II	NII
All	0.9890***	0.9998***	0.9998***	0.9994***	0.9995***	0.9990***	0.9998***
LSCB	0.9962***	0.9984***	1.0000***	0.9978***	0.9984***	0.9995***	0.9973***
SMCB	0.9914***	0.9997***	0.9998***	0.9997***	0.9996***	0.9995***	0.9997***

Note: *** implies significance at the 1% level.

7. Conclusions

This paper introduces a novel structural efficiency index to assess the structural efficiency of the Chinese banking sector. Theoretically, the paper extends the conventional DEA-based marginal efficiency contribution index into an MEA-based structural efficiency index. This innovative index endogenously identifies potential structural efficiencies, enabling the investigation of both overall and variable-specific structural efficiencies. Empirically, aligned with the actual evolution of the Chinese banking sector during financial structural reform, we propose a series of hypotheses and empirically analyze the structural efficiency of the Chinese banking sector. This analysis prioritizes industrial resource allocation over individual managerial efficiency. The findings reveal a significant difference between structural efficiency and technical efficiency within the Chinese banking sector. Furthermore, during the study period, *FA* and *NII* constituted the primary sources of structural inefficiency in the earlier and later periods, respectively, attributable to corresponding transformations within the Chinese banking system during economic transition.

In addition, the paper divides the Chinese banking sector into LSCBs and SMCBs. The structural efficiency of SMCBs surpasses that of LSCBs in both levels and patterns. One of the main reasons for this finding is that SMCBs based on market orientation can adjust their operational structure in a timely manner to meet the needs of banking development. Although LSCBs are less sensitive to banking structural adjustments, the structure of LSCBs has gradually improved under the promotion of a series of banking structural reforms. Therefore, the gap between LSCBs and SMCBs shows a declining trend during the study period.

A limitation of the paper lies in the fact that due to the computing power of our current PC, the sample size covered is limited. One more arguable limitation of the paper is the study period. To avoid external shocks, such as the COVID-19 pandemic, which might confuse the research results, the study period concludes in 2019. Although the study period appears a bit outdated, the paper still holds significant guiding importance for the development of the Chinese banking sector and that of other countries. The findings, such as overall and variable-specific structural efficiencies, are conducive to guiding the Chinese banking sector in reality to upgrade from "extensive total regulation" to "precise structural guidance". For example, by releasing the potential improvement of specific banks through differentiated policies, it can enhance the overall structural efficiency of the banking sector while preventing systematic risks caused by resource misallocation. Additionally, given a longer study period, we need to address how to ensure the independence of the study subjects, which is what we will explore next.

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Author contributions

Zhiqian Yu, Tomas Baležentis and Ning Zhu conceived the study and were responsible for the design and development of the data analysis. Zhiqian Yu and Biyin Ma were responsible for data collection and analysis. Ning Zhu, Yuning Liu and Biyin Ma were responsible for data interpretation. Ning Zhu and Yuning Liu wrote the first draft of the article.

Disclosure statement

Authors have no competing financial, professional, or personal interests from other parties.

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