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RESEARCH ARTICLE

Environmental, social, and governance (ESG) and market efficiency of China's commercial banks under market competition

Li Ji[1] · Yanan Sun[1] · Jiawei Liu[1] · Yung-ho Chiu[2]

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Abstract

As the leading financial institutions in China, it is crucial for commercial banks to pay attention to environmental protection (E), social responsibility (S), and corporate governance (G) in order to enhance operational efficiency and to advance the high-quality development of the country's social economy. This research explores the market share of banks as exogenous variables in the profit stage and the market and sustainability stage to investigate the efficiency of 20 listed banks in China over 2016–2020 and innovatively incorporates indicators such as green credit, social giving, executive compensation, and ESG score into the meta-dynamic two-stage SBM under the exogenous variable DEA model. The results demonstrate the following. (1) By integrating market share as an exogenous variable in the model, the efficiency estimate is more precise. (2) In overall, UCBs are the most efficient type of banks, JSCBs are the second, SOCBs are the least efficient. All three types of banks are more efficient in profit stage versus the market and sustainability stage, JSCBs perform best in the profit stage, where SOCBs perform best in the market and sustainability stage. The three different bank types' TGR performance is comparable to their efficiency value performance. (3) SOCBs lead in ESG investment and have the best ESG performance due to their distinct state-owned background. With their ongoing dedication to profit maximization and disregard for social responsibility and sustainable development, JSCBs have the worst ESG performance. (4) Policy recommendations are made based on the study's findings for commercial banks, stakeholders, and regulators to support ESG investment and to bring about long-term sustainable development. Finally, as ESG develops in China, future research can consider longer time scales and larger perspectives to investigate the sustainability efficiency of commercial banks themselves, as well as their role in the local economy and industrial transformation.

Keywords ESG · Bank · Sustainability · Two-stage SBM · DEA · Exogenous variables

Introduction

The occurrence of global climate extremes in recent years has prompted the international community to pay greater attention to the serious challenges posed by environmental issues, and the pursuit of sustainable and green development has become an important goal for many countries to mitigate conflicts between economic growth and environmental protection (Tian et al. 2022; Zhao et al. 2022). The concept of ESG was first introduced in the UN PRI (Principles for Responsible Investment) report in 2006, which is a non-financial corporate evaluation system focusing on environmental, social, and governance issues that incorporates three indicators into investment decisions: corporate environmental impact (E), fulfillment of social responsibility (S), and corporate governance structure (G). ESG investments have three levels of accountability that

Responsible Editor: Nicholas Apergis

✉ Yung-ho Chiu
echiu@scu.edu.tw

Li Ji
jilinantong@outlook.com

Yanan Sun
sun.yn@ntu.edu.cn

Jiawei Liu
18361136675@163.com

[1] School of Economics and Management, Nantong University, No. 9 Seyuan Road, Jiangsu 226019, People's Republic of China

[2] Department of Economics, Soochow University, No. 56, Kueiyang St., Sec. 1 , Taipei 100, Taiwan

demonstrate how a company impacts the long-term growth of all people.

The allocation of resources is a key responsibility of financial institutions. Tamazian et al. (2009) note that financial derivatives are essential for funding environmental protection projects and that financial instruments are frequently used in these projects, which are important for the growth of the economy. Commercial banks in China are the most significant practitioners in the ESG-responsible investing system and play a significant part in the country's entire financial system, accounting for more than 90% of the business scope and coverage. Green credit and wealth management with an ESG focus are the two key ESG product investment concepts that Chinese commercial banks implement in practice. Commercial banks have been increasing their investments, particularly in green credit, and by the end of 2021 the national green credit balance was 15.9 trillion yuan, primarily targeting initiatives that directly and indirectly reduce carbon emissions (Shen et al. 2022; Zhou et al. 2022). ESG has developed into a significant sustainable development approach that influences overall corporate performance. To increase operational effectiveness and pursue sustainable development, banks must carefully manage their ESG investments, which can aid high-quality socioeconomic development.

This paper's main contributions are as follows. 1) It is the first to consider ESG-related indicators (green credit, social donations, directors' and supervisors' remuneration, and ESG scores) in assessing the efficiency of commercial banks' profit and market and sustainability stages, thereby broadening the research scope of bank value theory and sustainability theory. 2) Market share is taken as an exogenous variable, and the meta-dynamic two-stage SBM under exogenous variable DEA model is used to evaluate the efficiency of 20 listed commercial banks in China, resolving the problem that the efficiency value of commercial banks is undervalued. 3) The listed banks are divided into three categories for comparison, SOCBs, JSCBs, and UCBs, allowing us to explore the efficiency of banks' sustainability under different ownerships. 4) The findings of this paper have significant reference value for commercial banks seeking a comprehensive understanding of the economic benefits of ESG responsibility fulfillment, as well as significant implications for Chinese financial institutions wanting to promote high-quality macroeconomic development.

The remainder of the paper runs as follows. The second section provides a review of the relevant literature. The third section describes the methodology and model. The fourth section describes the data and provides empirical findings and analysis. The fifth section provides conclusions and policy suggestions. The last section analyzes the study's limitations and future research directions.

Literature review

Theory summary

The majority of academic research on non-financial information disclosure is based on CRS, whereas ESG research is just in the infant stages. ESG is a broad extension of corporate social responsibility (CSR), which is a type of corporate self-monitoring that encourages stakeholders to actively fulfill their social responsibilities that can positively impact the environment (Mackey et al. 2007). Various stakeholders have different perspectives on CSR that address the needs via three dimensions, social, economic, and ecological (Barchiesi and Fronzetti Colladon 2021). According to Carroll (1991), the CSR framework has four dimensions: economic responsibility, legal duty, ethical obligation, and charitable culpability. Sheehy (2015) defines CSR as a crucial undertaking that affects a number of areas, including the legal, financial, political, and investment spheres. Additionally, she defined CSR as global private corporate monitoring and outlines normative goals based on Carroll (1991).

Husted and Sousa-Filho (2017) provide three definitions of ESG performance. (1) Environmental performance refers to the adoption of environmental-friendly policies and investments. (2) Social performance refers to internal and external stakeholders' social policies, including community investment, equal employment, and job security. (3) Governance performance is the implementation of sound corporate governance practices. ESG indicators denote the performance of a company across three dimensions: environmental, social, and governance. Currently, Morgan Stanley Capital International (MSCI), Bloomberg, and the Financial Stock Exchange (FTSE) are the leading global ESG rating organizations. Their ESG rating criteria and selection of indicators are distinct, but they all utilize both qualitative and quantitative analyses (Widyawati 2020). Tao et al. (2022) establish an evaluation framework and selected various measures to calculate the ESG index from three perspectives: environmental sustainability, social contribution, and corporate governance.

ESG and corporate governance

Freeman's (1984) stakeholder perspective that managers engage in ESG activities that help maximize their firm's long-term value is consistent with ESG-based bank governance. Improving shareholder satisfaction, increasing financial performance and firm value, assisting the firm in absorbing core strategic resources from outside (Barnett 2007), increasing the firm's value, and enhancing social relations are all objectives of corporate social responsibility (CSR) (Jo and Harjoto 2011). Some have argued that higher levels of social responsibility fulfillment are an inefficient use of resources and reduce corporate value (Alexander and Buchholz 1978; Friedman 1970), and ESG is viewed as an irrational use of resources (Aupperle et al. 1985), which states that socially responsible companies incur both higher costs and lower profits. Reviewing the causes of corporate social responsibility (CSR), shareholder value, corporate risk, and performance, Renneboog et al. (2008) conclude that no investors are willing to accept suboptimal financial performance in pursuit of CSR achievement. Kuo et al. (2021) argue that excessive corporate investment in ESG can weaken core business functions and negatively impact a firm's short-term performance.

Another section of the literature concludes that the influence of ESG on corporate performance is positive, and that companies with greater CSR engagement experience less information asymmetry, fewer financing constraints, a significant increase in Tobin's Q, and increased corporate value (Cheng et al. 2014; Hartzmark and Sussman 2019; Wong et al. 2021). Using UK and Germany data, Chouaibi et al. (2021) conclude that higher ESG scores of firms promote green innovation. It is discovered that the ESG-efficient frontier is a pricing factor in capital asset pricing models, particularly the E and S factors of ESG, which can result in a higher market valuation. Tan and Zhu (2022) conduct a quasi-natural experiment on Chinese A-share listed companies to investigate the impact of ESG ratings on corporate green innovation, indicating results that ESG ratings significantly contribute to the quantity and quality of corporate green innovation, while easing financial constraints and increasing managers' environmental awareness.

In terms of ESG investment performance, Bofinger et al. (2022) state that all investors should consider ESG criteria, which highly correlate with corporate valuation, whereby corporate ability levels play a significant role in enhancing share price, and that corporations should engage in social responsibility and profit from sustainable investment. According to Zhang et al. (2021), high ESG portfolios earn significantly higher excess returns than low ESG portfolios. Ouchen (2022) finds that ESG-integrated portfolios have higher returns and lower risk than traditional portfolios. Reber et al. (2022) discover that ESG ratings decrease the volatility and downside risk of a company's value in the first year after its IPO.

COVID-19 also provides additional evidence on the performance of ESG, and related studies have found that higher ESG scores can generate higher returns for firms during COVID-19, whereas firms with ESG concepts are more risk resistant (Yoo et al. 2021; Omankhanlen et al. 2021). Broadstock et al. (2021) investigate the role of ESG during the COVID-19-induced financial crisis and discover that ESG reduced financial risk and enhanced firm performance.

ESG and bank operations

In terms of environmental protection (E), green credit allocation has a substantial impact on the overall core competitiveness of banks and also has a positive impact on the return on interest-bearing assets of banks, thereby enhancing their financial performance (Ge et al. 2022; Lian et al. 2022; Luo et al. 2021). In Finger et al. (2018)'s study of the effect of the equatorial principle on the business performance of banks, the authors note that for banks in developing nations, adhering to the equatorial principle is a long-term strategic decision. In terms of social responsibility (S), the fulfillment of social responsibility can enhance the reputation of banks, assist them in enhancing their asset quality, and reduce the risk effect of banks on an aggregate level (Neitzert and Petras 2022; Shen et al. 2016). In terms of corporate governance (G), research focuses primarily on the influence of executive characteristics on bank performance (Luh Peter et al. 2022; Saerang et al. 2018; Skała and Weill 2018), commercial bank credit risk management (Chernobai et al. 2021; Ratnovski 2013; Santomero 1997), and bank profitability (Abbas et al. 2019; Omankhanlen et al. 2021).

In terms of ESG, after analyzing a decade of data from 235 European banks, Buallay (2019) concludes that ESG disclosure has a significantly positive impact on banks' performance, with varying results on ROA, ROE, and Tobin's Q. In a study of European banks, Di Tommaso and Thornton (2020) discover that ESG-based bank governance can support financial stability by reducing risk taking in specific situations, but at the expense of being prone to over-investment, which decreases the value of the bank. Through an analysis of European banks, Chiaramonte et al. (2022) determine that ESG strategies can reduce banks' vulnerabilities and improve their stability during financial distress—a performance that was especially evident during the financial crisis—and that they support banks' enhanced ESG disclosure.

Azmi et al. (2021) investigate the association between ESG activities and firm value for 251 banks in 44 emerging economies, concluding that the relationship between ESG and their firm value is non-linear. Low levels of ESG governance are effective, high levels of ESG governance demonstrate a diminishing return to scale effect, and among the three influencing factors of ESG, only the environmental factor affects bank performance, whereas an increase in ESG activities does not lower the default risk of banks.

DEA and bank efficiency

Data envelopment analysis (DEA) and its extended models have become the conventional method for measuring commercial bank efficiency. Seiford and Zhu (1999) propose incorporating market value, earnings per share, investment return, and other indicators that reflect banks' market valuation into the two-stage DEA model. They evaluated the profits stage efficiency and the competitive stage efficiency of 55 commercial banks in the USA. Decomposing the production process enables the identification of an inefficiency's root causes. Lewis and Sexton (2004) and Sexton and Lewis (2003) enhance the two-stage DEA model by stating that coherence between the two stages should be taken into account when evaluating DMU efficiency. In order to evaluate the efficiency of the second stage, the output of the first stage is used as its input.

Chen and Zhu (2004) develop a two-stage DEA model with different orientations: the first stage is an input-oriented BCC model, and the second stage is an output-oriented BCC model. They argue that intermediate variables should not increase or decrease during the production stage. Kao and Hwang (2008) assign the same weights to the same factors, assume the same input weights in the first and second stages, build the correlating two-stage DEA model, and demonstrate that the overall efficiency is the product of the efficiency of each substage with constant returns to scale. Chen et al. (2009) propose a weighted two-stage DEA model and use it to scale scenarios with both constant and variable payoffs. Wang et al. (2014) apply the two-stage model to the efficiency assessment of commercial banks based on Chen et al. (2009) and includes both good and bad outputs. In the first stage, fixed assets and the number of employees are inputs, and deposits are output; in the second stage, deposits are input, and non-interest income, interest income, and non-performing loans are outputs. The whole model takes deposits as intermediate factors. Traditional one-stage models overestimate the efficiency of commercial banks. In contrast, the two-stage DEA model is more accurate.

From the existing literature, the efficiency of commercial banks as established by DEA-based research methods is generally low, and some experts believe that taking exogenous variables into account when using DEA models to evaluate efficiency can prevent under- or overestimation of efficiency values (Lozano-Vivas et al. 2002; Shi et al. 2020). However, relatively few researchers have done so when examining the efficiency of commercial banks. Liu et al. (2020) analyze the changes in commercial banks' ownership structure via a two-stage meta-frontier DEA network model and regression models. They discover that state-owned commercial banks (SOCBs) in China have the highest level of technology and management, followed by joint-stock commercial banks (JSCBs) and urban commercial banks (UCBs) at the lowest. The efficiency of bank deposits is affected by who owns them and how concentrated they are, while the efficiency of bank loans is affected by who owns them and how liquid they are. Zha et al. (2016) use a dynamic two-stage SBM-DEA model to divide the business process of Chinese commercial banks into production and profit stages. Non-performing loans were treated as a carry over, putting them into the second stage of production. Shi et al. (2021) argue that the development of commercial banks is influenced not only by internal factors but also by external economic factors. They use GDP growth as an exogenous variable in their model and evaluated the efficiency of SOCBs, JSCBs, and UCBs in China from 2012 to 2018 by using a dynamic SBM-based model with exogenous variables.

In conclusion, the majority of existing literature on the evaluation of banks' efficiency focuses on internal factors such as operations and financial situation, whereas the majority of recent literature on ESG supports a positive impact on business performance. However, there is less literature on the role of ESG in the financial sector, particularly in banking institutions, and this strand is limited to the linear relationship between ESG and bank performance. Current literature lacks an ESG perspective to explore its impact on the sustainable development of Chinese commercial banks, which limits the popularity of ESG concepts in the financial sector and reduces the motivation of financial institutions to fulfill their ESG responsibilities. As a significant component of China's financial institutions, banks merit a comprehensive ESG examination. We shall investigate the impact of ESG on the long-term growth of banks and use this knowledge to help Chinese financial institutions become more conscious of their ESG responsibilities.

Research method

The CCR model of Charnes et al. (1978) is based on the concept of Farrell (1957). Banker et al. (1984) propose the BCC model, which replaced the CCR model's assumption of a fixed return to scale with variable return to scale (VRS). Tone (2001) proposed the slacks-based measure (SBM), which uses the slack variable as the basis for measurement and considers the difference between inputs and outputs (slack). The SBM approach is presented with non-radial estimation and a single value (scalar). In addition to the previously mentioned CCR, BCC, and SBM DEA models, a variety of other models have been discussed as follows.

The network DEA model was proposed by Färe et al. (2007), and unlike the traditional DEA model that considers secondary production techniques to be a "black box" that cannot be evaluated, the network DEA model employs secondary production techniques to examine the impacts of input allocation and intermediate outputs on the production process. Following Färe et al. (2007), Tone and Tsutsui (2009) introduce a weighted SBM network DEA model, which leverages the connectivity between the departments of the decision-making unit (DMU) as the basis for the network DEA model and treats the departments as sub-DMUs. The SBM model is then utilized to determine the best option. In the network DEA model, a dynamic approach is permitted in which DMUs are evaluated at multiple time periods and a carryover factor is used to connect the various stages that comprise DMUs at different time periods (Tone and Tsutsui 2010). The dynamic DEA model takes into account the constraints of using classic DEA when a business works across numerous time periods and evaluates the efficiency model throughout multiple time periods. Tone and Tsutsui proposed the weighted SBM dynamic network DEA model in 2014. This model uses the linkage between the departments of the DMU and carry-over activities as the basis for network DEA model analysis. Tone and Tsutsui (2014) do not consider exogenous and regional differences in the dynamic network SBM model. In order to understand the factors for exogenous and regional differences, our study combines Tone and Tsutsui's (2014) dynamic network DEA model with O'Donnell et al. (2008)'s meta-frontier model and exogenous factors to propose a meta dynamic two-stage SBM under exogenous variable DEA model. The description goes as follows.

Meta dynamic two-stage SBM under exogenous DEA model

Assume there are n DMUs ($o=1,\ldots, n$), k phases, and T periods ($t=1,\ldots, T$). In each period t, each DMU has its own inputs and outputs, which are linked through a carry-over variable to the following period $t+1$. The definitions of input, output, links, and carry-over are summarized in the following.

Inputs and outputs

$X^t_{iok} \epsilon R_+ (i=1,\ldots,m_k; o=1,\ldots,n; k=1,\ldots,K; t=1,\ldots,T)$ refers to input i at time period t for DMU_o division k.

X^t_{iok}: In stage 1 (profit stage), the number of employees and deposits are the inputs. In stage 2 (market and sustainability stage), total remuneration of directors, supervisors, and executives and social donations are inputs.

$Y^t_{rok} \epsilon R_+ (r=1,\ldots,r_k; o=1,\ldots,n; k=1,\ldots,K; t=1,\ldots,T)$ refers to output r in time period t for DMU_o division k.

Y^t_{rok}: Operating income is the output of stage 1, and market value, ESG index, and market capitalization per share are the outputs of stage 2.

Exogenous variable

$E_{ajt}(a=1\ldots u)$ is an outside variable of a given economic model that often impacts the outcome of the model. The percentage of network points is an exogenous variable.

Links

$Z^t_{o(kh)_l} \epsilon R_+ (o=1,\ldots,n; l=1,\ldots,L_{hk}; t=1,\ldots,T)$ are the period t links from DMU_o division k to division h, with L_{hk} being the number of k to h links.

$Z^t_{o(kh)_l}$: total profit and green credit are selected as the link indicators in the profit stage and market and sustainability stage.

Carry-overs

$Z^{(t,t+1)}_{ok_l} \epsilon R_+ (o=1,\ldots,n; l=1,\ldots,L_k; k=1,\ldots K; t=1,\ldots,T-1)$ refers to the carry-over of period t to period $t+1$ from DMU_o division k to division h, with L_k being the number of carry-over items in division k.

$Z^{(t,t+1)}_{ok_l}$: fixed assets are selected as the carry-over indicator in the profit stage and market and sustainability stage.

Other variables

$W^t(t=1\ldots T)$ is the weight given to period t, and $W^k(k=1\ldots k)$ is the weight given to division k.

Meta-frontier (MF) Suppose each $DMUo$ has an input and output at period t and a carry-over (link) to the next period $t+1$.

Due to differences in management type, environment, and resources, all vendors (N) consist of g groups of DMUs ($N=N1+N2+\ldots.+$). DMU k can choose the most favorable final output weight under the common boundary, so that its efficiency can be improved. Therefore, the efficiency of DMU k under the common boundary can be solved by the following linear programming procedure.

The following is the non-oriented model.

(a) Object function:

Overall efficiency:

$$\theta_0^* = min \frac{\sum_{t=1}^{T} W^t \left[\sum_{k=1}^{K} W^k \left[1 - \frac{1}{m_k + n\text{input}_k}\left(\sum_{g=1}^{G} \sum_{i=1}^{m_k} \frac{S^{t-}_{giok}}{x^t_{giok}} + \sum_{g=1}^{G} \sum_{k_l}^{n\text{input}_k} \frac{s^{(t,t+1)}_{gok_l}}{z^{(t,t+1)}_{gok_l}}\right)\right]\right]}{\sum_{t=1}^{T} W^t \left[\sum_{k=1}^{K} W^k \left[1 + \frac{1}{r_k + \text{link}_k}\left(\sum_{g=1}^{G} \sum_{r=1}^{r_k} \frac{s^{t+}_{grok}}{y^t_{grok}} + \sum_{g=1}^{G} \sum_{(kl)}^{link} \frac{s^t_{go(kl)}}{Z^t_{go(kl)}}\right)\right]\right]} \tag{1}$$

with $\sum_{t=1}^{T} W^t=1; \sum_{k=1}^{K} W^k=1.$

Subject to the following:

Profit stage

$$
\begin{aligned}
&X^t_{gio1} = \sum_{g=1}^{G}\sum_{o=1}^{n} X^t_{gio1}\lambda^t_{gio1} + s^{t-}_{gio1}(i = 1,\ldots,m_k, g = 1\ldots..G)\\
&y^t_{gro1} = \sum_{g=1}^{G}\sum_{o=1}^{n} y^t_{gro1}\lambda^t_{gro1} - s^{t+}_{gro1}(r = 1,\ldots,r_k, g = 1\ldots..G)\\
&Z^t_{go(12)} = \sum_{g=1}^{G}\sum_{o=1}^{n} Z^t_{go(12)}\lambda^t_{go(12)} - s^{t-}_{go(12)}(g = 1\ldots..G)\\
&\lambda^t_{gio1} \geq 0, \lambda^t_{gro1} \geq 0; s^{t-}_{gio1} \geq 0, s^{t+}_{gro1} \geq 0; s^{t-}_{go(12)} \geq 0
\end{aligned} \tag{2}
$$

s^{t-}_{gio1} and s^{t+}_{gro1} are stage 1 of input/output slacks, and $s^{t-}_{go(12)}$ is linkage slacks.

Market and sustainability stage:

$$
\begin{aligned}
&X^t_{gio2} = \sum_{g=1}^{G}\sum_{o=1}^{n} X^t_{gio2}\lambda^t_{gio2} + s^{t-}_{gio2}(i = 1,\ldots,m_k, g = 1\ldots..G)\\
&y^t_{gro2} = \sum_{g=1}^{G}\sum_{o=1}^{n} y^t_{gro2}\lambda^t_{gro2} - s^{t+}_{gro2}(r = 1,\ldots,r_k; g = 1\ldots..G))\\
&\lambda^t_{gio2} \geq 0, \lambda^t_{gro2} \geq 0; s^{t-}_{gio2} \geq 0, s^{t+}_{gro2} \geq 0
\end{aligned} \tag{3}
$$

s^{t-}_{gio2} and s^{t+}_{gro2} are stage 2 of input/output slacks.

$$
\begin{aligned}
&e\lambda^t_k = 1(\forall k, \forall t);\\
&E^t_{gao} = \sum_{g=1}^{G}\sum_{o=1}^{n} E^t_{gao}\lambda^t_{gao}(a = 1\ldots..u; g = 1\ldots..G)\\
&Z^{(t,t+1)}_{gok_l} = \sum_{g=1}^{G}\sum_{j=1}^{n} Z^{(t,t+1)}_{gok_l}\lambda^t_{gok_l} + s^{t(t,t+1)}_{gok_l}(g = 1\ldots..G)
\end{aligned} \tag{4}
$$

$s^{t(t,t+1)}_{gok_l} \geq 0$; and $s^{t(t,t+1)}_{gok_l}$ is carry − over slacks.

The period and division efficiencies are as follows:

(b1) Period efficiency:

$$
\partial^*_0 = min\frac{\sum_{k=1}^{K} W^k\left[1 - \frac{1}{m_k+ninput_k}\left(\sum_{g=1}^{G}\sum_{i=1}^{m_k}\frac{S^{t-}_{giok}}{x^t_{giok}} + \sum_{g=1}^{G}\sum_{k_l}^{ninput_k}\frac{s^{(t,t+1)}_{gok_l}}{z^{(t,t+1)}_{gok_l}}\right)\right]}{\sum_{k=1}^{K} W^k\left[1 + \frac{1}{r_k+link_k}\left(\sum_{g=1}^{G}\sum_{r=1}^{r_k}\frac{s^{t+}_{grok}}{y^t_{grok}} + \sum_{g=1}^{G}\sum_{(kl)}^{link}\frac{s^t_{go(kl)}}{Z^t_{go(kl)}}\right)\right]} \tag{5}
$$

(b2) Division efficiency:

$$
\varphi^*_0 = \min\min\frac{\sum_{t=1}^{T} W^t\left[1 - \frac{1}{m_k+ninput_k}\left(\sum_{g=1}^{G}\sum_{i=1}^{m_k}\frac{S^{t-}_{giok}}{x^t_{giok}} + \sum_{g=1}^{G}\sum_{k_l}^{ninput_k}\frac{s^{(t,t+1)}_{gok_l}}{z^{(t,t+1)}_{gok_l}}\right)\right]}{\sum_{t=1}^{T} W^t\left[1 + \frac{1}{r_k+link_k}\left(\sum_{g=1}^{G}\sum_{r=1}^{r_k}\frac{s^{t+}_{grok}}{y^t_{grok}} + \sum_{g=1}^{G}\sum_{(kl)}^{link}\frac{s^t_{go(kl)}}{Z^t_{go(kl)}}\right)\right]} \tag{6}
$$

(b3) Division period efficiency:

$$
\rho^*_0 = \min\frac{\left[1 - \frac{1}{m_k+ninput_k}\left(\sum_{g=1}^{G}\sum_{i=1}^{m_k}\frac{S^{t-}_{giok}}{x^t_{giok}} + \sum_{g=1}^{G}\sum_{k_l}^{ninput_k}\frac{s^{(t,t+1)}_{gok_l}}{z^{(t,t+1)}_{gok_l}}\right)\right]}{\left[1 + \frac{1}{r_k+link_k}\left(\sum_{g=1}^{G}\sum_{r=1}^{r_k}\frac{s^{t+}_{grok}}{y^t_{grok}} + \sum_{g=1}^{G}\sum_{(kl)}^{link}\frac{s^t_{go(kl)}}{Z^t_{go(kl)}}\right)\right]} \tag{7}
$$

From the above, the overall efficiency, period efficiency, division efficiency, and division period efficiency can be obtained using the meta-frontier model.

Group frontier (GF) As each DMU under the group frontier chooses the most favorable final weighted output, the DMU efficiencies under the group frontier are solved using the following equations:

(a) Objective function

Overall efficiency:

$$
\theta^{g*}_0 = \min\frac{\sum_{t=1}^{T} W^t\left[\sum_{k=1}^{K} W^k\left[1 - \frac{1}{m_k+ninput_k}\left(\sum_{i=1}^{m_k}\frac{S^{t-}_{iok}}{x^t_{iok}} + \sum_{k_l}^{ninput_k}\frac{s^{(t,t+1)}_{ok_l}}{z^{(t,t+1)}_{ok_l}}\right)\right]\right]}{\sum_{t=1}^{T} W^t\left[\sum_{k=1}^{K} W^k\left[1 + \frac{1}{r_k+link_k}\left(\sum_{r=1}^{r_k}\frac{s^{t+}_{rok}}{y^t_{rok}} + \sum_{(kl)}^{link}\frac{s^t_{o(kl)}}{Z^t_{o(kl)}}\right)\right]\right]} \tag{8}
$$

with $\sum_{t=1}^{T} W^t$=1; and $\sum_{k=1}^{K} W^k$=1.

Subject to the following:

Profit stage

$$
\begin{aligned}
&X^t_{io1} = \sum_{o=1}^{n} X^t_{io1}\lambda^t_{io1} + s^{t-}_{io1}(i = 1,\ldots,m_k)\\
&y^t_{ro1} = \sum_{o=1}^{n} y^t_{ro1}\lambda^t_{ro1} - s^{t+}_{ro1}(r = 1,\ldots,r_k)\\
&Z^t_{o(12)} = \sum_{o=1}^{n} Z^t_{o(12)}\lambda^t_{o(12)} - s^{t-}_{o(12)}\\
&\lambda^t_{io1} \geq 0, \lambda^t_{ro1} \geq 0; s^{t-}_{io1} \geq 0, s^{t+}_{ro1} \geq 0; s^{t-}_{o(12)} \geq 0
\end{aligned} \tag{9}
$$

s^{t-}_{io1} and s^{t+}_{ro1} are stage 1 of input/output slacks, and $s^{t-}_{o(12)}$ is link slacks.

Market and sustainability stage.

$$
\begin{aligned}
&X^t_{io2} = \sum_{o=1}^{n} X^t_{io2}\lambda^t_{io2} + s^{t-}_{io2}(i = 1,\ldots,m_k)\\
&y^t_{ro2} = \sum_{o=1}^{n} y^t_{ro2}\lambda^t_{ro2} - s^{t+}_{go2}(r = 1,\ldots,r_k)\\
&\lambda^t_{io2} \geq 0, \lambda^t_{ro2} \geq 0; s^{t-}_{io2} \geq 0, s^{t+}_{ro2} \geq 0
\end{aligned} \tag{10}
$$

s^{t-}_{io2} and s^{t+}_{ro2} are stage 2 of input/output slacks.

$$
\begin{aligned}
&e\lambda^t_k = 1(\forall k, \forall t);\\
&E^t_{ao} = \sum_{o=1}^{n} E^t_{ao}\lambda^t_{ao}(a = 1\ldots..u)\\
&Z^{(t,t+1)}_{ok_l} = \sum_{j=1}^{n} Z^{(t,t+1)}_{ok_l}\lambda^t_{ok_l} + s^{t(t,t+1)}_{ok_l}
\end{aligned} \tag{11}
$$

$s^{t(t,t+1)}_{ok_l} \geq 0$; and $s^{t(t,t+1)}_{ok_l}$ is carry − over slacks.

(b) Period and division efficiencies:

The period and division efficiencies are as follows:

(b1) Period efficiency:

Table 1 Classification of 20 commercial banks in China

Cluster	DMU
SOCBs	Industrial and Commercial Bank of China (ICBC), Agricultural Bank of China (ABC), Bank of China (BOC), China Construction Bank (CCB), Bank of Communication (BCM)
JSCBs	China Merchants Bank (CMB), China Industrial Bank (CIB), China Citic Bank (CNCB), Ping An Bank (PAB), China Everbright Bank (CEB), China Minsheng Bank (CMBC), Shanghai Pudong Development Bank (SPDB), Hua Xia Bank (HXB)
UCBs	Bank of Beijing (BOB), Bank of Ningbo (BONO), Bank of Hangzhou (BOHZ), Bank of Shanghai (BOS), Bank of Jiangsu (BOJS), Bank of Nanjing (BONJ), Bank of Guiyang (BOGY)

$$\partial_0^* = \min \frac{\sum_{k=1}^{K} W^k \left[1 - \frac{1}{m_k + ninput_k}\left(\sum_{i=1}^{m_k} \frac{S_{iok}^{t-}}{x_{iok}^t} + \sum_{k_l}^{ninput_k} \frac{s_{ok_l}^{(t,t+1)}}{z_{ok_l}^{(t,t+1)}}\right)\right]}{\sum_{k=1}^{K} W^k \left[1 + \frac{1}{r_k + link_k}\left(\sum_{r=1}^{r_k} \frac{s_{rok}^{t+}}{y_{rok}^t} + \sum_{(kl)}^{link} \frac{s_{o(kl)}^t}{Z_{o(kl)}^t}\right)\right]} \tag{12}$$

(b2) Division efficiency:

$$\varphi_0^* = min \frac{\sum_{t=1}^{T} W^t \left[1 - \frac{1}{m_k + ninput_k}\left(\sum_{i=1}^{m_k} \frac{S_{iok}^{t-}}{x_{iok}^t} + \sum_{k_l}^{ninput_k} \frac{s_{ok_l}^{(t,t+1)}}{z_{ok_l}^{(t,t+1)}}\right)\right]}{\sum_{t=1}^{T} W^t \left[1 + \frac{1}{r_k + link_k}\left(\sum_{r=1}^{r_k} \frac{s_{rok}^{t+}}{y_{rok}^t} + \sum_{(kl)}^{link} \frac{s_{o(kl)}^t}{Z_{o(kl)}^t}\right)\right]} \tag{13}$$

(b3) Division period efficiency:

$$\rho_0^* = min \frac{1 - \frac{1}{m_k + ninput_k}\left(\sum_{i=1}^{m_k} \frac{S_{iok}^{t-}}{x_{iok}^t} + \sum_{k_l}^{ninput_k} \frac{s_{ok_l}^{(t,t+1)}}{z_{ok_l}^{(t,t+1)}}\right)}{1 + \frac{1}{r_k + link_k}\left(\sum_{r=1}^{r_k} \frac{s_{rok}^{t+}}{y_{rok}^t} + \sum_{(kl)}^{link} \frac{s_{o(kl)}^t}{Z_{o(kl)}^t}\right)} \tag{14}$$

From the above results, the overall efficiency, the period efficiency, the division efficiency, and division period efficiency are obtained.

Technology gap ratio (TGR) As the meta-frontier model contains g groups, the technical efficiency of the meta-frontier (MFE) is less than the technical efficiency of the group frontier (GFE). The ratio value, or the technology gap ratio (TGR), is

$$TGR = \frac{\theta_0^*}{\theta_0^{g*}} = \frac{MFE}{GFE} \tag{15}$$

Input, desirable output, and undesirable output efficiencies

We use Hu and Wang's (2006) total-factor energy efficiency index to overcome any possible biases in the traditional efficiency indicators, for which there are nine key efficiency models: R&D personnel, R&D funding, published books, academic papers, granted patents, technology transfer income, national awards, academic conference exchange papers, and fixed assets investment. "I" represents area, and "t" represents time. The efficiency models are defined as follows.

$$\text{Input efficiency} = \frac{\text{Target input}}{\text{Actual input}} \tag{16}$$

$$\text{Output efficiency} = \frac{\text{Actual Desirable output}}{\text{Target Desirable output}} \tag{17}$$

If the target inputs equal the actual inputs, then the efficiencies are 1, which indicates overall efficiency. However, if the target inputs are less than the actual inputs, then the efficiencies are less than 1, which indicates overall inefficiency.

If the target desirable outputs are equal to the actual desirable outputs, then the efficiencies are 1, indicating overall efficiency. However, if the target desirable outputs are more than the actual desirable outputs, then the efficiencies are less than 1, indicating overall inefficiency.

Empirical analysis

Data description

Based on data availability, we take the data of Chinese listed banks between 2016 and 2020, eliminate some banks with no data and serious data deficiencies, and ultimately identify 20 listed commercial banks and divide them into three categories based on the nature of stock rights: SOCBs, JSCBs, and UCBs. Table 1 lists the specific banks within the three categories of commercial banks.

Table 2 presents the relevant indicators based on the two-stage efficiency framework of Chinese listed banks, with data obtained from Cathay Capital (CSMAR), website of China Banking Regulatory Commission, and website of Sino-Securities Index Information Service (Shanghai). The study is divided into two stages using meta-dynamic SBM in the exogenous model. The first stage is the profit stage, in which commercial banks primarily make loans and earn

Table 2 Input and output variables

Stage	Variable		Unit	Reference
Profit Stage	Input	Deposits	10^4 RMB	Seiford and Zhu (1999); Wang et al. (2014); Liu et al. (2020); Zha et al. (2016)
		Number of employees	Units	
	Output	Revenue	10^4 RMB	
	Link	Total profit	10^4 RMB	
	link	Green credit	10^4 RMB	
Carry-over		Fixed assets	10^4 RMB	
Market and Sustainability Stage	Input	Total remuneration of directors, supervisors, and executives (RDSE)	10^4 RMB	Seiford and Zhu (1999); Azmi et al. (2021)
		Social donation	10^4 RMB	
	Output	Market value	10^4 RMB	
		ESG index	Units	
		Earnings per share	RMB	
Exogenous Variable		Market share	%	Forster and Shaffer (2005); Bos and Kool (2006); Shi et al. (2021)

various returns. Total profit and green credit (E) are both outputs of the first stage and continue to be used as inputs in the second stage. Fixed assets are used as carry-over variables, while social donations (S) and total remuneration of directors, supervisors, and senior management (G) are used as inputs in the second stage, with market value, ESG index, and earnings per share as final outputs.

Specific explanations are as follows.

(1) Deposits. The total amount of deposits accepted by commercial banks consists of the funds deposited by individuals and businesses. The primary source of funds for commercial banks is deposits, which can be used to grant loans and engage in some investment activities. Deposits are the primary source for banks to realize the expansion of loans and investments and directly determine the carry income of commercial banks, and thus their profits and other economic benefits, and so we use this indicator as the input of stage 1.

(2) Number of employees. It refers to the number of commercial bank employees. All bank operations are dependent on the employees, and since the number of employees has a significant impact on bank operations, it is selected as a first-stage input indicator.

(3) Fixed assets. The net worth of fixed assets is chosen to represent the bank's assets. The majority consists of property, buildings that are still being constructed, equipment, vehicles, etc., and represented as cash.

(4) Revenue. The operating revenue generated by commercial banks through the acceptance of deposits, the issuing of loans, or other intermediate transactions serves as both an input to the second stage and an output of the first stage.

(5) Total profit. Commercial banks' yearly profits from operations represent the profitability of the banks as a whole and are influenced by a variety of internal and external factors. Total profit is the output of the first stage, which is then used as an input to the second stage.

(6) Green credit. Green credit is the term used by commercial banks to refer to loans invested in energy conservation and environmental protection industries, clean production industries, clean energy industries, ecological environment industries, infrastructure green upgrading industries, green service industries, and similar industries. This is an essential component of the ESG reports of commercial banks. It shows how far commercial banks have come in terms of social responsibility and green finance. This is a link indicator, which is a significant indicator of the sustainable development of commercial banks, as it is both the output of the first stage and the input of the second stage.

(7) Total remuneration of directors, supervisors, and executives (the total annual remuneration of directors, supervisors, and executives of commercial banks). Listed bank compensation must be accurately stated in the annual report to reflect the bank's investment in internal governance. Hereinafter, it is referred to as RDSE.

(8) Social donation (the relief activities of commercial banks to social groups, individuals, or other non-profit groups, taken from their social responsibility report). This metric demonstrates the bank's performance in terms of social responsibility. This is the second input stage.

(9) Market value. According to their social responsibility report, commercial banks provide assistance

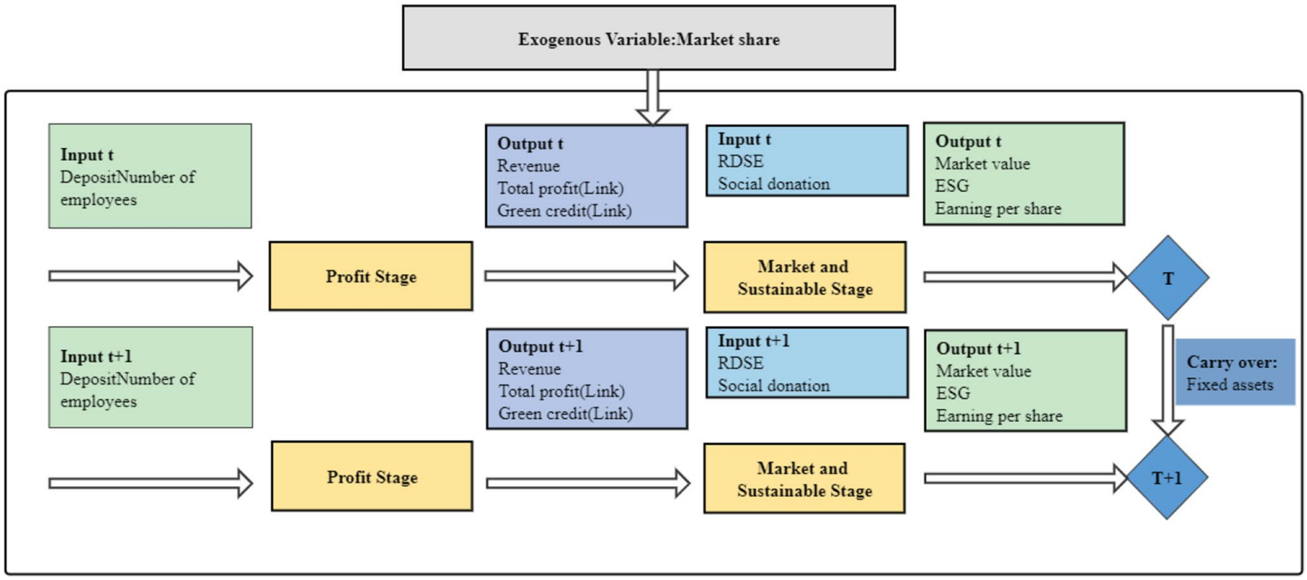

Fig. 1 Illustration of the proposed assessing framework

to social groups, individuals, and other non-profit organizations. This indicator, which assesses the size of the bank and its operational circumstances among other things and is influenced by both operational and non-operational elements, is the output of the second stage.

(10) ESG index. Sino-Securities Index Information Service (Shanghai), an ESG evaluation organization for Chinese A-shares, provides the index. The index system includes three primary indicators (environmental, social, and corporate governance), fourteen secondary indicators, twenty-six tertiary indicators, and more than one hundred and thirty bottom data indicators. The ESG score of a company is determined by matrix summation according to the weights from the bottom up, which is divided into a total of nine ratings from C to AAA, which are represented by 1–9 in this paper; the higher the value is, the better is the ESG performance.

(11) Earnings per share. This serves as a gauge of bank profitability and exhibits some relationship with the share price of the bank. As the second stage's output, it serves as a significant predictor of the company's sustainability.

(12) Market share. The number of branches of the bank in the country divided by the number of branches of all banks in the country is used as an exogenous variable to represent market share. The larger the value is, the higher is the market share and the higher is the concentration of outlets (Fig. 1).

Descriptive statistics

From 2016 to 2020, this study evaluates the market share, deposits, number of employees, revenue, total profit, green credit, fixed assets, total remuneration of directors, supervisors, and executives, social donation, market value, ESG score, and earnings per share of 20 listed Chinese banks. We compute each of the 12 variables' maximum, minimum, mean, and standard deviation and round the results to two decimal places. For details, please refer to Figs. 2, 3, and 4.

Figures 2, 3, and 4 show the statistical description of the input, output, exogenous, and carry-over variables by year. Figure 2(a) shows that the statistic of deposit shows a steady increase from year to year, similarly to revenue (Fig. 2c), total profit (Fig. 2d), and green credit (Fig. 2e). The number of employees (Fig. 2b) is declining, probably due to the increased digitalization of banks and the rise of mobile payments in China.

Different from stage 1, the social donation (Fig. 3b) variable in stage 2 is more volatile, with the maximum values in 2016 and 2020 being much higher than in the remaining 3 years. The input indicator RDSE (Fig. 3a) and the output indicators, ESG index (Fig. 3d), and earnings per share (Fig. 3e), fluctuate within the normal range, with ESG values being higher overall. The mean and standard deviation of market value (Fig. 3c), on the other hand, show an upward trend from year to year, increasing in volatility.

Market share (Fig. 4a) and number of employees (Fig. 2b) show the same trend, with the maximum value decreasing year on year, but the mean and S.D. are basically the same.

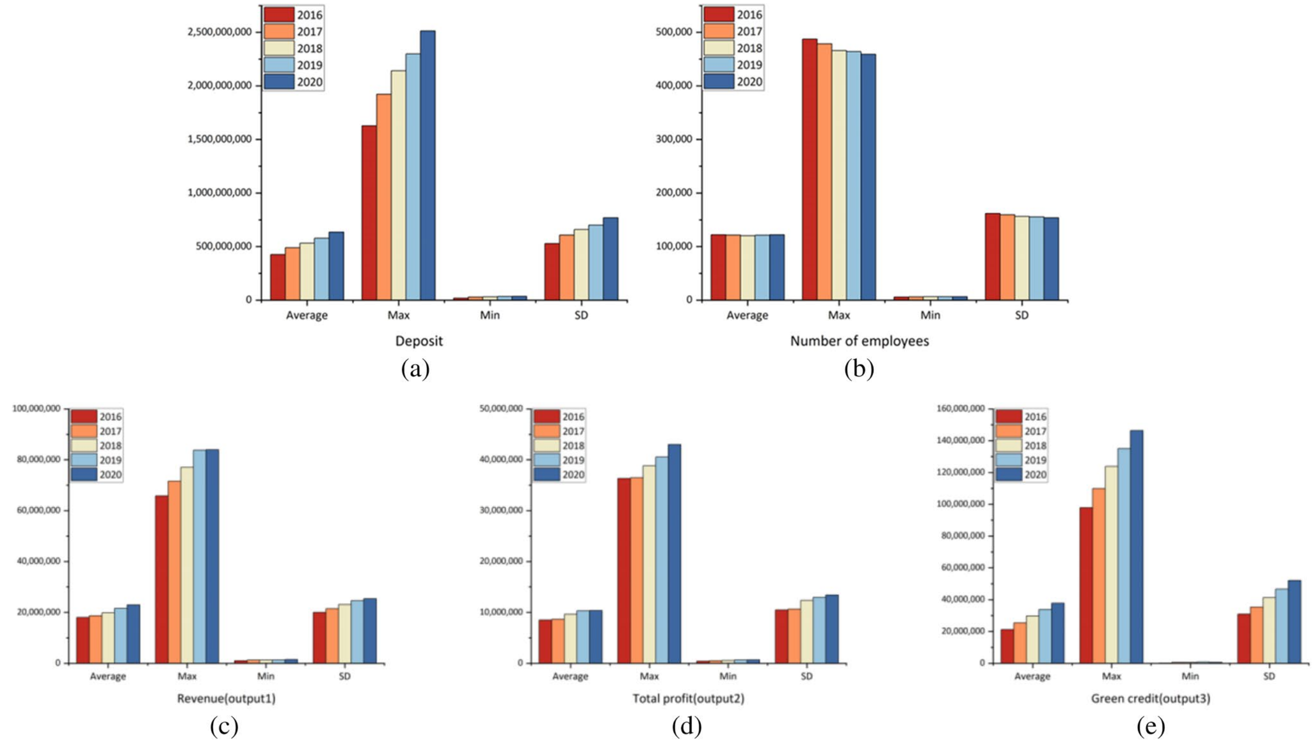

Fig. 2 The statistical analysis of input and output variables of stage 1

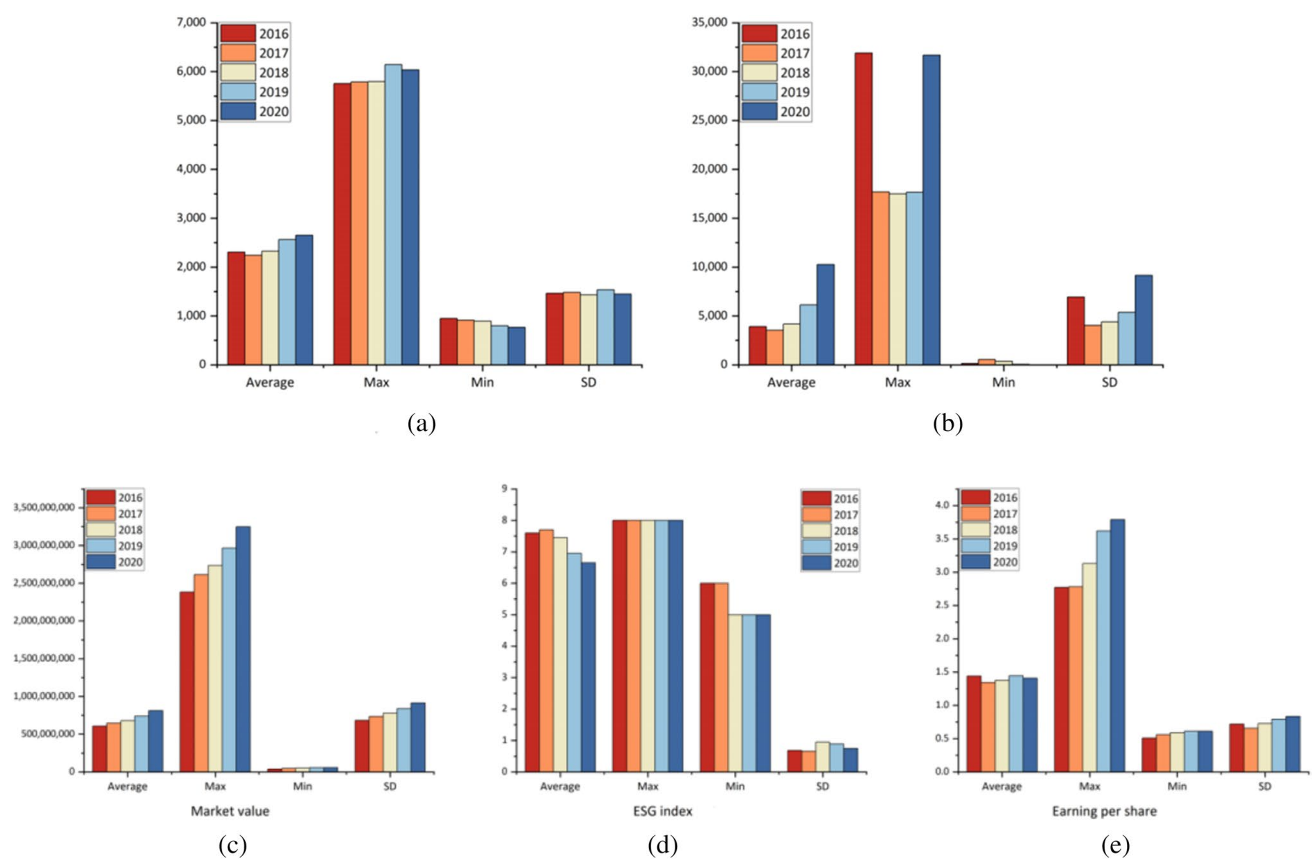

Fig. 3 The statistical analysis of input and output variables of stage 2

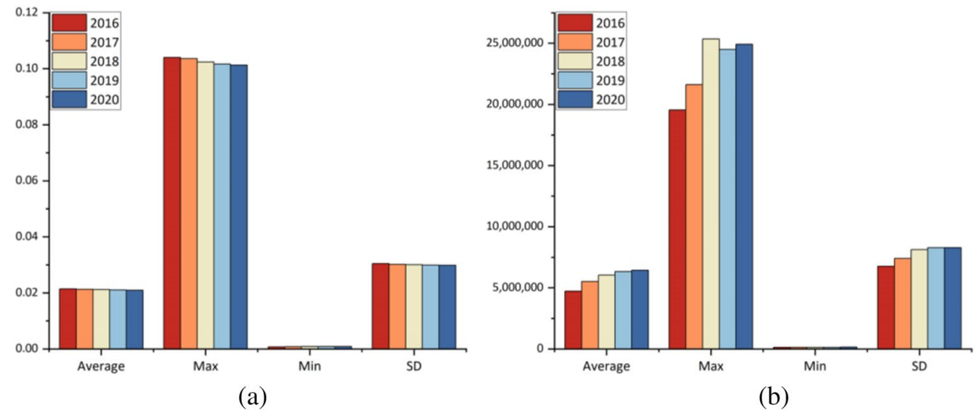

Fig. 4 The statistical analysis of exogenous variable and carry-over variable

The overall fluctuation of fixed assets (Fig. 4b) is within the normal range, with the mean and standard deviation increasing year on year.

Overall efficiency of two scenarios for 20 commercial banks

There exists a mechanism of interaction between market share and bank efficiency. The expansion of banks' market share can indicate their dominant market position and market power. Early on, the unique market position of SOCBs led to their high market share, and with the gradual opening of the market environment and the intensification of financial system reform, JSCBs and UCBs also developed a sound management system and a positive market reputation, thereby increasing their market share. The relatively open market environment compelled banks to reduce the duplication of investments in human, material, and financial resources, thereby enhancing market efficiency. According to Berger (1995)'s research, Staikouras and Wood (2004) argued that market share has a positive effect on bank profitability. Ray (2016) stated that an increase in market share and the number of locations leads to redundancy in fixed assets, operating expenses, and the number of employees, and that it is important to control the layout of outlets and reduce the redundancy of input factors triggered by physical business outlets to improve the level of operational performance.

We assess each DMU while taking into account (S) and excluding (S*) market share. Without taking exogenous factors into account, there are six banks with an overall efficiency of 0.8 or higher, including three JSCBs and three UCBs. After taking exogenous variables into account, there are 10 banks with an overall efficiency of at least 0.8, with 3 belonging to SOCBs, 4 to JSCBs, and 3 to UCBs. It is evident that the underestimation of efficiency values improves when we discuss market share as an exogenous component in the model.

By comparing the three types of banks, it becomes clearer that efficiency is significantly enhanced when exogenous variables are considered. The average efficiency value of all banks is 0.779, while UCBs perform the best with an efficiency value of 0.802. Due to their unique geographical advantages, flexible policies, and flat management, UCBs are better able to develop business models based on local market demands. JSCBs rank second in performance with an efficiency value of 0.773, whereas SOCBs perform the worst with a value of 0.761. In terms of the magnitude of the improvement, JSCBs improve the most, from 0.634 to 0.773 when exogenous variables are considered. See Table 3 for details.

Figure 5 illustrates that the efficiency values considering exogenous variables are significantly higher than those not considering exogenous variables. SOCBs show an increase, and JSCBs and UCBs both show a decrease followed by an increase.

Efficiency analysis between the profit stage and market and sustainability stage

SOCBs, JSCBs, and UCBs are generally more efficient during the profit stage than during the market and sustainability stage with an overall efficiency value of 0.779 for all types of banks room for improvement. Below we analyze efficiency in detail from the two stages. Profit is an important criterion for evaluating Chinese listed banks, and analyzing the profit stage's efficiency is essential. As can be seen in Table 4, the profit efficiency of commercial banks performs well over the period 2016–2020, with an overall average value of 0.891, and exhibits a year-on-year improvement that is inextricably linked to the rapid development of the country's macroeconomic environment, digital finance, and Internet finance.

JSCBs have the highest profit stage efficiency among these entities, with an average efficiency of 0.950. In recent years, JSCBs' rational corporate governance system and diversified investment entities have helped to increase

Table 3 Efficiency of each bank in the two scenarios, 2016–2020

Cluster	DMU	Overall		2016		2017		2018		2019		2020	
		S	S*	S	S*	S	S*	S	S*	S	S*	S	S*
SOCBs	ICBC	0.841	0.785	0.815	0.808	0.860	0.819	0.888	0.827	0.891	0.825	0.854	0.800
	ABC	0.830	0.698	0.664	0.376	1.000	0.776	1.000	1.000	1.000	1.000	1.000	1.000
	BOC	0.611	0.575	0.583	0.581	0.599	0.569	0.647	0.588	0.645	0.581	0.612	0.559
	CCB	0.820	0.747	0.738	0.728	0.793	0.731	0.844	0.747	0.844	0.744	0.911	0.830
	BCM	0.703	0.669	0.687	0.669	0.758	0.734	0.735	0.687	0.704	0.659	0.701	0.668
	Mean	0.761	0.695	0.697	0.632	0.802	0.726	0.823	0.77	0.817	0.762	0.816	0.771
JSCBs	CMB	0.607	0.607	0.728	0.728	0.703	0.703	0.657	0.657	0.651	0.65	1.000	1.000
	CIB	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	CNCB	0.775	0.315	1.000	0.407	0.619	0.364	1.000	0.383	1.000	0.416	1.000	0.364
	PAB	0.919	0.919	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.733	0.733
	CEB	0.539	0.538	0.912	0.912	0.866	0.865	0.561	0.577	0.570	0.595	0.562	0.558
	CMBC	0.811	0.222	1.000	0.563	1.000	0.493	1.000	0.438	0.592	0.498	1.000	0.509
	SPDB	0.838	0.837	1.000	1.000	1.000	1.000	1.000	1.000	0.733	0.732	0.728	0.718
	HXB	0.691	0.632	0.837	0.837	0.659	0.639	0.700	0.670	0.704	0.651	0.725	0.598
	Mean	0.773	0.634	0.935	0.806	0.856	0.758	0.865	0.716	0.781	0.693	0.844	0.685
UCBs	BOB	0.717	0.717	0.790	0.790	1.000	1.000	0.632	0.632	0.767	0.767	0.789	0.789
	BONO	0.564	0.561	1.000	1.000	0.550	0.548	0.479	0.497	0.533	0.535	0.521	0.525
	BOHZ	0.917	0.911	0.846	0.850	0.808	0.779	1.000	1.000	1.000	1.000	1.000	1.000
	BOS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	BOJS	0.699	0.665	0.630	0.632	0.701	0.687	0.700	0.676	0.763	0.708	0.761	0.702
	BONJ	0.720	0.594	0.861	0.844	0.783	0.631	0.655	0.527	0.824	0.647	0.793	0.602
	BOGY	1.000	0.857	1.000	0.912	1.000	0.855	1.000	0.861	1.000	0.850	1.000	0.875
	Mean	0.802	0.758	0.875	0.861	0.835	0.786	0.781	0.742	0.841	0.787	0.838	0.785

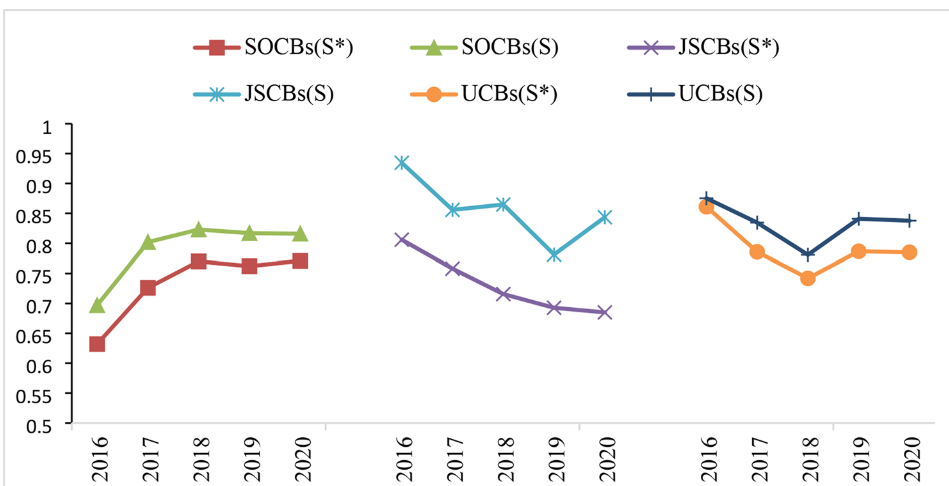

Fig. 5 Efficiency values of three types of commercial banks in China considering (S) and not considering (S*) exogenous variables, 2016–2020

Table 4 Efficiency of the profit stage for the three types of banks, 2016–2020

Cluster	Mean	2016	2017	2018	2019	2020
SOCBs	0.802	0.738	0.788	0.830	0.843	0.812
JSCBs	0.950	0.937	0.935	0.950	0.967	0.963
UCBs	0.920	0.918	0.885	0.933	0.926	0.938

Table 5 Market and sustainability stage efficiency of the three types of banks, 2016–2020

Cluster	Mean	2016	2017	2018	2019	2020
SOCBs	0.779	0.657	0.816	0.815	0.790	0.819
JSCBs	0.762	0.932	0.777	0.78	0.596	0.724
UCBs	0.748	0.832	0.784	0.629	0.756	0.738

commercial non-interest income, net interest income, and lending business, contributing to their increased profitability and allowing them to thrive in the banking industry's highly competitive environment. UCBs have the second highest profitability at an average of 0.920. In recent years, UCBs have achieved greater success by cultivating local markets intensively and utilizing their distinct geographical advantages. SOCBs have the lowest average efficiency at 0.802. China issued its first national strategic plan for inclusive finance in 2015, titled Plan for Promoting the Development of Inclusive Finance (2016–2020), and the development of inclusive finance has become the strategic planning content and key layout for SOCBs. Low-interest loans granted to special groups such as agricultural enterprises and small- and micro-level enterprises, as well as the policy of service fee waiver implemented for special service recipients, have impacted the efficiency of SOCBs in the profit stage negatively.

The sustainable development of commercial banks is affected by the efficient allocation of financial resources and the growth of the macroeconomy. We introduce ESG-related indicators (green credit, total remuneration of directors, supervisors, and executives, and ESG score) in the input and output factors of the market and sustainability stage in order to evaluate the social responsibility and sustainability of commercial banks. From Table 5, the overall average efficiency of the market and sustainability stage is 0.763, which is lower than the efficiency of the profit stage on average. SOCBs have the best performance at an efficiency of 0.779 and generally show rising efficiency. JSCBs are the second efficient with an efficiency of 0.762 and decreasing efficiency. With an efficiency of 0.748 and a decreasing efficiency value followed by an increasing U-shape trend, UCBs perform the worst. This is consistent with what Chinese commercial banks have actually been doing, where SOCBs have responded to the government's request to do more for green development, financial inclusion, and social responsibility. The mission of JSCBs is to provide resources and benefits to their stakeholders. This is consistent with the view of Aupperle et al. (1985) in that sustainable development is an irrational pursuit, and that companies that fulfill social responsibility will incur higher costs and lower profits.

From Fig. 6, 14 out of 20 banks are less efficient in the second stage compared to the first stage, and only six banks are more efficient or on par in the second stage compared to the first stage. In the second stage, ICBC has an efficiency of 1, which is 0.277 greater than in the first stage, CCB has an efficiency of 0.026 higher compared to the first stage, and BOHZ has an efficiency of 0.116 higher compared to the first stage. For both phases, the efficiencies of CIB, BOS, and BOGY are 1.

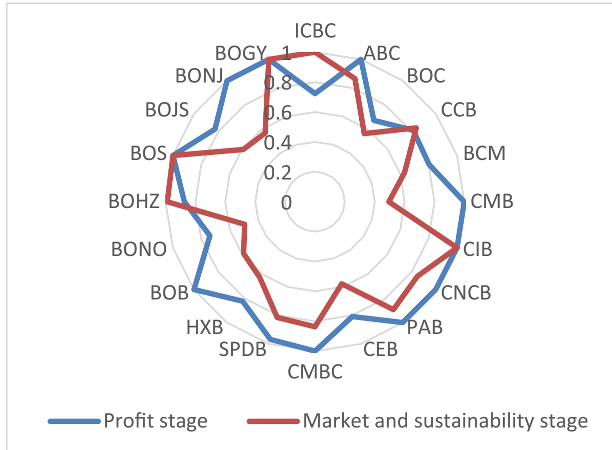

Fig. 6 Two-stage comparison of 20 commercial banks' efficiency under exogenous variables

Analysis of the efficiency values of major inputs and outputs

According to Table 6, the efficiency performance of the major input–output indicators for 2016–2020 is inconsistent. We cannot list the efficiency values of all input and output indicators due to space constraints. Instead, the effectiveness of key indicators is reported in two stages.

Sustainability indicators

(1) ESG index. SOCBs have the highest ESG performance efficiency. Earlier contributions to natural resources, climate change, social responsibility, and business ethics were made by SOCBs, and the extent of these contributions has been at the forefront of the industry, resulting in a greater degree of efficiency. In 2016 the ESG efficiency of SOCBs reached a peak of 0.963; the lowest year is 2019, with efficiency of 0.845, while the efficiency

Table 6 Efficiency of important input–output indicators

Cluster	Year	ESG index	Green credit	Social donation	RDSE	Total profit	Market value	EPS
SOCBs	2016	0.963	0.809	0.923	1.000	0.924	0.837	0.556
	2017	0.902	0.888	0.969	1.000	0.907	0.991	0.718
	2018	0.906	0.877	0.983	1.000	0.902	1.000	0.695
	2019	0.845	0.906	0.935	1.000	0.909	0.997	0.720
	2020	0.889	0.924	0.948	0.997	0.915	1.000	0.749
JSCBs	2016	0.915	1.000	1.000	1.000	1.000	0.980	0.930
	2017	0.813	0.927	0.915	0.974	0.988	0.966	0.766
	2018	0.842	0.899	0.919	1.000	0.983	0.960	0.759
	2019	0.612	0.956	0.724	0.995	0.970	0.962	0.666
	2020	0.712	0.914	0.930	0.982	0.959	1.000	0.713
UCBs	2016	0.992	0.925	0.784	0.994	0.963	0.986	0.845
	2017	0.854	0.853	0.934	0.928	0.947	0.983	0.755
	2018	0.721	0.880	0.729	0.900	0.960	0.999	0.633
	2019	0.877	0.871	0.859	0.828	0.972	0.990	0.837
	2020	0.817	0.885	0.741	0.964	0.984	0.970	0.825

for the other 3 years was around 0.9. The second-best performance was achieved by UCBs, whose shareholders are typically local governments, which influence the relevant local government functions and also make contributions. Four banks became listed in 2016 during the year of concentrated UCB listings. The ESG efficiency of UCBs value reached 0.992 and then declined by a certain amount, but the overall performance is stable with room for improvement. The efficiency of JSCBs is the lowest and fluctuates between years, with the highest year reaching 0.915 and the lowest year being 2019 with an efficiency of 0.612. This is consistent with a previous study that found JSCBs tend to pursue profit maximization, which is also the cause of low ESG efficiency.

(2) Green credit. All three types of banks overall have an efficiency above 0.8 in every year, with JSCBs performing the best, four years outstripping 0.9, and one year exceeding 1. The performance of SOCBs is second best, with two years surpassing 0.9 and three others exceeding 0.8. The performance of UCBs is marginally inferior, with one year exceeding 0.9 and four others exceeding 0.8. In 2012, the China Banking and Insurance Supervisory Commission and the People's Bank of China made the green credit index a non-administrative order and an important assessment indicator for the development of banks, directing commercial banks to issue high loan amounts and low interest rates for environmental protection industries and clean production industries in loan placement and low amounts and high interest rates for overcapacity industries such as high pollution agribusinesses in loan placement. This is conducive to the adjustment of industrial structure and the promotion of a low-carbon economy, which has been the focus of bank business development in recent years and is consistent with banks' current business situation. However, based on current national support policies and market demand, improving the efficiency of green credit delivery will continue to be a key growth area for all banks over the next few years, and green credit can be of great financial assistance to commercial banks (Lian et al. 2022).

(3) Social donation. The efficiency of SOCBs is consistently greater than 0.9, with the highest efficiency value of 0.983 in 2018 and the lowest efficiency of 0.923 in 2016. The most efficient year for JSCBs is 2016, with an efficiency of 1, while the least efficient year is 2019, with a performance of 0.724. The remaining years have stable performance between 0.915 and 0.930. UCBs have poor performance, with a maximum value of 0.934 and a minimum value of 0.729. The efficiency value is less than 0.8 in three out of five years, and the value fluctuates between high and low values, indicating that the social donation efficiency of UCBs is highly unstable and has room for improvement.

(4) Total remuneration of directors, supervisors, and executives (RDSE). SOCBs perform the best in terms of corporate governance, with a value of 1 in each of the years 2016 through 2019 and 0.997 in 2020. The next best performers are JSCBs, with two years of an efficiency value of 1 and three other years between 0.974 and 0.995. The worst performing year for UCBs is 0.828, with the remaining four years exceeding 0.9. The remuneration of directors, supervisors, and executives of listed banks has been strictly regulated in recent years due to national requirements limiting remuneration in the banking sector. As a result, the RDSE efficiency performance of all banks is generally good.

Profit and market indicators

(1) Total profit. The efficiency values of all three types of banks are greater than 0.9 each year, with JSCBs performing the best at a profit efficiency greater than 0.95 in every year, but also displaying a decreasing trend from 1 in 2016 to 0.959 in 2020. This is likely due to the intense market competition resulting in higher cost of deposit taking by banks, thereby decreasing profit efficiency. The UCBs show an incremental increase, which is related to the centralized IPO of four UCBs in 2016: BOHZ, BOS, BOJS, and BOGY. The management ability of these banks has vastly improved since their listing, and they now place a greater emphasis on the profit of their shareholders. As a result, their profit efficiency keeps increasing. As mentioned in the previous analysis, SOCBs focus more on implementing national policies and investing in non-profit businesses, but despite this, their annual efficiency value remains above 0.90.

(2) Market value. Generally speaking, the market value efficiency of the three types of banks is excellent. In the past 5 years, SOCBs have had 2 years with an efficiency value of 1 and 2 years with an efficiency value greater than 0.99, where 2016 is the least efficient year with a value of 0.837. JSCBs are more stable, with efficiency values ranging from 0.960 to 1 and optimal efficiency being reached in 2020. Additionally, the performance of UCBs is consistent from year to year, with efficiency values ranging between 0.97 and 0.999. According to the current regulatory regulations, the most important indicators for determining the market value of Chinese listed banks are capital base and capital ratio. The majority of listed banks perform well in terms of their capital adequacy ratio as determined by the Measures for the Administration of Capital Adequacy of Commercial Banks, which is the primary reason for the high market value of Chinese listed banks and demonstrates their high market value efficiency.

(3) Earnings per share (EPS). It is the least efficient of the profit and market indicators, and the performance of all three types of banks is poor. SOCBs are below 0.75 in every year between 2016 and 2020, with the highest efficiency year being 0.749 and the lowest efficiency year being only 0.695. This is due to the SOCBs' large size and chronically low earnings per share. JSCBs are more efficient. Their value reaches 0.930, and the remaining years have efficiency values below 0.8, with the lowest value being 0.666. Three years of UCBs have efficiency values greater than 0.80, and the lowest year is 0.633. It is consistent with the fact that China's publicly traded banks have a lower EPS efficiency due to their larger size and lower earnings per share.

Comparison of the three ownership systems of TGR

Tian and Lin (2018) noted that TGR represents a measure of the proximity of different bank frontiers to the meta-frontier. The greater TGR is, the closer the frontier technology of that evaluation object is to the meta-frontier. If TGR = 1, there is no gap between the group frontier technology and the meta-frontier technology. We analyze the technology gap ratios (TGR) of the three types of banks, overall, first stage, and second stage, and analyze the technology differences between them using TGR, as shown in Table 7.

It is evident in the majority of cases that TGR with exogenous variables considered is greater than TGR without exogenous variables considered. Under consideration of exogenous variables, the TGR values of SOCBs, JSCBs, and UCBs are 0.769, 0.797, and 0.836, respectively, which are 0.060, 0.049, and 0.048 higher than the case without consideration of exogenous variables. UCBs perform the best, with an average TGR of 0.836, or an improvement of 0.048 compared to when exogenous variables are not considered. There are four banks with TGR of 0.85 or more; BOS has TGR of 1 in both instances, and BOGY's TGR rose to 1 from 0.857. JSCBs perform second best, with TRG of 0.797, up from 0.748, and CIB with TGR reach optimal in both instances. Three banks achieve TGR of 0.85 or more, and CMBC shows the greatest improvement, from 0.509 to 0.811. SOCBs have the greatest improvement in TGR after accounting for exogenous variables, but still perform the worst, with ICBC having the highest TGR at 0.841 and BOC having the lowest at 0.650.

In the profit stage, after considering exogenous variables, TGR of SOCBs increases from 0.704 to 0.808 and that of UCBs increases from 0.844 to 0.920. which are 0.104 and 0.076 higher, respectively, than when exogenous variables are not considered. In contrast, JSCBs decrease from 1 to 0.981, and TGR decreases 0.019. TGR is highest for JSCBs at this stage. After accounting for exogenous variables, we find that ten of the twenty banks reach TGR of 1 in the first stage, while only two banks have TGR of below 0.80.

In the market and sustainability stage, after accounting for exogenous variables, the TGR values for SOCBs, JSCBs, and UCBs are 0.78, 0.77, and 0.781, respectively. Compared to the situation without exogenous variables, SOCBs remain unchanged, JSCBs improve by 0.074, and UCBs improve by only 0.009. However, the difference between the types of banks is not statistically significant, and TRG in this phase is lower than in the profit stage. This could be due to the fact that Chinese commercial banks are currently behind in the market and sustainability stage of research and are at a technical disadvantage due to their lack of ESG development experience.

Table 7 TGR for the three bank groups

DMU	Overall TGR		TGR of profit stage		TGR of market and sustainability stage	
	S	S*	S	S*	S	S*
ICBC	0.841	0.787	0.723	0.636	1.000	1.000
ABC	0.830	0.698	1.000	0.809	0.866	0.852
BOC	0.650	0.644	0.700	0.636	0.606	0.649
CCB	0.820	0.747	0.813	0.675	0.839	0.837
BCM	0.703	0.669	0.804	0.763	0.630	0.604
SOCBs	0.769	0.709	0.808	0.704	0.788	0.788
CMB	0.673	0.673	1.000	1.000	0.556	0.556
CIB	1.000	1.000	1.000	1.000	1.000	1.000
CNCB	0.775	0.671	1.000	1.000	0.848	0.568
PAB	0.919	0.919	1.000	1.000	0.893	0.893
CEB	0.612	0.633	0.921	1.000	0.633	0.633
CMBC	0.811	0.509	1.000	1.000	0.837	0.548
SPDB	0.852	0.853	0.999	0.995	0.815	0.816
HXB	0.737	0.723	0.929	0.990	0.627	0.600
JSCBs	0.797	0.748	0.981	1.000	0.776	0.702
BOB	0.797	0.797	1.000	1.000	0.677	0.677
BONO	0.564	0.561	0.739	0.753	0.494	0.490
BOHZ	0.917	0.911	0.873	0.864	0.989	0.987
BOS	1.000	1.000	1.000	1.000	1.000	1.000
BOJS	0.699	0.665	0.827	0.799	0.594	0.563
BONJ	0.877	0.724	1.000	0.753	0.713	0.689
BOGY	1.000	0.857	1.000	0.741	1.000	1.000
UCBs	0.836	0.788	0.920	0.844	0.781	0.772

Conclusions and suggestions

Conclusions

The research incorporates ESG-related indicators into the meta dynamic two-stage SBM under the exogenous variable DEA model, uses market share as an exogenous variable, and evaluates the overall efficiency, profit stage efficiency, and market and sustainability stage efficiency of SOCBs, JSCBs, and UCBs, followed by an analysis of the key input–output indicator efficiencies and the overall TGR and stage TGR of the three ownership systems. The following are the main findings of the study.

(1) In terms of overall effectiveness, UCBs perform the best, JSCBs the second best, and SOCBs the worst. It is noteworthy that adding market share as an exogenous variable to the model increases the efficiency of SOCBs, JSCBs, and UCBs. As a result, the model that considers market share can assess the effectiveness of commercial banks more precisely. The local government, which owns a large portion of UCBs and has a tight working connection with the bank, will favor local urban commercial banks by allocating a lot of resources to them, which will benefit them. Additionally, UCBs have more adaptable corporate strategies and flat internal administration. SOCBs, which are state owned and do not aim to maximize economic profits, instead have the responsibility of disseminating and carrying out the inclusive policies of the government. On the other hand, major occurrences like the massive opening of private banks, the expedited process of interest rate marketization, and the deposit insurance scheme have the greatest impact on them.

(2) The first stage's efficiency is higher than the second's when comparing the two phases. JSCBs are the most effective in the profit phase, followed by UCBs, while SOCBs are the least effective. SOCBs are the most effective in the market and sustainability stage, while UCBs are the least effective. The two stages' reflections of the outcomes diverge. SOCBs take on the strategic planning and layout duties assigned to the government in the development process, and so economic efficiency is not the main objective. SOCBs also make more contributions to the placement of green credits and inclusive finance, and they place more emphasis on investments in environmental protection, social responsibility, internal governance, and other sustain-

ability indicators. Despite sacrificing SOCBs' profitability, these investments have significantly accelerated their sustainable growth. JSCBs have sought to maximize profits, which is why they did best in the initial phase. However, JSCBs have failed to uphold their social responsibilities and adhere to the principles of sustainable development, which has resulted in subpar efficiency performance in the second stage and lackluster long-term prospects. When compared to SOCBs and JSCBs, UCBs started later, had a flawed mechanism, and still had the drawbacks associated with a single product. Additionally, they did not accumulate as much development experience as SOCBs and JSCBs.

(3) In terms of input–output efficiency of individual indicators, the efficiency values of the three types of banks in terms of the three indicators of RDSE, total profit, and market value are close to the highest, reflecting the comprehensive compensation system and solid business model of Chinese commercial banks. In terms of ESG index, SOCBs have the best performance, which reflects the environmental and social responsibility that banks with a state-owned background should assume and set a positive example for small- and medium-sized banks, which is consistent with their efficiency performance in the second stage. The stability of UCBs' ESG performance, which has been over 0.8 for the past 4 years, is also attributable to the fact that they are more heavily regulated by local governments and prioritize sustainable development. JSCBs and UCBs perform similarly in terms of earnings per share efficiency, whereas SOCBs have the worst performance due to their big size and long-term low earnings. In terms of green credit metrics, the efficiency of all three types of banks has been over 0.8 over the years, with JSCBs performing the best, SOCBs coming in second, and UCBs performing marginally worse. This suggests that all banks place a significant emphasis on the growth of green credit businesses.

(4) We apply TGR to the assessment of the technological gap between SOCBs, JSCBs, and UCBs, and it is evident that TGR also improves greatly when exogenous variables are used. Globally, the TGR performance of SOCBs, JSCBs, and UCBs corresponds to their efficiency performance, with UCBs performing the best, JSCBs performing second-best, and SOCBs performing the worst. In the profit phase, the TGR of all three types of banks is much greater than in the market and sustainability stage, and the overall performance in the profit stage is superior, with ten out of twenty banks obtaining a TGR of 1 in this phase, with JSCBs performing the best. In the market and sustainable stage, the average TGR for all three types of banks is less than 0.8, indicating greater technical development potential.

Suggestions

Commercial banks' ability to effectively discharge their social obligation has a favorable effect on the growth of their businesses. Whether the nation's economy grows in a high-quality manner depends on whether commercial banks can grow sustainably and healthily. ESG duties for banks are comparable to investing in intangible assets, which may not produce quick profits in the short term. but can lay a crucial foundation for operations and sustainable development of commercial banks in the medium term and long term. We provide the following recommendations for commercial banks, stakeholders, and regulators in combination with the research in this paper.

Suggestions to commercial banks To increase the effectiveness of operating profits, SOCBs should swiftly de-administrate, gradually minimize governmental administrative intrusion, and actively engage in market competition. They should also continue to boost ESG investment while concentrating on enhancing the effectiveness of green finance. Making green credit more efficient will benefit the entire industry and contribute more to the real economy's growth in a sustainable way, because SOCBs invest significantly more in green credit than other banks. While trying to make the most money possible, JSCBs should work hard to develop ESG. For example, they could spread credit funds to all industry sectors to help them do more to make manufacturing cleaner and better for the environment. At the same time, they should use their advanced digital technology, build an intelligent platform, invest more in financial technology and new projects, integrate ESG resources, and focus on managing ESG investments to make sustainable development more effective. UCBs should employ a "small but precise" rapid development strategy, which is based on local conditions, to improve their market recognition and grow the size of the market, which will make them more efficient in terms of market value. As a goal for growth, they should improve personalized financial services and build a regional brand. They should also take advantage of local advantages, work more closely with government and regulatory agencies, open more ESG investment channels, and come up with different ways to invest.

Suggestions to stakeholders Shareholders of commercial banks should know that ESG investments are good for the value of the company and pay attention to ESG information, such as the bank's environmental performance, social responsibility, and governance. Managers should be told to integrate and make the best use of ESG resources and use long-term strategies for sustainable development. When figuring out a bank's value and growth potential, its overall ESG performance should be taken into account and supported. This will help the bank grow in a way that will not hurt it in the long run.

Suggestions to regulators First, it is necessary to design and improve an ESG evaluation system with Chinese local characteristics and industry-specific characteristics. The ESG rating of businesses should take into account industry differences, particularly in the financial industry, whose large scale and capital-intensive characteristics differ from those of general industries, and the rating should be differentiated in order to adopt a differentiated ESG evaluation system consistent with banking institutions. Second, commercial banks should be encouraged to take the initiative to increase ESG investments and to play a guiding role as financial intermediaries in sustainable development in order to give robust support for high-quality economic development. Third, the oversight of ESG information disclosure should be tightened, and commercial banks should be actively and effectively directed to continually improve the openness of ESG information and to maintain continuous disclosure of social responsibility reports. The regulation of different sorts of banks should be varied.

Research limitations and perspectives for the future

This paper incorporates ESG-related indicators into the meta dynamic two-stage SBM under the exogenous variable DEA model and takes market share as an exogenous variable, in order to assess the efficiencies of the profit stage as well as the market and sustainability stage of 20 listed banks in China. It classifies listed banks as SOCBs, JSCBs, and UCBs. They are compared to investigate their viability under various ownerships. As an exploratory study, this paper has both theoretical and practical significance, but it also contains a number of weaknesses that must be investigated further in future research.

(1) Long-term observation of the influence of ESG on the sustainable growth of banks is still required, and there may be a lag in the effects of environmental, social, and governance input on banks. For instance, the data accumulation cycle following the formation of policies connected to sustainable development, such as green credit and social giving, is still relatively modest, and the influence is still emerging, necessitating continued long-term observation and study. During COVID-19, it is especially crucial to pay attention to and learn more about how the banking industry can leverage its ESG strengths to stimulate the lagging economy (You et al. 2022).

(2) The research sample is limited in certain ways. This study evaluates the impact of ESG-related indicators on the efficiency of Chinese commercial banks with respect to sustainable development. Due to the limited availability of data for non-listed banks and the fact that some listed banks do not disclose their annual social responsibility reports, the research objective of this paper is only 20 commercial banks listed on the A-share market, based on data consistency and availability. Due to this influence, the study focuses mostly on listed banks with a reasonably high level of development, and the findings do not apply to other commercial banks. As the number of listed banks increases in the future, the consistency of essential data will improve. For further research and validation, it is necessary to collect and analyze more data by bank size and ownership. This will allow more banks to utilize the research findings.

(3) The research perspective must be enhanced further. This article employs commercial banks as its object of study and focuses on assessing their efficiency after the incorporation of ESG metrics. As a large aspect of China's economic development, banks play a significant role in regional economic expansion and company industrial transformation. In the future, it will be crucial to learn more about the effect and influence mechanism of ESG on the entire economic system, following its impact on the efficiency of banks' sustainable development from the perspective of macroeconomic development, and to strengthen the synergy between the healthy operation of financial institutions and high-quality macroeconomic development.

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