A study on the measurement of operational efficiency of commercial banks--Analysis based on super-efficient DEA model and Malmquist index

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Abstract. The banking sector has a risk-intensive character and early warning of the risk of commercial bank failures is particularly important. In order to measure the efficiency of commercial banks in Poland and provide a cut-off line for bank failure efficiency, this paper firstly adopts the dichotomous method to pre-process the existing data, then selects three representative input indicators and two output indicators to construct an evaluation index system for bank efficiency, and uses the super-efficiency DEA model to measure the efficiency of banks, and concludes that comprehensive technical efficiency inhibits the rise of bank efficiency, and the efficiency of banks in 2017 -2021 banks' efficiency showed a zigzag fluctuation trend; secondly, based on the static analysis of super-efficient DEA, the dynamic efficiency of banks was estimated and decomposed based on the Malmquist index method; finally, the failure cut-off was determined by testing whether there was a significant difference in the mean values.

Keywords: Commercial bank operational efficiency, Super-efficiency DEA model, Malmquist index.

1. Introduction

The banking industry is growing rapidly in the context of economic globalization, but as financial institutions develop and innovate, the potential risks of the banking industry come to the fore. Banking risk refers to the economic loss of income and assets arising from the difference between the expected and actual earnings of a bank due to uncertainties in its business process. Banking risks are hazardous, contagious and weakly controllable. When banks have liquidity problems or even fail, the wider economy will be affected and it will be difficult to recover for a while, so it is important to avoid adverse situations and to effectively warn and control the risk of bank failure. At the same time, in the increasingly complex economic and financial situation, the competition for banks is becoming increasingly fierce. Improving and enhancing the banks' own defence against risks is one of their advantages in the competition, and only by better improving the early warning system for risks and enhancing their own competitiveness can the banking industry stand firm in the complex economic environment.

Since the 1990s, many foreign scholars have conducted research around measuring the level of bank efficiency. Abdul Qayyum, Muhammad Kasheer, Jahanzaib Haider, Omer Mehmood, A mjad Iqbal (2018) [1] Efficiency measurement of 21 listed commercial banks in Pakistan using DEA analysis for the period 2000-2017.Akber Aman Shah, Desheng Wu, Vladmir Korotkov (2019) [2] Scale efficiency of commercial banks using CCR and BCC models Laissez-faire and Malmquist productivity index to assess 9-year productivity of sustainable banks and compare with non-sustainable banks. wanke Peter, Skully Michael, Wijesiri Mahinda, Walker Thomas, dalla Pellegrina Lucia (2021) [3] A two-stage dynamic DEA model is used to study the relationship between bank ownership and efficiency of 58 Indian commercial banks between 2005 and 2017 before and after the global financial crisis of 2008-2009. The study shows that foreign banks outperformed their domestic competitors, with bank size and profitability being the main drivers. Milenković Nada, Radovanov Boris, Kalaš Branimir, Horvat Aleksandra Marcikić (2022) [4] A two-stage model is used to explore the efficiency analysis and factors influencing banks in the Western Balkan countries for the period 2015-2019, and the results show that there are differences in the level of efficiency between and within countries over the time period considered.

Based on the availability and comparability of data on sample variables, the object of study in this paper is the efficiency of commercial banks in Poland, and the bank failure efficiency cut-off is provided through measurement: firstly, a dichotomous approach is adopted to pre-process the existing data, which requires the selection of three representative input indicators and two output indicators, combined with the construction of an evaluation index system for the efficiency of banks, and the super-efficiency DEA model is applied to the efficiency of banks Secondly, based on the static analysis of super-efficiency DEA, the dynamic efficiency of banks was estimated and decomposed based on the Malmquist index method; finally, the failure cut-off line was determined by testing whether there was a significant difference in the mean values.

2. Efficiency analysis of Polish banks based on the super-efficient DEA model and Malmquist index

2.1. Sample data pre-processing

Data quality analysis is a powerful guarantee for solving practical problems. The accuracy and reliability of bank risk forecasting requires the collection of a large amount of accurate data to support it. By observing, collating and analyzing the raw data information, it is found that there are still cases of data indiscipline in the table such as containing special symbols and the existence of abnormal data. In order to facilitate the subsequent model building, it is necessary to first eliminate or make up the abnormal values. Based on the dichotomy method, the zero theorem is first used to determine the equation$f(x)$ and the existence interval of$[a, b]$, then the interval containing the roots$[a, b]$ The interval with roots is then divided into, and the interval with roots is reduced by half by discriminating the sign of the function of the pair of points to$[a, (a+b)/2]$. Repeat the above procedure to reduce the interval of existence of the roots to a sufficiently small size to find an approximation of the roots that satisfies the accuracy requirement.

2.2. Selection of input-output indicators

The central issue to be addressed in this paper is the use of input-output data to provide a reasonable evaluation of the efficiency of each bank [5]. By differentiating the input and output indicators in the processed data, three input indicators and two output indicators are selected as the core positive indicators to measure the efficiency of banks, the higher the value of the indicator data, the higher the efficiency of the bank. The input indicators are equity/total assets, paid-in capital/fixed assets and working capital, while the output indicators are net profit/total assets and gross profit/sales, as defined below.

Table 1. A study on the measurement of operational efficiency of commercial banks

Tier 1 indicators	X_j	Variable Description
Input indicators	X_1	Equity/total assets
	X_2	Paid-in capital / fixed assets
	X_3	Working capital
Output indicators	X_4	Profit/total assets
	X_5	Gross profit/sales

2.3. Super-efficient DEA efficiency model for Polish banks

(1) Standard DEA model

The DEA model is an analytical method for measuring the relative effectiveness of homogeneous decision-making units (DMUs) [6]. Compared to the stochastic frontier gravity model, the DEA model does not assume a specific production function and distribution of inefficiency terms, which allows for a more accurate assessment of the situation when DMUs have multiple outputs and can reduce the negative impact of subjective factors. The efficiency values are obtained without the need to set a specific production function or to subjectively assign weights to the variables.

For any decision unit, the BBC model can usually be measured in depth to obtain the combined efficiency in the case of variable payoffs to scale, i.e.,$TE = PTE \times SE$, with a specific linear programming as

$$min\left[\theta - \varepsilon\left(\hat{e}^{T} S^{-} + e^{T} S^{+}\right)\right] \tag{1}$$

$$s.t.\begin{cases} \sum_{j=1}^{n} X_j\lambda_j + S^{-} = \theta X_0 \\ \sum_{j=1}^{n} Y_j\lambda_j + S^{+} = Y_0 \\ \lambda_j \geq 0, j = 1,2,\dots,n \\ S^{-} \geq 0, S^{+} \geq 0, \sum_{j=1}^{n} \lambda_j = 1 \end{cases} \tag{2}$$

Where$\lambda_j (j = 1,2,3,\dots,n)$ is the planning decision variable.$^{S^-}(S_1{}^{+}, S_2{}^{+}, \dots, S_n{}^{+})^T$ is the vector of slack variables, and$\theta(0 \leq \theta \leq 1)$ is the target planning value.

(2) Super-efficient DEA model

We chose the super-efficiency DEA method to assess the level of bank efficiency because the super-efficiency DEA method allows for the ranking of the efficiency magnitude of multiple efficient DMUs, allowing efficient DMUs to be compared with each other [7] The expression of the super-efficiency DEA model can be obtained by adjusting equation (1):

$$min\left[\theta - \varepsilon\left(\hat{e}^{T} S^{-} + e^{T} S^{+}\right)\right] \tag{3}$$

$$s.t.\begin{cases} \sum_{j=1}^{n} X_j\lambda_j + S^{-} = \theta X_0 \\ \sum_{j=1}^{n} Y_j\lambda_j + S^{+} = Y_0 \\ \lambda_j \geq 0, j = 1,2,\dots,n \\ S^{-} \geq 0, S^{+} \geq 0, \sum_{j=1}^{n} \lambda_j = 1 \end{cases} \tag{4}$$

The super-efficiency value of an effective DMU is > 1. A larger super-efficiency value indicates a higher level of bank efficiency, while the super-efficiency DEA value of an ineffective DMU is still equal to the standard DEA efficiency value.

2.4. Malmquist index model of efficiency fluctuations for Polish banks

$Fare$et al. (1989) used a staticDEA model based on the proposed transition from$t$ period to$t + 1$ period$Malmquis$ index$M(x^{t+1}, y^{t+1}, x^t, y^t)$ in order to explore the dynamics of efficiency [8] where$S^t(x^{t+1}, y^{t+1})$ and$S^t(x^t, y^t)$ denote, respectively, the change in efficiency at$t$ when the period is taken as the base, the$t$ period and$t + 1$ the distance functions between the evaluation objects for periods$S^{t+1}(x^{t+1}, y^{t+1})$ and$S^{t+1}(x^t, y^t)$ are similar in meaning.

$$M(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\frac{S^t(x^{t+1}, y^{t+1})}{S^t(x^t, y^t)} \times \frac{S^{t+1}(x^{t+1}, y^{t+1})}{S^{t+1}(x^t, y^t)}\right]^{\frac{1}{2}} \tag{5}$$

Disaggregating bank efficiency $(Tfpch)$ Decomposed into combined technical efficiency$(Effch)$ and the rate of technological progress$(Techch)$ where the combined technical efficiency $(Effch)$ can be decomposed into pure technical efficiency $(Pech)$ and scale efficiency$(Sech)$ Equation (5) can then be decomposed into Equation (6):

$$M(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{S^{t+1}(x^{t+1}, y^{t+1}|VRS)}{S^t(x^t, y^t|VRS)} \cdot \frac{S^{t+1}(x^{t+1}, y^{t+1}|CRS)}{S^{t+1}(x^t, y^t|VRS)} \cdot \frac{s^t(x^{t+1}, y^{t+1}|VRS)}{s^t(x^t, y^t|VRS)} \left[\frac{S^t(x^{t+1}, y^{t+1})}{S^t(x^t, y^t)} \times \frac{S^{t+1}(x^{t+1}, y^{t+1})}{S^{t+1}(x^t, y^t)}\right]^{1/2} = pech \times sech \times techch = tfpch \tag{6}$$

Bank efficiency is broken down into overall technical efficiency and the rate of technological progress, where overall technical efficiency can be broken down into pure technical efficiency and scale efficiency.

3. Results

3.1. Bank efficiency evaluation solutions and results

Based on the input-oriented BCC model, the data for each indicator were substituted into the DEAP 2.1 software in order to calculate the overall efficiency (TE), pure technical efficiency (PTE), scale efficiency (SE) and scale efficiency (RTS) for the 2019-2021 development level of each bank, and the evaluation results are shown in Table 2.

Table 2. Combined efficiency values of commercial banks in Poland, 2017-2021

Year	Tfpch	Techch	Effch	Pech	Sech
2016-2017	1.446	1.503	0.962	0.937	1.027
2017-2018	1.752	1.752	1.000	1.004	0.996
2018-2019	1.207	1.072	1.126	1.036	1.087
2019-2020	1.155	1.325	0.872	0.936	0.932
2020-2021	1.075	1.171	0.918	1.027	0.894
Mean	1.306	1.344	0.972	0.987	0.985

Overall, from the analysis in the table above, the efficiency of the bank from 2017-2021($Tfpch$) The mean value of the dynamic change is 1.306, with a downward trend of 25.6% in 2021 compared to 2017 in terms of bank efficiency. The decomposition of the Malmquist index results in [9] , the main source of the 25.6% decline in efficiency is the rate of technological progress($Techch$) which has declined by 22.1% with a mean dynamic change of 1.344 over the period 2017-2021. At the same time, the combined technical efficiency($Effch$) is less than 1 [10] indicating that the combined technical efficiency inhibits the rise in bank efficiency, with pure technical efficiency($Pech$) rose by 9.0% and scale efficiency($Sech$) declined by 12.9%. This is somewhat indicative of an increase in the level of bank development over the period under review, but a decrease in returns to scale.

3.2. Solution and results for the bank failure divider

The pre-processed data were brought into the above DEA model and analyzed and calculated by SPSS software to obtain the results of the dividing line between failed banks and normally operating banks for each indicator as shown in Table 3.

Table 3. Breakdown of failed banks

X_j	Variable Description	Failed banks	Regularly operating banks
X_1	Equity/total assets	9.64	13.59
X_2	Paid-in capital / fixed capital	5.21	10.78
X_3	Working capital	22.69	66.28
X_4	Net profit/total assets	-99.56	30.29
X_5	Gross profit/sales	3.39	25.57

The above five indicators show significant differences in both insolvent and healthy banks and can be reasonably selected for inclusion in the model. In the SPSS software by measuring $Wilks'lambda$ test volume to test for the presence of significant differences, the results of the mean test are shown in Table 4.

Table 4. Means test results

X_j	$Wilks'lambda$	F	$df1$	$df2$	Sig
X_1	0.879	28.802	1	137	0.000
X_2	0.869	20.656	1	137	0.000
X_3	0.506	13.318	1	137	0.000
X_4	0.343	0.329	1	137	0.000
X_5	0.983	4.202	1	137	0.000

As can be seen from the table above, at the 0.01 level of significance, i.e., the means of the above five variables are significantly different between the two groups of failed banks and healthy banks and can be reasonably selected for inclusion in the model.

4. Conclusion

This paper firstly adopts the dichotomous method to pre-process the existing data, then selects three representative input indicators and two output indicators to construct an evaluation index system for banks' efficiency, and uses the super-efficiency DEA model to measure banks' efficiency, concluding that comprehensive technical efficiency inhibits the rise of banks' efficiency, and that banks' efficiency shows a zigzag fluctuation trend from 2017 to 2021; secondly, on the On the basis of conducting the static analysis of super-efficient DEA, the dynamic efficiency of banks was estimated and decomposed based on the Malmquist index method; finally, the failure cut-off line was determined by testing the existence of significant differences in the means.

References

[1] Abdul Qayyum, Muhammad Kasheer, Jahanzaib Haider, Omer Mehmood, Amjad Iqbal. IMPACT OF OWNERSHIP, COMPETITION, AND MANAGEMENT PRACTICES ON EFFICIENCY OF BANKING SECTOR[J]. Polish Journal of Management Studies, 2018, 18 (1).

[2] Akber Aman Shah, Desheng Wu, Vladmir Korotkov. Are Sustainable Banks Efficient and Productive? A Data Envelopment Analysis and the Malmquist Productivity Index Analysis [J]. Sustainability, 2019, 11 (8).

[3] Wanke Peter, Skully Michael, Wijesiri Mahinda, Walker Thomas, dalla Pellegrina Lucia. Does ownership structure affect firm performance? Evidence of Indian bank efficiency before and after the Global Financial Crisis [J]. International Transactions in Operational Research, 2021, 29 (3).

[4] Milenković Nada, Radovanov Boris, Kalaš Branimir, Horvat Aleksandra Marcikić. External Two Stage DEA Analysis of Bank Efficiency in West Balkan Countries[J]. Sustainability, 2022, 14 (2).

[5] Feng Xiaoyu. A study on the efficiency of digital financial inputs and outputs of commercial banks based on a three-stage DEA model [J]. Marketing World, 2022 (18): 74 - 76.

[6] Lv Kejing. An empirical study on the operational efficiency of commercial banks based on DEA model [J]. China Agricultural Accounting, 2022 (04): 64 - 65. DOI: 10.13575/j.cnki.319.2022.04.030.

[7] Tian Ting. Research on the efficiency of commercial banks in China based on DEA method [J]. Business Manager, 2021 (08): 78 - 79.

[8] Yang Wang, Xu Huilin, Tan Xiaofen, Xue Xiangyu. Fintech and commercial bank efficiency - an empirical study based on DEA-Malmquist model [J]. International Financial Studies, 2020 (07): 56 - 65. DOI: 10.16475/j.cnki.1006 - 1029.2020.07.006.

[9] Dong Fenyi, Liang Xiao. An empirical study on the efficiency of listed commercial banks based on DEA and Malmquist model [J]. Henan Science, 2020, 38 (01): 164 - 172.

[10] Liu YH. A comparative study of enterprise business efficiency evaluation methods [J]. Modern Economic Information, 2018 (08): 22 - 23.