Efficiency Measurement of China's Commercial Banks Under the Background of Digital Economy–Based on DEA-Malmquist Model

Mao Wang(✉)

School of Economics and Management, Beijing JiaoTong University, Beijing, China
maom_idyllic@163.com

Abstract. With the wide spread of China's digital economy, the banking is also in the development of continuous innovation and gradually towards intelligent. As the pillar of the banking, how commercial banks adapt to the background of digital economy to play a more meaningful role and produce more efficient is worth in-depth study. Collecting the data of 16 commercial banks in 2014–2020, the paper gives actual measurement on bank efficiency by using the Data Envelopment Analysis (DEA), and compares the efficiency size and change trend of commercial banks with different attributes. It is found that for state-owned commercial banks and national joint-stock commercial banks, the core reason for the reduction of comprehensive efficiency is scale efficiency, while for urban commercial banks, the pure technical efficiency mainly leads to their reduction of comprehensive efficiency. Moreover, the overall level of total factor productivity of banks in China shows the result of rising, and technological progress factor plays an indispensable role in the growth process. Finally, the paper provides some suggestions to further perfect the efficiency and development direction of China's commercial banks.

Keywords: Commercial Bank · Data Envelopment Analysis · Malmquist Productivity Index · Bank Efficiency

1 Introduction

With the rapid growth of digital economy, the software and the Internet have further penetrated the banking industry to achieve innovation in data management and data application capabilities. Cloud computing and big data make the internal and external links of the bank smoother and more accurate. The promotion of mobile banking, smart window and digital currency has created smart achievements of this era. Under this background full of opportunities and challenges, China's banking industry tries to find the way to realize reform and transformation. In the face of the sudden epidemic, China's commercial banks give full play to the various resource advantages formed in the development of digital economy, and realize the value of data to overcome the environmental pressure. The number of listed commercial banks in China has also increased

D. Qiu et al. (Eds.): ICBBEM 2022, AHIS 5, pp. 482–493, 2023.
https://doi.org/10.2991/978-94-6463-030-5_49

year by year. By the end of 2020, there were 54 listed banks with their own characteristics. However, in the process of increasing the use of digital tools, the adaptability and management mode of the introduction of digital technology are ignored, resulting in the waste of resources [11]. Facing the changing market environment, how to effectively occupy the market share and rise the non-performing loans, commercial banks need to adjust and adapt under a series of macro and micro impacts to maintain the trend of continuous growth of bank efficiency.

Commercial bank efficiency reflects whether banks have effectively allocated their resources [14]. It is the general term of bank input-output ability and sustainable development ability. At present, scholars have implemented in-depth and multiple perspectives research on the bank efficiency. Firstly, for technical efficiency, the early research found obvious technical inefficiency, which is mainly due to its scale inefficiency of state-owned banks [8]. Besides, with the increase of bank assets, the efficiency level shows an observable and clear trend of first increasing and then decreasing. In the later stage, after more comprehensive calculation [10], China's commercial banks generally improve their operating efficiency, and point out that most commercial banks have the problem of excess input of production factors from the different perspectives of returns to scale. For cost efficiency and profit efficiency, the research indicates methodically that the profit efficiency of commercial banks (54%–69%) is clearly lower than the cost efficiency (73%–89%) [9]. The banking industry in the United States has also found that there is poor efficiency in cost and profit [1], and believes that the latter is more important than the former. Some scholars also compare the efficiency of Chinese banks with that of foreign banks [15].

In terms of research methods of commercial bank efficiency, Data Envelopment Analysis (DEA) is one of the nonparametric methods. It originated from linear programming and was first applied to the exploration of commercial bank efficiency by Sherman and Gold (1985) [12]. Nonparametric method is more suitable for commercial banks with small sample size, multiple input and multiple output and uncertain production function [2]. Based on the C2R model in DEA and combined with the analysis of Malmquist, Cui and Xu (2015) [3] pointed out the efficiency differences and investigated the dynamic impact of efficiency on the output index in time series. Subsequently, scholars continuously optimized the DEA model, upgraded it to two-stage network DEA [5] and DEA three-stage model [4], and applied it into the comprehensive evaluation of the efficiency of 27 urban commercial banks, to find the obvious regional characteristics of urban commercial banks [7]. In addition, some other efficiency research methods on commercial banks, such as Stochastic Frontier Analysis (SFA) [6], SBM model [13], Multidirectional Efficiency Analysis (MEA) [16], have been applied by scholars.

The paper selects the input and output indicators and the samples of listed commercial banks in China to make an efficiency evaluation. Through quantitative analysis, the paper calculates the comprehensive technical efficiency and Malmquist from the static and dynamic perspectives, and analyses the efficiency size and change trend of different types and characteristics of banks. The research results and suggestions will have important practical guiding value for China's commercial banks to integrate into the market environment and improve bank efficiency, have far-reaching significance in maintaining

the normal operation of China's financial market. It will also contribute to building a modern economic system and enhancing the sustainability of economic development.

2 Methodology

2.1 Efficiency Measurement Method: Data Envelopment Analysis

Data Envelopment Analysis (DEA), an efficiency evaluation method of nonparametric estimation, is a forceful way to judge the relative efficiency of decision-making units first proposed and attempted to use by the American operational research scientists Copper, Charnes and Rhodes in 1978. According to the input index and output index, it uses the method of linear programming to form a relatively effective evaluation of the same type of units that can be compared. This method is based on the "two inputs and one output" model, and then extended to the "multi input and multi output" model to calculate the production front of the tested unit. The efficiency value is 1, and other efficiency values not on the boundary are 0–1. The result of efficiency can judge whether there is input surplus and output deficiency in the decision-making unit, which is helpful to calculate the optimal input-output.

Based on whether the return to scale is variable, with accurate calculation, DEA model can be divided into CCR model and BCC model. The former, for the constant return to scale, evaluates the resource allocation capacity and utilization efficiency of the decision-making unit, and measures the comprehensive technical efficiency (TE). Based on CCR model, BCC model considers the variable scale effect, removes the influence of scale change from the overall efficiency, and obtains pure technical efficiency (PTE). Pure technical efficiency means that the production and operation efficiency of an enterprise affected by qualifications such as its management methods and core technology. Moreover, scale efficiency (SE) reflects the difference between the existing scale and the optimal scale under the premise of determined regulations. The relationship between them is as follows: PTE = TE/SE.

2.2 Malmquist Index

Malmquist index was proposed tentatively by Malmquist, a Swedish economist and statistician, in 1953. It was originally used to analyse the changes and trends of consumption in different periods. Later, in 1982, Caves and others first used it as a productivity index to form a nonparametric Malmquist index method, which was then widely used in various fields. It provides a dynamic analysis of efficiency. The expression is as follows.

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

(x^t, y^t) and (x^{t+1}, y^{t+1}) show the input-output vectors in T period and T + 1 period respectively. If $M > 1$, it indicates the efficiency is improved; If $M < 1$, it shows the efficiency is reduced.

Table 1. Selection of input and output indicators.

Input Items	Output Items
Net Fixed Assets	Interest Income
Operating Expenses	Non-Interest Income
Number of Employees	Total Loans

Table 2. Selection of 16 Commercial Banks.

Type of Commercial Bank	Name of Commercial Bank
State-Owned Commercial Bank	Industrial and Commercial Bank of China
	Bank of China
	Agricultural Bank of China
	China Construction Bank
	Bank of Communications
Joint-Stock Commercial Bank	China CITIC Bank
	China Merchants Bank
	China Minsheng Bank
	Shanghai Pudong Development Bank
	Huaxia Bank
	Industrial Bank of China
	Ping An Bank
Urban Commercial Bank	Bank of Beijing
	Bank of Nanjing
	Bank of Ningbo
	Bank of Zhengzhou

Malmquist index, according to its algorithm and definition, can be divided into technical change (Techch) and efficiency change (Effch). Efficiency change can also be further decomposed into pure technical efficiency change (Pech) and scale efficiency change (Sech), expressed as: Tpfch = Effch × Techch = (Pech × Sech) × Techch.

2.3 Input and Output Indicators

Different from the general input-output enterprises, banks have particularity and have various effects on China's financial industry, so they need to be measured from various angles when considering the input and output factors. The input items and output items determined in this paper are shown in Table 1.

2.4 Sample Selection and Data Source

In order to make the research more reasonable and comprehensive, and meet the condition that the number of decision-making unit samples is not less than twice the sum of indicators in DEA model, the paper chooses 16 listed commercial banks in China, including 5 state-owned commercial banks, 7 national joint-stock commercial banks and 4 urban commercial banks, as shown in Table 2. The selected sample banks cover most regions of China.

Based on the China Financial Yearbook and supplemented by the annual reports of each bank, the annual data of 16 commercial banks from 2014 to 2020 were obtained.

3 Efficiency Measurement Results

3.1 Static Analysis Based on DEA

According to the above selected input-output indicators, the data of 16 Chinese commercial banks from 2014 to 2020 are statistically processed by Deap2.1. The measurement results of efficiency according to the three types of state-owned commercial banks, national joint-stock commercial banks and urban commercial banks are shown in Table 3.

In the comprehensive technical efficiency of sample banks, the average efficiency of Chinese commercial banks was more than 0.9 from 2014 to 2017, while the average efficiency decreased from 2017 to 2020. It reflects the level that the efficiency of China's commercial banks in these years is not very effective, but the development state is good. According to the analysis, it may be related to the background of digital economy. To accelerate the realization of digital economy innovation and achieve new policy objectives, banks need time to adapt and consider the later reform direction, clarify the information platform construction of digital asset management and online products and services. This requires banks to weigh the source of funds and the use and distribution of resources, and constantly explore the appropriate ratio of input and output. In addition, Due to the epidemic factors in 2020, the overall business development level and operation management of the bank have been seriously affected, resulting in a large amount of input cannot get the due output, and the efficiency has not achieved ideal results.

In order to judge the efficiency measurement results of different types of commercial banks more clearly, the paper analyses the comprehensive technical efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE) respectively.

3.1.1 Analysis of Comprehensive Technical Efficiency

The average comprehensive technical efficiency of China's commercial banks from 2014 to 2020 is shown in Fig. 1.

According to Fig. 1, from the five-year trend, the comprehensive technical efficiency of those three types of banks has formed the characteristics of declining volatility. Among them, the state-owned banks have the similar trend with the joint-stock banks. It can also be seen that these two forms of banks occupy an important position in China's banking industry.

Table 3. Efficiency values of three types of commercial banks from 2014 to 2020.

Type of Commercial Bank	Efficiency	2014	2015	2016	2017	2018	2019	2020
State-Owned Commercial Bank	TE	0.941	0.931	0.822	0.920	0.751	0.740	0.734
	PTE	0.989	0.994	0.994	1.000	1.000	1.000	1.000
	SE	0.950	0.935	0.827	0.920	0.751	0.740	0.734
Joint-Stock Commercial Bank	TE	0.971	0.980	0.943	0.976	0.938	0.903	0.902
	PTE	0.983	0.986	0.983	0.980	0.958	0.958	0.951
	SE	0.988	0.994	0.957	0.996	0.979	0.944	0.950
Urban Commercial Bank	TE	0.902	0.938	0.932	0.949	0.864	0.760	0.762
	PTE	0.937	0.950	0.942	0.970	0.898	0.919	0.895
	SE	0.963	0.987	0.990	0.979	0.957	0.829	0.847
Mean	TE	0.945	0.954	0.902	0.952	0.861	0.816	0.815
	PTE	0.973	0.979	0.976	0.984	0.956	0.961	0.952
	SE	0.970	0.974	0.925	0.968	0.902	0.852	0.857

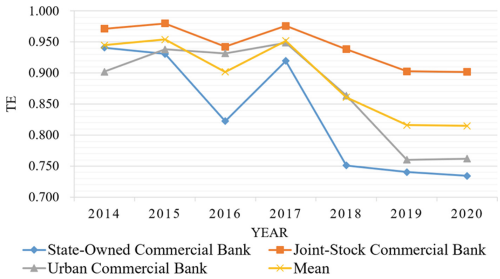

Fig. 1. Average comprehensive technical efficiency of China's commercial banks from 2014 to 2020.

In contrast, joint-stock banks have the highest comprehensive technical efficiency, and the average value in five years is the closest to 1.000, which is closely related to the high-quality management and continuous innovation of joint-stock banks. It is the goal of joint-stock commercial banks to continue to be at the forefront of business management, explore diversified business models, use the platform to create a "financial+" integration scene, and build a financial ecosystem for travel, medical treatment, shopping, government affairs and so on. Moreover, it is relatively excellent in grasping the asset quality level, to maintain a good state and continuously accumulate experience, which can further improve the efficiency.

3.1.2 Analysis of Pure Technical Efficiency

Pure technical efficiency can judge the management level and the reasonable allocation of production resources of commercial banks under the given investment scale. The

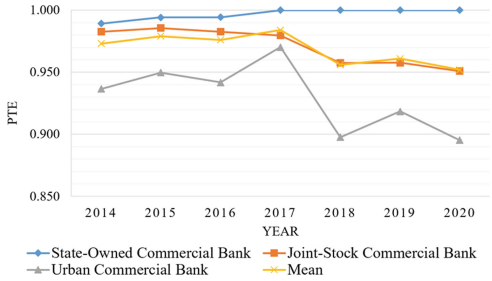

Fig. 2. Average pure technical efficiency of China's commercial banks from 2014 to 2020.

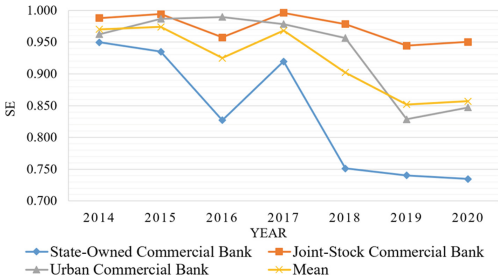

Fig. 3. Average scale efficiency of China's commercial banks from 2014 to 2020.

average pure technical efficiency of China's commercial banks from 2014 to 2020 is shown in Fig. 2.

In Fig. 2, the overall pure technical efficiency level of China's commercial banks has achieved a great state of more than 0.950. Compared with other types of banks, state-owned banks have the highest pure technical efficiency and reach pure technical efficiency to 1 from 2017 to 2020. State owned commercial banks have early establishment and directly be controlled by the Ministry of Finance. They are relatively mature in terms of technology and internal management. They can also obtain unified command and strict control in terms of financial innovation and intellectual empowerment. However, the level of internal management of local banks is not uniform, and the level of internal management of local banks needs to be improved.

3.1.3 Analysis of Scale Efficiency

Scale efficiency has a strong restrictive effect on the scale utilization of banks, which can measure the distance between the investment scale and the optimal scale. The average scale technical efficiency of China's commercial banks from 2014 to 2020 is shown in Fig. 3.

In Fig. 3, the joint-stock banks have the highest average scale efficiency in recent years, while that of state-owned banks is poor. Combined with Table 4, it can also be clear that the five state-owned banks in 2020 are in the stage of diminishing returns to scale.

Table 4. Returns to scale of 16 commercial banks in 2020.

Name of Commercial Bank	Returns to Scale
Industrial and Commercial Bank of China	Drs
Bank of China	Drs
Agricultural Bank of China	Drs
China Construction Bank	Drs
Bank of Communications	Drs
China CITIC Bank	Drs
China Merchants Bank	Drs
China Minsheng Bank	Drs
Shanghai Pudong Development Bank	-
Huaxia Bank	Drs
Industrial Bank of China	Drs
Ping An Bank	-
Bank of Beijing	-
Bank of Nanjing	Irs
Bank of Ningbo	Irs
Bank of Zhengzhou	Irs

In Table 4, both state-owned banks and joint-stock commercial banks show decreasing and constant returns to scale, and the proportion of output increase is less than that of input increase. On the contrary, the performance of urban commercial banks is that the return to scale remains unchanged and increases, which is due to the insufficient input of production factors. State owned commercial banks have the characteristics of wide range of assets and many business outlets, while the digital economy drives the opening of banking platforms and online businesses, and users can complete business processing independently on mobile phones or computers. Therefore, the utilization rate of offline business outlets has decreased significantly. In addition, in terms of personal consumption, as the payment scene is in the hands of Internet enterprises, the existence of third-party payment has a tremendous impact on banks, resulting in a large proportion of the asset scale generated by loan consumption cannot be met.

3.2 Dynamic Analysis Based on Malmquist Index

The increase or decrease of factor characteristics every year will jointly affect the productivity of commercial banks. Since the total factor productivity index indicates the change of efficiency between two years, the paper defaults the Malmquist value in 2014 to 1, and the calculation results from 2015 to 2020 are shown in Table 5.

Table 5. Malmquist index and its decomposition of China's commercial banks from 2014 to 2020.

Year	Effch	Techch	Pech	Sech	Tfpch
2014–2015	1.010	1.036	1.006	1.004	1.046
2015–2016	0.942	1.189	0.999	0.943	1.120
2016–2017	1.061	0.899	1.008	1.053	0.954
2017–2018	0.895	1.183	0.970	0.923	1.059
2018–2019	0.948	1.078	1.012	0.937	1.022
2019–2020	0.997	1.032	0.992	1.005	1.029
Mean	0.974	1.065	0.998	0.976	1.037

Table 6. Malmquist index and its decomposition of 16 commercial banks.

Name of Commercial Bank	Effch	Techch	Pech	Sech	Tfpch
Industrial and Commercial Bank of China	0.932	1.082	1.000	0.932	1.008
Bank of China	0.975	1.046	1.000	0.975	1.020
Agricultural Bank of China	0.977	1.052	1.012	0.966	1.027
China Construction Bank	0.947	1.085	1.000	0.947	1.027
Bank of Communications	0.968	1.100	1.000	0.968	1.065
China CITIC Bank	0.990	1.076	1.000	0.990	1.066
China Merchants Bank	0.970	1.088	1.000	0.970	1.056
China Minsheng Bank	0.977	1.107	0.985	0.992	1.082
Shanghai Pudong Development Bank	1.000	1.039	1.000	1.000	1.039
Huaxia Bank	0.976	1.077	0.973	1.003	1.052
Industrial Bank of China	0.996	1.036	1.000	0.996	1.031
Ping An Bank	1.000	1.035	1.000	1.000	1.035
Bank of Beijing	1.000	1.025	1.000	1.000	1.025
Bank of Nanjing	0.977	1.024	0.991	0.987	1.001
Bank of Ningbo	0.949	1.096	1.003	0.946	1.040
Bank of Zhengzhou	0.955	1.074	1.000	0.955	1.025
Mean	0.974	1.065	0.998	0.976	1.037

According to Table 5, in the sample period, the average TFP of China's commercial banks is 1.037, reflecting that the overall level of it of China's banks is on the rise. For decomposition, the average value of efficiency change decreased by 2.6% and the average value of technical change increased by 6.5%. Combined with the analysis of the comprehensive technical efficiency of commercial banks in the previous section, it

indicated a downward trend as a whole and the decline was greater than the rise, which has a direct inhibitory effect on the change of total factor productivity.

Furthermore, by examining the heterogeneity of total factor productivity, the paper finds that the average Malmquist index of 16 sample banks is above 1, as shown in Table 6.

Moreover, the technical progress efficiency of each sample bank has increased. Thus, it can be considered that the technical progress factor of commercial banks as a key force to enhance the growth of total factor productivity. In the process of adapting to the era of digital economy, commercial banks improve their technical level by using technological means and scientific equipment. It can not only improve the efficiency and accuracy of business processes for banks, but also bring convenience to customers and promotes the realization of digital development.

4 Conclusions and Suggestions

According to the efficiency measurement results, the comprehensive efficiency of commercial banks under the digital economy reform has not reached DEA efficiency, and the efficiency of different types of commercial banks varies greatly. For state-owned banks and national joint-stock banks, the reduction of comprehensive efficiency is mainly formed by scale efficiency, while for urban commercial banks, the reduction of efficiency is mainly caused by pure technical efficiency. Based on the analysis of Malmquist index, the efficiency of China's commercial banks displayed an overall upward trend from 2014 to 2020. Among them, technological progress mainly promotes the improvement of comprehensive efficiency.

The paper uses scientific statistical software to consider the efficiency and phenomena of commercial banks, and then gives reasonable suggestions for further improvement. For the comprehensive technical efficiency, a crucial way to enhance the technological efficiency is to adapt to and make use of the digital economy environment and realize the diversified development and innovation of commercial banks. Relying on modern financial technology and blockchain technology to strengthen management, can make the judgment and decision-making ability of commercial banks more accurate and promote the strategic transformation of banks. It also needs to expand the development space of banking business, analyse bank customer behaviour through big data to break through the homogenization of products and services. For the pure technical efficiency, the essential measure is that the bank needs to continuously strengthen the internal system construction, which includes bank asset management and organization management. In the process of providing asset loans, commercial banks should establish a credit decision-making mechanism and standardized risk assessment with the help of big data and information processing technology. For scale efficiency, commercial banks need to appropriately adjust the scale and number of branches to form a configuration pattern of "the sparrow may be small but it has all the vital organs". In addition, the entry of foreign banks can create a benign competition platform in the industry, which will appropriately stimulate the development potential of domestic commercial banks to form high-quality output results.

References

1. Berger, A.N. and Mester L, J., Inside the Black Box What Explains Differences in Efficiencies of Financial Institutions [J]. Journal of Banking and Finance, 1997 (21): 895–947.
2. Chen Fusheng. Evaluation and Analysis on the Measurement Theory of Business Efficiency of Commercial Banks–An Analysis of Business Efficiency of Commercial Banks in China [J]. Fujian Finance, 2010 (03): 17–19.
3. Cui Zhiwen, Xu Fang. Efficiency Evaluation of Commercial Banks Based on DEA Method [J]. Friends of Accounting, 2015 (15): 26–29.
4. Fried, H.O, Lovell, S. Schmidt, et.al. Accounting for the Environment Effects and Statistical Noise in Data Envelopment Analysis [J]. Journal of Productivity Analysis, 2002.
5. Han song, Wang Erming. The Study on Research on Chinese Commercial Banks Overall Efficiency–Based on Composite Network DEA Model with Intermediate Input and Intermediate Output [J]. Economic Theory and Business Management, 2015 (08): 81–91.
6. Hou Yu, Zhan Mingjun. Empirical Study of Efficiency of Commercial Banks and Its Influencing Factors [J]. Taxation and Economy, 2012 (01): 20–28.
7. Jiang Shubin. Efficiency Evaluation of China's Urban Commercial Banks from 2009 to 2013--An Empirical Analysis Based on Three-Stage DEA Model [J]. Journal of Finance and Economics, 2016 (01): 60–63.
8. Liu Hantao. Measurement of the Efficiency of China's Commercial Banks: Application of DEA Method [J]. Economic Science, 2004 (06): 48–58.
9. Liu Xing, Zhang Jianbin. A Study of the Cost Efficiency and Profit Efficiency of China's Listed Commercial Banks [J]. Contemporary Finance and Economics, 2010 (03): 61–67.
10. Liu Yihong. Efficiency Evaluation of Commercial Banks in China Based on DEA Model [J]. Financial Theory & Practice, 2019 (09): 69–77.
11. Lu Minfeng, Wang Tingting. Research on Digital Asset Operation and Management Strategy Based on Digital Economy Background–Taking Commercial Banks as an Example [J]. Southwest Finance, 2019(11): 80–87.
12. Sherman, H. D. and GoId, F., Bank Branch Operating Efficiency an Evaluation with the Date Envelopment Analysis [J]. Journal of Banking and Finance, 1985 (9): 297–315.
13. Wang Bing, Zhu Ning. Research on Efficiency and Total Factor Productivity of Chinese Listed Commercial Banks under the Constraint of Non-Performing Loans--An Empirical Analysis Based on SBM Directional Distance Function [J]. Journal of Financial Research, 2011 (01): 110–130.
14. Wang Cong, Tan Zhengxun. Influence of Macro Factors, Property Rights Institution and Market Structure over the Efficiency Structure of Chinese Commercial Banks [J]. Economic Research Journal, 2007 (07): 110–123.
15. Zhang Jianhua, Wang Peng. A Study on Bank Efficiency and Its Impact Factors—International Comparison of Banking Industry [J]. Journal of Financial Research, 2011 (05): 13–28.
16. Zhu Ning, Liang Lin, Shen Zhiyang, Du Wenjie. Endogenous Efficiency of Chinese Commercial Banks and Its Decomposition under the China's New Normal Economy [J]. Journal of Financial Research, 2018 (07): 108–123.