Operating Efficiency Analysis of Listed Companies in Digital Industry: A Malmquist Approach

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Abstract. This paper aims to use nonparametric frontier techniques to investigate the extent and causes of operating efficiency changes of listed companies in the digital industry in China. 54 listed companies from 2018 to 2020 are selected as samples, their total factor productivity is calculated by using the Malmquist productivity index method by Deap2.1 software and decomposed into changes in technical efficiency and technological progress. The results given by software show that the operation efficiency of China's digital industry listed companies need to be further improved. Technological progress is the main factor restricting the efficiency of operation. The pure technical efficiency and scale efficiency have declined in the period of 2019–2020, which is most likely to be affected by COVID-19. With the stability of the epidemic in China and the further development and growth of the digital economy, listed companies in the digital industry should pay attention to the balance between the expansion of business scale and the improvement of pure technical efficiency while focusing on improving technological innovation.

Keywords: Digital Industrialization · Malmquist Productivity Index Method · Operating Efficiency · China

1 Introduction

In the early days, the digital economy in China was mainly based on information construction and e-commerce development. Since 2015, with the implementation of a series of Internet policies, China's digital economy has shown blowout growth. In 2017, the term 'digital economy' appeared in the government work report for the first time. At present, promoting the development of digital economy has become a key force for China to implement major national strategies.

Digital economy takes digital knowledge and information as the key production factors, digital technology innovation as the core driving force, and modern information network as the important carrier. In the process of deep integration with the real economy, Digital Industrialization and Industrial Digitization are divided into two directions. Digital Industrialization refers to the development of information industry, while

D. Qiu et al. (Eds.): ICBBEM 2022, AHIS 5, pp. 1410–1418, 2023.
https://doi.org/10.2991/978-94-6463-030-5_140

Industrial Digitization refers to the digital transformation of traditional industries. As an economic entity under Digital Industrialization, digital industry listed companies cover electronic information manufacturing industry, telecommunications industry, software and information technology service industry and Internet industry. They represent the latest development direction and achievements of the new generation of information technology and are committed to providing technologies, products, services and digital solutions for the Industrial Digitization. They are the forerunner of the development of digital economy. Analyzing and studying the business performance of such companies and finding out the key pain points and weaknesses are of great practical significance to the development of companies, the development of digital industry and the high-efficiency supply of Industrial Digitization.

Malmquist productivity index method, one of the methods in the Data Envelopment Analysis, is widely used to dynamically analyze the efficiency changes in each decision-making unit over time without explaining specific standards of conduct. This method can effectively avoid the impact of different dimensions, different units and insufficient data on the results. Li et al. observed over 10 years data of 742 Chinese listed companies and suggested that Malmquist offers insights into the competitive position of a company in addition to accurate financial distress predictions based on the DEA efficiency measures [8]. Agashe et al. compared and discussed the productivity changes of passenger vehicles in the automobile sector for the period of five years through the Malmquist productivity index [1]. Naz et al. decomposed the Malmquist productivity index into technical efficiency and technological progress, and determined their contribution to the growth of Pakistan mutual fund. On the basis of analyzing the impact of relevant incentive policies on the innovation efficiency of China's high-end manufacturing industry [9]. Li & Liu uses Malmquist productivity index method to measure the impact of incentive policies related to high-end manufacturing industry on dynamic innovation efficiency of China's high-end manufacturing industry in 2012–2017 [7]. Junior et al. used Malmquist productivity index method to analyze the efficiency of infrastructure and flight consolidation efficiency of public and private international airports in Brazil, and confirmed that there are significant differences in efficiency between government-managed airports and those under concession to the private sector [6]. Gurjar et al. found that banks in India adopted financial innovation to earn more profits through various off-balance sheet tools, so they used the Malmquist method to study the impact of these items on the efficiency of selected banks [5]. Wang et al. used Malmquist model to assess the total productivity growth rates of top 14 seaport companies in Vietnam, and decomposed it into technical efficiency change and technology investment [10]. Alam analyzed all the 24 life insurance companies' productivity performance in India from the financial year 2012–2013 to 2016–2017 using the Malmquist index [2]. Chen et al. evaluated the scale effect in the sector by employing a parametric Malmquist index based on a heteroscedastic true fixed-effects stochastic frontier model to estimate technical efficiency and total factor productivity for China's 30 grid companies [3].

By analyzing the literature, it is found that there are few studies focusing on the actual production efficiency and operation results of digital industrial economic entities, and fewer studies quantitatively exploring the dynamic trend and evolution of efficiency of such companies in the current period. Therefore, according to the needs of the development of digital industry, based on the data of listed companies, this paper uses Malmquist productivity index method to analyze and evaluate its operation efficiency from a dynamic perspective, finds the factors restricting the improvement of business performance, and provides decision support for the development of China's digital industry and its economic entities.

2 Materials and Methods

In order to analyze the operation efficiency of China's digital industry economic entities in recent years from a dynamic perspective, these research questions need to be verified: How does the productivity of digital industry change? Is the changing operating efficiency influenced by technological progress? Were the changes in operating efficiency significantly influenced by a technical efficiency? Therefore, the Malmquist productivity index method is selected.

2.1 Methods

Malmquist productivity index method is based on the concept of non-parametric distance function to measure productivity. Using the geometric mean of the Malmquist productivity index of the t and (t + 1) period, Färe et al. constructed the productivity variable M index from t to (t + 1) [4]. The Malmquist index for decision unit productivity improvement from t to (t + 1) period is defined as following mathematical expression.

$$M_0(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{D_0^{t+1}(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_t, y_t)} \times \frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^t(x_t, y_t)} \right]^{1/2} \tag{1}$$

In Eq. (1), (x_t, y_t), (x_{t+1}, y_{t+1}) are input-output vectors of time t and t + 1 respectively, D_0^t, D_0^{t+1} are the distance functions between the actual output and the optimal output in the ideal state at time t and t + 1 respectively.

Moreover, Färe further identified the key factors, which affect the ineffectiveness of total factors productivity (TFP) in decision-making units, from the perspectives of comprehensive technological efficiency fluctuations, pure technology efficiency fluctuations, scale efficiency fluctuations, and technological progress fluctuations.

$$M_0(x_t, y_t, x_{t+1}, y_{t+1}) = TC_{t,t+1} \times TEC_{t,t+1} \tag{2}$$

$$TC_{t,t+1} = \left[\frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_{t+1}, y_{t+1})} \times \frac{D_0^t(x_t, y_t)}{D_0^{t+1}(x_t, y_t)} \right]^{1/2} \tag{3}$$

$$TEC_{t,t+1} = PTEC_{t,t+1} \times SEC_{t,t+1} \tag{4}$$

$$PTEC_{t,t+1} = \frac{D_0^{t+1}(x_{t+1}, y_{t+1} / VRS)}{D_0^t(x_t, y_t / VRS)} \tag{5}$$

$$SEC_{t,t+1} = \frac{D_0^{t+1}(x_{t+1}, y_{t+1} / CRS)}{D_0^t(x_t, y_t / CRS)} \times \frac{D_0^t(x_t, y_t / VRS)}{D_0^{t+1}(x_{t+1}, y_{t+1} / VRS)} \quad (6)$$

In Eqs. (2)–(6): TC is technological change and TEC is technological efficiency change. PTEC is pure technological efficiency change and SEC is scale efficiency change. VRS and CRS stand for variable return to scale technical assumption and constant return to scale technical assumption. The total factor productivity change can be divided into technological progress change and technological efficiency change. The technological efficiency change can be divided into pure technological efficiency change and scale efficiency change.

2.2 Data

The input and output variables are selected according to the relevant research on the evaluation indicator system of operating efficiency and combine with the characteristics of digital industry. The input and output variables are shown in Table 1.

Operating efficiency input variables are often selected from the perspective of resources consumed by operation. This paper chooses the number of employees to measure the human resources invested by the companies, the operating cost to measure the material resources consumed in the operation process, and the total assets to measure the capital, intangible assets and other assets invested by the companies. As R&D is the lifeline of the development of digital industrial and has a significant impact on the business performance of companies, the R&D investment variable is increased and measured by the total R&D investment, so as to form a more comprehensive investment indicator system composed of human capital, cost, assets and expenses.

Output variables often reflect the operating conditions of enterprises, which are usually selected from income variables and profit variables. The commonly used revenue variables are operating income, while there are many profit variables. Because the digital industry is greatly affected by government subsidies, the Net Profits after Deduction of Nonrecurring Profits and Losses is selected as the variable to measure the profitability.

Because the term ‘Digital Economy’ first appeared in the government work report in 2017, 2018–2020 is selected as the research time. According to the listed companies covered by digital economy concept stocks in Choice Financial Database, a total of 54 enterprises is obtained as the research sample. All the data come from the annual report of companies disclosed by Cninfo Website.

3 Results and Discussion

Based on the input and output data, the Malmquist productivity index method is used to calculate the operating efficiency of 54 listed companies in digital industry by Deap2.1 software. Malmquist productivity index and its decomposition results from 2018 to 2020 are shown in Table 2.

As can be seen from Table 2, the total factor productivity of the operating efficiency of listed companies in digital industry in 2018–2020 was 0.956, which shows that the operating efficiency in 2020 decreased by 4.4% compared with that in 2018. This is

Table 1. Input and output variables used for evaluate operating efficiency.

Variable Type	Variable Name	Description
Input Variables	Human Resources	Total employees of the company(Number)
	Material Resources	Operating Cost disclosed at the end of the period (Million yuan)
	Capital & Assets	Total Assets disclosed at the end of the period (Million yuan)
	R&D Investment	Total amount of R&D expenditures (Million yuan)
Output Variables	Income	Business Income disclosed at the end of the period (Million yuan)
	Profit	Net Profits after Deduction of Nonrecurring Profits and Losses disclosed at the end of the period (Million yuan)

Table 2. Dynamic changes of operating efficiency of listed companies in digital industry under Malmquist method in 2018–2020.

Year	TEC	TC	PTEC	SEC	TFP
2018–2019	1.040	0.904	1.030	1.009	0.940
2019–2020	0.957	1.015	0.996	0.961	0.972
Mean	0.998	0.958	1.013	0.985	0.956

because the average change of technical efficiency and technological progress in 2018–2020 were less than 1. In 2020, compared with 2018, the technical efficiency decreased by 0.2%, and the technical progress decreased by 4.2%.

From 2018 to 2019, the pure technical efficiency and scale efficiency in 2019 were improved compared with 2018, however, due to the slowdown of technological progress, the total factor productivity of operating efficiency was 0.940, less than 1. It can be seen that technological progress is the main factor hindering the improvement of operating efficiency. From 2019 to 2020, the pure technical efficiency fluctuation and scale efficiency fluctuation were 0.996 and 0.961 respectively, suggesting that pure technical efficiency decreased by 0.4% and the scale efficiency decreased by 3.9%. This is most likely due to the influence of COVID-19, which made operation management and personnel management of listed companies in digital industry more difficult, resulting in a decline of pure technical efficiency. At the same time, the speed of traditional enterprise informatization and cloud computing suddenly accelerated, and the listed companies in the digital industry was not enough to meet the surging market demand, resulting in a larger scale efficiency decline. Under the influence of the epidemic, companies paid more attention to technological innovation, and the technological progress increased by 1.5% in 2020.

According to the results of Malmquist productivity index of each company from 2018 to 2020, the distribution of TFP of 54 listed companies is shown in Table 3. From

Table 3. Total factor productivity distribution of 54 listed companies in digital industry in 2018–2020

Direction and Degree of TFP Change	Value or Range of TFP Change	Number of Companies	Proportion
Decrease, more than15%	[0.701,0.844]	4	7.41%
Decrease, (10%-15%]	[0.853,0.892]	5	9.26%
Decrease, (5%-10%]	[0.900,0.949]	11	20.37%
Decrease, (0%-5%]	[0.953,0.998]	22	40.74%
Increase, [0%-5%]	[1.003,1.038]	9	16.67%
Increase, (5%-10%]	1.092	1	1.85%
Increase, (10%-15%]	1.153	1	1.85%
Increase, more than15%	1.252	1	1.85%

2018 to 2020, there were 12 companies with total factor productivity exceeding 1, and the highest TFP was 1.252, which means that the operating performance of the enterprise in 2020 increased by 25.2% compared with 2018. The total factor productivity of each of the remaining 42 companies was less than 1, accounting for 77.78% of the sample companies. It can be seen that the impact of the epidemic on digital economy enterprises was relatively extensive. There are 22 companies that the total factor productivity decreased by less than 5%, 11 companies that the total factor productivity decreased by 5%–10%, 5 companies that the total factor productivity decreased by 10%–15%, and 4 companies that the total factor productivity decreased by more than 15%. The company with the lowest TFP was 0.701, that means its operating performance decreased by 29.9% in 2020 compared with 2018.

According to the decomposition results of Malmquist productivity index of each company, the changes of total factor productivity, technical efficiency and technological progress of 54 companies are summarized, as shown in Table 4, and then the reasons for the changes of operating efficiency are analyzed.

It can be seen from Table 4 that among the 12 listed companies in the digital industry whose operating efficiency is increasing, 7 companies have achieved the common growth of technical efficiency and technological progress. The growth of total factor productivity of 4 companies is mainly affected by the growth of technical efficiency and 1 company is affected by the growth of technological progress. Among the companies with total factor productivity less than 1, 19 companies decreased their operating efficiency mainly due to

Table 4. Reasons for changes in operating efficiency of Listed Companies in digital industry in 2018–2020.

TFP	Reason		Number of Companies
TFP > 1	TEC ≥ 1, TC ≥ 1	Caused by the joint improvement of TEC and TC	7
	TEC ≥ 1, TC < 1	Caused by improvement of TEC	4
	TEC < 1, TC ≥ 1	Caused by improvement of TC	1
TFP < 1	TEC ≥ 1, TC < 1	Caused by decline of TC	19
	TEC < 1, TC ≥ 1	Caused by decline of TEC	4
	TEC < 1, TC < 1	Caused by the joint decline of TEC and TC	19

the decline of technological progress, 4 companies decreased their operating efficiency mainly due to the decline of technological efficiency, and the remaining 19 companies decreased their operating efficiency jointly due to technological progress and the decline of technological efficiency. Among the 54 enterprises, 24 enterprises showed a decline in technological efficiency, accounting for 44.44%, and 42 enterprises showed a decline in technological progress efficiency, accounting for 77.78%, of which 38 enterprises showed a decline in operating efficiency due to technological progress efficiency. It can be seen that the operating efficiency of 54 listed companies in digital industry is greatly affected by technical efficiency and technological progress, and the impact of technological progress is greater than that of technical efficiency.

4 Conclusions

This paper uses Malmquist productivity index method by Deap2.1 software to calculate the operating efficiency of 54 listed companies in digital industry from 2018 to 2020. The results given by Deap2.1 software show that on the whole, the operating efficiency of listed companies in digital industry in China needs to be further improved. Both technical efficiency and technological progress have a great impact on operating efficiency, and technological progress is the more important factor restricting the improvement of operating efficiency.

The decline of technical efficiency is more likely to be affected by COVID-19. With the stabilization of epidemic situation in China, the decline of pure technical efficiency and scale efficiency is temporary. But companies need to pay attention to that, with the expansion of business scale, higher requirements for the management system, organization structure and resource allocation in the listed companies of digital industry will inevitably be required. While improving scale efficiency, companies should pay special attention to the integration of digital business segments and the coordination of management, so as to avoid the decline of pure technical efficiency while improving scale efficiency.

Technological innovation is an important aspect for listed companies in the digital industry to improve their operating efficiency. Technological progress has increased in 2020 but slightly, and from the perspective of companies, the decline of operating efficiency of many companies is caused by the decline of technological progress. Compared with other companies, the new technologies widely recognized in the industry or maintain an advantageous position in the rapid change of technological innovation is particularly important for the sustainable operation of companies in digital industry. Listed companies in the digital industry should continue to improve their R&D capabilities, devote themselves to developing efficient and energy-saving digital equipment and systems, so that to promote technological progress,then promote the operating efficiency.

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