Evaluation on the Operation Efficiency of Medical Device Enterprises Under the Background of Digital Transformation

—Empirical Analysis Based on DEA-Malmquist

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Abstract

Based on the panel data of 15 listed medical device companies in the Yangtze River Delta region of China from 2015 to 2020, this paper uses the DEA-BCC model and the Malmquist index to measure their operating efficiency. The results show that from a static point of view, the average comprehensive efficiency, the average technical efficiency, and the average scale efficiency of the listed medical device companies in the Yangtze River Delta region are 0.916, 0.947 and 0.965 respectively. The operating efficiency is affected by both the pure technical efficiency and the scale efficiency. From the dynamic point of view, the operating efficiency of listed medical devices companies in the Yangtze River Delta region is fluctuating; The digital transformation of medical device enterprises is still in the initial stage. Based on the above research, this paper puts forward some countermeasures and suggestions, such as strengthening the independent innovation ability of Chinese medical device enterprises, accelerating the process of digital transformation, and increasing the government's support.

Keywords: medical device company, digitization, performance appraisal, Malmquist Index

1. Introduction

Medical devices belong to China's high-tech industry, which has received extensive policy support and capital attention in recent years. In December 2021, the Ministry of Industry and Information Technology, together with ten departments, issued the "Fourteen-five Medical Equipment Industry Development Planning", which pointed out that seven major equipment fields, including diagnostic and testing equipment, therapeutic equipment, monitoring and life support equipment, should be developed to support the development of original, innovative and intelligent medical equipment. As the aging population accelerates, China's demand for medical devices continues to rise. In 2019, China's medical device market ranked the second largest in the country, with market size of 623.75 billion yuan. In recent years, the growth rate has been rapid. It is expected to exceed 900 billion yuan in 2022. According to statistics, in the first half of 2021, China's medical device financing amount exceeded 30.6 billion yuan, up 50.73% year-on-year; There were over 217 financing incidents, representing a year-on-year increase of 77.87%, of which over half were of RMB100 million, reaching 105. The Yangtze River Delta region is a relatively mature gathering place for the development of China's medical device industry. The number of financing projects in the first half of the year was remarkable. Shanghai ranked first among cities with 44 projects, and Jiangsu Province ranked first among provinces with 51 projects.

Digitalization has changed the original traditional medical and health system, and Internet medical care has expanded rapidly. For medical device companies in the "golden era", how to transform and upgrade with the help of digitalization in the fierce market competition and become a sustainable enterprise important issue for development. Compared with pharmaceutical companies, the digital transformation of medical device companies is still in its infancy, and few scholars have studied the level of operational efficiency of listed medical device companies in China. This paper intends to select listed companies in the Yangtze River Delta region where the medical device industry is relatively developed as the research object, and use the DEA-BCC model and the Malmquist index to measure their operating efficiency, in order to provide useful ideas for the digital transformation of medical device companies.

2. Literature Review

With the rise of technologies such as artificial intelligence, blockchain, cloud computing, and big data, modern

society has moved from the era of the traditional industrial economy to the era of the digital economy. Fischer et al. (2020) proposed that digital transformation is the process of using digital technology to achieve business optimization, efficiency improvement and value reshaping. Digital transformation generally uses digital data to connect systems and use data analysis and automation to create intelligence in order to provide a reference for organizational decision-making. More and more companies see digital transformation as an important opportunity to achieve rapid growth and pursue digital value dividends. The research of Jiegen Huang et al. (2021) shows that differences in demand motivation lead to heterogeneity in the level of digitalization in different industries.

As an important part of the medical and health system, the medical device industry is also actively seeking innovation and accelerating the process of digital transformation. The global medical device giants have already started their layout. Philips is committed to creating overall solutions around diseases. Siemens' digital strategy will be divided into three stages: product digitalization, production process digitalization, and service digitalization. GE focuses on digital medical applications and solutions. Xiaotong Chen et al. (2018) believe that with the continuous application of new technologies and new materials, the medical device industry will definitely become an important part of the national economy, and we need to strengthen the innovation of medical device products. Ningying Mao and Dandan Ma (2018) analyzed the development path of medical device industry innovation from a dynamic perspective based on the data of the Yangtze River Delta region and the theoretical framework of the industrial innovation system.

To sum up, most of the scholars discuss the development status of the medical device industry from the macro level, and measure the efficiency of medical device companies from the perspective of technological innovation and financing at the micro level. There are many research methods for efficiency evaluation, DEA is widely used because of its advantages of dealing with multi-output and multi-input problems and judging whether the decision-making unit is located at the effective frontier. Wuyi Zhang and Yunfei Yang (2014) used the DEA-Malmquist model to measure the economic development efficiency of 30 provinces in mainland China. Jicheng Liu et al. (2018) based on the data of wind power equipment manufacturing enterprises, conducted an accounting of the operating performance of wind power equipment listed companies. Xinmei Guo et al. (2020) based on the data from 2011 to 2018, used DEA to measure the operating efficiency of 51 listed retail companies, and found that the impact of technological progress brought about by the digital transformation of the retail industry has not been fully reflected. Shubin Xu et al. (2020) An innovation efficiency index system using the number of patents and intangible assets as output indicators, and R&D personnel and R&D funds as input indicators, using the three-stage DEA model to study the innovation efficiency of artificial intelligence listed companies.

Based on the above analysis, this paper takes the digital transformation of the medical device industry as the background, uses the DEA-BCC model and the Malmquist index to quantitatively discuss the operating efficiency of 15 listed medical device companies in the Yangtze River Delta region from static and dynamic perspectives. Find the path and direction for improving the operating efficiency of listed medical device companies.

3. Research Design

3.1 Research Method

3.1.1 DEA Model

DEA model is to judge the relative efficiency of each decision-making unit by comparing it with the effective production frontier. The input-oriented DEA-BCC model proposed by BANKER et al. (1984) is shown in formula (1).

$$\min[\theta - \varepsilon(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+)] - V_d(\varepsilon) = 0 \tag{1}$$

$$s.t. \begin{cases} \sum_{j=1}^{n} X_j \beta_j + s_i^- = \theta X_0 \\ \sum_{j=1}^{n} Y_j \beta_j - s_i^+ = Y_0 \\ \sum_{j=1}^{n} \beta_j = 1 \\ \beta_j, s_i^-, s_r^+ \geq 0, 0 \leq \theta \leq 1 \end{cases}$$

Assuming that there are n decision-making units DUM, each decision-making unit DUM has m kinds of inputs and S kinds of outputs, which are expressed as X_j and Y_j, respectively, θ is the measured operating efficiency value of medical device listed companies in the Yangtze River Delta region, s_i^+ and s_i^- are slack variables. Represents the efficiency value of the i subject, the value range is (0, 1), the closer to 1, the higher the efficiency, and the highest efficiency of the decision-making unit. If and only if θ=1 and $s_i^+ = s_i^- = 0$, the DEA of the listed company is valid, otherwise the DEA is invalid.

3.1.2 Malmquist Index Model

Early scholars (CAVES et al., 1982; Fare et al., 1994) continued to establish and improve the Malmquist productivity index method based on the research results of some scholars (Wuyi Zhang and Yunfei Yang, 2014), the Malmquist index is further decomposed.

$$M(x_{t+1}, y_{t+1}, x_t, y_t) = \left[\frac{d_t(x_{t+1}, y_{t+1})}{d_t(x_t, y_t)} * \frac{d_{t+1}(x_{t+1}, y_{t+1})}{d_{t+1}(x_t, y_t)}\right]^{\frac{1}{2}} * \frac{d_{t+1}(x_{t+1}, y_{t+1})}{d_t(x_t, y_t)} = techch * pech * sech \qquad (2)$$

$d_t(x_t, y_t)$, $d_t(x_{t+1}, y_{t+1})$ are the output distances of the input and output vectors in periods t and t+1, respectively. Efficiency under the technical environment in period t，$d_{t+1}(x_t, y_t)$、$d_{t+1}(x_{t+1}, y_{t+1})$ are the efficiency functions of the output distance of the input and output vectors in the t and t+1 periods respectively under the technical environment of the t+1 period, techch represents the technological progress of the industry, pech represents the change in pure technical efficiency, and sech represents the change in scale efficiency.

3.2 Data Sources

3.2.1 DEA Model

This article takes the medical device listed companies in the Yangtze River Delta region (Jiangsu, Zhejiang, Shanghai, Anhui) announced by Shenwan Industry as the initial sample, excludes companies with incomplete data, and finally selects the companies with business activities in 2015-2020. 15 listed companies in the medical device industry. See Table 1 for details.

Table 1. Sample list of medical device companies in the Yangtze River Delta region

DUM	Company	Securities Code	Core Business	Location
A01	Iray Technology	688301	R&D, Production, Sales and Service of Digital X-ray Detector	Shanghai
A02	Vishee Medical	688580	Provide safe and effective rehabilitation products and overall solutions for medical and professional institutions	Jiangsu
A03	Micro-Tech	688029	R&D, Manufacturing and Sales of Minimally Invasive Medical Devices	Jiangsu
A04	Apon Medical	300753	Specializing in the field of pain management and nasal cavity care medical equipment products	Jiangsu
A05	Zhende Medical	603301	Production, R&D and Sales of Medical Dressing	Zhejiang
A06	Nanfang Medical	603880	Band-aids, adhesive tapes and bandages are among the industry's leading producers	Jiangsu
A07	Getein Biotech	603387	R&D, production, sales and service of in vitro diagnostic reagents and instruments	Jiangsu
A08	Autek	300595	R&D, production and sales of optometry products and related ancillary products, as well as optometry services	Anhui
A09	Kindly Enterprise	603987	R&D, production, sales and service of medical devices such as medical needles, medical infusion devices and interventional devices	Shanghai
A10	Medicalsystem	300439	R&D, production and sales of in vitro diagnostic products and providing third-party medical diagnostic services	Zhejiang
A11	Kinetic Medical	300326	R&D, Production and Sales of Minimally Invasive Interventional Surgery System in Orthopedics	Shanghai

A12	David Medical	300314	R&D, product and sales of baby care equipment	Zhejiang
A13	Dian Diagnostics	300244	Medical services and sales of in vitro diagnostic products	Zhejiang
A14	Yuyue Medical	002223	R&D, manufacturing and selling medical device products and providing related solutions	Jiangsu
A15	Kehua Bio-Engineering	002022	R&D, production and sales of in vitro diagnostic reagents and medical inspection instruments	Shanghai

Note: All the metrological data in this paper are derived from Wind and the data in each annual report of each listed company.

3.3 Variable Selection and Definition

Digital transformation helps to improve the income and profitability of enterprises and brings remarkable financial value. From the perspective of Chinese listed medical device companies, according to the construction principle of index system and referring to other scholars' research on operating efficiency, the operating income and net profit of medical device enterprises are selected as output variables (Xinmei Guo et al., 2020; Yunfei Yang et al., 2020). In the process of promoting digital transformation, enterprises will increase the investment in infrastructure such as equipment and software, as well as the increase in operating costs. Therefore, total assets, management expenses, staff salaries and fixed assets are selected as input variables.

Because some decision-making units have losses, and DEA model requires that the input and output variables cannot have negative numbers. Thus, this study standardizes all data, and the formula is as follows:

$$y_i = 0.1 + 0.9 \times \frac{x_i - min(x_i)}{max(x_i) - min(x_i)}, 1 \leq i \leq 15 \tag{3}$$

4. Empirical Results and Analysis

4.1 Static Analysis Model Based on DEA-BCC Model

According to the DEA-BCC model, the input-output data of medical device enterprises in the Yangtze River Delta region from 2015 to 2020 are calculated using DEAP2.1 software, and the average of the data results is taken as the static efficiency value, as shown in Table 2.

Table 2. DEA calculation results of operating efficiency of medical device enterprises

Company name	Comprehensive efficiency	Technical efficiency	Scale efficiency
Iray Technology	1.000	1.000	1.000
Vishee Medical	0.954	1.000	0.954
Micro-Tech	0.834	0.882	0.941
Apon Medical	0.955	0.985	0.969
Zhende Medical	0.974	0.986	0.988
Nanfang Medical	0.960	1.000	0.960
Getein Biotech	0.969	0.974	0.994
Autek	0.996	1.000	0.996
Kindly Enterprise	0.863	0.896	0.956
Medicalsystem	0.794	0.853	0.922
Kinetic Medical	0.757	0.846	0.895
David Medical	0.776	0.853	0.915
Dian Diagnostics	0.987	1.000	0.987
Yuyue Medical	0.952	0.956	0.995
Kehua Bio-Engineering	0.960	0.969	0.991
Mean	0.916	0.947	0.965

It can be seen from Table 3 that from 2015 to 2020, the average comprehensive efficiency, average technical efficiency and average scale efficiency of medical device enterprises in the Yangtze River Delta are 0.916, 0.947 and 0.965 respectively, all of which have not reached the effective frontier. Overall, the efficiency of medical device enterprises in the Yangtze River Delta region of China is low. The comparison analysis shown in Figure 1.
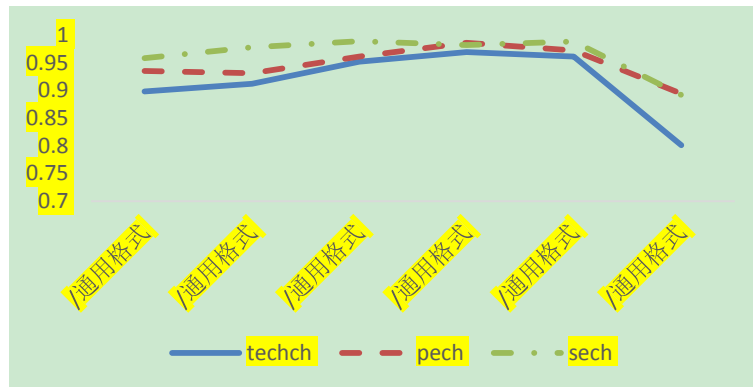

Figure 1. Average comprehensive efficiency, pure technical efficiency and scale efficiency from 2015 to 2020

As can be seen from Figure 1, the trend of comprehensive efficiency, pure technical efficiency and scale efficiency of medical device enterprises in the Yangtze River Delta region of our country from 2015 to 2020 tend to be synchronous, and the overall trend is downward. It can be seen from this that there are many reasons for the low efficiency of medical device enterprises.

4.2 Dynamic Analysis of Medical Device Operation Efficiency Based on Malmquist Index

The Malmquist productivity index of 15 medical device enterprises in the Yangtze River Delta region from 2015 to 2020 is obtained by measuring the data of 15 medical device enterprises for 6 years with DEAP2.1 software. The specific results are shown in Table 3.

Table 3. Changes of Malmquist Productivity Index of Medical Device Enterprises in Yangtze River Delta from 2015 to 2020

Year	Technical efficiency change	Technical progress index	Pure technical efficiency index	Scale efficiency index	Total factor productivity index
2015-2016	1.017	0.996	0.995	1.022	1.013
2016-2017	1.050	0.864	1.038	1.012	0.907
2017-2018	1.020	1.061	1.028	0.992	1.082
2018-2019	0.992	1.278	0.985	1.007	1.268
2019-2020	0.814	0.861	0.909	0.895	0.701
Mean	0.975	1.001	0.990	0.984	0.975

Based on the total factor productivity index, the operating efficiency of medical device enterprises in the Yangtze River Delta region showed a fluctuating downward trend, with an average value of 0.975 from 2015 to 2020 and an average annual decrease of 2.5%. The index of technological progress has slightly increased, and the technological progress effect brought by the digital transformation to the enterprises has shown. The decline of operating efficiency of medical device enterprises is mainly caused by the decline of technical efficiency, and the average change of technical efficiency is 0.975, less than 1; The average value of the technological progress index is 1.001, which indicates that the technical level of medical device industry has slightly improved, and the development of medical device enterprises at present mainly depends on technological progress. In addition, the change of technical efficiency is further decomposed into pure technical efficiency change and scale efficiency

change for analysis. From 2015 to 2020, the average change of pure technical efficiency is 0.990, and the average change of scale efficiency is 0.984, both of which are less than 1, which shows that the independent innovation ability of medical device companies still needs to be strengthened to promote technical efficiency and promote medical device companies to reach the optimal production scale stage as soon as possible. Combined with the above analysis, the decline of operating efficiency of listed medical device companies is caused by the decline of pure technical efficiency and scale efficiency.

The heterogeneity of enterprises makes the resource investment and planning and construction in the process of digital transformation different. To further analyze the different levels of operating efficiency between the medical device listed companies, the total factor productivity index of operating efficiency and its decomposition of 15 sample enterprises from 2015 to 2020 are calculated and obtained, as shown in Table 4.

Table 4. Total factor productivity and its decomposition of medical device enterprises in the Yangtze River Delta from 2015 to 2020

Company name	Technical efficiency change	Technical progress index	Pure technical efficiency index	Scale efficiency index	Total factor productivity index
Iray Technology	1.000	0.968	1.000	1.000	0.968
Vishee Medical	1.010	0.980	1.000	1.010	0.990
Micro-Tech	0.960	1.009	0.984	0.975	0.968
Apon Medical	1.000	0.999	1.008	0.992	0.999
Zhende Medical	1.012	1.050	1.000	1.012	1.063
Nanfang Medical	0.947	0.962	1.000	0.947	0.911
Getein Biotech	0.960	0.971	0.967	0.993	0.932
Autek	0.996	0.982	1.000	0.996	0.978
Kindly Enterprise	0.892	1.026	0.928	0.962	0.916
Medicalsystem	0.926	1.085	0.923	1.003	1.004
Kinetic Medical	0.966	1.109	1.036	0.933	1.071
David Medical	1.059	0.947	1.083	0.978	1.003
Dian Diagnostics	0.985	0.954	1.000	0.985	0.940
Yuyue Medical	0.935	0.996	0.941	0.994	0.931
Kehua Bio-Engineering	0.985	0.990	0.992	0.993	0.975
Mean	0.975	1.001	0.990	0.984	0.975

From 2015 to 2020, the total factor productivity of medical device enterprises in the Yangtze River Delta region showed an increasing trend, with only four samples greater than 1, namely Zhende Medical (1.063), Medical system Biotechnology (1.004), Kinetic Medical (1.071) and David Medical (1.003), and the rest were between 0.9 and 1.0, indicating that the operating efficiency of the medical device listed companies in the Yangtze River Delta region of our country has little difference and the whole company is in a good development trend. Zhende Medical is mainly engaged in the production, R&D, and sales of medical clinics. In recent years, the digital application has been integrated into the whole production process, which has promoted the reduction of labor costs and the improvement of management efficiency. Medical system Biotechnology strives to build information system projects to meet the digital needs of the company's growing business scale. Kinetic Medical owns high-value consumable product lines such as spine, trauma and joints, and is a leading enterprise of spine minimally invasive in China. It has cooperated with Taimei Medical Technology to build an enterprise clinical

research information management and operation system, helping to improve the efficiency of process management and project management. David Medical actively expands its business, with the help of internal independent research and development, and at the same time expands its product line, which continues to enrich its product line. However, because it is still in the exploratory stage, the effect has not yet fully appeared.

From the decomposition of the total factor productivity index, five listed companies, Iray Technology (1.000), Vishee Medical (1.010), Apon Medical (1.000), Zhende Medical (1.012) and David Medical (1.059), have a technical efficiency change index greater than or equal to 1. David Medical's pure technical efficiency is significantly higher than other companies, ranking first. Through its wholly-owned subsidiary, Verkaidi, David Medical has established its position as the leader of the domestic endoscopic stapler from both technical and manufacturing aspects. The change index of technical efficiency of the other 10 listed companies is between 0.9 and 1.0, which indicates that the technical level of listed companies of medical devices in the Yangtze River Delta region of China is generally good. There are 5 companies whose technological progress index is greater than or equal to 1, namely Micro-Tech (1.009), Zhende Medical (1.050), Kindly Enterprise (1.026), Medical system Biotechnology (1.085) and Kinetic Medical (1.109). Although the other 10 companies have declined to vary degrees, they remain above 0.9. With the support and attention of the national strategic level to the medical device industry, China's medical device industry as a whole has continuously strengthened the technology research and development, laying the foundation for domestic substitution import.

From the decomposition of technical efficiency change, the pure technical efficiency of 6 listed medical device companies showed a negative growth trend, and the scale efficiency index of 11 listed companies showed a negative growth trend, which further indicated that the decline of operating efficiency of listed medical device companies in the Yangtze River Delta region of China was jointly affected by the decline of pure technical efficiency and scale efficiency.

5. Conclusion and Suggestion

Based on the panel data of 15 medical device listed companies in the Yangtze River Delta region from 2015 to 2020, this paper uses the DEA-BCC model and Malmquist index to measure their operating efficiency, and draws the following conclusions: (1) From a static point of view, the trend of comprehensive efficiency, pure technical efficiency and scale efficiency of medical device listed companies in the Yangtze River Delta region in China tend to be synchronous from 2015 to 2020, with only one reaching the DEA effective level, accounting for 6.67% of the total sample. (2) From a dynamic point of view, the operating efficiency of listed medical device companies in the Yangtze River Delta region showed a fluctuating trend, with an average value of 0.975 from 2015 to 2020, with an average annual decrease of 2.5%. (3) Among the 15 sample enterprises, Kelly Tai and Zhende Medical performed best in operating efficiency, benefiting from the integration of digital applications into production and management, which improved the operating efficiency of the enterprises.

According to the conclusions, the following suggestions are put forward: Firstly, strengthen the independent innovation capability of medical device enterprises in our country. As a representative region with a high economic and high-tech level in China, the Yangtze River Delta region is at the forefront of China's medical device industry development. It should play a leading role in jointly constructing an efficient cooperation mechanism to promote the development of China's medical device industry. Secondly, promote the process of digital transformation. On the one hand, apply digitalization to enterprise management to improve enterprise operation efficiency; On the other hand, it applies digitalization to production and sales, helps product upgrade, and grasps product terminal information to improve profit rate. Thirdly, increase government support. China's medical device industry has a fragmented competition pattern with fewer large-scale enterprises. Therefore, small and medium-sized technology enterprises are the main force in the development of the industry, and the development of the industry is usually driven by the research and development and innovation of small and medium-sized technology enterprises. Therefore, special financial support policies are formulated for such enterprises to encourage their research and development of innovative products to be promoted and promote the coordinated development of the industry.

References

Banker, R.-D., Charnes, A., & Cooper, W.-W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, *30*(9), 1078-1092. https://doi.org/10.1287/mnsc.30.9.1078

Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982). The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica*, *50*(6), 1393-1414. https://doi.org/10.2307/1913388

Chen, X.-T., Zou, M.-F., Yu, H.-C., & Wang, G. (2018). Present situation and technical development of medical device industry in China. *China Medical Device Information, 49*(12), 1726-1732.

Fare, R., Grosskopf, S., Norris, M., *et al.*. (1994). Productivity growth, technical progress, and efficiency change in industrialized countries. *American Economic Review*, *8*(5), 1040-1044.

Fischer, M., Imgrund, F., Janiesch, C., & Winkelmann, A. (2020). Strategy archetypes for digital transformation: defining meta objectives using business process management. *Information & Management*, *57*(5), 103262. https://doi.org/10.1016/j.im.2019.103262

Guo, X.-M., Shen, R., & Xu, X.-M. (2020). Evaluation on the Operation Efficiency of China's Retail Listed Companies under Digital Background, *Commercial Times*, (16), 174-176.

Huang, J.-G., Ji, X.-X., & Li, Y.-X. (2021). Research on the influence of digitalization level on enterprise innovation performance---Empirical evidence from Shanghai and Shenzhen A-share listed companies. *Jiangxi Social Sciences*, *41*(5), 14.

Liu, J.-C., Yan, W.-J., & Yan, S.-L. (2018). Performance Evaluation of Listed Companies in Wind Power Equipment Manufacturing Industry Based on DEA. *Communication of Finance and Accounting*, (20), 42-46.

Mao, N.-Y., & Ma, D.-D. (2018). Dynamic Research on the Efficiency of Factor Allocation of Medical Device Industry Innovation System in Yangtze River Delta Region. *Chinese Journal of Pharmaceuticals*, *49*(12), 1726-1732.

Xu, S.-B, Li, X.-W., & Li, G. (2020). Evaluation of Innovation Efficiency of Artificial Intelligence Listed Enterprises Based on Three-stage DEA. *Science and Technology Management Research*, *40*(5), 165-172.

Yang, Y.-F., Gao, W.-Y., Zhang, Y.-F., & Hua, L.-L. (2020). Research on the Operation Efficiency of Listed Companies in China's Artificial Intelligence Industry. *Friends of Accounting*, (14), 115-121.

Zhang, W.-Y., & Yang, Y.-F. (2014). AN Evaluation on Regional Economic Development Efficiency in China---Based on DEA and Malmquist Index. *East China Economic Management*, *28*(11), 63-67.