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Research Article

Evaluation on Technology Innovation Efficiency of Big Data Enterprises Based on DEA

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ABSTRACT

Discussing the technological innovation efficiency of big data enterprises and carrying out in-depth research on big data enterprises will help to accurately evaluate the development status of big data industry and guide the development of big data industry. This paper uses DEA-BCC model to evaluate the technological innovation efficiency of 21 big data enterprises. It is found that the technological innovation efficiency of big data enterprises is better. The average values of technological efficiency, pure technological efficiency and scale efficiency are 0.587, 0.772 and 0.750, respectively. The technological efficiency of big data enterprises is lower, and the individual differences are larger. At the same time, the research shows that there are 15 big data enterprises need to further expand the scale, and then improve production efficiency.

1. INTRODUCTION

Data become the basic strategic resources of the country. The Platform for Action to Promote Big Data Development and the Big Data Industry Development Plan (2016–2020) issued by the State Council and the Ministry of Industry and Information Technology in 2015 have aroused strong repercussion. "Outline" points out that encouraging financial institution to strengthen and improve financial services, increase support for big data enterprises, and continue to enhance the prosperity of the big data industry. The Development Planning of Big Data Industry (2016–2020) [1] proposes that promoting the development of big data industry is of great significance to improving government governance ability, optimizing public services for people's livelihood, promoting economic transformation and innovation and development; studying and establishing an evaluation system for the development of big data industry is of great significance to the construction of big data resources, the degree of openness and sharing, the ability of industrial development and the level of application in China and other regions. It is of great significance to monitor, analyze and evaluate the development of the big data industry, compile and publish the development index of the big data industry, and guide and evaluate the development of the national big data.

As for the definition of big data industry, foreign scholars have not made a clear distinction between big data industry and big data. Laney [2] earlier proposed to use volume, variety and velocity to define big data. Later scholars improved the definition of big data from different perspectives. In addition, Gaff et al. [3] believes that in the development of the big data industry, the protection of big data privacy is very important, and the government should strengthen the protection. Johnson (2012) [4] put forward the formula of "Big Data + Big Analytics = Big Opportunities", pointing out that the two key driving factors of big data industry are big data and big data technology. Sun [5], a domestic scholar, first defined the data industry. He believed that the data industry can be divided into broad sense and narrow sense. The broad sense of the data industry includes the information industry, while the narrow sense of the data industry only refers to the information processing industry and the information service industry. Zhong and Zhang [6] proposed that the big data industry is an information service industry based on the collection of a large amount of information through the internet, the internet of things, cloud computing and other channels. Document issued by Guizhou Province [7] points out that the big data industry refers to the synthesis of all economic activities related to the generation and agglomeration of big data, organization and management, analysis and discovery, application and service. The "Big Data Industry Development Plan (2016–2020)" [1] issued by the Ministry of Industry and Information Technology defines the Big Data Industry as the activities of data resource construction, development, sale and leasing of big data hardware and software products, and related information technology services. The definition of big data enterprises in this paper refers to Guizhou Province's "Outline of the Development and Application Planning of Guizhou's Big Data Industry" [7], Ministry of Industry and Information Technology's "Development Planning of Big Data Industry (2016–2020), State Council's" Action Plan for Promoting

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Big Data Development" [8] and Hefei's definition of big data enterprises [9]: those engaged in big data storage, big data. According to data collection and management, big data analysis and mining, big data presentation and application, traditional industry big data fusion, forming the core independent intellectual property rights of enterprises, and on this basis, enterprises carrying out business activities can be identified as big data enterprises. As for the research on the efficiency of technological innovation, the academia generally believes that DEA is a mature and universal method to measure the efficiency of technological innovation. Cha and Cai [10] think the innovation ability and performance of big data enterprises are the important supporting force to cultivate the core competitiveness of big data industry. To carry out the research on innovation performance evaluation of big data enterprises is of great practical significance for promoting the healthy and sustainable development of China's big data industry. Cai [11] uses DEA to measure the comprehensive efficiency, pure technical efficiency and scale efficiency of innovation in the whole big data industry, and further analyses the influencing factors of innovation performance in the big data industry, so as to improve the effectiveness of innovation activities and decision-making basis for big data enterprises and promote the development of big data enterprises. Li [12] based on DEA-BCC, super-efficiency DEA and Malmquist index, empirically measures the operating performance of 36 big data enterprises in China from 2013 to 2016. The related research on big data enterprises is conducive to realizing the optimal allocation of big data enterprises' resources, saving expenditure, thus promoting the vigorous development of big data industry and contributing to the economic development of the country.

In summary, scholars have made fruitful achievements in the research of big data industry, and have carried out a lot of empirical research on the evaluation of technological innovation efficiency, and discussed in detail the evaluation index system and evaluation methods, which has great guiding significance. However, these studies rarely conduct in-depth research on big data enterprises, nor do they have literature to measure the technological innovation efficiency of big data enterprises. Therefore, this paper uses DEA to measure the technological innovation efficiency of listed big data enterprises, which is helpful for further in-depth study of big data enterprises.

2. DEA-BCC MODEL

DEA model is used to evaluate the relative efficiency of decision making units with multi-input and multi-output structure. DEA-BCC is based on increasing returns to scale or decreasing returns to scale. In 1984, Banker, Charnes and Cooper established four axioms of convexity, inefficiency, irradiation unrestricted and minimum extrapolation for the possible set of production. The concept of Shepherd distance function was introduced to decompose Technology Efficiency (TE) into Pure TE (PTE) and Scale Efficiency (SE), namely: TE = PTE * SE. This paper uses BCC model to measure the technological innovation efficiency of big data enterprises. Assuming that there are n production Decision Making Units (DMU), j = 1, 2, …, n, each DMU has m input $x_j = (x_{1j}, x_{2j}, \ldots, x_{mj})$ and s output $y_j = (y_{1j}, y_{2j}, \ldots, y_{sj})$, the efficiency evaluation model of the jth DMU is established by adding restrictions on the weight of λ, and $I\lambda = 1$, $I = (1, 1, \ldots, 1)_{1\times t}$:

$$\begin{cases} \min \quad \theta \\ s.t. \quad \sum_{j=1}^{t} \lambda_j x_j \le \theta x_0 \\ \qquad \sum_{j=1}^{t} \lambda_j x_j \ge y_0 \\ \qquad I\lambda = 1 \\ \qquad \lambda_j \ge 0,\ j = 1, 2, \ldots, t \end{cases}$$

Pure technical efficiency can be obtained from the objective function. Scale efficiency can be calculated from TE/PTE. PTE measures the distance between DMU and production frontier when scale reward is variable; SE measures the distance between production frontier when scale reward is variable and production frontier when scale reward is constant.

3. EMPIRICAL ANALYSIS

3.1. Evaluation Index System of Technological Innovation Efficiency and Sample Data

The definition of enterprise technological innovation efficiency is defined as: the utilization ratio of innovation resources invested by enterprises relative to the innovation results of output, reflecting the contribution degree of input resources of technological innovation to output, i.e., the allocation efficiency of technology innovation resources [13]. Therefore, the selection of technical innovation efficiency indicators for big data enterprises should take into account the input of innovation resources and the results of innovation output. Based on the principles of index system establishment, this paper establishes an index system which includes three input indicators and two output indicators when evaluating the technological innovation efficiency of big data enterprises. The evaluation index system of technological innovation efficiency of big data enterprises is shown in Table 1. Among them, the input indicators include the amount of Research and Development (R&D) investment, the number of R&D personnel and the capital R&D investment. The amount of R&D investment includes capitalized R&D investment and expenditure R&D investment. The number of R&D personnel reflects the investment of innovators. Capitalized R&D investment is counted into cost of products; output indicators include the number of patent applications for invention and the increase rate of intangible assets. The number of patent applications, including invention patents, utility model patents and design patents, refers to the number of patents that have applied for patents but have not yet obtained patent rights; Intangible assets, such as

Table 1 | Evaluation index system of technological innovation efficiency of big data enterprises

Input	R&D investment amount (million yuan) Number of R&D (person) Capitalized R&D investment (million yuan)
Output	Number of patent applications (piece) Increase rate of intangible assets (%)

intellectual property, technology, management, brand, system and innovation ability, measure the promotion and protection of intangible assets to technological innovation.

The selection of big data enterprise, referring to the definition mentioned above, and combined with the main business scope published in the annual report, this paper selected 21 big data enterprises to evaluate their technological innovation efficiency. The index data come from the annual report of listed big data enterprises in 2017 and the State Intellectual Property Office.

3.2. The Evaluation Results of Technological Innovation Efficiency of Big Data Enterprises

As part of the index data is 0 or negative, while the DEA data need to be all positive, so the data need to be standardized. The standardized formulas for data are as follows:

$$Y = 0.1 + 0.9\frac{X - X_{\min}}{X_{\max} - X_{\min}}$$

Among them, Y is the index value after standardization; $X_{\max}$ and $X_{\min}$ are the maximum and minimum of a certain index respectively. X is the value of an index in a DMU, i.e., the original value. Standardized values range from 0 to 1. Then using DEAP Version 2.1 software; the DEA evaluation values of technological innovation efficiency of big data enterprises are calculated. Software calculates the input redundancy value and output deficiency value as shown in Table 2.

3.3. Efficiency Analysis and Analysis of Input Redundancy and Output Insufficiency

Technical efficiency is a comprehensive measure and evaluation of resource allocation ability and resource utilization efficiency of DMU. TE is the product of PTE and scale efficiency. DEA efficiency, i.e. technical efficiency reaches 1, is an optimal state in which both PTE and scale efficiency reach 1. According to the results of the technical efficiency evaluation in Table 1, in 2017, the technical efficiency of Haikvision, Si-Tech, Dahua Technology, Vastdata and Goodix Technology and Technology reached 1, which shows that the input and output of these five big data enterprises are comprehensive and effective, i.e., technology and scale are effective at the same time, accounting for 23.81% of the decision-making unit. On average, in 2017, the average technical efficiency was 0.587. The technical efficiency of ZTE, Ultrapower Software, Venustech, Taiji Computer, Join-Cheer Software, Thunisoft, Navinfo, Dawning Information, Baosight Software, Nsfocus Information Technology, Beyondsoft and Tsinghua Tongfang did not reach 0.587, indicating that big data enterprises as a whole have not yet fully realized effective. The technical efficiency of the above 13 big data enterprises needs to be improved.

Pure technical efficiency reflects the production efficiency of input factors of DMU under certain conditions (optimal scale). PTE is influenced by management and technology, and reflects the utilization rate of resources. PTE is equal to 1, which means that resources have been fully utilized at the current level of technology; or there is a waste of resources. In 2017, the PTE of ZTE, Haikvision, Si-Tech, Dahua Technology, Vastdata and Goodix Technology reached 1,

Table 2 | DEA value of technological innovation efficiency and input redundancy and output deficiency

Big data enterprise name	Technical efficiency	Pure technical efficiency	Scale efficiency	Scale remuneration	Input redundancy			Output insufficiency	
					R&D investment amount (million yuan)	Number of R&D (person)	Capitalized R&D investment (million yuan)	Number of patent applications (piece)	Increase rate of intangible assets (%)
ZTE	0.318	1.000	0.318	drs	0	0	0	0	0
Hikvision	1.000	1.000	1.000	–	0	0	0	0	0
Inspur Software	0.609	0.703	0.865	irs	−63.828	−280.548	−0.042	0	0.236
Iflytek	0.228	0.246	0.924	irs	−863.205	−4325.445	−0.306	0	0.145
Digital China	0.654	0.945	0.691	irs	−5.401	−11.393	−0.006	0.021	0
Ultrapower Software	0.510	0.583	0.875	irs	−85.274	−607.460	−0.072	0	0.214
Venustech	0.351	0.726	0.484	irs	−128.905	387.512	−0.038	0.089	0.341
Taiji Computer	0.421	0.754	0.558	irs	−70.835	−398.185	−0.033	0.050	0.425
Join-Cheer Software	0.531	0.932	0.570	irs	−16.671	−113.19	−0.007	0.058	0.354
Thunisoft	0.327	0.601	0.543	irs	−131.86	−864.661	−0.066	0.049	0.451
Si-Tech	1.000	1.000	1.000	–	0	0	0	0	0
Merit Data	0.996	1.000	0.996	irs	0	0	0	0	0
Dahua Technology	1.000	1.000	1.000	–	0	0	0	0	0
Navinfo	0.435	0.466	0.934	irs	−487.53	1436.29	−0.114	0.002	0
Dawning Information	0.320	0.476	0.673	irs	−121.637	−520.217	−0.110	0.015	0.444
Baosight Software	0.462	1.000	0.462	irs	0	0	0	0.134	0.087
Nsfocus	0.515	0.683	0.753	irs	−91.752	−416.218	−0.046	0.018	0.313
Beyondsoft	0.552	0.920	0.600	irs	−10.828	−148.101	−0.009	0.024	0.508
Tsinghua Tongfang	0.093	0.182	0.515	irs	−1136.684	−1045.217	−0.451	0	0.728
Vastdata	1.000	1.000	1.000	–	0	0	0	0	0
Goodix Technology	1.000	1.000	1.000	–	0	0	0	0	0
Average value	0.587	0.772	0.750	–	–	–	–	–	–

drs, diminishing returns to scale; irs, increasing returns to scale.

and the enterprise resources were fully utilized, accounting for 33.33% of the DMU. In 2017, 10 big data enterprises, including Inspur Software, Iflytek, Ultrapower Software, Venustech, Taiji Computer, Thunisoft, Navinfo, Dawning Information, Nsfocus Information Technology and Tsinghua Tongfang, were lower than the average net technical efficiency value of 0.772. These big data enterprises made less use of resources and needed further to improve utilization level of resources.

Scale efficiency reflects the production efficiency affected by the scale of DMUs. The relative effectiveness of scale efficiency means that there is no difference between the TE of a DMU under fixed scale reward and that under variable scale reward, namely scale efficiency is 1. In 2017, the scale efficiency of Haikvision, Si-Tech, Dahua Technology, Vastdata and Goodix Technology, the five big data enterprises, was 1, and the scale efficiency accounted for 23.81%. The average scale efficiency of 21 big data enterprises is 0.750. Among them, ZTE, Venustech, Taiji Computer, Join-Cheer Software, Thunisoft, Baosight Software and their counterparts have low scale efficiency, which needs further improvement.

In 2017, ZTE showed diminishing returns to scale (drs), indicating that the size of enterprises should be moderately reduced to match input and output; Haikvision, Si-Tech, Dahua Technology, Vast data and Goodix Technology showed that returns to scale remained unchanged (–), indicating that these five big data enterprises should maintain their current size. At present, the scale of enterprises matches input and output; the other 15 big data enterprises all show increasing returns to scale (irs), which indicates that these 15 big data enterprises should expand their scale moderately to match input and output, so as to improve production efficiency.

Those 13 big data enterprises have the problems of input redundancy and insufficient output. After data standardization, the input redundancy and output insufficiency rate should be used for analysis. References for calculating input redundancy rate and output deficiency rate [14]. Taking Navinfo as an example, in 2017, if the amount of R&D input is reduced by 487.52 million yuan, R&D personnel are reduced by about 1437 people, capitalized R&D investment is reduced by 54.3%, while the number of patents applied for invention is increased by 1.67%, and the Navinfo can achieve DEA validity. There are great differences in the number of R&D personnel and R&D input among big data enterprises. Some enterprises have big redundancy in R&D input, which indicates that enterprises may have blind investment, redundancy of personnel and insufficient output, which needs to be paid attention to by enterprises.

4. CONCLUSION

This paper uses DEA-BCC to measure the technological innovation efficiency of big data enterprises. Specifically, firstly, it establishes the index system of input and output, standardizes the index data, and uses DEAP Version 2.1 software to measure the technological efficiency, PTE, scale efficiency, scale reward, input redundancy and output deficiency of big data enterprises, and makes analysis. Empirical research finds that: big data enterprises are not effective as a whole; there are not many big data enterprises with high technical efficiency and scale efficiency, only 6; PTE of big data enterprises is slightly higher than technical efficiency and scale efficiency; from the perspective of scale compensation, most big data enterprises should continue to expand their scale to ensure that the size of enterprises matches input and output.

CONFLICTS OF INTEREST

The authors declare they have no conflicts of interest.

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