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An Analysis of Spatial Differences in the Efficiency of Regional Industrial Enterprises in China

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[Abstract]

This paper analysis of spatial differences in the efficiency of regional industrial enterprises in China from 2011 to 2021. The efficiency analysis uses the DEA-CCR model. The input variables for efficiency analysis are total assets and annual average employees, and the output variables are revenue from principal business and total profits. Using trend surface analysis and gravity center model, to analysis the spatial differences of efficiency in different regions. From the results of the gravity center model, the coordinates of the gravity center of China's regional industrial enterprise efficiency in 2011 are 112.303°E & 34.239°N, and 2021 are 111.753°E & 33.791°N, which indicates that the gravity center of the efficiency of China's regional industrial enterprises in the 2011-2021 period generally moves to the southwest. From the results of the trend surface analysis, the efficiency of industrial enterprises in China's regional industrial enterprises appears to show spatial differences in both the eastwest and the northsouth directions.

▸ **Key words**: China, Industrial Enterprises, Efficiency, Spatial Differences, Gravity Center Model

[요 약]

본 연구는 2011-2021년을 분서기간으로 중국의 공업기업의 효율성의 지역차이를 분석하고 있다. 효율성은 DEA-CCR 모형을 이용하고 있다. 효율성 분석의 투입변수는 자산총계, 연평균 취업자수를 이용하고 산출변수는 주요영업수입과 이윤총액을 이용하고 있다. 효율성의 지역차이는 Trend Surface 분석방법과 Gravity Center Model을 이용하고 있다. Gravity Center Model의 분석결과에 의하면 2011년의 중국 공업기업의 효율성의 Gravity Center는 112.303°E & 34.239°N이고 2021년은 111.753°E & 33.791°N이다. 이 결과는 2011-2021년 기간 동안 중국 공업기업의 효율성의 Gravity Center는 서남방향으로 이동하고 있다고 해석할 수 있다. Trend Surface 분석결과에 의하면 중국 공업기업의 효율성은 동서 방향과 남북 방향으로 공간차이가 존재하고 있다.

▸ **주제어**: 중국, 공업기업, 효율성, 공간차이, Gravity Center Model

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I. Introduction

Industry is an important embodiment of a country's comprehensive strength, and a country's economic development cannot be separated from the support of industry. China's industrial enterprises above designated size have reached a new performance after years of development. According to data from the China Statistical Yearbook, the total assets of China's industrial enterprises reached 146,671.63 billion yuan in 2021, increased by 12.5% from 2020, and the number of industrial enterprises reached 441,517. With industry accounting for 32.6% of China's GDP in 2021, the industrial economy plays an important pulling role for China's economy. The rapid development of China's industrial enterprises is also showing regional imbalances, with Guangdong's total assets, in 2021, ranking first in the country. The total assets of Guangdong industrial enterprises are 17,574.6 billion yuan, and the number of employees is 13.54 million. In 2021, Xizang ranked last in the country in terms of total assets. The total assets of Xizang industrial enterprises are 225.33 billion yuan, and the number of employees is 27,000. The scale of industrial enterprises in different regions of the gap is very large.

In the complex international context, China's industrial enterprises and manufacturing industries are also facing complex issues[1]. China needs to upgrade its industrial manufacturing. The growth model of high-input and extensive enterprises should also be changed. It is not sufficient to consider only the scale of industrial enterprises. So we need to think about the efficiency of industrial enterprises.

China's regions have different levels of industrial enterprise development, and there are differences in regional industrial enterprise efficiency. But will the efficiency of regions with high industrial enterprise efficiency always be high? Will the efficiency of regions with low efficiency always be low? With the change of time, it is worth considering which regional efficiency gap is decreasing and which regional efficiency gap is increasing. The problem of regional coordinated development is one of the issues that China pays great attention to. Therefore, it is necessary to consider the spatial differences in the efficiency of industrial enterprises in China's regions. The analysis of the efficiency of industrial enterprises can show the level of resource allocation and the level of inputs and outputs of industrial enterprises in each region. The spatial difference analysis of the efficiency of industrial enterprises is of great significance for the government to adjust the structure of regional industrial enterprises and improve the level of industrial enterprises. The analysis also provides reference for the government to make policies.

Many scholars have analyzed the efficiency of industrial enterprises. Sun, et al.(1999) used the DEA model earlier to research the efficiency of 28 manufacturing industries in China, and to analyze the influences on technical efficiency[2]. Xu(2004) researched the technical efficiency and scale efficiency of industrial enterprises in Zhejiang using the DEA method[3]. This research reflects the efficiency of industrial enterprises in specific regions. Kim and Ma(2007) researched the industry efficiency of industrial enterprises in regions[4]. This research is much more comprehensive. There are also research on the efficiency of an industrial industry[5]. Many scholars have done the spatial difference analysis of efficiency. Xu, et al.(2017), used the gravity center model to analyze the spatial evolution of industrial production efficiency in Jiangsu[6]. Yu, et al.(2019), used the gravity center model to analyze the spatial gravity center changes of technical efficiencies, pure technical efficiencies and scale efficiencies of Chinese township enterprises[7]. Qin, et al.(2022), and Ma, et al.(2022), analyzed the spatial distribution of efficiency and spatial change trends using trend surface analysis[8][9].

In general, many researches have analyzed the efficiency of industrial enterprises from multiple perspectives. Difference from previous research, this paper analysis of spatial differences in the efficiency of 31 regions(excluding Hong Kong, Macao, and Taiwan region) industrial enterprises in China by combining two methods of trend surface analysis and gravity center model. The academic significance of the analysis is that it expands the research of industrial enterprise efficiency, and inform the research of spatial differences in efficiency. The practical significance is that it shows the spatial differences in the efficiency of regional industrial enterprises, which can provide a reference for the government to formulate policies.

II. Model Construction

1. DEA-CCR model

This paper uses DEA method to analyze the efficiency of regional industrial enterprises in China. DEA is a non-parametric statistical method, it can be used to evaluate the efficiency of more input and more output. Charnes, et al.(1978) proposed a CCR model with constant returns to scale[10]. The input orientated CCR-based model is formulated as (1)[11].

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

In the formula (1), X indicates input variables, Y indicates output variables, n indicates the number of decision-making units (DUMs), θ indicates technical efficiency, λ indicates weight variables, and S^- and S^+ indicate slack variables.

2. Gravity center model

In order to show the spatial differences in the efficiency of regional industrial enterprises in China, this paper uses the gravity center model for analysis. Efficiency that falls on the gravity center point indicates that relative balance is maintained in all directions, and the gravity center of efficiency moves toward a region when that region has a larger share of efficiency and a faster growth rate [12]. The formula for the gravity center model is (2)[13].

$$\overline{X} = \frac{\sum_{i=1}^{n} C_i X_i}{\sum_{i=1}^{n} C_i} \qquad (2)$$
$$\overline{Y} = \frac{\sum_{i=1}^{n} C_i Y_i}{\sum_{i=1}^{n} C_i}$$

In the formula (2), n is the number of research units, ($\overline{X}, \overline{Y}$) is the gravity center coordinates of industrial enterprise efficiency, (X_i , Y_i) is the coordinates of each research unit, and C_i is the value of regional industrial enterprise efficiency.

3. Trend surface analysis method

Using the trend surface analysis method to analyze the efficiency of Chinese industrial enterprises can more directly reflect the spatial change trend of the efficiency of regional industrial enterprises in China. In this paper, we measure the efficiency of regional industrial enterprises in China, using second-order polynomials, and the formula for the trend surface analysis is (3)[14].

$$Z_i(x_i, y_i) = T_i(x_i, y_i) + \epsilon_i$$
$$T_i(x_i, y_i) = \beta_0 + \beta_1 x + \beta_2 y + \beta_3 x^2 + \beta_4 y^2 + \beta_5 x, y \qquad (3)$$

In the formula (3), $Z_i(x_i, y_i)$ is the value of the efficiency of regional industrial enterprises, x_i and y_i are the plane spatial coordinates, $T_i(x_i, y_i)$ is

the trend surface function, ϵ_i indicates the autocorrelation stochastic error, and β indicates the estimation of the terms of the second-order polynomials[15].

III. Variable Selection and Data Processing

1. Variable selection

This paper uses DEA method to analyze the efficiency of regional industrial enterprises in China. To ensure the rationality of variable selection, referring to previous studies, the input variables in this paper are selected from two aspects, capital input and labor input[4][5][16][17]. Capital inputs are selected as total assets, because total assets are a sound indicator of the resources and size of the enterprise. For labor inputs, the annual average employees are selected because the average number of employees is an important labor input to the production activities of the enterprise. The output variables are selected as revenue from principal business and total profits, because revenue from principal business and total profits can show the operation of the enterprise, and can measure the income of the enterprise. Because of the change in the statistics of industrial enterprises in the China Statistical Yearbook starting in 2011, this paper selects 2011-2021 as the research period.

2. Data processing

The source of data for this paper is the China Statistical Yearbook for each year(data excluding Hong Kong, Macao, and Taiwan region). But the 2012, 2013 and 2014 China Statistical Yearbooks do not have the annual average employees by industrial enterprises. Annual average employees in 2012 and 2013 is made up using linear interpolation. 2014's data have a per capita revenue from principal business, which could be calculated to obtain annual average employees (revenue from principal business / per capita revenue from principal business). Starting from 2018, China Statistical Yearbook does not count revenue from principal business of industrial enterprises, and this paper substitutes it with business income.

IV. Empirical Analysis

1. DEA-CCR method analysis

This paper analyzes the efficiency of regional industrial enterprises in China from 2011 to 2021 by using the DEA-CCR method, and the results of the mean value of industrial enterprise efficiency are as table 1.

Table 1. Mean value of efficiency of industrial enterprises in the region, 2011-2021

Region	Mean	Region	Mean
Beijing	0.986	Hubei	0.835
Tianjin	0.969	Hunan	0.891
Hebei	0.827	Guangdong	0.735
Shanxi	0.537	Guangxi	0.832
Inner Mongolia	0.945	Hainan	0.908
Liaoning	0.798	Chongqing	0.791
Jilin	0.917	Sichuan	0.757
Heilongjiang	0.681	Guizhou	0.688
Shanghai	0.932	Yunnan	0.699
Jiangsu	0.885	Xizang	0.478
Zhejiang	0.669	Shaanxi	0.858
Anhui	0.818	Gansu	0.793
Fujian	0.856	Qinghai	0.628
Jiangxi	1.000	Ningxia	0.661
Shandong	0.947	Xinjiang	0.757
Henan	0.810		

As can be seen in table 1, only Jiangxi has an mean efficiency value of 1 in 2011-2021, which indicates that the inputs and outputs of industrial enterprises in Jiangxi are optimal and the allocation of resources is reasonable in 2011-2021. The mean value of the efficiency of industrial enterprises in Beijing is 0.986, the mean value of the efficiency of industrial enterprises in Tianjin is 0.969, and the mean value of the efficiency of industrial

enterprises in Shandong is 0.947, which indicates that the efficiency of industrial enterprises in Beijing, Tianjin, and Shandong is high, and industrial enterprises have optimized inputs and outputs in some years from 2011-2021, with an efficiency value of 1. The mean value of the efficiency of industrial enterprises in Qinghai is 0.628, the mean value of the efficiency of industrial enterprises in Shanxi is 0.537, and the mean value of the efficiency of industrial enterprises in Xizang is 0.478. It shows that the industrial enterprises in Qinghai, Shanxi, and Xizang are less efficient, and the resources are not reasonably allocated. Overall the efficiency level of Chinese industrial enterprises in 2011-2021 is not high. There is a big gap in the development of different regions, so this paper will further analyze the spatial differences and changes in the efficiency of industrial enterprises in China.

In 2021, Beijing's GDP is 4026.96 billion yuan, Tianjin's is 1569.50 billion yuan, In 2021, Shanxi's GDP is 2259.02 billion yuan, and Xizang's is 208.02 billion yuan. It can be seen that, in general, industrial enterprises in regions with high GDP are more efficient. However, as in the case of Shanxi, industrial enterprises in regions with high GDP are not necessarily efficient.

2. Gravity center model analysis

In this paper, the position of the gravity center and the direction of movement of the efficiency of industrial enterprises in China's regions are measured by ArcGIS software using gravity center model from 2011 to 2021. The results are as follows, the gravity center coordinates of the efficiency of industrial enterprises in China's regions in 2011 are (112.303°E, 34.239°N), 2021 gravity center coordinates are (111.753°E, 33.791°N), this indicates that the gravity center of efficiency of industrial enterprises in China's regions generally moves to the southwest from 2011 to 2021. the proportion of industrial enterprise efficiency in the southwest region increases in the country.

From the perspective of efficiency value, the efficiency value of industrial enterprises in Sichuan is 0.703 in 2011, and 0.822 in 2021. the efficiency value of industrial enterprises in Guizhou is 0.529 in 2011, and 0.746 in 2021. the efficiency value of industrial enterprises in Yunnan is 0.595 in 2011, and 0.860 in 2021. the efficiency of industrial enterprises in southwest China has been greatly improved.

Table 2. Coordinates and direction of movement of the gravity center of efficiency of industrial enterprises in the region, 2011-2021

Year	Coordinate X(E)	Coordinate Y(N)	Movement direction
2011	112.303°	34.239°	-
2012	112.157°	34.303°	northwest
2013	112.376°	34.378°	northeast
2014	112.193°	34.083°	southwest
2015	112.286°	33.792°	southeast
2016	112.100°	33.662°	southwest
2017	111.808°	33.507°	southwest
2018	111.864°	33.473°	southeast
2019	111.905°	33.554°	northeast
2020	111.873°	33.540°	southwest
2021	111.753°	33.791°	northwest

The efficiency value of industrial enterprises in Heilongjiang is 0.945 in 2011 and 0.606 in 2021. The efficiency value of industrial enterprises in Jilin is 0.967 in 2011 and 0.817 in 2021.The efficiency value of industrial enterprises in Liaoning is 0.936 in 2011 and 0.818 in 2021.The efficiency value of industrial enterprises in Liaoning is 0.936 in 2011 and 0.818 in 2021. It can be seen that the efficiency of industrial enterprises in regions located in the southwest region increases and the efficiency of industrial enterprises in regions located in the northeast region decreases in 2011-2021, which leads to an overall shift of the gravity center of the efficiency of China's industrial enterprises in the direction of the southwest from 2011 to 2021.

Southwest China is in the Pan-Pearl River Delta (PRD) region, and the development of industrial enterprises is promoted by the PRD region. China's

Western Development Policy, the implementation of policies such as tax benefits for enterprises in the western region. Local government support for advantageous industries. For example, Sichuan industrial 7+3 industrial development plan, the development of electronic information industry, equipment manufacturing and other advantageous industries. Guizhou industrial ten industry revitalization plan and other policies to implement the development of electric power industry, chemical industry, etc., Local governments provide fiscal, tax and financial support. Promoted industrial efficiency growth in the southwest.

These regions of Heilongjiang, Jilin and Liaoning have seen a decline in the advantages of traditional industries dominated by heavy industry and a lack of development of new industries[18]. The efficiency of industrial enterprises in northeast China has declined under the influence of many factors, such as the serious population loss in northeast China and the depletion of resources in northeast China in recent years.

3. Trend surface analysis

In order to analyze in more detail the spatial differences and variations in the efficiency of regional industrial enterprises in China. Using ArcGIS, make spatial trend surface maps of the efficiency of regional industrial enterprises in China for four years, 2011, 2014, 2017 and 2021. In the figure, the Z-axis indicates the efficiency of industrial enterprises in each province, the direction of the arrow on the X-axis indicates the east, the direction of the arrow on the Y-axis indicates the north, and the two trend lines indicate the fitted lines of the points in the spatial to the projected points in the X-Z and Y-Z planes [9]. The results of the trend surface analysis are as follows.

In 2011, the trend surface of the efficiency of regional industrial enterprises in China shows a trend of higher in the east and lower in the west, and higher in the north and lower in the south. This indicates a significant gap in the efficiency of industrial enterprises in both the eastwest and the northsouth directions.

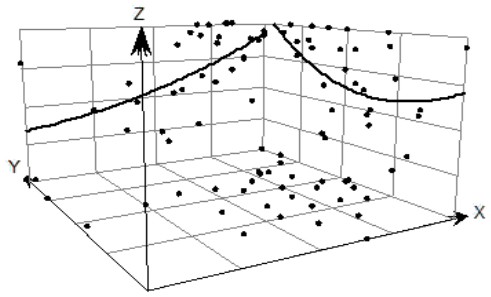

Fig. 1. Trend surface map of efficiency of industrial enterprises in 2011

In 2014, the spatial trend in the efficiency of industrial enterprises is the same as in 2011, showing a trend of higher in the east and lower in the west, and higher in the north and lower in the south. However, the gap between the north and south regions is less in 2014 than in 2011.

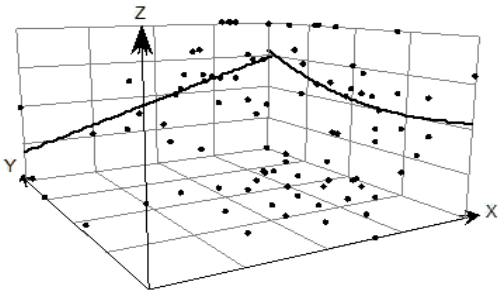

Fig. 2. Trend surface map of efficiency of industrial enterprises in 2014

In 2017, the efficiency of regional industrial enterprises in China shows a trend of higher in the east and lower in the west, and higher in the south and lower in the north. The trend in the eastwest direction is the same as in 2011 and 2014, but the difference in the northsouth direction is the opposite of 2011 and 2014.

In 2021, the efficiency of regional industrial enterprises in China shows a trend of high in the east and low in the west. The difference in the northsouth direction in 2021 is not the same as in previous years. The trend line in the northsouth

direction is relatively flat, efficiency with a small gap.

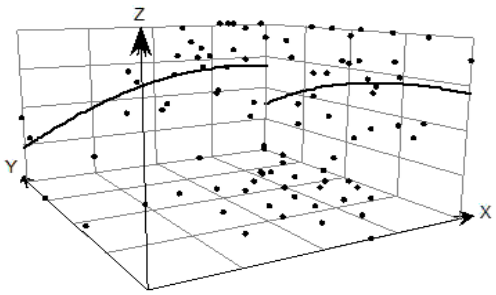

Fig. 3. Trend surface map of efficiency of industrial enterprises in 2017

In 2021, the efficiency of industrial enterprises in the eastwest direction shows a trend of inverted U-shape change, but the inverted U-shape distribution is not significant, and the efficiency of industrial enterprises in the east is still higher than that in the west.

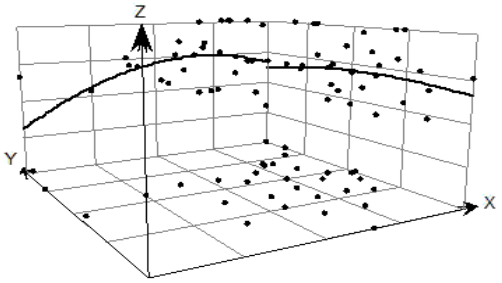

Fig. 4. Trend surface map of efficiency of industrial enterprises in 2021

From the eastwest direction, the efficiency of industrial enterprises in the east has always been higher than that in the west. The gap between the efficiency of industrial enterprises in the east and west is large in 2011 and 2014, and although the gap between the efficiency of industrial enterprises in the east and west directions narrows in 2017 and 2021, the efficiency of industrial enterprises in the east is still higher than that in the west. The efficiency of industrial enterprises in the east has always been higher than that in the west, which is mainly due to the foundation of industrial enterprises in the east and the large industrial scale. For example, in Jiangsu in the east, the total assets of industrial enterprises in 2021 are 15376.80 billion yuan, and in Qinghai in the west, the total assets of industrial enterprises in 2021 are 665.53 billion yuan, and the enterprise scale of the industrial enterprises in the eastern regions is much larger than that of the western regions, and the larger scale of the enterprises leads to a larger market share, and the enterprise technology level and management level are at a higher level, so the efficiency of the industrial enterprises in the east is higher than that in the west.

From the northsouth direction, the efficiency of regional industrial enterprises in China shows a trend of high in the north and low in the south in both 2011 and 2014, and began to show a trend of high in the south and low in the north in 2017, and the efficiency of the south and the north will be almost the same in 2021, with a very small gap. In 2011 and 2014, the efficiency of industrial enterprises in the north is higher than that in the south, which may be due to the abundant coal, oil, metals and other resources in northern regions such as Shaanxi and Inner Mongolia. The advantage of natural resources leads to large-scale industrial enterprise development and high industrial enterprise efficiency. In 2017, the efficiency of industrial enterprises in the south is higher than that in the north, and in 2021, the efficiency of industrial enterprises in the south is slightly higher than that in the north. Perhaps due to the accelerated adjustment of China's industrial structure in recent years, the Made in China 2025 policy was proposed in 2015, which mentioned supporting the development of new materials, new energy and aerospace and other high-tech industries. For example, Guangxi in the south, during the period of 2016-2020, strengthened the development of emerging industries, created a number of hundred billion yuan industries such as automobiles and electronics, and introduced a number of high-tech enterprises such as Huawei and BYD[19]. In addition, high-tech industrial enterprises in regions such as Guizhou and Yunnan

have also developed rapidly, leading to an increase in the efficiency of industrial enterprises.

V. Conclusion

Overall the efficiency level of China's regional industrial enterprises in 2011-2021 is not high, only Jiangxi has an efficiency of 1, with optimal inputs and outputs, and economically developed regions such as Beijing have an efficiency of 1 in some years, with a more reasonable allocation of resources. The mean value of the efficiency of industrial enterprises in remote regions such as Qinghai is low, and no year reaches DEA effective, industrial enterprises are less efficient, and the allocation of resources is unreasonable. This shows the significant regional unbalance in the efficiency of industrial enterprises in China.

The gravity center coordinates of the efficiency of industrial enterprises in China's regional in 2011 are(112.303° E, 34.239° N), coordinates of the gravity center in 2021 are(111.753° E, 33.791° N). The gravity center of industrial enterprise efficiency in China's regional industrial enterprises generally moves in the southwest direction from 2011 to 2021. It shows that the efficiency of industrial enterprises in regions in the southwest direction, such as Sichuan, Guizhou and Yunnan, has been improved. The proportion of industrial enterprise efficiency in the southwest region increases in the country. The results of the trend surface analysis show that the efficiency of industrial enterprises has been higher in the east than in the west, but this gap is decreasing. The gap between the spatial trends in the efficiency of industrial enterprises in the south and the north is decreasing, with the north being higher and the south lower, then the south higher and the north lower, and finally the south and the north almost the same.

Faced with the problems of low efficiency of regional industrial enterprises and the unbalanced efficiency of industrial enterprises among regions, regions should take advantage of the opportunities offered by the government's support for high-tech industries in industrial enterprises and its policy support for remote and backward regions, and strive to develop high-tech industries and to improve and upgrade the backward industries in industrial enterprises. Efforts are made to improve the efficiency of industrial enterprises in each regions, to narrow the gap between the efficiency of industrial enterprises in each regions, and finally to improve the efficiency of industrial enterprises as a whole. Through a research of Spatial Differences in the Efficiency of Regional Industrial Enterprises in China, this paper also has some shortcomings and does not analyze the slack of input variables and the influencing factors of efficiency, and these limitations need to be further studied.

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