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Analysis on Innovation Efficiency of High-tech Industries in the Three Coastal Economic Zones in Eastern China

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Abstract: The high-tech industry is an important force in promoting the upgrading of traditional industries and the transformation of economic growth mode. Its technological innovation directly affects the innovation efficiency and economic development level of the region. The three major economic zones of Bohai Rim, Yangtze River Delta, and Pan Pearl River Delta are the most active areas for China's economic development and independent innovation, with a level of technological development far exceeding the average level of China, becoming the three growth poles driving China's economic growth. This article first uses the three-stage DEA Windows method to measure the innovation efficiency of high-tech industries in China's Yangtze River Delta, Pan Pearl River Delta, and Bohai Rim economic zones from 2016 to 2022, and considers the dynamic evolution characteristics of innovation efficiency in each region over time. Secondly, the impact of environmental variables on the redundancy of input variables in high-tech industries in the three major economic zones was studied. Finally, the differences of innovation efficiency values among the three major economic zones were examined. Research has found that after controlling for environmental factors and random errors, the overall innovation efficiency values of the three major regions have not reached the forefront of production, and have shown an increasing trend year by year. Low scale efficiency is the main factor affecting the R&D efficiency of the three regions, and further coordinated planning is urgently needed.

Keywords: Three Coastal Economic Zones in Eastern China, High-tech Industry, Three Stages DEA-Windows, Innovation Efficiency.

1. Introduction

Innovation efficiency is an important indicator for measuring industrial development, but in China, the average conversion rate of scientific and technological achievements is only 30%, far lower than that of developed countries. The low efficiency of innovation directly affects the transformation and upgrading of China's economic development mode.

High-tech industries are an important force in promoting the upgrading of traditional industries and the transformation of economic growth models, playing an extremely important role in innovation driven strategies. The efficiency of innovation determines the innovation capability of the entire industry and the process of building a path of development through innovation in China. In recent years, the development of China's high-tech industry has been significantly slow, facing increasingly fierce international competition. How to effectively utilize research and development investment and optimize resource allocation is an urgent problem that needs to be solved in China's high-tech industry.

The three major economic zones of Bohai Rim, Yangtze River Delta, and Pan Pearl River Delta are the main concentrated areas for the development of high-tech industries in China. The development of their high-tech industries can largely reflect the current situation of China's overall high-tech industry. Therefore, this article selects the Bohai Rim, Yangtze River Delta, and Pan Pearl River Delta regions as research objects to dynamically analyze the innovation efficiency of high-tech industries, objectively evaluate the innovation capabilities of the three regions, and identify the factors that affect innovation efficiency within the regions. Helps to comprehensively and systematically understand the innovation level of various regions, identify innovation shortcomings, and propose strategies to promote sustainable development of research and development innovation; Helps provide important strategic support for the development of innovative enterprises; More conducive to improving the economic development level of these three major economic regions and the whole country.

2. Research Method and Variable Selection

2.1. Model Construction

From the perspective of measurement methods, there are two commonly used innovation efficiency evaluation methods: The first type is the parametric analysis method represented by stochastic frontier model (SFA), which has advantages in the processing of measurement errors and statistical interference, but it must presuppose the production function, and its application scope is limited to a certain extent. For example, Bai Junhong et al. [1] used the SFA method to conduct an empirical analysis of China's regional innovation efficiency, and the research shows that China's regional innovation efficiency is on the rise. The second type is the non-parametric analysis method represented by the data envelopment analysis model (DEA). It can evaluate the relative efficiency of multi-input and multi-output DMU without setting the production frontier function in advance, and avoid the estimation bias caused by model selection errors. However, it does not consider the impact of environmental variables and statistical noise on the efficiency value of DMU, and it cannot analyze multiple DMU of the same type under the same external environment. For example, Jiang Bo [2] used the Malmquist index method of DEA model

to investigate the growth sources and differences of R & D efficiency in China's high-tech industries. In view of the advantages and disadvantages of SFA and DEA, many scholars have improved the two methods. Fried et al. [3] proposed a three-stage DEA model, and Charnes et al. [4] put forward a DEA-Windows analysis method that can evaluate the dynamic change of efficiency, which improved the accuracy and rationality of the measurement results to a certain extent.

Therefore, this paper combines the input-oriented three-stage DEA model and DEA-Windows analysis method to build a three-stage DEA-Windows model. The specific steps are as follows: First, an input-oriented DEA-Windows model is constructed to calculate the average input-output efficiency value and the input relaxation variable without considering environmental factors and statistical noise.

Second, the stochastic frontier model is used to separate environmental factors, random factors and management inefficiencies from input relaxation variables in the first stage, that is, input relaxation variables are taken as dependent variables and environment variables are taken as independent variables, and similar SFA regression functions are constructed:

$$s_{ki} = f(z_i; \beta_k) + v_{ki} + \mu_{ki} \quad (1)$$

Among them, s_{ki} is the relaxation value of the k-th input of the i-th DUM; z_i is the environmental factor, β_k is the coefficient of the corresponding factor, v_{ki} is the random factor, follows an $N(0, \sigma_v^2)$ distribution, μ_{ki} is the management inefficiency term, follows a non-negative truncated normal distribution.

Using the SFA regression results to estimate values, adjust all decision units to the same external environment, that is, the situation where they are most affected by external environmental factors and subject to maximum random interference.

Thirdly, input the adjusted input and origin data into the DEA Windows model and calculate the adjusted average input-output efficiency values for each decision unit.

2.2. Variable Selection

This paper selects the panel data of high-tech industry R & D input and output of 18 provinces and cities in the three economic zones from 2016 to 2022.

2.2.1. Innovation input

Refer to the research of Li Yue et al. [5], the development of innovation activities in high-tech industry cannot be separated from the two elements of capital and labor. In this paper, the full-time equivalent of R & D personnel is selected to reflect the input of innovation in human capital, and the internal R & D funds and new product R & D funds are selected to reflect the input of innovation in physical capital.

2.2.2. Innovation output

For R & D output, we can divide it into two stages: technology development and achievement transformation. The output of technology development stage is mainly based on knowledge scientific and technological achievements, which is measured by effective invention patents. The output of the results transformation stage can reflect the economic benefits brought by the R & D and innovation of high-tech industries, which is measured by the sales revenue of new products.

2.2.3. Environment variables

Environmental variables refer to those external factors that affect the innovation efficiency of high-tech industries but are not subject to the subjective control of samples or cannot be changed in the short term. Based on the characteristics of the development of high-tech industries in three regions, this paper selects Regional economic environment, Degree of opening up, Quality of workers, Collaborative innovation capability, Government support as environmental variables from two aspects within and between regions.

3. Empirical Results and Analysis

3.1. The First Stage: Efficiency Measurement of Output-oriented SBM Model

In order to clearly demonstrate the difference between traditional DEA and DEA Windows, this article uses traditional DEA and DEA Windows methods to measure innovation efficiency in each province, and sets the DEA Windows's period to 3.

Table 1. The innovation efficiency of six provinces measured by the traditional DEA method in 2016-2022

Year	Peking	Tianjin	Jiangsu	Anhui	Kwangtung	Yunnan
2016	0.95	1	0.48	0.45	1	1
2017	1	0.91	0.91	0.55	0.88	1
2018	1	1	0.79	0.75	1	1
2019	1	1	0.59	1	1	1
2020	1	1	0.73	0.99	1	0.79
2021	0.98	1	0.75	0.95	1	0.96
2022	1	1	1	0.98	1	0.79

Table 2. The innovation efficiency of six provinces measured by the DEA-Windows method in 2016-2022 (before the adjustment)

Year	Peking	Tianjin	Jiangsu	Anhui	Kwangtung	Yunnan
2016	0.7	1	0.46	0.37	0.68	0.84
2017	1	0.84	0.82	0.53	0.88	1
2018	0.97	0.96	0.66	0.63	0.94	0.85
2019	0.91	1	0.57	0.87	0.88	0.91
2020	0.87	0.94	0.66	0.85	0.89	0.68
2021	0.86	1	0.67	0.87	0.95	0.91
2022	0.95	0.68	0.73	0.86	1	0.78

From Table 1 and Table 2, it can be seen that without considering environmental and random factors, the innovation efficiency values of Peking, Tianjin, Kwangtung, and Yunnan calculated using traditional DEA methods have remained at 1 for several consecutive years. This result is highly likely to be inconsistent with reality and cannot be dynamically compared. The results of the DEA Windows method used in this article show that the innovation efficiency values of these provinces are basically not 1, which allows us to understand the dynamic evolution of innovation efficiency in the same province over different years. Among them, the efficiency value of Yunnan in 2016 was 0.84, higher than the efficiency values of Jiangsu and Peking in the same year. During the three years of 2020-2022, the innovation efficiency value of Jiangsu has been fluctuating around 0.7, lower than that of Anhui and Yunnan. Tianjin's efficiency value has shown a trend of first increasing and then decreasing in the past three years, with an efficiency of only

0.68 in 2022, the lowest among the six provinces. It can be found that the level of innovation efficiency does not match the level of economic development, that is, regions with high levels of economic development have lower innovation efficiency values, while regions with low levels of economic development have higher innovation efficiency values. The reason for this result may be due to the lack of consideration of environmental factors and random interference in different regions, which once again reflects the shortcomings of traditional DEA methods.

3.2. The Second Stage: SFA Regression Analysis

The input relaxation variable measured in the first stage was taken as the explained variable, and the five environmental variables of regional economic environment, degree of opening to the outside world, quality of workers, collaborative innovation ability and government support were taken as the explanatory variables. The impact of environmental variables on the three input relaxation variables was investigated, and a stochastic frontier analysis model was constructed.

Table 3. SFA Analysis Results

	R & D internal expenditure	New product development funds	R & D personnel equivalent to full-time equivalent
Constant	-9.67E+04*** (1.00E+00)	-7.47E+04*** (1.00E+00)	8.27E+01*** (1.00E+00)
Regional economic environment	9.14E+00*** (1.99E+00)	9.77E+00*** (1.73E+00)	1.20E-01*** (1.49E-02)
Degree of opening up	-1.07E+06*** (1.00E+00)	-8.15E+05*** (1.00E+00)	-7.23E+05*** (1.00E+00)
Quality of workers	-1.40E+02*** (2.80E+01)	-1.54E+02*** (2.58E+01)	-2.74E+00*** (2.78E-01)
Collaborative innovation capability	-1.08E+01* (6.30E+00)	-1.94E+00 (7.74E+00)	7.00E-02** (2.92E-02)
Government support	4.05E+05*** (1.00E+00)	3.97E+05*** (1.00E+00)	7.32E+03*** (1.00E+00)
σ^2	5.18E+10***	5.74E+10***	1.17E+08***
γ	0.88***	0.74 ***	1.00***
likelihood	-1.68E+03	-1.70E+03	-1.27E+03

As can be seen from Table 3, the coefficients of other environmental variables have passed the significance test, except that the coefficient of collaborative innovation capability has no significant effect on the relaxation variable of NPD funds. This indicates that the selected environmental variables have a significant impact on the relaxation value of R & D input in high-tech industries, and the σ^2 and γ values of the three input relaxation variables all pass the significance test at the 1% level. Further analysis shows that the γ values of the three input relaxation variables are all large, indicating that the influence of management inefficiency factors on the relaxation variables is a large proportion, while the influence of random interference terms on the relaxation variables is small. Therefore, it is necessary to use SFA model to control the influence of environmental factors and random disturbances on innovation efficiency, so that all decision-making units are in the same external environment.

3.3. The Third Stage: DEA Efficiency Analysis of Adjusted Input-output Variables

Based on the estimation results of the second stage SFA stochastic frontier analysis, the adjusted input data and the original output data are brought into the DEA-Windows model to measure the pure technical efficiency, scale efficiency and technical efficiency. In this stage, the influence of environmental factors and random disturbance is excluded, and all decision-making units are placed in the same environment. The results show that the innovation efficiency of high-tech R & D activities in each region changes greatly before and after the adjustment. The average innovation efficiency of each region in 2016-2022 are shown in Table 4.

Table 4. Average innovation efficiency of each region in 2016-2022 (after the adjustment)

Region	TE	PTE	SE
Peking	0.86	0.94	0.91
Tianjin	0.85	0.95	0.89
Hebei	0.21	0.83	0.26
Liaoning	0.31	0.73	0.43
Shandong	0.59	0.61	0.96
Shanghai	0.51	0.66	0.77
Jiangsu	0.87	0.94	0.93
Zhejiang	0.58	0.67	0.86
Anhui	0.44	0.91	0.47
Kwangtung	0.97	0.98	0.99
Fujian	0.56	0.70	0.81
Jiangxi	0.26	0.82	0.31
Hunan	0.46	0.83	0.56
Guangxi	0.12	0.96	0.12
Hainan	0.08	1.00	0.08
Sichuan	0.50	0.80	0.60
Guizhou	0.17	0.86	0.20
Yunnan	0.14	0.99	0.15
Bohai Rim	0.56	0.81	0.69
Yangtze River Delta	0.60	0.79	0.76
Pan-pearl River Delta	0.36	0.88	0.42
Three regions	0.47	0.84	0.57

From a regional perspective, it can be seen from Figure 1 that after controlling the influence of environmental factors and random disturbance factors, the average comprehensive efficiency of the three economic zones has decreased, among which the pan-Pearl River Delta economic zone has the largest decline, with a decrease of 44.5 percentage points,

followed by the Bohai Rim economic Zone, while the comprehensive efficiency of the Yangtze River Delta economic zone has an insignificant decline, only less than 1%. Since the reform and opening up, the Pan-Pearl River Delta economic zone has received strong support from the government and has a high degree of opening up. In addition, attractive talent introduction policies have been proposed in recent years, and the quality of workers has also been improved to a certain extent. The region enjoys rich R & D resources, and it is reasonable that the efficiency value has decreased significantly after controlling environmental factors. The Bohai Rim Economic Zone is the largest industrial intensive area in China, which not only has the advantages of resources and market, but also has strong scientific and technological strength. The scientific and technological personnel of scientific research institutes and colleges and universities in Peking and Tianjin alone account for a quarter of the country. In addition, the development strategy of the region also relies on inter-regional collaborative innovation to achieve. When these external environmental factors are abandoned, the innovation efficiency will inevitably decline. The Yangtze River Delta Economic zone is positioned to target the world's scientific and technological frontier, stimulate the power, vitality and ability of innovation subjects and entrepreneurial talents, and become an important hub of the national innovation network, and an important resource for major international scientific development, original technological inventions and high-tech industry cultivation. As the new vanguard of China's scientific and technological innovation, the innovation efficiency will not change significantly because of environmental factors.

Based on the adjusted data, the innovation efficiency of high-tech industries in each region is further analyzed:

The average technical efficiency of the Yangtze River Delta region during 2016-2022 is 0.6, which is the highest among the three regions, and the average values of pure technical efficiency and scale efficiency are close to 0.8. The overall efficiency increased from 0.38 to 0.71 in 7 years, an increase of 84.3 percentage points. The annual level of pure technical efficiency and scale efficiency is relatively close, stable between 0.6 and 0.9, indicating that the Yangtze River Delta region maintains a leading position in technological innovation and institutional management. Specifically, the innovation efficiency value of Jiangsu in recent years is close to 1, which is at the forefront of production. However, the innovation efficiency of Shanghai and Zhejiang is not very high, especially in recent years, the innovation efficiency of Shanghai is only about 0.5, while that of Zhejiang is only about 0.6, which is inconsistent with the existing research and general opinion. Combined with the input-output data, it is found that a large amount of capital and manpower have been invested in these two regions, but the output effect is not very satisfactory. The reason may be that there are too many scientific and technological innovation talents and capital gathered in these two regions, and the excessive investment leads to the unreasonable use of R & D resources. In addition, the product market in Shanghai and Zhejiang is not as large as that in Jiangsu and Guangdong, which is not conducive to the sales of new products. In this paper, the index of sales revenue of new products is chosen to reflect the output, which may lead to the phenomenon of insufficient output.

The average comprehensive efficiency of the Bohai Rim region is 0.56, ranking second, and the scale efficiency has fluctuated between 0.6 and 0.7 over the years. Due to the low scale efficiency, the comprehensive efficiency level is not ideal. Specifically, the innovation capacity of Peking and Tianjin has always been at a high level, and the comprehensive efficiency level fluctuates between 0.7 and 1, which is inseparable from the rich R & D resources, human capital and policy support of Peking and Tianjin. In contrast, the R & D efficiency of Hebei and Liaoning is very low, which has been below 0.3. According to the data, Hebei and Liaoning are large resource-consuming industrial provinces, which mainly rely on the secondary industry to drive economic development, and it is easy to produce resource waste and industrial inefficiency. In the critical period of "speed change", if the industrial transformation and upgrading cannot be completed in time, it will inevitably affect the research and development efficiency of the entire Bohai Rim region.

The pan-Pearl River Delta region has the lowest comprehensive efficiency, with the highest efficiency value being 0.42 in 2022 and the lowest efficiency value being 0.24 in 2016. Except for Guangdong Province, whose comprehensive efficiency level is at the forefront of production, the efficiency values of other provinces are not ideal. This may be because Guangdong Province belongs to the Pearl River Delta region, is an important engine of national economic development, is the gateway to the opening up of the South, has strong policy support, is close to the economically developed Hong Kong, and has unique resource advantages, so it has high innovation efficiency. Other regions, such as Guangxi, Guizhou and Yunnan, are limited by geographical factors and lack of talents and resources, so the innovation effect is not ideal, which reduces the efficiency of the pan-Pearl River Delta region.

According to the above analysis of the efficiency values of the three regions, we can find that the low scale efficiency is the main reason for the low technical efficiency, followed by the innovation imbalance in the provinces within the region, the dispersion degree of efficiency values is large, and the efficiency between regions also has a relatively significant difference.

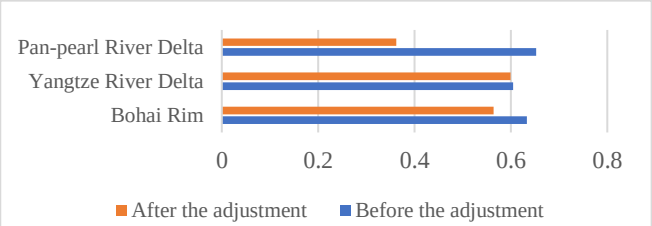

Figure 1. Comparison of average technical efficiency before and after the adjustment in the three economic zones

4. Conclusion

Based on the three-stage DEA model and DEA-Windows analysis method, this paper evaluates the innovation efficiency of high-tech industries in the Yangtze River Delta, pan-Pearl River Delta and Bohai Rim economic zones from 2016 to 2022. Different from previous studies that used traditional DEA model to evaluate innovation efficiency, this paper considers the dynamic evolution of DUS over time through DEA-Windows analysis method from the perspective that the internal collaborative innovation environment factors affect the input-output efficiency, and controls the interference of external environment and random factors through three-stage DEA. It reflects the innovation efficiency

and dynamic evolution characteristics of the three economic zones. This paper overcomes the shortcomings in the analysis of regional R & D efficiency stability and time dynamic evolution in the previous literature. The main conclusions are as follows:

First, the three-stage DEA-Windows model can effectively control the environmental factors and random noise in the R & D and innovation of high-tech industries in the three economic zones of the Yangtze River Delta, pan-Pearl River Delta and Bohai Rim, so that all provinces and cities are in the same environment and natural state, and the measured efficiency value can more truly and effectively reflect the R & D activities of high-tech industries in the three economic zones. More in line with the level of economic development in various regions.

Second, The second stage SFA regression results show that the improvement of regional economic environment and the strengthening of government support will increase the redundancy value of input variables, that is, reduce the input-output efficiency; The improvement of the degree of opening to the outside world, the quality of workers and the ability of collaborative innovation can significantly reduce the redundant value of input variables, that is, can significantly improve the utilization efficiency of input resources.

Third, the adjusted DEA-Windows analysis results show that after eliminating the impact of environmental factors and random errors, the average comprehensive efficiency level of the three major economic zones has decreased, among which the pan-Pearl River Delta economic zone has the largest decline, decreasing by 44.5 percentage points, followed by the Bohai Rim economic Zone. The overall efficiency of the Yangtze River Delta economic zone decreased by less than 1%. On the whole, although the overall technical efficiency value of the three major economic zones is not high, the overall trend is rising year by year, from 0.340 in 2016 to 0.521 in 2022, with an average annual increase of 7.3 percentage points.

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