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Analysis of Regional Differences in Comprehensive Performance of Scientific Research Institutions in China

(An Empirical Study Based on FA-SFA Model)

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Abstract. Based on FA model and SFA model, this paper selects data of scientific research institutions of 28 provinces in 4 regions of China from 2010 to 2016, measures the comprehensive performance of domestic scientific research institutions, analyzes the impact of Manpower and capital input and environmental factors on the comprehensive performance of scientific research institutions and the stochastic convergence of the comprehensive performance of scientific research institutions. We found that: Firstly, The overall performance of domestic scientific research institutions is related to geographical regions. The eastern region has the highest performance with its output human-driven. The central region has the fastest improvement in performance and the western region has the lowest performance which fluctuates greatly with time. Both the eastern and western regions are capital-driven. Secondly, environmental factors affect different areas in different degrees.

1. Introduction

At present, the overall scientific research performance of scientific research institutions is not high enough, and the effects of various policies and measures for scientific research management are not obvious, which indicates that there are some problems in the scientific research management mechanism of domestic scientific research institutions that need to be improved. But under the current conditions in recent years, how the policy and economic environment of personnel, funds and scientific research institutions affects the comprehensive performance of scientific research institutions? These need further empirical test to clarify the focus of in-depth reform and make targeted improvements to the management of scientific research institutions.

In recent years, domestic scholars have put forward many views on comprehensive performance evaluation of scientific research institutions. Chen Yanyu (2015) used AHP analysis method to calculate the weight of indicators, and used fuzzy mathematical comprehensive evaluation method and to evaluate[1]. Zhu Jinlong (2018) used SFA to analyze the innovation performance of 17 colleges and universities in Jiangsu province [2].

Most scholars used DEA to analyze performance of scientific research institutions. But it doesn't consider the influence of random error and technical inefficiency, which may cause the result inaccurate. Moreover, the efficiency of effective productions unit are all 1, so the comparability between effective samples is poor. Conversely, the SFA method is more reasonable to calculate the random error and explain the technical efficiency. the estimated efficiency of it is more in line with the actual situation. Whatever, it can estimate the influence of environmental factors. In other research fields, SFA is more used to estimate technical efficiency. For example, instead of using DEA model, Wang Chengdong (2017) set environmental factors from three aspects by using SFA model to analyze industrial R&D efficiency[3]. Zhang Manyin (2019) established the influential variables to calculate the industrial innovation efficiency of Beijing-Tianjin-Hebei by using SFA method[4].

Now, more researches focused on the small samples of scientific research institutions such as universities. And most scholars used DEA to analyze the performance. Moreover, when analyzing the performances by regions, none of them verified the significant influence of regions on the performance. So, this paper selected the panel data of input and output in scientific research

institutions of 28 provinces to analyze performance. Through establishing of SFA model, this paper normalized all outputs, estimated the performance of institutions and analyzed the input-output relationship and the influence of environmental factors to give advises on improving the efficiency of scientific research institutions pertinently.

2. Research Design

2.1 Data sources and variable definitions

This paper selected panel data of provinces from 2010 to 2016 in "China statistical yearbook of science and technology" and "China statistical yearbook". Considering the scarcity of scientific research resources in some provinces and the fact that multiple indicators are 0, the data of Tibet, Qinghai and Ningxia are excluded in this paper. So there are data of 28 provinces in total over 7 years, and the total sample size is 196.

According to the characteristics of the activities of scientific research institutions, the following variables are selected:

The input variables are the full time equivalent of R&D personnel and the capital stock of R&D funds; From the research benefits, economic benefits and social benefits of scientific research institutions, 7 indicators of output variables are selected; 5 indicators of input variables are selected including region, GDP, policy support, market demand and cooperation degree with enterprises.

Indicator Settings are shown in table 2:

Table 1 index design and definition

First-level index	second-level index	third-level index
Input variables	R&D personnel full time equivalent	L
	Capital stock of R&D funds	K
Output variables	Number of patent applications	Y_1
	Number of published papers	Y_2
	Number of scientific and technological works published	Y_3
	Income from patent ownership transfer and license	Y_4
	Technical contract amount	Y_5
	Number of special activities for popular science	Y_6
	Number of participants for popular science	Y_7
Environment variables	Region (national analysis only)	reg
	GDP	gdp
	Policy support	gov
	The market demand	mar
	Degree of cooperation with enterprises	com

2.2 Model building

(1) construction of stochastic frontier production function.This paper built the c-d production function model based on the model proposed by Battese and Coelli (1995), and the expression is:

$$\ln(Q_{it}) = \beta_0 + \beta_1 \ln(K_{it}) + \beta_2 \ln(L_{it}) + v_{it} - u_{it}. \quad (1)$$

$$\gamma = \frac{\sigma_u^2}{(\sigma_v^2 + \sigma_u^2)}. \quad (2)$$

$$TE_i = \exp(-u_{it}). \quad (3)$$

Ln (Q_{it}) is the log score of the comprehensive output of the ith institution in year t; Ln (K_{it}) and ln(L_{it}) represent the log score of capital and labor input of the ith institution in year t respectively; β_0 is the unknown parameter vector, β_1 is the capital output coefficient, β_2 is the human output coefficient; v_{it} is random noise. It's supposed v_{it} ~N(0,σ2) and no correlation with u; u_{it} is a

non-negative random variable, assuming $u_{it} \sim N(m_{it}, \sigma 2)$; γ is the variance parameter. The closer it is to 1, the more it indicates that the model has invalid effect of technology, and the more suitable the data are to use the stochastic frontier model for analysis.
Meanwhile, the technical inefficiency function is introduced:

$$m_{it} = z_{it}\delta = \delta_0 + \delta_1 * reg_{it}. \quad (4)$$

$$m_{it} = z_{it}\delta = \delta_0 + \delta_2 * gdp_{it} + \delta_3 * gov_{it} + \delta_4 * mar_{it} + \delta_5 * com_{it}. \quad (5)$$

m_{it} is the comprehensive performance of research institutions, z_{it} is the p by 1 vector, and δ is by p vector.Formulas (4) and (5) represent two different assumptions related to environmental variables and comprehensive performance of scientific research institutions.

3. Empirical Analysis

3.1 Conversion of excess output into yield per unit area based on FA model

Performing KMO and bartley spheroid tests. This paper used SPSS 22.0 software to conduct principal component analysis on multi-output indexes of each province in each year. It can be seen that, from table 2, the KMO value of output indicators in each year from 2010 to 2016 is between 0.6-0.8, and each year has passed the significance test, indicating that it is suitable for factor analysis. Using the method of extraction by principal component analysis, this paper extracted the common factor according to the way of eigenvalue greater than 1, so that its cumulative interpretation variance is more than 60%. In order to further clarify the structure of each common factor, this paper used the maximum variance method to rotate the index orthogonal, so as to maximize the variance between the common factors in the load matrix, which can better explain the factor variables. We weighted and summarized the proportion of variance contribution rate of each factor as the weight, and obtained the comprehensive score Z. The component score coefficients of each annual output index are shown in table 2.

Table 2 component scoring coefficient matrix of each year

indicators	2010	2011	2012	2013	2014	2015	2016
Number of patent applications	0.187	0.240	0.165	0.208	0.169	0.172	0.165
Number of published papers	0.186	0.242	0.164	0.209	0.171	0.173	0.167
Number of scientific and technological works published	0.184	0.243	0.161	0.206	0.168	0.167	0.165
Income from patent ownership transfer and license (ten thousand yuan)	0.166	0.109	0.156	0.196	0.166	0.150	0.164
Technical contract amount	0.185	0.241	0.165	0.207	0.169	0.171	0.165
Number of special activities for popular science	0.015	-0.020	0.107	-0.003	0.030	0.083	0.068
Number of participants for popular science	0.151	0.025	0.155	-0.002	0.169	0.170	0.166
Sum of scoring coefficients	1.074	1.080	1.073	1.021	1.042	1.086	1.060

3.2 Comprehensive analysis of national scientific research institutions

The first step: Assuming that regional factors have a significant impact on the comprehensive performance of national scientific research institutions, the central and western regions are selected as dummy variables to analyze functions (1), (2), (3) and (4). This paper analyzed all the data with Frontier4.1 software, and got the estimated results shown in table 3.

Table 3 national SFA model estimation results 1

variable	coefficient	standard-error	t-ratio	
beta 0	3.96	1.16	3.41	
beta 1	1.55	0.26	5.87	***
beta 2	-0.48	0.21	-0.95	
delta 0	-0.32	0.89	-0.36	
delta 1	1.17	0.55	2.15	***
delta 2	1.33	0.59	2.25	***
gamma	0.78	0.10	8.08	***
Efficiency mean =		0.40		
log likelihood function =		-224.31		***
LR test of the one-sided error =		30.72		
with number of restrictions=		4		

Note: *,**and***represent statistical significance at the significance level of 10%, 5% and 1% respectively

From table 5 and figure 1, the human factor is under the 1% level by significance test, capital coefficient is almost under the 10% level by significance test. R&D personnel of full-time equivalent positively related to the scientific research output, capital stock may have negative relationship with scientific research output, the average efficiency of scientific research institutions in the fluctuating has risen year by year, the whole situation is relatively stable upward trend. This reflects that, in domestic scientific research institutions, researchers are the main driving force for the overall output growth of domestic scientific research institutions. And the input of scientific research funds does not play an ideal role in promoting output growth, which may be caused by the unreasonable structure or improper use of scientific research funds. The sum of manpower coefficient and capital coefficient is more than 1, indicating the diseconomies of scale in scientific research institutions.From the perspective of environmental variables, both delta1 and delta2 pass the significance test at the level of 1%, indicating that this hypothesis is valid and the region does have a significant impact on the comprehensive performance of scientific research institutions. Therefore, according to the regional division determined by the National People's Congress in 1986 and revised in 2000 and the overall economic development level of the whole country, this paper divides the national scientific research institutions into east, middle and west three areas for detailed analysis.

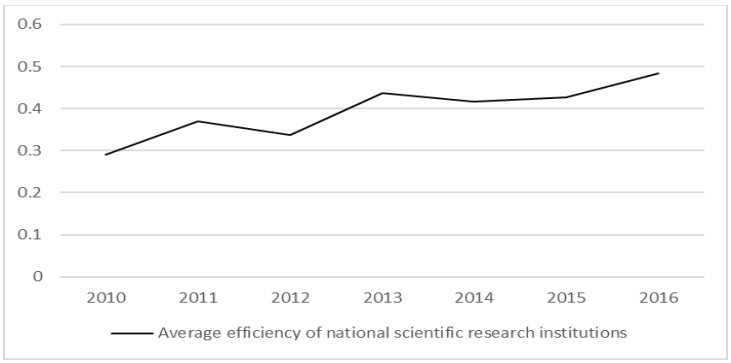

Fig. 1 average efficiency of national scientific research institutions

The second step: Since the hypothesis is valid, we substituted environment variables GDP, gov, mar and com for environment variables reg to analyze functions (1), (2), (3) and (5), and obtained the estimated results as shown in table 4.

Table 4 national SFA model estimation result 2

variable	coefficient	standard-error	t-ratio	
beta 0	3.96	1.16	3.41	
beta 1	1.22	0.25	4.90	***
beta 2	-0.17	0.19	-0.88	
delta 0	14.23	2.21	6.45	
delta 1	-0.94	0.20	-4.61	***
delta 2	-0.02	0.11	-0.19	
delta 3	-0.44	0.11	-4.01	***
delta 4	-0.22	0.04	-5.20	***
gamma	0.86	0.08	11.45	***
Efficiency mean =		0.40		
log likelihood function =		-195.06		***
LR test of the one-sided error =		27.82		
with number of restrictions=		89.20		

Note: *,**and***represent statistical significance at the significance level of 10%, 5% and 1% respectively

As can be seen from table 6, GDP, market demand and cooperation degree of enterprises all pass the significance test at the level of 1%, and are positively correlated with the comprehensive performance of scientific research institutions.This indicates that economic growth and positive market environment have positive effects on the improvement of comprehensive research performance.The relationship between policy support and comprehensive performance of scientific research institutions is not obvious.The specific reasons are further explained in the analysis by region.

3.3 comprehensive analysis of scientific research institutions in various provinces

Frontier4.1 software estimation results are shown in table 5.

Table 5 SFA model estimation results for each region

variable	The eastern region		The central region		the western region	
	coefficient	t-ratio	coefficient	t-ratio	coefficient	t-ratio
beta 0	2.12	2.69	-4.74	-4.65	7.35	397.42
beta 1	1.63***	6.28	1.01***	3.23	-0.41 ***	-93.54
beta 2	-0.42**	-1.97	0.90***	3.99	0.98 ***	378.44
delta 0	9.15	3.28	0.09	0.09	0.59	0.47
delta 1	-0.47***	-2.02	-0.43**	-1.1	0.35 ***	1.85
delta 2	0.06	0.52	0.17	0.19	0.27	0.83
delta 3	-0.61***	-1.84	0.85**	1.21	-1.13 ***	-4.29
delta 4	-0.27***	-5.78	0.14	0.79	-0.27 *	-1.09
gamma	0.56***	3.12	0.99***	91.18	0.99 ***	7173475
Efficiency mean =	0.53		0.35		0.30	
log likelihood function =	-45.45***		-49.15***		-46.79***	
LR test of the one-sided error =	72.06		34.86		33.12	
with number of restrictions=	6		6		6	

3.3.1 Input-output relationship and environmental impact analysis

(1)Analysis of the east: According to table 7, the coefficient of manpower and capital in the eastern region passed the significance test. The full time equivalent of R&D personnel is positively correlated with research output, while the capital stock is conversely, which indicates that the eastern region has shifted from capital-driven to human-driven. The sum of manpower coefficient and capital coefficient is greater than 1, which is consistent with the overall situation of the whole country, indicating that the scientific research level in the eastern region has reached the point of scale economy, and the improvement of scientific research efficiency cannot be promoted by

expanding the scale. The average efficiency of scientific research institutions in the eastern region is 0.53, higher than the national average, indicating that their scientific research level is in a leading position in China.

From the perspective of environmental factors, except the unclear relationship between government input and scientific research performance in the eastern region, other factors are significantly positively correlated with the performance of scientific research institutions. This may be related to the fact that the economy and scientific research in the eastern region are the most developed among the three regions, and the number of scientific research institutions is so large that simply increasing the scale can no longer promote the improvement of regional scientific research performance. Delta3 coefficient is the largest of the three significant environmental variables, indicating that market demand has the greatest impact on the comprehensive performance of the eastern region. If the east wants to further improve research efficiency, it must shift from scale to innovation. Only through some measures, such as closely combining the trend of economic development with the trend of market technology, combining production, education and research, and attracting a large number of talents, can the level of scientific research be further improved.

(2)Analysis of the middle:The coefficient of manpower and capital in the central region has passed the significance test, and the capital stock of R&D expenditure and the full time equivalent of R&D personnel are positively correlated with research output. Capital coefficient is higher than manpower coefficient, explaining that central area is capital-driven.The average efficiency of scientific research institutions in the central region is 0.35, which is lower than the national average, indicating that the efficiency of scientific research in the central region needs to be improved.

From the perspective of environmental factors, the relationship between the degree of policy support and cooperation with enterprises and the efficiency of scientific research in the region is not clear, while the GDP is positively correlated with the efficiency of scientific research and the market demand is negatively correlated. In recent years, the GDP growth rate of the central region exceeds that of the eastern region, which will inevitably drive the comprehensive performance development of scientific research institutions in the central region and affect the overall scientific research environment of the region. Based on the analysis of the market demand and the degree of cooperation between enterprises, although the receipt of enterprise funds can improve the comprehensive performance of scientific research institutions, the performance does not match the market demand, which may be due to the large difference in the development of different regions in the central region. For example, the economic and scientific research of cities in the middle and lower reaches of the Yangtze river with Wuhan as the center develops rapidly, while the central plains urban agglomeration with Zhengzhou as the center is relatively backward. meanwhile, the investment of government funds in the central region does not have the proper effect, which indicates that there may be some inefficiency in the allocation and use of government funds by scientific research institutions in this region.

(3)Analysis of the west:The coefficient of capital and human resources in western China has passed the significance test. The capital stock of r&d expenditure is positively correlated with scientific research output, while the coefficient of human resources is opposite. The capital coefficient is higher than the manpower coefficient, indicating that the western region is capital-driven, and the sum of the two is less than 1, indicating that the scientific research development in the western region has not yet reached the scale economy. In the western region where the development speed and the overall form of economic research are relatively poor, capital and scale are the main factors affecting the output of scientific research. In addition, the average efficiency of scientific research institutions in western China was 0.30, lower than the national average.

From the perspective of environmental factors, except policy support, all the factors are significantly correlated with the regional scientific research efficiency, GDP is negatively correlated with the total efficiency of regional scientific research, and other factors are positively correlated with the regional scientific research efficiency. The reasons for the non-significant correlation of government support may be similar to those in the eastern and central regions. The investment

funds of the government cannot be reasonably and fully utilized in various regions, leading to the unexpected effect of government investment in scientific research projects. The negative correlation of GDP may be due to the backward economic and scientific research status of the region, and the government cannot support the economic and scientific research development at the same time. In addition, capital input, market demand and degree of cooperation with enterprises all play an important role in improving the efficiency of scientific research institutions in this region, indicating that economic development can indeed promote the development of scientific research in the western region. but the first step is to ensure that the capital investment in the market and economy will not restrict the funding of scientific research activities.

3.3.2 Comprehensive efficiency analysis

As shown in figure 2, from 2010 to 2016, the performance of scientific research institutions in the eastern region has never been lower than the national average, and its change range is small. But the overall trend is gentle and the growth rate is lower than the national average. According to the analysis above, a mature scientific research system has been formed in the eastern region, and the level of scientific research has reached the point of scale. It is impossible to improve the efficiency of scientific research by simply increasing the scale.

The overall efficiency of scientific research institutions in the central region is on the rise, with the largest range of performance change and the fastest development of regional scientific research. This indicates that despite the influence of internal uncoordinated development in the central region, the central region has relatively greater space and potential for scientific research development.Since the sum of the human resource coefficient and capital coefficient is larger than 1 indicating that the central region is not suitable to increase the number of scientific research institutions to promote the improvement of its scientific research efficiency. However, through appropriate policy support, such as improving the proportion of government funds invested in various scientific research institutions, the scientific research efficiency of the central region will be greatly improved.Increasing financial support and adjusting the structure of scientific research institutions in the region will effectively promote the transition of the central region to a mature scientific research system similar to that in the eastern region, so as to improve the comprehensive performance of scientific research institutions in the central region.

The overall efficiency of scientific research institutions in the western region shows a gradual rise, but the fluctuation of their scientific research efficiency is the most intense, indicating that the instability of scientific research output in the western region may be caused by the uncoordinated development of scientific research in various provinces within the region and the input-output ratio. On the whole, for the western region, both research and development funds and researchers are in a state of urgent need to be supplemented. Increasing investment in capital and manpower or increasing the scale of scientific research institutions in the western region will have a significant positive effect on the output of scientific research in the western region.

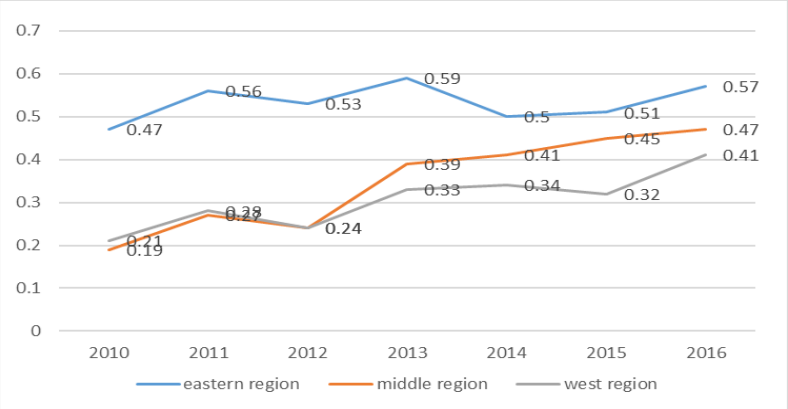

Fig. 2 average efficiency of scientific research institutions in different regions from 2010 to 2016

3.4 Random convergence analysis

Table 6 random convergence test results

region	The estimate	Im, Pesaran and Shin W-stat	ADF-Fisher Chi-square	PP-Fisher Chi-square
The national	Statistic	-1.51063	99.9881	175.763
	Prob.	0.0654	0.0003	0
The eastern region	Statistic	-1.98631	59.2095	111.108
	Prob.	0.0235	0.0001	0
The eastern region	Statistic	0.22346	15.138	20.3085
	Prob.	0.5884	0.6525	0.3157
The eastern region	Statistic	-0.67395	25.6406	44.3457
	Prob.	0.2502	0.0287	0.0001

As shown in table 9, according to the majority principle, the results of stochastic convergence are consistent with the above analysis results.

4. Conclusions and Suggestions

The main research conclusions are:

(1)The overall research efficiency of domestic research institutions has been steadily increasing, which is human-driven. However, due to unreasonable structure or improper use of research funds, research funds have not brought ideal positive effects on the output of research institutions. At the same time, the overall scale of domestic scientific research has reached saturation, a large-scale increase in the number of scientific research institutions cannot promote the improvement of scientific research efficiency.

(2)Scientific research institutions in east have formed a relatively mature scientific research system. The efficiency of domestic scientific research institutions is mainly driven by the eastern region, and its scientific research output is human-driven. The output of scientific research institutions in other regions are all capital-driven. The central region has a rapid development trend of scientific research, while the western region is more capital-driven due to the poor input-output ratio, and its efficiency fluctuation is more significant.

(3)Different environmental factors have different influences on the comprehensive performance of regional scientific research institutions. GDP has different influences on the comprehensive performance of regional scientific research due to the economic development of different region. The analysis of policy support factors reflects domestic research institutions have low efficiency and poor effect in using government research funds, which makes the government's investment in scientific research funds fail to bring expected results. Market demand and enterprise cooperation degree reflect the influence of industry-research cooperation on comprehensive scientific research performance. It can be seen that for regions with significant internal differentiation and unbalanced economic development, the increase of market demand and enterprise cooperation degree will inhibit the improvement of efficiency of scientific research institutions.

The recommendations are:

(1)The input of resources should not be planned by quantity, but be considered with its impact of the structure of input-output and whether it matches with regional development. Promoting the balanced development of each province is conducive to reduce the fluctuation range of the efficiency of scientific research institutions. Moreover, it should be noted that the unreasonable structure of investment in scientific research institutions has been relatively obvious, and combining various factors to improve structure of funds is urgent.

(2)The eastern region is the force of scientific research institutions in science and technology, and it should improve the scientific and technological funding structure. Also, it should adjust the personnel structure, promote the integration of industry, education and research to vigorously drive the growth of China's scientific and technological strength. The central region has the most development potential, so it should increase the investment of scientific research funds, focus on

solving the problem of unbalanced development within the region to promote the transition of scientific research system to the eastern region. In the western region with the urgent need of development of domestic scientific research institutions, low level of economic results in a scientific research institutions in the weak scientific research atmosphere. Regional development is slow, in turn, the low level of science and technology and will stifle economic growth, which creates a vicious circle. Overall development situation here is bad, it not only should increase funds and personnel, but promote the economic development, increase scientific research and economic double input, to ensure the efficiency of scientific research institution steadily improving.

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