

Research Article

An Empirical Study on Scientific Research Performance of Universities in Different Regions of China Based on PCA and Malmquist Index Method

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Received 3 June 2021; Revised 21 July 2021; Accepted 30 July 2021; Published 13 August 2021

Academic Editor: Ehsan Namaziandost

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This paper uses principal component analysis (PCA) and entropy method to construct the evaluation index system of the scientific research performance of universities in 31 provinces and cities in China. Based on the traditional DEA model, the development trend of the scientific research performance of the research objects from 2015 to 2019 is dynamically evaluated by the Malmquist index method. The results show that the scientific research performance of universities in various regions of China is not ideal, and the level of scientific research performance is declining. The total factor productivity of scientific research in the central and western regions is much higher than that in the eastern region. The main factor that hinders the improvement of scientific research performance is the efficiency of technological progress. Finally, aiming at the existing problems, some feasible suggestions are put forward to further improve the input-output efficiency of scientific research in universities.

1. Introduction

With the continuous development of the construction of an innovative country, science and technology have penetrated into all aspects of China's economic development, social progress, and human life, becoming the most active factor in productivity and a strong driving force for national development. Since the 21st century, more and more national governments have realized the importance of science and technology for national development and have begun to implement the strategy of "powering the country with science and technology". Science and technology innovation has become a major part of most countries, especially developed countries, to enhance their overall national strength and their core competition. And our country is also soberly aware that only by following the path of independent innovation and building an innovative country it can stand firm in the world and remain undefeated. In 2006, Comrade Hu Jintao delivered an important speech at the National Science and Technology Conference, proposing to "build my

country into an innovative country in 2020, and make science and technology a strong driving force for economic and social development." In 2012, the report of the 18th National Congress of the Communist Party of China once again proposed the implementation of the innovation-driven development strategy, emphasizing that scientific and technological innovation should be placed at the center of the overall national development and provide strategic support for improving social productivity. In 2014, General Secretary Xi Jinping emphasized at the Twelfth Academician Conference of the Chinese Academy of Engineering that scientific and technological innovation is the foundation of the country's prosperity and the soul of national progress. It is necessary to maximize the potential of science and technology as the primary productive force. The National Science and Technology Innovation Conference held on May 30, 2016 emphasized that science and technology are a weapon of the country, and scientific and technological innovation must be placed in a more important position to sound the clarion call for building a worldwide scientific and

technological power. The national medium and long-term education reform and development plan outline (2010–2020) puts forward: “Give full play to the important role of universities in the national innovation system, and encourage universities to make contributions in knowledge innovation, technological innovation, national defense technology innovation, and regional innovation.” In 2021, the “14th Five-Year Plan” pointed out that it is necessary to adhere to the core position of innovation in the overall modernization drive and put scientific and technological self-reliance at the top of all scientific and technological tasks. Obviously, the talent, knowledge, and technology-intensive colleges and universities provide a solid knowledge base and technical support for building a scientific and technological power.

As an important new force in the implementation of the innovation-driven development strategy, universities not only undertake the important task of cultivating high-level scientific and technological talents for the country but also undertake the major mission of realizing technological transformation and promoting the development of the local regional economy. Scientific research performance is an important criterion for measuring the comprehensive strength of universities. The level of scientific research directly affects the quality of training, discipline construction, and achievement output of universities. In recent years, the state has continuously increased its investment in scientific research in colleges and universities, and scientific research funding has shown rapid growth. Data from the “Compilation of Statistics on Science and Technology of Higher Education Institutions” compiled by the Department of Science and Technology of the Ministry of Education show that the state’s investment in scientific research in universities has increased from 122.27 billion yuan in 2014 to 205.27 billion yuan in 2019, with an average annual growth rate of 9.02%. However, a basic fact is that due to the geographical location, the history of running a school, and the basis of development, there are big differences between different universities in obtaining school funding and scientific research output. What we are concerned about is, in the context of very tight educational resources, in terms of scientific research, have these colleges and universities achieved the best output under the established conditions of input? How their scientific research performance can be compared? Which regions have high scientific research performance of universities? In which regions are universities having low scientific research performance? What are the main reasons for universities with relatively low scientific research performance? How should it be improved, etc.? Obviously, recognizing these issues can convey a lot of useful decision-making information to relevant authorities and universities, which has certain practical significance for promoting the development of universities.

At present, the state attaches great importance to education reform, and incentive policies have been introduced one after another, such as the improvement of the budget allocation system for colleges and universities and the active establishment of scientific research platforms. These measures have promoted a substantial increase in the

number of scientific research achievements of various colleges and universities. Research on the performance of scientific research in Chinese universities has achieved certain results, but, compared with developed countries, there are still many shortcomings. The first is the serious imbalance in the development of regional education. This imbalance is inevitable for China, which has a wide area, but reducing differences and improving the overall level is particularly important for my country to achieve sustainable development. Secondly, despite the large number of scientific and technological personnel in colleges and universities, there is a serious lack of high-level innovative talents. The scarcity of scientific research leaders has restricted scientific research to a certain extent. Coupled with the unsound management system, the inactive development of scientific and technological activities and other reasons, the current situation of the efficiency of scientific research in my country’s universities is not promising.

In summary, improving the scientific research performance of colleges and universities, improving the performance evaluation system, and analyzing the impact of key factors in a targeted manner will help colleges and universities in “short-board” areas to recognize their own problems and increase the ratio of scientific research input and output. Against this background, in order to realize the driving and advancement of scientific research to my country’s economy, it is necessary to conduct in-depth research and analysis on the performance of scientific research in universities and improve the status quo of scientific research in universities, so that it can move towards a high-quality, multi-innovative, specialized, and low-dispersion prospects for development.

2. Literature Review

At present, scholars have made a lot of fruitful exploration on the performance evaluation of scientific research in colleges and universities. The research mainly focuses on the following aspects.

First is the discussion on the construction of the performance evaluation index system of scientific research in colleges and universities. Different evaluation index systems will produce different evaluation results, and the rationality of their design can promote the improvement of scientific research performance in universities to a certain extent.

Wang et al. [1] adopted the weighting method combining the subjective and objective aspects of the analytic hierarchy process (AHP) and entropy value method to construct an evaluation index system with three levels, which not only followed the principle of index construction, but also complied with the objective reality. Zhu and Sun [2], based on the effects of research resources, research process, research impact, and other factors on the performance of scientific research in universities, designed an index evaluation model, which provided reference measurement standards for the analysis of performance management. Based on the DEA-CCR model, Liu and Fu [3] improved the evaluation index system constructed in China’s existing literature research and established a more scientific and

reasonable evaluation index system based on the characteristics of the research objects.

The second is the discussion on the evaluation methods of scientific research performance in universities. Qualitative and quantitative evaluation are mainly used to evaluate scientific research performance in colleges and universities. Qualitative evaluation methods include Delphi method, peer review method, and case analysis method. Quantitative evaluation includes literature analysis, analytic hierarchy process, and principal component analysis. In addition, some new methods, such as fuzzy comprehensive evaluation method, data envelopment analysis method, and grey decision evaluation method, have been applied to the research of scientific research performance evaluation in colleges and universities.

Zhang [4] used the TOPSIS method to comprehensively evaluate the scientific research performance of 19 agricultural colleges and universities and found the differences among the performance of each university and analyzed the reasons. Huang et al. [5] used principal component analysis and data envelopment analysis to conduct an empirical analysis on the scientific research performance of provincial universities in Jiangsu Province. Liu et al. [6] evaluated the performance of intellectual property ability of 38 “985” universities in China based on AHP-fuzzy comprehensive evaluation method, and the results showed that the intellectual property ability of “985” universities in different regions formed a three-step ladder.

Thirdly, the research performance of different evaluation units is discussed. The evaluation units can be further divided into three categories.

Among them, the first type of performance research is conducted with different university categories as evaluation units. For example, Qiu [7] analyzed the scientific research performance of 32 agricultural colleges from 2012 to 2015 by DEA and Malmquist index method and found that China’s agricultural and forestry colleges were in a non-DEA effective state on the whole. Zhong [8] used factor analysis method to dynamically evaluate the scientific research performance of five types of universities in China from 2012 to 2016, including comprehensive universities, agricultural and forestry colleges, normal colleges, engineering colleges, and medical colleges, and found that there was a “catch-up effect” among all kinds of colleges and universities, and the gap was narrowing.

The second kind is to take the specific university as the evaluation unit to conduct the performance evaluation research. For example, Ruan et al. [9] calculated the scientific and technological innovation performance of 39 universities in Shandong Province from 2013 to 2017 based on PCA/DEA model, and the research showed that the overall scientific and technological innovation performance showed an upward trend, but the fluctuation range was large. Chen and Liang [10] conducted an empirical analysis of the research performance of universities directly under the Ministry of Education based on principal component analysis and Malmquist index method and found that the overall research efficiency showed a downward trend.

The third category is the performance research with the universities in a certain region as the evaluation unit. For example, Cao [11] took “Double Tops” universities in Jiangsu, Zhejiang, and Shanghai as research objects and analyzed their scientific research performance from 2012 to 2016 based on Malmquist index and found that technological progress was the main factor affecting the improvement of scientific research performance. Zhang et al. [12] selected universities in the Yangtze River Delta as the research objects, carried out static and dynamic evaluation on their scientific research innovation performance from 2008 to 2017 with the help of DEA-Malmquist-Tobit model, and explored the influencing factors of scientific research performance.

To sum up, the existing studies have discussed in detail both the construction of index system and the application of research methods; however, the evaluation method adopted by most of the studies is relatively simple, and the research objects are mostly concentrated in key universities such as “985”, “211,” and “Double Tops”. Moreover, most of the studies choose to analyze from the static dimension, and lack of empirical research on the dynamic development trend of university research performance at the overall level. Based on this, this paper selected universities in 31 provinces and cities of China as research objects. Firstly, principal component analysis and entropy method were used to construct a reasonable evaluation index system, and the scores and rankings of scientific research input-output performance of universities in different regions were calculated. Then, based on the traditional DEA model, Malmquist index method is used to evaluate the research performance of universities in different provinces and cities dynamically.

3. Research Methods and Data Sources

3.1. Research Methods

3.1.1. Principal Component Analysis Method. Principal component analysis (PCA) is a kind of using dimension reduction; the loss will be less information under the premise of the original number of relevant variables $x_1, x_2, x_3, \dots, x_n$ (assuming a total of n indicators) converted into a multivariate statistical method for a few unrelated variables. The index evaluation system for measuring the performance of scientific research in colleges and universities is a multilevel and multiquantity comprehensive system. There may be strong correlation between input and output variables, and the reflected information overlapped to a certain extent. As a result, the effectiveness of decision-making units is generally close to 1, and the evaluation results lack differentiation. Principal component analysis (PCA), through dimensionality reduction and concentration of input-output indexes, not only retains the vast majority of information of original variables, but also eliminates the correlation between evaluation indexes, making indexes more concise and more objective. The basic principles of PCA are as follows.

- (1) Construct a variable matrix of order $n \times p$, $(x_{ij})_{n \times p}$:

$$X = X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2p} \\ \vdots & \vdots & \cdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{np} \end{bmatrix}. \quad (1)$$

- (2) The original data of the variable matrix of order $n \times p$ is standardized to eliminate the dimension of orders of magnitude:

$$\hat{X}_{ij} = \frac{(X_{ij} - \min X_j)}{(\max X_j - \min X_j)}. \quad (2)$$

Among them, X_{ij} is the original data of the i -th sample index j ; $\max X_j$ and $\min X_j$ are the maximum and minimum values of index j , respectively.

- (3) Calculate the correlation coefficient matrix of the standardized data matrix:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ \vdots & \vdots & \cdots & \vdots \\ r_{p1} & r_{p2} & \cdots & r_{pp} \end{bmatrix}, \quad (3)$$

$$r_{ij} = \frac{\sum_{k=1}^n (x_{ki} - \bar{x}_i)(x_{kj} - \bar{x}_j)}{\sqrt{\sum_{k=1}^n (x_{ki} - \bar{x}_i)^2 \sum_{k=1}^n (x_{kj} - \bar{x}_j)^2}}. \quad (4)$$

- (4) Find the eigenvalues of R λ_i , and the corresponding eigenvectors require $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_p \geq 0$, $\|e_i\| = 1$, which is $\sum_{j=1}^p e_{ij}^2 = 1$, and e_{ij} represents the j -th component of the vector e_i .
- (5) Calculate the contribution rate of principal components b_i and the cumulative contribution rate a_p :

$$b_i = \frac{\lambda_i}{\sum_{k=1}^p \lambda_k}, \quad (i = 1, 2, \dots, p), \quad (5)$$

$$a_p = \frac{\sum_{k=1}^i \lambda_k}{\sum_{k=1}^p \lambda_k}, \quad (i = 1, 2, \dots, p). \quad (6)$$

According to the principle of selection of principal components, generally the first, second, m ($m < p$) principal components corresponding to eigenvalues whose cumulative contribution rate is greater than 85% are selected.

3.1.2. Entropy Method. Entropy value method is a mathematical method to measure the degree of system disorder. By measuring the degree of dispersion of data, the influence degree of different indexes on the comprehensive evaluation can be judged more objectively. If the entropy value of an index is larger, it means that the index provides more

information and plays a greater role in the comprehensive evaluation, and the weight determined accordingly is higher. Using entropy value method to determine the weight of each principal component can make up for the deficiency of using variance contribution rate as weight in PCA method and avoid the influence of subjective factors. The process of index weighting and evaluation is as follows:

- (1) Normalize the data indicators to eliminate the influence of dimensions on the results.
- (2) Calculate the proportion of the i sample under the j index:

$$P_{ij} = \frac{\hat{X}_{ij}}{\sum_{i=1}^n \hat{X}_{ij}}, \quad i = 1, 2, \dots, n, j = 1, 2, \dots, m. \quad (7)$$

- (3) Calculate the entropy value of the j index:

$$e_j = -k \sum_{i=1}^n p_{ij} \ln(p_{ij}), \quad j = 1, 2, \dots, m, \quad (8)$$

$$k = \frac{1}{\ln(n)} > 0, \quad \text{therefore } 0 \leq e_j \leq 1. \quad (9)$$

- (4) Calculate the entropy redundancy of the j index:

$$d_j = 1 - e_j, \quad j = 1, 2, \dots, m. \quad (10)$$

- (5) Calculate the weight of the j index:

$$w_j = \frac{d_j}{\sum_{j=1}^m d_j}, \quad j = 1, 2, \dots, m. \quad (11)$$

- (6) Calculate the comprehensive score of the i sample:

$$s_i = \sum_{j=1}^m w_j p_{ij}, \quad i = 1, 2, \dots, n. \quad (12)$$

3.1.3. Malmquist Index Analysis Method. Malmquist index was first proposed by Malmquist Sten in 1953, which was used to construct consumption index. Later, Caves et al. extended its scope to the measurement of the change of total factor productivity. Through longitudinal analysis of panel data, the dynamic change and development trend of the efficiency of the multi-input multioutput structure were better described, which has become an effective non-parametric production frontier method to measure the efficiency change. Under the condition of constant returns to scale, Malmquist index can be decomposed into the product of Comprehensive Technical Efficiency Change (effch) and Technical Progress Index (techch). With variable returns to scale, the change of comprehensive technical efficiency can be further decomposed into two parts: Pure Technical Efficiency Index (Pech) and Scale Efficiency Index (Sech). The decomposition process is expressed as follows:

$$M(x_{t+1}, y_{t+1}, x_t, y_t) = \left[\frac{D_t(x_{t+1}, y_{t+1})}{D_t(x_t, y_t)} \times \frac{D_{t+1}(x_{t+1}, y_{t+1})}{D_{t+1}(x_t, y_t)} \right]^{(1/2)} \times \frac{D_{t+1}(x_{t+1}, y_{t+1})}{D_t(x_t, y_t)}, \quad (13)$$

$$\text{Tfpch} = \text{Effch} \times \text{Techch} = \text{Pech} \times \text{Sech} \times \text{Techch}. \quad (14)$$

Among them, (x_t, y_t) represents the input variable in the t period; (x_{t+1}, y_{t+1}) represents the output variable in the $t + 1$ period; D_t and D_{t+1} represent the distance function of period t and period $t + 1$, respectively. If the index > 1 , it means that the total factor productivity is on the rise in two adjacent periods, and the efficiency has improved. If the index $= 1$, it means that there is no change in total factor productivity in the two adjacent periods. An index < 1 indicates that total factor productivity is on a downward trend in two adjacent periods, and efficiency has decreased.

3.2. Data Source. This paper takes universities in 31 provinces, municipalities, and autonomous regions of China as the research objects. All data are from the Statistical Resources of Science and Technology of Colleges and Universities compiled by the Department of Science and Technology of the Ministry of Education, China. Considering that the output of scientific research activities has a certain lag with respect to the input, this paper defines the lag period of input and output as 1 year by referring to relevant literature; that is, the input data are selected as the sum of 2014–2018, and the output data are selected as the sum of 2015–2019. Data processing and analysis are carried out on SPSS23.0, DEAP2.1, EXCEL, and other software.

4. Construction of Evaluation Index System

4.1. Index Selection. To evaluate the performance of scientific research in colleges and universities, a set of index evaluation systems conforming to the characteristics of scientific research in colleges and universities should be established on the basis of the principles of comprehensiveness, science, and operability, so as to fully reflect the law of scientific research performance in colleges and universities. Due to the different research methods of different scholars, it is difficult to have a unified standard for the selection of indicators. On the basis of referring to the existing research results and considering the factors such as the systematization and availability of data, this paper preliminarily selects 11 input indicators and 11 output indicators to construct the evaluation index system of scientific research performance in universities, as shown in Table 1.

The selection of input indexes is mainly considered from three aspects: scientific research talents, scientific research funds, and scientific research projects. Among them, human resource is the most active factor in carrying out innovation activities in colleges and universities, which plays an important supporting role in scientific research progress and knowledge innovation. To some extent, the number of

scientific research talents reflects the importance and development level of scientific research and development activities in universities. In terms of funding input, two indexes are mainly selected: “total allocation of scientific research funds” and “internal expenditure of scientific research funds”. The internal expenditure mainly includes the research personnel fees, business expenses, fixed assets purchase fees, and taxes paid, which are needed to carry out scientific and technological research and development activities, but not the funds transferred to other units [13]. In terms of project investment, four indexes are mainly selected: “total number of projects”, “number of people invested in the year”, “funds allocated in the current year” and “expenditure for the year”. It is a key force to promote scientific and technological progress to carry out projects with social value and development potential in colleges and universities.

The output index is mainly selected from four aspects: paper works, achievement award, patent license, and technology transfer. Among them, the paper works are not only the literal embodiment of the scientific and technological research and development achievements of universities, but also an important factor to measure their scientific and technological innovation ability. Achievement award can reflect the quality of scientific research achievements in universities and is the main criterion to judge the success of scientific research activities. Patent license, as a key index of scientific research output, can better reflect the benefits and values brought by scientific and technological innovation activities. Finally, technology transfer can measure the economic benefits generated by scientific research and technological development in universities. This paper mainly uses two indexes, “number of signed contracts” and “actual income of the year” to illustrate.

4.2. Extract the Principal Components Based on the PCA Method. Before the principal component analysis, in order to eliminate the impact caused by the difference of dimension and unit among indicators, it is necessary to standardize the original data. Then, PCA method is used to extract the principal components from the initial evaluation index system and calculate the eigenvalue, variance contribution rate, and cumulative variance contribution rate of each principal component. Generally speaking, the principle of extracting principal component is that its eigenvalue is greater than 1. However, considering the degree of commonality among variables, too much missing information of one dimensional data will lead to deviation in the analysis of empirical results. Therefore, a principal component with an eigenvalue of 0.711 was selected in this paper, which was conducive to optimal model effect and more reasonable and accurate result analysis. The specific results are shown in Table 2.

According to PCA method, two principal components are extracted from input and output indexes, respectively, and a new evaluation index system of S&T innovation performance in colleges and universities is constructed. According to the contribution of each component to the 22

TABLE 1: Initial evaluation index system of scientific research performance in universities.

First-level indicator	Second-level indicator	Third-level indicator
A research input	A1 Research talents	A11 Teaching and research staff/person
		A12 Number of scientists and engineers in teaching and research staff/person
		A13 Research and development personnel/person-year
		A14 Number of scientists and engineers among R&D personnel/person-year
		A15 Research and development full-time equivalent personnel/person-year
	A2 Research funding	A21 Total scientific research funding/thousand yuan
		A22 Internal expenditure of scientific research funds/thousand yuan
		A31 Total number of projects/item
	A3 Science and technology projects	A32 Number of people invested in the year/person
		A33 Funds allocated in the current year/thousand yuan
		A34 Expenditure for the year/thousand yuan
B research output	B1 Paper works	B11 Number of works/part
		B12 Word count/thousand words
		B13 Total academic papers/piece
		B14 Foreign and national publications/articles
	B2 Achievement award	B21 Achievement awards/item
		B22 Number of national awards/item
		B31 Invention patent/item
	B3 Patent license	B32 Utility model/item
		B33 Appearance design/item
	B4 Technology transfer	B41 Number of signed contracts/item
		B42 Actual income of the year/thousand yuan

TABLE 2: Principal component analysis of input and output indexes.

	The principal components	The eigenvalue	Variance contribution %	Cumulative variance contribution rate %
Input indicators	F1	9.644	87.677	87.677
	F2	0.711	6.464	94.141
Output indicators	F3	8.226	74.779	74.779
	F4	1.233	9.072	85.992

indicators, the four principal components are respectively the total investment of scientific research personnel, research funding and expenditure, paper achievements and patents, transfer revenue and number of contracts signed. This new indicator system eliminates the strong correlation between the original indicators and makes the evaluation of the scientific and technological innovation performance of universities in various regions more objective and reasonable. The new index evaluation system is shown in Table 3.

4.3. Determining Index Weight Based on Entropy Method. The principal components of the index system were weighted according to the entropy value method, and the results are shown in Table 4.

According to the analysis and measurement results, the index weight of scientific research input is 0.516, which has a more important impact on the performance evaluation of colleges and universities than the output of scientific research. Among them, the weight of the total investment index of scientific research personnel is 0.283. It can be seen that paying attention to the introduction of talents can promote the cultivation and improvement of the scientific and technological innovation ability of universities to a certain extent. The index weight of the input and

expenditure of scientific research funds is 0.233, which plays a key role in promoting the performance of scientific research in universities. However, some provinces and cities still have the phenomenon of inefficient use of funds and serious waste. Therefore, corresponding management systems should be established to improve the unreasonable allocation of funds and control the intensity of investment. Paper achievements and patents, with a weight ratio of 0.403, account for the largest weight in scientific and technological output, which is a crucial breakthrough that affects the scientific research performance of universities. The achievements of scientific research are the embodiment of the innovation level of academic research in colleges and universities, and the education departments in all regions should continue to support and promote the development of knowledge innovation. The weight of the index of transfer income and signed contract number is only 0.081, indicating that this index still has a large room for improvement in improving the scientific research performance of colleges and universities. Meanwhile, it also reflects from the side that the current transformation effect of scientific research achievements in various provinces and cities is not good, which seriously affects the improvement of scientific and technological innovation ability of colleges and universities.

TABLE 3: The new index evaluation system of university science and technology performance based on principal component.

First-level indicator	Second-level indicator	Third-level indicator
Research input	Research talents	Total investment of scientific research personnel
	Research funding	Research funding and expenditure
Research output	Research achievements	Paper achievements and patents
	Technology transfer	Transfer revenue and number of contracts signed

TABLE 4: Principal component weighting based on entropy method.

First-level indicator	First-level weight	Second-level indicator	Second-level weight	Third-level indicator	Third-level weight
Research input	0.516	Research talents	0.283	Total investment of scientific research personnel	0.283
		Research funding	0.233	Research funding and expenditure	0.233
Research output	0.484	Research achievements	0.403	Paper achievements and patents	0.403
		Technology transfer	0.081	Transfer revenue and number of contracts signed	0.081

5. Result and Discussion

5.1. Research Performance Score and Ranking of Universities. According to the abovementioned index system and the index weights determined by the entropy method, the comprehensive scores of scientific research input and scientific output of China's 31 provinces and cities from 2015 to 2019 are calculated in turn. Then, divide the arithmetic mean of the comprehensive scores of scientific research output by the arithmetic mean of the comprehensive scores of scientific research input to obtain the scientific research performance scores of universities in each province and municipality [14]. The results are as shown in Table 5.

Through analysis, it is not difficult to find that there is a certain difference between the rankings of scientific research input and scientific research output. The number of scientific research output of universities in various provinces and cities does not match the scale of their huge investment in human and financial resources. The top 10 provinces and cities in terms of scientific research investment scores are Beijing, Jiangsu, Guangdong, Shanghai, Hubei, Shandong, Zhejiang, Liaoning, Sichuan, and Shaanxi. Among these 10 provinces and cities, with the exception of Hubei Province, which is located in the central region, Sichuan Province and Shaanxi Province are located in the western region, and the others are located in the eastern region. This also shows that universities in the eastern region have attracted a large amount of scientific research investment from the state and society and have certain advantages in the acquisition of funds, equipment, and other resources, while universities in the central and western regions are affected by their geographical location and economic development level, and their resource investment is relatively low. The top 10 provinces and cities in terms of scientific research output scores are Jiangsu, Beijing, Zhejiang, Shanghai, Guangdong, Hubei, Shaanxi, Sichuan, Shandong, and Liaoning. The output rankings of the top 10 provinces and cities in terms of input remain in the top 10, but the rankings of the provinces and cities have changed to some extent.

From the perspective of the comprehensive scores of scientific research performance from 2015 to 2019, the performance scores of provincial and municipal universities in the central and western regions are relatively high, while the eastern region is at the end of the performance rankings due to the mismatch of scientific research output and input intensity and low production efficiency. The top 10 provinces and cities in the overall performance score are Jiangsu, Zhejiang, Chongqing, Shaanxi, Hainan, Sichuan, Gansu, Hubei, Guizhou, and Yunnan. Among them, the comprehensive performance score ranking of Beijing, which ranked the first in scientific research investment, fell to the 23rd; Guangdong Province ranking the 3rd in scientific research investment and Shandong Province ranking the 6th in comprehensive performance scores dropped to the 31st and 6th place, respectively. In sharp contrast, Chongqing's comprehensive performance score ranking, which ranked the 20th in scientific research investment, rushed to the third place; Hainan Province, which ranked the 29th in scientific research investment, rose to 5th. Scientific research investment ranked the 24th. The rankings of Guizhou Province and Yunnan Province, which were the 23rd, have risen to the 9th and 10th, respectively. This shows that although universities in the eastern region have attracted a large number of national scientific and technological resources, they have a wealth of high-level talents and advanced machinery and equipment; their scientific research input and output efficiency is not high; and some are affected by geographical location, economic development, history, and the scale of universities. Universities in the central and western regions affected by other objective factors can continuously improve the efficiency of scientific research by adopting measures such as optimizing the allocation of resources, balancing the level of input and output, and improving the performance management mechanism.

5.2. Malmquist Index Analysis of Scientific Research Performance in Colleges and Universities. With the help of DEAP2.1 software and based on the constructed index evaluation system, the input-output research efficiency of

TABLE 5: Research performance scores and rankings of universities in different provinces and cities from 2015 to 2019.

Region	Province	Ranking		Performance composite score	Ranking
		Input	Output		
East	Beijing	1	2	0.888	23
	Tianjin	15	19	0.786	28
	Hebei	16	16	1.004	11
	Liaoning	8	10	0.921	21
	Shanghai	4	4	0.823	26
	Jiangsu	2	1	1.332	1
	Zhejiang	7	3	1.179	2
	Fujian	17	17	0.956	15
	Shandong	6	9	0.942	19
	Guangdong	3	5	0.699	31
	Guangxi	19	22	0.746	29
	Hainan	29	28	1.045	5
Central	Shanxi	22	23	0.946	18
	Jilin	14	18	0.814	27
	Heilongjiang	11	12	0.927	20
	Inner Mongolia	26	26	0.907	22
	Anhui	13	14	0.717	30
	Jiangxi	21	20	0.982	13
	Henan	18	11	0.879	24
	Hubei	5	6	1.034	8
	Hunan	12	13	0.973	14
West	Chongqing	20	15	1.175	3
	Sichuan	9	8	1.040	6
	Guizhou	24	24	1.024	9
	Yunnan	23	21	1.010	10
	Tibet	31	31	1.001	12
	Shaanxi	10	7	1.120	4
	Gansu	25	25	1.037	7
	Qinghai	30	30	0.955	16
	Ningxia	28	29	0.950	17
	Xinjiang	27	27	0.858	25

universities in 31 provinces and cities in China is analyzed. The output-oriented BCC model is adopted to measure the technical efficiency, pure technical efficiency, scale efficiency, and research total factor productivity of universities in each province and city. The results are shown in Table 6.

On the whole, the total factor productivity of scientific research in universities of all provinces and cities in China shows a downward trend, decreasing by 4.7% annually, mainly due to the decrease of technological progress efficiency and comprehensive technological efficiency to varying degrees, which are 4.5% and 0.3% respectively. This shows that the technical level of Chinese universities in recent years has not reached the best state, and the existing technical ability can not meet the needs of scientific research and production but need to be further improved. Although the comprehensive efficiency value is close to the effective frontier, there are still some deficiencies in resource scale management. It is necessary to continuously optimize resource allocation, find the optimal scale output point, and improve the input-output efficiency. At the same time, only 6 provinces and cities have R&D total factor productivity greater than 1, basically maintaining an upward trend, accounting for 19.4% of the total. The other 25 provinces and cities' R&D total factor productivity has shown a downward trend, indicating that the overall scientific research performance of universities in

China's 31 provinces and cities is not ideal. It is necessary to carefully analyze the reasons, grasp the root of the problem, prescribe the right remedy, and continuously adjust and improve.

In terms of different regions, there is a regional imbalance in the total factor productivity of scientific research in universities in eastern, central, and western China. The overall technical efficiency of the eastern region is the best, followed by the central region, and the western region is the worst. However, the total factor production efficiency of scientific research in the eastern region is not ideal and is the lowest among the three. The main reason for this phenomenon is that its technical efficiency value is low, indicating that the eastern region's universities are seriously inadequate in terms of technological innovation and resource allocation and should be further improved. The level of scientific research management should be improved continuously and the efficiency of scientific research production should be enhanced. The central region has the best scientific research and all-factor production efficiency. This may deviate from our expectations. The main reason is that the traditional advantages of the eastern region have led to its insufficient development potential. In contrast, the central region has more room for improvement. The rising trend of production efficiency is obvious. The low value of

TABLE 6: Malmquist index evaluation results of scientific research performance of universities in different provinces and cities from 2015 to 2019.

Region	Province	Effch	Techch	Pech	Sech	Tfpch
East	Beijing	0.951	1.006	0.969	0.982	0.957
	Tianjin	1.002	0.953	0.994	1.007	0.955
	Hebei	1.015	0.916	1.005	1.010	0.930
	Liaoning	1.024	0.982	1.021	1.003	1.006
	Shanghai	0.962	1.019	0.962	1.000	0.981
	Jiangsu	1.000	1.011	1.000	1.000	1.011
	Zhejiang	1.012	0.937	1.000	1.012	0.948
	Fujian	0.963	0.931	0.964	0.999	0.897
	Shandong	1.000	0.973	1.000	1.000	0.973
	Guangdong	1.024	0.948	1.011	1.012	0.970
	Guangxi	0.999	0.915	1.000	0.999	0.914
	Hainan	0.995	0.945	1.000	0.995	0.940
Central	Shanxi	1.000	0.935	1.028	0.973	0.935
	Jilin	0.971	0.947	0.992	0.979	0.919
	Heilongjiang	1.023	0.907	1.020	1.003	0.928
	Inner Mongolia	0.952	0.939	0.949	1.004	0.894
	Anhui	0.977	0.939	0.977	1.000	0.918
	Jiangxi	1.030	0.941	1.026	1.004	0.969
	Henan	1.000	1.005	1.000	1.000	1.005
	Hubei	1.006	1.007	1.009	0.997	1.013
	Hunan	1.033	0.925	1.035	0.997	0.955
West	Chongqing	0.988	0.975	0.994	0.993	0.963
	Sichuan	1.045	0.975	1.039	1.006	1.018
	Guizhou	1.003	0.951	1.002	1.001	0.953
	Yunnan	0.978	0.947	0.996	0.982	0.925
	Tibet	1.000	0.942	1.000	1.000	0.942
	Shaanxi	1.033	1.009	1.040	0.993	1.042
	Gansu	0.992	0.947	0.993	0.999	0.940
	Qinghai	0.997	0.939	0.998	0.999	0.936
	Ningxia	0.981	0.927	0.989	0.992	0.910
	Xinjiang	0.977	0.940	1.002	0.975	0.919
	Eastern average	0.995	0.961	0.997	0.998	0.956
	Central average	0.994	0.995	1.000	0.994	0.988
	Western average	0.991	0.990	0.998	0.994	0.982
	Overall average	0.997	0.955	1.000	0.997	0.953

pure technical efficiency in the western region is the main reason for the decline in its scientific research total factor productivity, which shows that the western region needs to be further improved in terms of self-management control and resource allocation. At the same time, the western region has neglected the large-scale construction work in the development process. In the case of insufficient input or excessive input, the ratio between input and output should be balanced, and reasonable planning should be made to achieve the optimal state of scientific research output.

In terms of provinces and cities, the comprehensive technical efficiency, pure technical efficiency, and scale efficiency of six provinces and cities including Liaoning, Jiangsu, Henan, Hubei, Sichuan, and Shaanxi are all greater than 1, and the performance of scientific research continues to increase, which improves the overall performance of the country. As for the performance level, due to the impact of pure technical efficiency and scale efficiency, universities in Beijing, Shanghai, and other provinces and cities have shown a downward trend in scientific research performance. As a strong province of educational resources and an important

base for talent training, the two have unique advantages in resource acquisition. The state has invested a huge amount of education funds. Therefore, it is necessary to continuously improve the efficiency of resource utilization and optimize the internal management system to ensure that scientific research output is both in quantity and quality. All of the above have reached the optimal state, thereby improving the efficiency of scientific research input and output. The total factor productivity of scientific research in Shandong, Jiangxi, Guangdong, and other provinces and cities is close to 1. It shows that the scientific progress is slow and the research is at a stagnant stage. The main reason is that the efficiency of technological progress has played a lower role. Therefore, it is necessary to continuously tap the internal potential and introduce advanced technology. To improve the level of scientific research. Fujian, Heilongjiang, Ningxia, and other provinces and cities are seriously inadequate in terms of resource management and technical level, and the level of scientific research performance is showing a continuous downward trend. The relevant management departments should formulate targeted measures to improve this unfavorable situation.

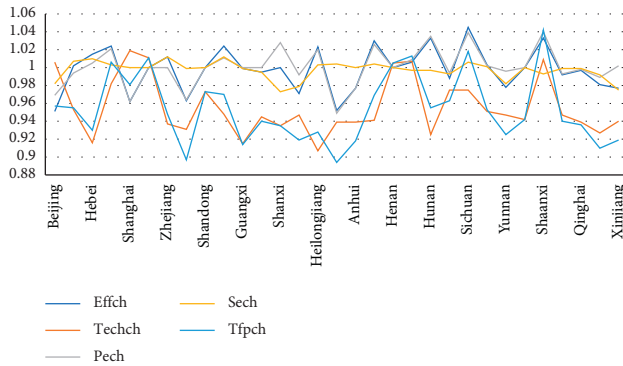


FIGURE 1: Malmquist index evaluation results of scientific research performance of universities in different provinces and cities from 2015 to 2019.

Figure 1 further visually analyzes the dynamic trend of scientific research performance of universities in different provinces and cities in China. It can be seen from the figure that the total factor productivity of scientific research in universities is affected by the joint changes of comprehensive technical efficiency and technological progress efficiency, but it is more consistent with the changing trend of technological progress efficiency and has obvious volatility. Except for Shanxi, Inner Mongolia, and Xinjiang, where the scale efficiency is obviously low, other provinces and cities are almost the same without much fluctuation. This also shows that pure technical efficiency is the main factor that affects the overall technical efficiency changes, and the fluctuations of the two are relatively close. Among them, the pure technical efficiency values of Shanghai, Fujian, and Heilongjiang are obviously low, and the overall technical efficiency is showing a downward trend; the pure technical efficiency of Hunan, Sichuan, and Shaanxi has an obvious upward trend, and the overall technical efficiency is greatly improved.

6. Conclusion and Recommendation

This paper uses a combination of PCA and entropy method to construct a scientific research performance evaluation index system for colleges and universities, based on DEA's Malmquist index method to dynamically evaluate the scientific research performance of 31 provinces and cities in China from 2015 to 2019, and compares different provinces and cities. The differences among the comprehensive technical efficiency, technical progress efficiency, pure technical efficiency, scale efficiency, and total factor productivity of universities in different regions mainly draw the following conclusions.

- (1) On the whole, the development of total factor productivity of scientific research in universities in different provinces and cities in China has slowed down, showing a downward trend. Both the comprehensive technical efficiency and the efficiency of technological progress have played a role in the reduction to varying degrees. From the perspective of different regions, the central and the total factor

productivity of scientific research in the western region is much higher than that in the eastern region, and the trend of development and progress is obvious. The main factor hindering the improvement of the scientific research performance of universities is the efficiency of technological progress.

- (2) From 2015 to 2019, the average scientific research total factor productivity of universities in different provinces and cities was 0.953, with an average annual decline of 4.7%, which was the result of a combined effect of a 0.3% drop in comprehensive technical efficiency and a 4.5% drop in technological progress efficiency, mainly due to technological progress. The influence of efficiency factors: among them, the pure technical efficiency value is 1, and the scale efficiency value is 0.997, indicating that universities in different provinces and cities still have room for improvement in terms of resource scale control and capital investment.
- (3) The total factor productivity of scientific research in universities in different provinces and cities differs greatly. Among them, the TFP index of 6 provinces and cities is greater than 1, basically maintaining an upward trend, accounting for 19.4% of the total. The TFP indexes of the other 25 provinces and cities are all less than 1. Total factor productivity is on a downward trend, and the level of scientific research input and output needs to be further improved. From the perspective of specific components, 17 provinces and cities have a comprehensive technical efficiency index greater than 1, while only 6 provinces and cities have a technological progress index greater than 1. Therefore, it is necessary to take targeted measures to improve technological innovation capabilities and promote technological progress.

In view of the various problems in the scientific research performance of universities in different provinces and cities in China, in order to promote the balanced development of the region and improve the overall scientific research level, the following improvement measures are proposed:

- (1) From a long-term perspective, a dynamic competition funding mechanism based on the comprehensive evaluation results of scientific research performance should be gradually established. At present, there is a serious mismatch between the scale of resource input and the benefit of scientific research output in various provinces and cities, and there are phenomena such as "emphasis on quantity, light on quality, emphasis on awards, and light on benefits". In order to improve the overall efficiency of scientific research allocation in universities, it can be introduced in the capital allocation. The competition mechanism dynamically adjusts the scale of funding according to the results of the comprehensive evaluation of scientific research performance and allocates high-quality resources to universities with better scientific research performance. At present,

universities in the central and western regions have a relatively high level of scientific research performance. The amount of scientific research funding should be appropriately increased to encourage them to produce more high-quality scientific research results. The eastern region is in a state of insufficient development potential, and the education authority should appropriately reduce funding and optimize its resource input structure.

- (2) In order to reduce the differences in scientific research performance of universities in different regions, exchange and learning between universities in different regions should be strengthened, and resource sharing should be gradually realized. For low-performance provinces and cities, we must continue to learn from the excellent experience of the frontier provinces and cities to formulate long-term scientific research development plans, so as to continuously improve scientific research productivity and resource management. At the same time, the central and local resource input should be balanced and coordinated to change the current situation of insufficient support for universities in the central and western regions. For example, in terms of talent introduction, we should formulate incentive policies for scientific research teams and strengthen the echelon construction of scientific research teams in universities in the central and western regions, so that more scientific and technological talents are willing to stay in universities in the central and western regions and make contribution, thereby achieving a steady improvement in the level of scientific research performance of universities.
- (3) Continuously improve the scientific research performance management mechanism and optimize the internal organizational structure. The university's own resource allocation and management system are important factors that affect the efficiency of scientific research input and output. For universities with low-performance levels, it is necessary to adjust the extensive development path, formulate scientific and reasonable guidelines and policies, and effectively control the ratio of scientific research input and scientific research output. For example, a special scientific research performance supervision and management department can be established within the university to keep abreast of scientific research input and output and supervise and evaluate it, so as to continuously improve the performance of scientific research input and output.

Data Availability

All the data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This paper was one of the research results of the Liaoning Provincial Department of Science and Technology Project (Project name: Research on the Performance Evaluation and Improvement PATH of Liaoning Province Science and Technology Expenditure Based on DEA Model, project batch number: 2019-ZD-0474).

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