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Original scientific paper

Assessment of Research Efficiency in China's Universities Based on Data Envelopment Method

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Abstract: To investigate the static and dynamic trends of scientific research efficiency of different types of universities in China during the period of 2016 - 2020. Methods: Based on the scientific research data of six types of universities nationwide from 2016 to 2020, which are classified by the Compendium of Science and Technology Information of Higher Education Institutions published by the Department of Science and Technology of the Ministry of Education. We selected the full-time personnel (person-years) of research and development personnel and Internal expenditure for the year of science and technology funds (thousand yuan) as input evaluation indexes, and the number of Academic papers published abroad (articles), the number of international projects acceptance (item), the number of patent authorizations (item), and the number of Actual income of technology patents in the current year (thousands of yuan) as output evaluation indexes, and constructed the evaluation index system of scientific research efficiency of six types of universities nationwide. SPSS version 23.0 software was used for descriptive data statistics, and DEA-BCC model and DEA-Malmquist index model of DEAP2.1 software were used for static and dynamic evaluation of its scientific research efficiency from 2016 to 2020, respectively. Results ① Overall analysis: the level of scientific research efficiency of all types of universities is high, but the total factor productivity of scientific research shows a trend of rising and then declining during the 13th Five-Year Plan period, and the overall scientific research efficiency of universities has limited room for improvement. ② Comparative analysis: universities of comprehensive, science and technology, medicine and other universities have the highest level of scientific research efficiency, followed by universities of teacher training and lower universities of agriculture and forestry. ③ From 2017 - 2020, full-time personnel, internal expenditures of agriculture and forestry universities are input redundancy, patent authorization number and the actual income of agriculture and forestry universities are insufficient output. In 2020, full-time personnel, internal expenditures of normal universities are input redundancy, patent authorization number of normal universities is output insufficient. Conclusion: During the period of 2016 - 2020, all kinds of universities nationwide have achieved high research efficiency with high input and high output, which provides a strong reference for the national research management to allocate university research funds more scientifically and reasonably. This result to optimize the allocation of resources of university's scientific research in China and improve the economic benefit of university's scientific research has important theoretical and practical significance.

Key word: data envelopment analysis; malmquist; scientific research efficiency university

1 INTRODUCTION

According to the national science and technology investment data publicly released on the website of the National Bureau of Statistics, during the period of 2016 - 2020, in 2016, it was 1567.7 billion yuan, an increase of 11.06% compared with 2015, and in 2020 it reached 2442.6 billion yuan, an increase of 10.3% compared with 2019, and an increase of 172.38% compared with 2015. According to the input of scientific and technological funds of six categories of Universities published by the Science and Technology Department of the Ministry of Education, during the period of 2016 - 2020, it shows that in 2016, 135.612 billion yuan is increased by 8.99% as compared with 2015, and in 2020, 245.820 billion Yuan is increased by 11.98% as compared with 2019. Compared with 2015, 2020 is an increase of 197.56%. As a result, the input of funds is increased by more than 10% every year.

At present, Amazing scientific research results have been achieved, by investing a large number of researchers and research funds. However, compared with high input, high-level scientific research results do not show a complete synchronous output. How to rationally allocate limited scientific research resources and improve scientific research innovation ability is a major issue related to the scientific and technological development of the country, society and universities. Based on this, this research has selected the scientific and technological data of various domestic universities which have the greatest contribution to the national science and technology as the sample, using the data envelopment analysis (DEA) method and the Malmquist index analysis method to analyze the static and dynamic trends of scientific research efficiency. And according to the research results, it discusses the changing rules of scientific research efficiency of Chinese universities and the blocking points that affect scientific research efficiency, and puts forward scientific management and improvement. The results of this study on optimizing the resources distribution of scientific research and raising economical benefit of scientific research of university in China have important theoretical and practical significance.

2 LITERATURE REVIEW

The research on the evaluation of scientific research efficiency in universities started very early in foreign countries, and gradually transited from the initial single research on the efficiency of scientific research input or scientific research output to the research on the efficiency of scientific research input and output. In the process of this research, more and more foreign scholars used the method of parameter or non-parameter to make empirical analysis. Due to the characteristics of Data Envelopment Analysis (DEA), such as multi-input, multi-output, strong objectivity and obvious economic significance, more and more scholars have introduced the DEA model into the research field of higher education since the 1990s, and obtained many research results. Among them, Colbert·Shanet MC(2000) and other scholars used DEA method to evaluate the research efficiency of the top 25 MBA programs in the United States [1]. Gorman B and Kelly T(2011) and other scholars used DEA method to measure and analyze the research efficiency of universities in order to study the factors affecting the research efficiency of universities, and put forward suggestions for improvement [2]. Johnes Geraint and Johnes Jill Cy (2009) use data envelopment analysis (DEA) method to analyze the input cost and performance of British universities from

2000 to 2003. In the process, a new estimation method is found for the multi-output cost function of universities [3]. L.Cherchye, Piet Vanden Abeele, regard all universities in Australia as a whole, and use data envelopment analysis to analyze and conclude that its scientific research efficiency is relatively high. However, the author believes that the evaluation result is not a reflection of the real situation because the large-scale scientific research equipment is not purchased by the university itself but is funded by the government. At the same time, the author points out that the efficiency value obtained by the method is a relative score, and the high efficiency value does not indicate that the university's scientific research efficiency is absolutely high, and the university still has room for improvement [4]. Anderson, T. R. and other scholars (2007) used DEA method to measure the technology conversion efficiency of American universities and found that the technology conversion efficiency of top universities is generally higher [5]. David Andres Munoz (2016) used DEA to evaluate the scientific research performance of universities in Chile. The research found that only a few universities' scientific research efficiency is DEA-efficient, and there is a difference in scientific research efficiency between public universities and private universities [6]. Many domestic scholars have also made more achievements in the evaluation and analysis of scientific research efficiency of universities by using DEA method. Xu Juan (2009) selected universities in 31 provinces and cities in China in 2006 as decision-making units, and selected internal expenditure of scientific and technological funds, scientific research personnel, research and experimental development personnel and project expenditure of the current year as measurement indicators of scientific research input, and used non-parametric data envelopment analysis method to evaluate its input and output efficiency. It is pointed out that there is no inevitable connection between the efficiency of scientific research in universities in various provinces and the regional economy, and the source of scientific research development in universities is the high efficiency that brings high scientific research output [7]. Li Xiaojing and other scholars (2015) combined with the current situation of the management of scientific research funds in universities, established an evaluation index system for the efficiency of the use of scientific research funds in universities, and applied the DEA-CCR model to make an overall and categorical empirical analysis of 62 "211" and "985" universities in the country from 2008 to 2010, and obtained the DEA efficiency scores of scientific research funds in various universities. It was considered that most universities had problems of excessive input or insufficient output of scientific research funds [8]. Zhang Qing et al(2013) take the input-output data of scientific research of local universities in 31 provinces (including municipalities directly under the central government) of our country as samples, use the data envelopment analysis method to conduct empirical analysis, and compare and sort the performance. The research results show that the performance of scientific research in these universities is uneven. Compared with pure technical control, scale control is more effective in improving the level of scientific research performance [9]. Li Yanhua et al. (2019) applied DEA and Malmquist model to deeply analyze the current situation and internal differences of scientific research efficiency in China's "double-top" universities from 2014 to 2017. It is found that the total factor productivity of scientific research in universities first decreases and then increases with the change of technological progress index. It is believed that the key to sustainable development is to maintain the improvement of the overall level of scientific research efficiency and the index of technological progress [10]. Referring to the above research results, we selected various domestic public universities to evaluate their research efficiency during the period of 2016 - 2020.

3 MATERIALS AND METHODS

3.1 Data Collection

According to the letter (No. 4 (2014)) issued by the Education and Technology Commission entitled "Evaluation Index System and Evaluation Essentials of Science and Technology Classification in Universities", based on the input-output theory, combined with the general situation of science and technology activities in universities, and following the five interrelated basic principles of systematicness, scientificity, orientation, comparability and feasibility, and referring to the previous studies [8, 11-14] by domestic scholars, the input-output index system is constructed with the aim of improving the quality and innovative level of scientific research outputs and taking into account the availability of data. The "Compendium of Scientific and Technological Information of Universities" is used as the data source (This compilation does not contain the data of scientific and technological activities of universities in Taiwan Province and Hong Kong and Macao Special Administrative Regions of China).

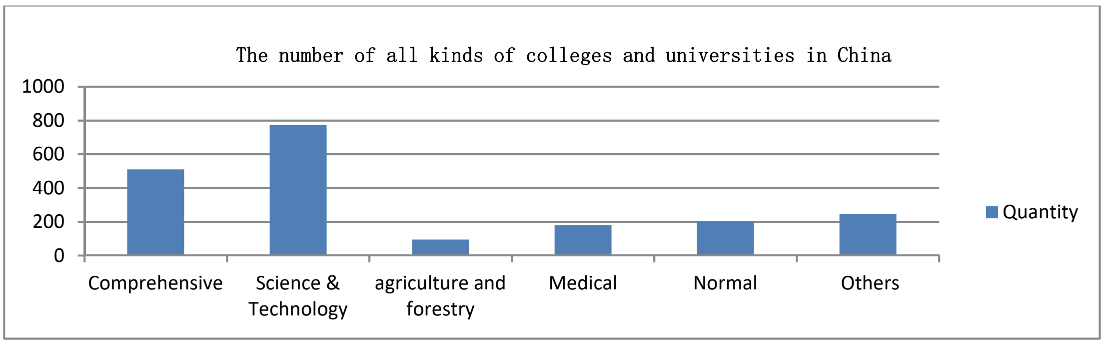

Figure 1 Figures are derived from the document assembly of scientific and technological research activities of higher education institutions in the period of 2015 - 2020 by the Science & Technology Department of the Ministry of Education of China.

According to the "Compendium of Scientific and Technological Information of Universities", the 2007 universities in China are classified into six types according to different professional settings, including 510 comprehensive universities (25%), 774 engineering universities (39%), 94 agriculture and forestry universities (5%), 180 medical universities (9%), 203 universities (10%), 246 other universities (12%). Fig. 1. shows Comprehensive University (DMU1), Engineering University (DMU2), Agriculture and Forestry University (DMU3), Pharmaceutical University (DMU4), Normal University (DMU5) and Other Universities (DMU6) taken as decision-making units respectively.

3.2 The Construction of a Scientific Research Efficiency Evaluation System in Universities

The scientific research activities in universities are a complex systematic project, which includes the scientific research outputs of people, money and things involved. It should be noted that the investment in scientific research and material resources in universities is mainly concentrated on the fixed assets of scientific research equipment. Due to the fact that the value of this indicator is unchanged for a short period of time and the difficulty of data collection, the selection of this indicator is not considered for the time being [15]. In order to evaluate the effectiveness of the results, the selection of the investment indicator is considered from both scientific research manpower and scientific research financial resources. In this study, two input evaluation indicators are selected: ① Full-time personnel (person-years) of research and development personnel: it refers to the personnel engaged in scientific research work or in the application of scientific research achievements, scientific and technological services and scientific research management work for 90% or more of their total working time in the statistical year. ② Internal expenditure for the year of science and technology funds (thousand yuan): including research and development funds, funds for application of achievements and science and technology services and funds for other scientific and technological activities.

Considering the principle of comprehensiveness and effectiveness, this variable is selected as an indicator of scientific research financial investment. Four output evaluation indicators are selected: ① Academic papers published abroad (articles): another important output of academic research achievements in universities, especially the achievements of basic research and applied research, which are mostly in the form of academic papers and have high academic value published by international public journals. ② Acceptance of international projects (item): refers to the outputs that can reflect the international recognition of the scientific research and academic achievements of universities and have academic and technological innovations. ③ Number of patent authorizations: refers to the ability of universities in technological inventions, knowledge creation and transformation into potential economic benefits, which is an important indicator to measure the scientific research output of universities. ④ Actual income of technology patents in the current year (thousands of yuan): it is the ultimate embodiment of the transformation of scientific research achievements into economic value and social value in universities, and also an important indicator of the output of scientific research achievements. All the samples vertically cover the evaluation index of scientific research input and output in the five years of 2016 - 2020 period, and horizontally cover the six major universities in the country. Finally, the evaluation index system of university scientific research efficiency constructed in this paper is shown in Tab. 1.

Table 1 Evaluation indicators of various types of high scientific research efficiency in China

Level 1 Indicator	Level 2 Indicator	Unit	Code
Input indicator	Research and development personnel full-time staff	Person/Year	X1
	Internal expenses	1000 yuan	X2
Output indicators	Academic papers published abroad	Article	Y1
	Acceptance of international level projects	Item	Y2
	Quantity of authorized patents	Item	Y3
	Actual patent revenue of the year	1000 yuan	Y4

3.3 The Construction of an Evaluation Model for the Efficiency of Scientific Research in Universities

Data Envelopment Analysis (DEA) has no dimensionless processing and weight setting for data, so it has strong objectivity and easy operation. It has absolute advantages in dealing with the effectiveness evaluation of multi-output and multi-input, and has become a mature tool for systematic evaluation. It has unique applicability and superiority in the evaluation of scientific research efficiency in universities. The static analysis of DEA-BCC model with variable returns on scale focuses on the comparison of the scientific research efficiency level of various universities at a certain point in time, while the dynamic analysis of Malmquist index model focuses on the evaluation of the change trend within a certain period of time.

3.3.1 Construction of Static DEA-BCC Model

The BCC model is a model under the premise of variable returns on scale, which can calculate the pure technical efficiency value [16]. Using the VRS method of DEAP 2.1 software, assuming that there are n decision-making units (DMUs), each DMUj has m inputs and q outputs, which are respectively denoted as $X_j = (X_{1j}, X_{2j}, ..., X_{mj})$, $Y_j = (Y_{1j}, Y_{2j}, ..., Y_{qj})$, the linear programming model of the DMU is obtained by equivalent transformation and dual processing, and the obtained model is:

$$
s.t\begin{cases} min\left[\theta-\varepsilon\left(e^{\wedge T}s^{-}+e^{\wedge T}s^{+}\right)\right] \\ \sum_{j=1}^{n}X_j\lambda_j+s^{-}=\theta X_0 \\ \sum_{j=1}^{n}Y_j\lambda_j-s^{+}=Y_0 \\ \sum_{j=1}^{n}\lambda_j=1 \\ s^{+}\geq 0,\ s^{-}\geq 0,\ \lambda_j\geq 0,\ j=1,\ 2,\ ...,\ n \end{cases}
$$

where n represents the number of universities, m represents the number of input indicators, u represents the number of output indicators, X_{ij} represents the input variable, Y_{ij} represents the output variable, λ_j represents the weight of some combinations of scientific research in n universities, and s represents the slack variable, representing the input redundancy; s^+ is the residual variable, indicating insufficient output [17]. In the model, θ represents the scientific research efficiency value of the Jth university and satisfies $0 \leq \theta \leq 1$. ε is Archimedes infinitesimal, e is a vector with element 1, if $\theta = 1$, it indicates that DMU is technically valid. Otherwise, it indicates that the DMU is technically invalid. Technical efficiency reflects the level of scientific research efficiency, i.e. overall efficiency. This indicator can be decomposed into pure technical efficiency and scale efficiency. Among them, pure technical efficiency is the efficiency of scientific research which is influenced by factors such as scientific research management and innovation. Scale efficiency is the scientific research efficiency that is influenced by the scale of scientific research investment and can reflect whether the optimal scale of scientific research resources is reached. The three efficiency scores are all between 0 and 1. The higher the score, the higher the efficiency. A score equal to 1 is called DEA efficient. When the value of scale efficiency is equal to 1, the scale reward is unchanged. Returns to scale are less than 1 when increasing or decreasing, indicating inadequate funding and redundancy. From the explanation and measurement of total technical efficiency, pure technical efficiency and scale efficiency, it can be seen that the so-called technical efficiency refers to the fact that the input and output are in the most ideal state and the maximum output can be obtained relative to the existing input. As technical efficiency consists of pure technical efficiency and scale efficiency, there is a production scale factor in technical efficiency, and pure technical efficiency is to separate the scale factors, so as to eliminate the influence of scale factors in the process of short-term efficiency analysis of the organization.

3.3.2 Construction of Dynamic DEA-Malmquist Index Model

DEA-Malmquist index model is used to analyze and evaluate the dynamic trend of the span sample data of more than two periods. It reflects the change of total factor productivity in two adjacent periods of each DMU. Total factor productivity is an important indicator to measure technological progress and technological innovation. It can better reflect the efficiency of DMU in resource development and utilization economically. Sten·Malmquist (1953) proposed the concept of Malmquist Index as a consumption index [18]. Caves (1982) first combined Malmquist Index with DEA theory as a production efficiency index, and widely applied it in future performance evaluation research [19]. In 1994, Fare et al. improved the DEA method and established the Malmquist productivity index [20]. A Malmquist productivity index (*TFP*) uses a directed output method or an input method to define a distance function to measure total factor productivity growth by evaluating the progress efficiency of each DMU. It is suitable for the efficiency analysis of panel data with multiple inputs and multiple outputs. Its greatest feature is that it divides the reasons of productivity changes into changes in the level of technological progress and changes in technological efficiency, and further decomposes changes in technological efficiency into changes in pure technological efficiency and changes in scale efficiency.

The definition of the Malmquist index is reflected by the distance function, which measures the distance between the DMU and the optimal production front. Assuming that n, m, s and θ represent the input type, output type, production technology and optimal output increase proportion of the production department respectively, the output distance function can be expressed as:

$$D\left(x, y\right) = inf\left\{\left(x, y/\theta\right) \in s\right\}$$

If T and $t + 1$ are respectively represented as two different production periods, the Malmquist index from T to $t + 1$ is respectively represented as:

$$M_0^t = N_0^t\left(x^{t+1}, \mathrm{y}^{t+1}\right) \Big/ D_0^t\left(x^t, \mathrm{y}^t\right)$$

$$M_0^{t+1} = N_0^{t+1}\left(x^{t+1}, \mathrm{y}^{t+1}\right) \Big/ D_0^{t+1}\left(x^t, \mathrm{y}^t\right)$$

In 1994, RolfFar, Grosskopf and others assumed that the scale efficiency would not change (CRS), and decomposed the Malmquist index of production efficiency change into two parts: for one thing, technical efficiency change (*EC*) and for another, technical progress (*TC*). Among them:

$$EC = \frac{D^{t+1}\left(x^{t+1}, \mathrm{y}^{t+1}\right)}{D^t\left(x^t, \mathrm{y}^t\right)}$$

$$TC = \left[\frac{D^t\left(x^{t+1}, \mathrm{y}^{t+1}\right)}{D^{t+1}\left(x^{t+1}, \mathrm{y}^{t+1}\right)} \cdot \frac{D^t\left(x^t, \mathrm{y}^t\right)}{D^{t+1}\left(x^t, \mathrm{y}^t\right)}\right]^{1/2}$$

Therefore, the total factor productivity index can be expressed as:

$$M_{t,t+1} = \left(x^t, y^t, x^{t+1}, \mathrm{y}^{t+1}\right) = \frac{D^{t+1}\left(x^{t+1}, \mathrm{y}^{t+1}\right)}{D^t\left(x^t, \mathrm{y}^t\right)} \times$$

$$\times \left[\frac{D^t\left(x^{t+1}, \mathrm{y}^{t+1}\right)}{D^{t+1}\left(x^{t+1}, \mathrm{y}^{t+1}\right)} \cdot \frac{D^t\left(x^t, \mathrm{y}^t\right)}{D^{t+1}\left(x^t, \mathrm{y}^t\right)}\right]^{1/2} = TEC \times TP =$$

$$= SEC \times PTCE \times TP$$

Total factor productivity index (*TFP*) and *TFP* value > 1 indicate that the overall scientific research efficiency has been improved from t to $t + 1$. *TFP* value < 1 indicates that the overall scientific research efficiency has declined, and *TFP* value = 1 indicates that the overall scientific research efficiency has not changed. The *TC* value represents whether the technology is progressing or not, i.e. the "growth effect". It measures the movement level of DMU's production front in the two periods from $t - 1$ to T and from T to $t + 1$. The geometric mean of the pure technology efficiency change index (*PTEC*) and the scale efficiency change index (*SEC*) is used to express the technology efficiency change index (*TEC*), which describes the catching-up degree of the decision-making unit to be evaluated to the production front from the T period to the $t + 1$ period. Also known as "catch-up effect", if *TEC* > 1, it indicates that the improvement of scientific research and training of the

DMU benefits from the improvement of management or system and if *TEC* < 1 is less than 1, the overall technical efficiency of the DMU will decrease. But if *TEC* = 1, the overall technical efficiency of this DMU has not changed. The value of *SEC* represents that the revenue from scale of the DMU is different in the preceding and following periods, i.e. "revenue effect". And if the value of *SEC* > 1, it indicates that the revenue from scale of this DMU is increasing. When this method is used for evaluation and analysis, it can be known whether the factors affecting productivity are caused by technological progress or self-management level [21].

3.4 Statistical Methods

SPSS version 23.0 software was used for descriptive data statistics, and DEA-BCC model and DEA-Malmquist index model of DEAP2.1 software were used for static and dynamic evaluation of its scientific research efficiency of six types of universities nationwide from 2016 to 2020, respectively.

4 RESULTS

4.1 Descriptive Evaluation of the Selected Samples

As the sample selection is a national public university with six major disciplines and major types, the values of input-output indicators of various universities are quite different. Therefore, descriptive statistical analysis is required for each variable data. This paper uses SPSS version 23.0 software to select the original data of input-output indicators of six major types of universities from 2016 to 2020 as research samples for statistical analysis. The results are shown in Tab. 2.

Table 2 Basic descriptive data of national scientific research input-output indicators of various universities

Input-output indicators	Classification of universities	Maximum	Minimum	Average	Standard deviation	Skewness	Kurtosis
Research and development full-time staff (person years)	University	170428	100069	118622.40	29536.87	2.03	4.23
	Engineering	189168	102093	126948.40	35517.87	2.01	4.19
	Agricultural and forestry	28969	17178	20795.40	4662.44	2.00	4.31
	Medical	80320	56619	65185.20	9779.29	1.09	0.40
	Normal schools	32422	21977	24857.00	4361.81	1.92	3.79
	Other Universities	8361	5475	6633.40	1135.76	0.97	0.22
The expenditure on science and technology projects in the current year (thousand yuan)	University	44006505	27503615	34285522.60	6833326.03	0.63	−1.00
	Engineering	67103644	44433879	54040159.60	9537293.23	0.58	−1.62
	Agricultural and forestry	8341323	5752315	7049243.20	1094281.54	0.18	−2.20
	Medical	6475394	3530992	4712371.80	1187228.66	0.89	−0.39
	Normal schools	5033918	3236023	4006849.40	744555.07	0.43	−1.25
	Other Universities	835349	465270	607652.20	154411.66	0.85	−0.58
Academic papers published abroad	University	206180	128025	163644.00	31177.30	0.43	−1.15
	Engineering	205275	112200	151169.60	36433.04	0.81	−0.07
	Agricultural and forestry	26978	15112	19653.80	4856.53	0.95	−0.13
	Medical	45603	24014	33678.20	8254.36	0.54	−0.02
	Normal schools	29784	20334	24392.40	3588.78	0.71	0.63
	Other Universities	5252	2709	3821.60	1037.53	0.49	−1.27
Number of patents granted (item)	University	60705	35723	47596.60	9674.46	0.28	−0.70
	Engineering	103155	65272	85626.80	15217.05	−0.33	−1.32
	Agricultural and forestry	13729	7800	10102.40	2358.99	1.06	0.32
	Medical	10568	3625	6092.20	2701.65	1.49	2.44
	Normal schools	13978	7971	11374.60	2524.04	−0.45	−1.66
	Other Universities	4430	1590	3304.00	1135.01	−0.82	0.25
Acceptance of international projects (item)	University	1515	1059	1263.40	192.52	0.16	−1.74
	Engineering	3064	1438	2181.80	766.64	0.45	−3.03
	Agricultural and forestry	171	36	109.40	52.37	-0.33	−0.43
	Medical	143	81	122.20	24.02	−1.78	3.61
	Normal schools	81	41	62.40	17.74	−0.09	−2.48
	Other Universities	66	8	26.40	23.08	1.81	3.46
Actual income from technology transfer for the year (in thousands of yuan)	University	948251	429128	686119.80	204851.25	0.08	−1.17
	Engineering	16051218	1478293	4793680.80	6310954.29	2.21	4.89
	Agricultural and forestry	214718	114965	140045.60	41955.47	2.18	4.80
	Medical	170581	102685	128784.60	27769.45	0.93	−0.15
	Normal schools	131711	76171	107009.20	21111.32	−0.62	0.15
	Other Universities	51209	14387	24088.80	15371.75	2.09	4.44

The 2007 universities in the sample data are classified according to disciplines and specialties, and the average value of each index of scientific research input-output is significantly different among all types of universities. The statistical results show that the overall scientific research strength of universities in science and engineering and comprehensive categories is stronger than other types of universities, and the total amount of scientific research input and output is the largest, which makes scientific research more efficient. Compared with other five types of universities in 2007 universities, the input-output index of science and technology universities in China is higher than that of other five types of universities. The output index is not different from that of comprehensive universities except for the number of academic papers published abroad. The actual income of international-level project acceptance items, patent licenses and technology patents in that year is significantly higher than that of comprehensive universities. This result indicates that science and technology universities in China have abundant input resources such as research manpower and financial resources compared with agriculture, forestry, medicine, normal universities and other types of universities, which results in more research outputs. What is worth our attention is that the actual amount of income in the year of scientific research expenditure in the science and technology input index and the average technology transfer in the output index is much higher than that of the other five universities, indicating that the science and technology universities have a higher level of scientific and technological development and a higher conversion rate of scientific and technological achievements, which can attract more and better talents to work for development. This also brings significant positive impact to the scientific research output results, as shown in Tab. 3.

Table 3 Comparison of average annual input and output of six major types of universities in China from 2016 to 2020

Type of institution	Average actual income from technology transfer in the current year (in thousands of yuan)	Average International Project Acceptance (Item)	The average number of academic papers published abroad is (1)	Average number of patents granted (item)	The average expenditure on science and technology projects in the current year (thousand yuan)	Average R&D FTE (person years)
Overall	2929.61	1.88	197.49	81.76	52168.31	180.89
University	1345.33	2.48	320.87	93.33	67226.51	232.59
Engineering	6193.39	2.82	195.31	110.63	69819.33	164.02
Agricultural and forestry	1489.85	1.16	209.08	107.47	74991.95	221.23
Medical	715.47	0.68	187.10	33.85	26179.84	362.14
Normal schools	527.14	0.31	120.16	56.03	19738.17	122.45
other	97.92	0.11	15.53	13.43	2470.13	26.97

4.2 Static Analysis of Scientific Research Efficiency Based on DEA-BCC Model

4.2.1 Overall Analysis

The data in Tab. 4 show that the scientific research efficiency of the six types of universities in 2016 is at a high level, with the mean value of *TEC* being 1, the mean value of *PTE* and the mean value of *SE* being 1, and there is no change in scale income. It shows that the six types of universities have great advantages in scientific research efficiency management. In 2017 and 2018, the overall level of scientific research efficiency of the six types of universities decreased by 4.1% and 4.3%, and the average value of *PTE* and *SE* decreased to 2.8%, 2.7% and 1.6%, 1.8% respectively, only the scale of agriculture and forestry universities decreased. In 2019 and 2020, the overall level of scientific research efficiency of the six types of universities showed a trend of recovery, with only 2.9% and 2.7% decrease. The average value of *PTE* increased significantly from the previous two years, with only 0.8% and 0.9% decrease respectively. The average value of *SE* continued to decline, with 3.3% and 2.8% decrease respectively. The decline in scale was still in agriculture and forestry universities, among which the normal universities also showed a decline in scale in 2020. It shows that the allocation ability and use efficiency of scientific research resources of these two types of universities have shown a certain downward trend, especially in agriculture and forestry. It shows that there is room for improvement in scale control over the improvement of scientific research efficiency level of various universities in China as compared with pure technology control. On the whole, during the period of 2016 - 2020, the overall level of scientific research efficiency of the country's six types of universities was relatively high, which was mainly due to the remarkable achievements of the national key construction policies for the development of scientific and technological innovation. If the output is increased, it is necessary to increase more input.

Table 4 Overall Analysis of Scientific Research Efficiency of Various Universities in China

DEA efficiency	Efficiency value characteristic	2016	2017	2018	2019	2020
Technical efficiency, *TE*	average value	1	0.959	0.957	0.971	0.973
	TE = 1	6	5	5	5	4
Pure Technology Efficiency, *PTE*	average value	1	0.972	0.973	0.992	0.991
	PTE = 1	6	5	5	5	5
Scale efficiency, *SE*	average value	1	0.984	0.982	0.977	0.982
	SE = 1	6	5	5	5	4
Revenue from scale	decrease by degrees/gradually/progressively/successively	0	1	1	1	2
	increase successively	0	0	0	0	0
	unchanged	6	5	5	5	4

4.2.2 Comparative Analysis

The data in Fig. 2 to Fig. 4 show that comprehensive, science and engineering, pharmaceutical and other universities have maintained DEA efficiency for 5 consecutive years, indicating that the scientific research resources of these four universities can be allocated effectively, scientific and standardized management and use of scientific research funds, and the innovation ability of scientific research and production technology is high. However, the difference in *TE* among the six types of universities in the country is small, and basically stays between 0.96 and 1.0. In 2016, all six types of universities had a *TE* of 1. In the three consecutive years of 2017, 2018 and 2019, except for agricultural and forestry universities, which had a low *TE* of only 0.74 - 0.82, and the other five types of universities all had a *TE* of 1. In 2020, only comprehensive, science and engineering, pharmaceutical and other types of universities had a *TE* of 1, while agricultural and forestry universities had a *TE* of 0.922 and

0.917, respectively. In addition, the average *TE* of most universities was higher as a whole, accounting for 66.67 - 100% of the total sample. It can be seen from this that there is generally limited room for improvement in the allocation and use efficiency of scientific research resources in various universities. The average *PTE* of the six universities in the country is very small. The number of effective universities accounts for 83.33% of the total sample, while the average *PTE* of only agriculture and forestry universities is 0.913, which indicates that the scientific research management system of these six universities is perfect and the technical level is highly developed. The difference in *SE* among the six types of universities is very small, basically maintaining at 0.977 - 1.0. The number of universities with effective *SE* accounts for 66.67 - 100% of the total number of university samples, and the *SE* as a whole is relatively stable and tends to be stable. Judging from the state of scale income, agricultural and forestry universities remained unchanged in 2016, but declined for four consecutive years from 2017 to 2020. Normal universities remained unchanged for four years from 2016 to 2019, but declined in 2020, but their *PTE* scores were all 1. This indicates that the main reason for the low efficiency of scientific research in normal universities is the inefficiency of scale, the failure to effectively use the scientific research resources invested, and the possible waste and idle phenomena. From 2017 to 2020, the scores of *PTE* and *SE* of agricultural and forestry universities were all less than 1, which was due to the decrease of both pure technology and scale efficiency, and was uneconomical in scale. Further analysis shows that the *TE* of agricultural and forestry universities is lower than that of *PTE* and *SE*, which may be related to the redundancy of researchers and funds, indicating that the improvement of scientific research efficiency level of these universities depends on the improvement of scientific research resources utilization rate, scientific research production technology innovation ability and scientific research management level. The comprehensive, science and engineering, pharmaceutical and other universities are all in the best condition, and their returns on scale remain unchanged. Therefore, the increase in investment and scientific research output will increase in proportion. Although there is little difference between different types of universities, the scientific research managers of universities should pay attention to the problems of technology or scale efficiency, and suit the remedy to the case, in order to improve the scientific research efficiency of such universities.

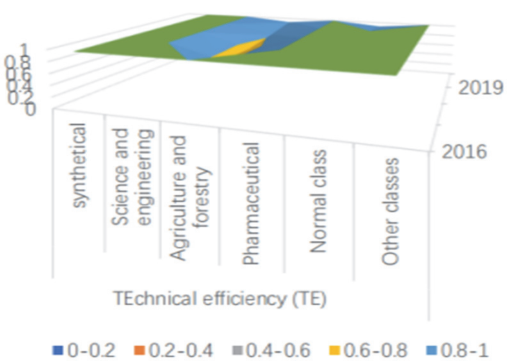

Figure 2 Comparative analysis of *TE* in 6 kinds of Universities during 2016 - 2020

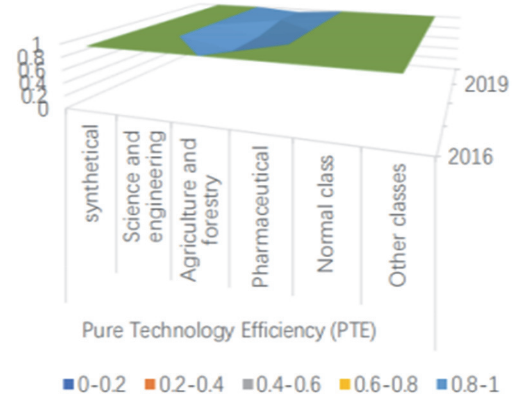

Figure 3 Comparative analysis of *PTE* in 6 kinds of Universities during 2016 - 2020

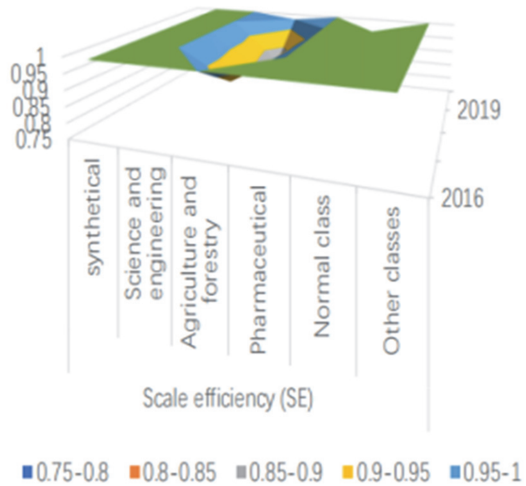

Figure 4 Comparative analysis of *SE* in 6 kinds of Universities during 2016 - 2020

4.3 Input Redundancy and Output Deficiency in Universities of DEA Ineffective

According to the projection analysis of the DEA method, it was calculated respectively by amount of input redundancy and output deficiency of scientific research in agriculture and forestry universities (2017-2020) and normal university (2020), as shown in Tab. 5. Under the condition of scientific research output unchanged, slack variable S_1^- and S_2^- can respectively reduce the quantity of research and development personnel full-time staff, and Internal expenses in DMU. Under the condition of scientific research input unchanged, Surplus variable S_1^+, S_2^+, S_3^+, S_4^+ can respectively increase the quantity of academic papers published abroad, acceptance of international level projects, quantity of authorized patents and actual patent revenue of the year in DMU. From 2017 - 2020, full-time personnel, internal expenditures of agriculture and forestry universities are input redundancy, patent authorization number and the actual income of agriculture and forestry universities are insufficient output. In 2020, full-time personnel, internal expenditures of normal universities are input redundancy, patent authorization number of normal universities is output insufficient. Based on the above results the cause of input redundancy is low efficiency of researchers, the cause of output deficiency is a waste of funds or lack of achievement transformation.

Table 5 Quantity of input redundancy and output deficiency in DMU of DEA ineffective

Years	DMU	efficiency	input redundancy		output deficiency			
			S_1^-	S_2^-	S_1^+	S_2^+	S_3^+	S_4^+
2017	DMU3	0.754	4677.82	1571741.42	0	0	106.01	39919.41
2018	DMU3	0.744	5001.33	1724935.59	0	0	17.3	90082.96
2019	DMU3	0.824	3392.23	1412811.27	0	0	72.3	96689.42
2020	DMU3	0.922	2253.29	648812.36	0	0	131.63	1370198.83
2020	DMU5	0.917	2683.86	416702.02	0	0	56.98	0

4.4 Dynamic Analysis of Scientific Research Efficiency Based on DEA-Malmquist Index

4.4.1 Overall Analysis

The data in Tab. 6 show: ① From the analysis of *TFP* growth: *TFP* value increased by 4.8% in 2016 - 2017, 6.9% in 2017 - 2018, 3.3% in 2018 - 2019 and 0.2% in 2019 - 2020. However, the annual average increased by 2.2%, and these four periods showed the trend of rising, rising again, falling and rising, but they were all close to 1, which indicated that the *TFP* of scientific research in all kinds of universities in China fluctuated to some extent in each period, but the overall trend was relatively stable. ② According to the growth of *TEC*, *TEC* showed a slight decline and then showed a positive growth trend in three periods, with *TEC* being −4.1%, −0.2%, 1.8% and 0.6% respectively, with an average annual decline of 0.5%. *TEC* growth was not consistent with *TC* growth, and *TC* showed an obvious rising to falling trend, which was 9.0%, 7.1%, −6.0%. ③In the decomposition index of *TEC*, the average annual growth rates of *PTEC* and *SEC* from 2016 to 2020 are −0.1% and −0.4%, respectively. *PTEC* is basically maintained at around 1, and it is higher than *SEC* in 2017 - 2018 and 2018 - 2019, and *SEC* is higher than *PTEC* in 2016 - 2017 and 2019 - 2020. Specifically, in 2016 - 2017, *TEC*, *PTEC* and *SEC* were less than 1, *TC* was greater than 1, which indicated that *TFP* growth was mainly caused by technological progress, and *TEC* decrease was caused by the decrease of *PTEC* and *SEC*, which reflected that the research efficiency of six types of universities improved rapidly in 2016 - 2017, but there were still unreasonable resource allocation methods, the level of research management needed to be improved, and the scale of resources investment needed to be adjusted. From 2017 to 2018, *TFP*, *TEC*, *PTEC*, *SEC* and *TC* of six types of universities all improved, indicating that the efficiency of scientific research input and output of six types of universities reached the best in this year. In 2018 - 2019, *TFP* decreased by 3.3%, *TC* decreased by −6.0%, *TEC* increased by 1.8%, *PTEC* increased by 2.4% and *SEC* decreased by −0.5%, which was mainly due to the decline of scientific research technology level, because *TC* decreased the most, which directly led to the decline of *TFP*, while the level of scientific research management was improving. From 2019 to 2020, *SEC* increased by 0.8%, *PTEC* decreased by −0.2%, resulting in *TEC* increasing by 0.6%, but *TC* decreased by −0.3%, resulting in *TFP* increasing by 0.2%, which shows that the scientific research technology of six types of universities is relatively stable and the scale of scientific research resources investment is effective in the whole year.

Table 6 Overall Dynamic Analysis of Scientific Research Efficiency of Public Universities in China from 2016 to 2020

Year	*TFP* (standard deviation)	*TEC* (standard deviation)	PEC (standard deviation)	*SEC* (standard deviation)	*TC* (standard deviation)
2016 - 2017	1.048 (0.194)	0.959 (0.100)	0.972 (0.068)	0.984 (0.038)	1.090 (0.148)
2017 - 2018	1.069 (0.163)	0.998 (0.005)	1.001 (0.001)	0.997 (0.007)	1.071 (0.163)
2018 - 2019	0.967 (0.157)	1.018 (0.043)	1.024 (0.058)	0.995 (0.013)	0.940 (0.136)
2019 - 2020	1.002 (0.466)	1.006 (0.065)	0.998 (0.004)	1.008 (0.069)	0.997 (0.465)
average/mean value	1.022 (0.261)	0.995 (0.063)	0.999 (0.046)	0.996 (0.038)	1.027 (0.255)

4.4.2 Comparative Analysis

The data in Fig. 5 to Fig. 9 show that the investment in scientific research of the six types of universities increased from 2016 to 2020. The *TFP* value in 2016 - 2017 varies greatly among the different types of universities, with the standard deviation reaching 0.194. Among them, the *TFP* of comprehensive, pharmaceutical, normal and other types increased by 4.2%, 2.2%, 4.9% and 38.9% respectively, but the *TFP* of science and engineering decreased by −0.5% and that of agriculture and forestry decreased by −21.2%. Among them, other universities have the fastest growth rate, with a growth rate of 38.9%, which is mainly due to the growth of technological progress, and its *SEC* and *PTEC* are both 1, indicating that such universities have optimized their resource allocation and reasonable investment scale in scientific research activities. The decline of *TFP* in agriculture and forestry universities was obvious, which was closely related to the decline of its *PTEC* and *SEC*. Although *TC* increased by 4.4%, it could not stop the decline of *TFP*, indicating that the negative growth of *TFP* in these universities was mainly related to the inadequate allocation of resources and the unreasonable scale of investment in scientific research activities. In 2017 - 2018, the difference of *TFP* values among different types of universities slightly narrowed, with the standard deviation reaching 0.163. Among them, *TFP* of agriculture and forestry, medicine, normal education and other categories increased by 3.1%, 5.5%, 3.0% and 39% respectively, but that of comprehensive category decreased by −6.3% and that of science and engineering category only decreased by −3.0%. Similarly, the forms of *TC* and *TFP* are completely similar, except that the *TEC* of agricultural and forestry universities decreased by 1.3%, and the *SEC* and *PTEC* of other university types are all 1, further indicating that the increase in *TFP* value is caused by the increase in technological progress. The difference between the *TFP* values of different types of universities in 2018 - 2019 further narrowed, with the standard deviation reaching 0.157, a decrease of 4.4% as a whole. Among them, universities of science and technology, medicine and other categories all showed a downward trend, being −16.2%, −9.0%, −24.7% respectively, while universities of comprehensive, agriculture, forestry and normal education all showed an upward trend, being 8.4%, 14.8.% and 7.1% respectively. However, the *TC* value and the *TFP* form are completely similar, except that the *TEC* of agricultural and forestry universities increased by 10.6%, the *PTEC* increased by 14.2%, and the *SEC* decreased by 3.1%. The *SEC* and *PTEC* of other universities are all 1, which further indicates that the increase of *TFP* value of agricultural and forestry universities is caused by the change of *PTEC*, i.e. the "catch-up effect". In 2019 - 2020, the difference of *TFP* value among different types of universities widened, with the standard deviation reaching 0.466. The universities of science, technology and medicine all showed obvious upward trend, being 92.3% and 1.7% respectively; Comprehensive category, agriculture and forestry category, normal category and other categories showed a downward trend, being −27.5%, −11.9%, −28.6%, −24.6% respectively. Among them, the *TFP* progress of science and technology reached a high point of 92.3%, while *TC* also reached 92.3%. Its *TEC* and *PTEC\SEC* are all 1, which further illustrates the "growth effect" brought by technological progress. However, the normal universities experienced a 24.6% decrease in *TFP*, a 22.2% decrease in *TC*, a 7.3% decrease in *TEC* and *SEC*, and a 1 in *PTEC* during the year, indicating that the decrease in *TFP* was caused by both technological progress and technological efficiency.

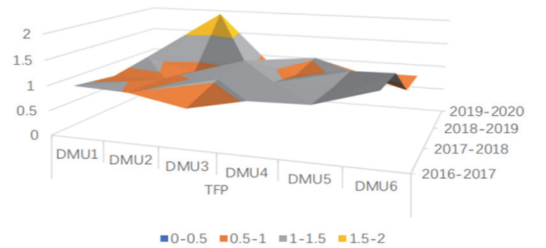

Figure 5 Comparative analysis of *TFP* in 6 kinds of Universities during 2016 - 2020

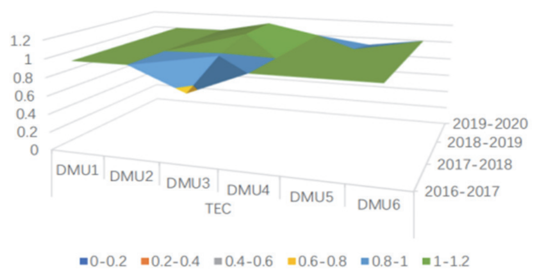

Figure 6 Comparative analysis of *TEC* in 6 kinds of Universities during 2016 - 2020

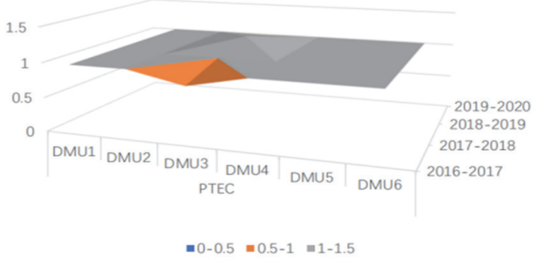

Figure 7 Comparative analysis of *PTEC* in 6 kinds of Universities during 2016 - 2020

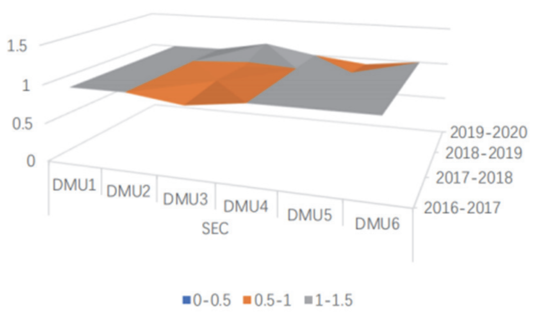

Figure 8 Comparative analysis of *SEC* in 6 kinds of Universities during 2016 - 2020

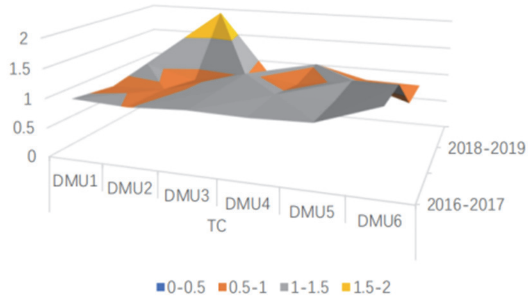

Figure 9 Comparative analysis of *TC* in 6 kinds of Universities during 2016 - 2020

5 DISCUSSION

First of all, the level of scientific research efficiency of China's six types of universities is relatively high, with *PTE* equal to 1 for five consecutive years, indicating that China's various types of universities have done a good job in strengthening the internal control of scientific research management, effectively allocating and avoiding the blocking and idle phenomenon of the transfer of scientific research funds. Among them, comprehensive, science and technology, pharmaceutical and other universities have kept DEA effective for 5 consecutive years, i.e. they are ahead of other universities in terms of both management and scale control, indicating that the investment in scientific research funds, operation of scientific research management mechanism and innovation ability of scientific research and production technology of various universities in China are all in "ideal" condition, but there is still room for improvement.

Secondly, agricultural and forestry universities are in a state of diminishing returns to scale from 2017 to 2020 and normal universities in 2020. According to the projection theory of DEA method, it is proved that the structure and quantity of scientific research expenditures in agricultural and forestry universities are unreasonable. The low income in the year of technology transfer is related to the insufficient number of patents and the insufficient output of poor transformation of scientific research achievements. However, normal universities failed to effectively use the scientific research manpower and financial resources already invested in 2020, which resulted in the waste and idleness of personnel and funds. These two types of universities should use the data in Tab. 5 as a reference for scientific research activities, so that scientific research manpower and financial resources can be reasonably allocated and utilized, and finally scientific research efficiency can be rapidly improved.

Thirdly, the annual growth rate of scientific research investment and the fluctuation of *TFP* of various universities in China are generally stable. There is almost no big fluctuation in *TE*, especially in *SE*. We can find that the more investment, the faster the improvement of scientific research efficiency. The growth of scientific research efficiency depends on the level of scientific research technology and the scale of scientific research activities. Judging from the results of the analysis of time span and classification, *TC* and *SE* are the main factors that affect the scientific research *TFP* of various universities in China. Therefore, to improve the scientific research efficiency of universities, efforts should be made to improve the scientific research technology and the transformation of scientific and technological achievements, and secondly, the scale of scientific research should be adjusted, and the allocation of scientific research investment resources should be optimized, so as to truly achieve a good situation of giving consideration to the scale, structure, quality and efficiency of scientific research.

On the whole, the index selection of theoretical model construction still needs to be improved, because of the data availability and limitations of DEA model itself and other reasons, only the full-time research and development personnel and the current year's internal expenditure index of all kinds of universities in China are selected as input variables for research, and only the number of foreign academic papers published by those universities, the number of international projects accepted, the number of patent authorizations and the current year's actual income index of technical patents are selected as output variables for research. Although this rigorous assumption is closer to the international standard, it also has certain limitations. In the follow-up research, the specific scientific and technological data of each university will be used to establish a more complete index system or the output index data and with a lag of 2 years will be used for empirical analysis, and more accurate research results may be obtained to verify the research conclusions.

6 CONCLUSIONS

All kinds of universities in China are a mainstay of the national development of science and technology innovation, a large amount of state funding for universities; it carries the key scientific research project. All kinds of universities in China have a large number of science and technology innovation teams. Experimental research condition is superior; therefore, this paper could truly reflect the static and dynamic trend of scientific research efficiency by analyzing the scientific research data of Chinese universities. During 2016 - 2020, the evaluation results had an importance of theoretical and practical significance in that they optimized resources of science and technology and improved the economic benefits of scientific research in Chinese universities.

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