Research on the Measurement and Dynamic Evolution of Scientific and Technological Innovation Efficiency in Universities

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Abstract

Colleges is an important part of the national innovation system, scientific and technological innovation in colleges and universities plays an important role in promoting the construction of an innovative country. Based on the data of scientific and technological innovation in universities from 2009 to 2017, a three-stage DEA model is used to estimate the efficiency of scientific and technological innovation in universities, which can eliminate the influence of external environmental factors and random interference factors. Then, the Bootstrap method is used to correct the efficiency value. The results show that the external environmental factors and random error interference factors have a significant impact on the efficiency of scientific and technological innovation in universities; the efficiency of scientific and technological innovation in Universities in different regions is generally not high, the average efficiency of scientific and technological innovation in 30 provinces and cities has not reached the frontier, and there are great differences among provinces and cities. The efficiency of scientific and technological innovation in universities in the eastern coastal economic complex zone is the highest, while that in the Northwest Economic complex zone is the highest. The value of scientific and technological innovation efficiency is the lowest; while keeping the output level of scientific and technological innovation unchanged, by improving the management level, the input of innovative elements can be reduced by 35.5% on average, or by maintaining the current input level of elements, the level of innovation output can be increased by 35.5%. Nuclear density estimates show that the efficiency of scientific and technological innovation of universities is in a state of growth, with the northern coast, the central part, the middle reaches of the Yellow River and the Yangtze River. There is obvious polarization in the middle reaches, and the nuclear density curve in the southwest region is right-tailed.

Keywords: *Three-stage DEA, bootstrap-DEA, university science and technology innovation efficiency, nuclear density estimation*

I. Introduction

Scientific and technological innovation is the fundamental driving force to support the development of the country. Many historical experiences and lessons tell us that only by increasing innovation can we not be controlled by others in key areas. In the report of the 19th CPC National Congress, China should be in the forefront of innovative countries by 2035. The establishment of the national innovation system is not an overnight contribution. As an important part of the national innovation system, colleges and universities bear the burden of cultivating innovative talents, innovating technology, spreading innovative knowledge and so on. The far-reaching influence of scientific and technological innovation on economy and society in colleges and universities is not only conducive to promoting the modernization of our country, but also the key to establishing the strategic advantage position in the future international competition [1-3].

With the new promotion of scientific and technological innovation by the state, the input of scientific and technological resources in colleges and universities is increasing, but the utilization rate of innovative resources is low. In the top 100 list of the world's most innovative universities in 2018, universities in China occupied only five seats, with the highest ranking being 44. In this case, how to increase the output of scientific and technological

ISSN: 0010-8189

innovation under effective resources is particularly important. Therefore, this paper employs the three-stage DEA + Bootstrap-DEA model to scientifically evaluate the efficiency of scientific and technological innovation in China's universities, to strengthen the rational allocation of resources in the case of scarcity of scientific and technological innovation resources, and to provide pertinent decision-making basis for the formulation and promulgation of relevant policies.

II. Literature Review

At present, the literature on the innovation efficiency of colleges and universities is quite rich. In 1957, Farrel [4] put forward the concept of technical efficiency evaluation, and in 1978 Charnes et al. [5] introduced DEA method to calculate efficiency. Efficiency measures began to rise and have since been applied to various fields.

In terms of the object of study, it is mainly concentrated in key national colleges and universities or in a certain region. Parteka et al. [6] used DEA-malmquist to analyze scientific and technological innovation in seven European countries from 2001 to 2005. The results show that there are great differences in innovation efficiency among countries. Zhao Rongying et al. [7] studied the scientific research efficiency of electronic database in 985 colleges and universities in China, which shows that the electronic database of most schools has not been used effectively. Wang Shuqiao et al. [8] used the non-radial and non-angle SBM model to calculate the scientific research efficiency of 36 engineering colleges and universities in China, and analyzed the dynamic evolution process of scientific research efficiency. Lin Deming et al. [9] used DEA method to measure the effectiveness of technology dressing efficiency in colleges and universities. The research shows that the average efficiency of technology transfer in 985 colleges and universities in China is not high, and most of them are non-DEA effective. Wang Haitao et al. [10] ranked the comprehensive efficiency, pure technical efficiency and scale efficiency of some 985 engineering colleges and universities. Wang Qingjin et al. [11] evaluated the input-output efficiency of scientific and technological innovation in 61 colleges and universities directly under the Ministry of Education in 2016 from the perspective of "Taking of political, industrial and academic research funds".

In terms of efficiency treatment methods, Li Lu [12] used SBM model and Malmquist productivity decomposition index to study the allocation and innovation efficiency of science and technology resources of universities in Beijing, Tianjin and Hebei, and compared the differences among the science and technology resources models of the three places' universities. Song Weiwei et al. [13] constructed the evaluation index system of the efficiency of scientific and technological innovation in colleges and universities from the input of human and financial resources and new products and the output of scientific and technological achievements, and analyzed the efficiency of scientific and technological innovation in colleges and universities in Hubei Province. Luo Xi et al. [14] used DEA-Malmquist index evaluation model to measure and analyze the transformation efficiency of scientific and technological achievements in 32 colleges and universities in Jiangsu Province from 2009 to 2014, and pointed out that national policy, regional environment and organizational behavior are important factors affecting the difference of transformation efficiency.

To sum up, scholars have achieved excellent achievements in studying the efficiency of scientific and technological innovation in colleges and universities. However, when the influence of efficiency caused by interference of external environment and error factors is less considered, this will affect the calculation of innovation efficiency to a certain extent. Therefore, in this study, the static analysis method is used to estimate the influence of excluding external environmental factors and random interference terms based on the three-stage DEA model, and then the Bootstrap-DEA model is used to control the influence of random shock and correct the DEA efficiency. This paper calculates the scientific and technological innovation efficiency of colleges and universities in various regions of our country as accurately as possible, and analyzes the dynamic evolution trend of scientific and technological innovation efficiency of colleges and universities in the whole country and each region through the method of nuclear density estimation, in order to comprehensively and objectively evaluate the efficiency of scientific and technological innovation in colleges and universities in China.

ISSN: 0010-8189

III. Model setting and variable selection

3.1 Model selection

The evaluation of scientific and technological innovation efficiency in colleges and universities is a multi-input and multi-output problem. At present, the mainstream methods of this kind of problems are parametric method, nonparametric method and exponential method. The early evaluation of technological innovation mainly starts with the evaluation index, evaluation method and evaluation model, the quantitative analysis is relatively single, and the conclusion is not persuasive. The four-stage DEA model was proposed by Fried et al. [15] in 1999 to eliminate the influence of external environmental factors. In 2002, Fried et al. [16] put forward a three-stage DEA model. This method can not only eliminate the external factors that do not affect the efficiency of enterprise technological innovation. Moreover, the random interference term and the management inefficiency term can be proposed to reflect the efficiency more realistically.

Stage 1: DEA model. In this stage, DEA is used for analysis, and DEA method is proposed by Charnes, a famous American operations research scientist, to measure the efficiency of scientific and technological innovation in colleges and universities. The input-oriented BCC model is adopted to reflect the efficiency level of scientific and technological innovation in colleges and universities. At this stage, the comprehensive efficiency of scientific and technological innovation in 30 provinces and cities in China from 2009 to 2017 is obtained.

Stage 2: SFA analysis of relaxation variables. In the first stage, the input relaxation values of each decision making unit can be calculated by DEA model, and the results will be affected by environmental factors and error interference. In this stage, the SFA model is used to calculate the influence of the above three factors on innovation efficiency, to separate the influence of external environmental factors, management inefficiency and random error on technological innovation efficiency, and to readjust the input and output. Each relaxation variable is analyzed by SFA to determine whether the input relaxation variable is affected by environmental variables so as to make up for the shortcomings of the first stage super-efficiency DEA model.

Stage 3: Adjusted DEA model. In this stage, the adjusted input data from the previous stage is used instead of the original input data, and the DEA model is used to calculate again, and the efficiency value after excluding environmental factors and random errors is obtained, which reflects the efficiency of provincial and municipal forest parks more objectively. The innovation input variable of the third stage is revised again, and the comprehensive efficiency value of the third stage is obtained by using the BCC model of DEA.

Stage 4: Bootstrap-DEA method. The new efficiency values are obtained by using the three-stage DEA method to obtain the adjusted input elements and the initial output, and then the method of repeated sampling is used to infer and correct the deviation of the sample parameters through the method of repeated self-sampling for 2000 times.

3.2 Variable selection and data source

In measuring the efficiency of scientific and technological innovation in colleges and universities, due to the integrity and availability of data, this paper selects 30 provinces and cities in China from 2009 to 2017 as samples. Due to the great differences in educational resources and educational level among different regions, 30 provinces and cities are divided into eight regions to make a comparative analysis. According to the eight comprehensive economic zones divided by the Development Research Center of the State Council, the Northeast includes Liaoning, Jilin and Heilongjiang; the North includes Beijing, Tianjin, Hebei and Shandong; the East includes Shanghai, Jiangsu and Zhejiang; the South includes Fujian, Guangdong and Hainan; and the middle reaches of the Yellow River includes Shaanxi, Shanxi, Henan and Inner Mongolia. The middle reaches of the Yangtze River include Hubei, Hunan, Jiangxi and Anhui; the southwest includes Yunnan, Guizhou, Sichuan, Chongqing and Guangxi; and the northwest includes Gansu, Qinghai, Ningxia, Tibet and Xinjiang. Due to the fact that there are

ISSN: 0010-8189

too many missing data in the data statistics in Tibet, this paper will remove Tibet at the time of the study. The data comes from the Compilation of Scientific and Technological Statistics of Colleges and Universities in 2009 ~ 2017, and the Yearbook of Science and Technology Statistics in China. When measuring the efficiency of the scientific and technological innovation of the university, the main variables are as follows: (1) Innovation output. In this paper, the publication of scientific and technological works, the publication of academic papers, the number of patents and the national three-awards are selected as the output variables. (2) Innovation investment. In this paper, the research and development of all provinces and cities, the internal expenditure of R & D and the number of scientific and technological subjects are used as input targets. (3) Environment variable. Environmental variables refer to the variables that will ultimately affect the efficiency but can not be controlled by the unit. [17]. In this paper, the number of GDP, colleges and universities per capita and the expenditure of education funds are used as environmental variables.

IV. Empirical analysis

4.1 The empirical results of the first stage

The efficiency values were analyzed by using the DEA model and the results are shown in Table 1. From Table 1, it can be found that the average efficiency of science and technology innovation of universities in 30 provinces and cities in China was 0.857 in 2009 and 0.862 in 2017, without considering the interference of environmental factors and random factors. The average national comprehensive efficiency showed a trend of rising first and then declining, and the efficiency value (0.905) reached its peak in 2013. From observing the average value of scientific and technological innovation efficiency in colleges and universities from 2009 to 2017, Beijing, Jiangsu, Shaanxi and other provinces and cities are at the forefront of efficiency; all years are in the effective stage, and Anhui, Guangdong and other provinces and cities ranked low in the value of scientific and technological innovation efficiency. Among the eight regions, the average efficiency of the eastern coastal comprehensive economic zone is the highest, and that of the southwest coastal comprehensive economic zone is the lowest.

Table 1 Phase I efficiency of scientific and technological innovation in colleges and universities

Provinces	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean
Beijing	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tianjin	0.708	0.712	0.683	0.585	0.710	0.798	0.760	0.727	0.671	0.706
Hebei	0.973	1.000	1.000	0.986	1.000	0.776	0.783	0.819	0.827	0.907
Shandong	0.849	1.000	1.000	0.703	0.809	0.917	1.000	0.837	0.772	0.876
Northern Coast	0.883	0.928	0.921	0.819	0.880	0.873	0.886	0.846	0.818	0.872
Liaoning	0.935	1.000	1.000	1.000	0.940	0.913	0.938	0.884	0.817	0.936
Jilin	0.837	0.778	0.673	0.702	0.723	0.701	0.859	0.907	0.855	0.782
Heilongjiang	0.896	1.000	1.000	1.000	0.930	1.000	1.000	1.000	1.000	0.981
Northeast	0.889	0.926	0.891	0.901	0.864	0.871	0.932	0.930	0.891	0.900
Shanghai	0.948	1.000	0.936	0.922	0.773	0.910	0.869	0.879	0.818	0.895
Jiangsu	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Zhejiang	1.000	1.000	1.000	0.919	1.000	1.000	0.930	0.931	0.878	0.962
Eastern Coast	0.983	1.000	0.979	0.947	0.924	0.970	0.933	0.937	0.899	0.952
Fujian	0.793	0.914	0.856	1.000	1.000	1.000	0.967	0.520	0.492	0.838
Guangdong	0.676	0.811	0.636	0.666	0.705	0.729	0.641	0.655	0.686	0.689
Hainan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.989	1.000	0.999
Southern Coast	0.823	0.908	0.831	0.889	0.902	0.910	0.869	0.721	0.726	0.842
Shanxi	0.705	0.751	0.673	0.761	0.696	0.778	0.799	1.000	1.000	0.796

ISSN: 0010-8189

Shaanxi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Henan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Inner Mongolia	0.695	1.000	0.877	1.000	0.934	1.000	1.000	1.000	1.000	0.945
Middle Reaches of the Yellow River	0.850	0.938	0.887	0.940	0.907	0.944	0.950	1.000	1.000	0.935
Anhui	0.743	0.681	0.543	0.600	0.630	0.597	0.686	0.686	0.715	0.653
Jiangxi	0.526	0.619	0.946	0.799	1.000	0.909	0.938	0.903	0.942	0.842
Hubei	1.000	1.000	1.000	0.920	1.000	0.902	0.951	1.000	1.000	0.975
Hunan	0.926	0.748	0.955	0.807	0.856	0.900	0.794	0.825	0.890	0.856
Middle Reaches of the Yangtze River	0.799	0.762	0.861	0.781	0.872	0.827	0.842	0.853	0.887	0.832
Guangxi	0.585	0.624	0.769	0.812	0.897	0.872	0.902	0.682	0.573	0.746
Chongqing	0.904	0.856	1.000	0.894	0.935	1.000	0.826	0.737	0.747	0.878
Sichuan	0.620	0.669	0.649	0.734	0.760	0.849	0.811	0.757	0.761	0.734
Guizhou	0.708	0.761	0.686	0.912	0.855	0.724	0.731	0.713	0.738	0.759
Yunnan	0.837	1.000	1.000	0.937	1.000	0.960	1.000	0.812	0.795	0.927
Southwest China	0.731	0.782	0.821	0.858	0.890	0.881	0.854	0.740	0.723	0.809
Gansu	1.000	0.874	0.739	0.786	1.000	0.874	0.938	0.951	0.969	0.903
Qinghai	1.000	1.000	0.996	1.000	1.000	0.856	0.910	1.000	0.976	0.971
Ningxia	1.000	1.000	1.000	1.000	1.000	0.847	0.715	0.652	0.798	0.890
Xinjiang	1.000	1.000	1.000	1.000	1.000	1.000	0.898	0.811	0.994	0.967
northwest China	1.000	0.968	0.934	0.946	1.000	0.894	0.865	0.854	0.934	0.933
National average	0.857	0.856	0.888	0.894	0.905	0.881	0.887	0.893	0.862	0.880

4.2 Evaluation results of the second stage

Because the results of the first stage include the interference of environmental factors, random errors and so on, further analysis is needed to truly reflect the comprehensive efficiency of scientific and technological innovation in 30 provinces and cities in 2009. The results of the first stage analysis, that is, the relaxation variable of each input variable is taken as the dependent variable, the environmental variable is taken as the independent variable, and the SFA analysis is carried out by using Frontier4.1 software to obtain the influence of environmental factors and random errors on innovation efficiency. The results of the analysis are shown in Table 2.

Table 2 SFA estimates

Variable	Research and Development Full-time Personnel	T value	Internal expenditure of R&D funds	T value	Number of scientific and technological topics	T value
Constant term	-1022.34**	-2.33	-88210.18***	-10904.46	-5471.56***	-7.01
Per capita GDP	0.01**	2.15	1.38***	7.23	0.05***	4.99
Number of Institutions of Higher Learning	-2.99	-0.92	75.08	0.65	-13.02**	-2.40
Education expenditure	1255.54***	17.86	-114964.47***	-87365.05	19507.01***	294.84
sigma-squared	1.24E+07		1.13E+10		3.26E+07	
γ	8.09E-01		6.88E-01		8.18E-01	
log likelihood	-2.40E+03		-3.38E+03		-2.53E+03	

ISSN: 0010-8189

LR test	1.80E+02***	1.01E+02***	1.90E+02***

Note: *, *** and *** are significant at 10%, 5% and 1% respectively.

It can be seen from Table 2 that most of them have passed the test and tend to be close to 1, indicating that there are some differences in technical efficiency, and the role of random factors is relatively small. It is appropriate to use SFA in this part of the study. The relaxation variable of each input factor is the opportunity cost of scientific and technological innovation in colleges and universities. When the regression coefficient is positive, it indicates that environmental factors inhibit the improvement of scientific and technological innovation in colleges and universities. On the contrary, it shows that the increase of environmental factors contributes to the promotion of scientific and technological innovation in colleges and universities.

(1) Per capita GDP. The results show that this variable is significantly positive with the relaxation variable regression coefficients of full-time research and development personnel, internal expenditure of R &D funds and the number of science and technology projects, indicating that per capita GDP has a significant impact on the redundancy of these three inputs. With the improvement of per capita GDP, these investment factors will lead to redundancy, reflecting that in that areas with the higher per capita GDP in China, although the investment elements of scientific and technological innovation in colleges and universities are large, there is no good planning and allocation.

(2)Number of institutions of higher learning. The results show that the regression coefficients of the relaxation variables between the variables and the number of scientific and technological projects are significantly negative, while the regression coefficients of the internal expenditure of full-time personnel and R&D funds are not significant. This shows that the increase of the number of institutions of higher learning is conducive to reducing the redundancy of investment in the number of scientific and technological projects.

(3)Expenditure on education. The results show that the regression coefficient of this variable is significantly positive for the full-time personnel and the number of scientific and technological projects, and significantly negative for the internal expenditure of R&D expenditure. It shows that educational expenditure can reduce the redundancy caused by the internal expenditure of R&D expenditure and promote the rational utilization of scientific and technological innovation funds in colleges and universities.

The above three environmental factors may cause inaccurate phenomena in estimating the efficiency of scientific and technological innovation in colleges and universities. Therefore, we must separate the external environmental factors from each other. Only when all decision-making units are on the same level platform, can we measure the real level of efficiency.

4.3The empirical results of the third stage

According to the input relaxation variable value of innovation resources, the original input factors of scientific and technological innovation are adjusted, and then the adjusted input factors and output data are calculated by DEA. The estimated efficiency values of scientific and technological innovation of universities in various provinces and cities are shown in Table 3.

Table3 Efficiency of scientific and technological innovation in colleges and universities in the third stage

Provinces	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean
Beijing	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tianjin	0.566	0.622	0.631	0.587	0.668	0.712	0.733	0.741	0.698	0.662
Hebei	0.660	0.682	0.677	0.726	0.725	0.692	0.701	0.816	0.836	0.724
Shandong	0.885	0.910	0.837	0.860	0.867	0.939	0.965	0.899	0.892	0.895

ISSN: 0010-8189

Northern Coast	0.777	0.804	0.786	0.793	0.815	0.836	0.850	0.864	0.856	0.820
Liaoning	0.852	1.000	1.000	1.000	0.911	0.933	1.000	0.981	0.952	0.959
Jilin	0.636	0.689	0.678	0.640	0.693	0.643	0.749	0.868	0.772	0.707
Heilongjiang	0.681	0.785	0.846	0.881	0.816	0.802	0.858	0.976	1.000	0.849
Northeast	0.723	0.825	0.841	0.840	0.806	0.793	0.869	0.941	0.908	0.839
Shanghai	0.981	1.000	1.000	1.000	0.932	0.934	0.941	1.000	0.954	0.971
Jiangsu	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Zhejiang	0.996	1.000	1.000	0.843	0.860	0.943	0.931	1.000	0.939	0.946
Eastern Coast	0.992	1.000	1.000	0.948	0.931	0.959	0.957	1.000	0.964	0.972
Fujian	0.494	0.494	0.494	0.545	0.478	0.502	0.526	0.530	0.543	0.512
Guangdong	1.000	1.000	0.996	0.986	0.972	0.874	0.889	0.857	0.830	0.934
Hainan	0.201	0.320	0.352	0.378	0.529	0.421	0.384	0.378	0.412	0.375
Southern Coast	0.565	0.605	0.614	0.636	0.660	0.599	0.600	0.588	0.595	0.607
Shanxi	0.435	0.479	0.495	0.533	0.477	0.530	0.532	0.679	0.736	0.544
Shaanxi Province	0.882	0.857	0.932	0.920	0.885	0.864	0.995	1.000	1.000	0.926
Henan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Inner Mongolia	0.340	0.374	0.470	0.476	0.503	0.476	0.811	0.825	0.644	0.547
Middle Reaches of the Yellow River	0.664	0.677	0.724	0.732	0.716	0.718	0.835	0.876	0.845	0.754
Anhui	0.636	0.773	0.685	0.674	0.672	0.728	0.718	0.715	0.701	0.700
Jiangxi	0.528	0.622	0.621	0.628	0.669	0.635	0.526	0.610	0.640	0.609
Hubei	1.000	1.000	1.000	1.000	1.000	1.000	0.959	1.000	1.000	0.995
Hunan	0.854	0.914	0.874	0.832	0.843	0.827	0.886	0.917	1.000	0.883
Middle Reaches of the Yangtze River	0.755	0.827	0.795	0.783	0.796	0.798	0.772	0.811	0.835	0.797
Guangxi	0.590	0.551	0.566	0.578	0.593	0.591	0.580	0.586	0.538	0.575
Chongqing	0.604	0.682	0.657	0.772	0.733	0.685	0.741	0.742	0.762	0.709
Sichuan	0.794	0.784	0.791	0.818	0.817	0.847	0.928	0.932	0.916	0.848
Guizhou	0.389	0.446	0.414	0.434	0.470	0.452	0.496	0.558	0.572	0.470
Yunnan	0.464	0.504	0.542	0.618	0.555	0.650	0.634	0.714	0.648	0.592
Southwest China	0.568	0.593	0.594	0.644	0.634	0.645	0.676	0.706	0.687	0.639
Gansu	0.510	0.594	0.523	0.578	0.602	0.622	0.680	0.683	0.624	0.602
Qinghai	0.094	0.097	0.121	0.131	0.143	0.113	0.127	0.178	0.150	0.128
Ningxia	0.178	0.241	0.261	0.246	0.252	0.266	0.238	0.290	0.346	0.257
Xinjiang	0.370	0.402	0.446	0.433	0.430	0.479	0.519	0.554	0.505	0.460
northwest China	0.288	0.334	0.338	0.347	0.357	0.370	0.391	0.426	0.406	0.362
National average	0.654	0.694	0.697	0.704	0.703	0.705	0.735	0.768	0.754	0.713

Compared with the situation before the adjustment, the average efficiency of scientific and technological innovation in colleges and universities decreased from 0.880 to 0.713. For provinces and municipalities, after eliminating the interference of environmental factors and random factors, Beijing, Jiangsu and other provinces and municipalities are at the forefront. Among the eight regions, the average efficiency of the eastern coastal comprehensive economic zone is still the highest, and the average efficiency of the northwest coastal integrated economic zone is the lowest. The efficiency values vary from region to region, and Hainan, Qinghai, Ningxia and other provinces and cities have dropped by a large extent, indicating that the factor of environment has put great influence on it. The efficiency of scientific and technological innovation in colleges and universities in Guangdong, Sichuan and Shanghai has increased slightly, indicating that environmental and random factors have a significant impact on the efficiency of scientific and technological innovation in colleges and universities in various regions.

4.4 Bootstrap empirical results

After eliminating the external environmental factors and random interference factors, the accuracy of the efficiency value has been greatly improved, but it is still affected by the error that there is a deviation in the efficiency. After using Bootstrap to correct the error, the efficiency of high efficiency scientific and technological innovation is finally obtained, and the results are shown in Table 3. As can be seen from the Table 4, the efficiency of scientific and technological innovation in colleges and universities in various regions has declined to varying degrees, with the overall average value falling by 0.068. From a regional point of view, the average value of scientific and technological innovation efficiency of colleges and universities in Guangdong, Hubei and Liaoning is in the forefront, while the average value of scientific and technological innovation efficiency in Hainan, Qinghai and Ningxia is lower. The average efficiency of scientific and technological innovation in colleges and universities in the eastern coastal areas is the highest (0.824), and the average efficiency of scientific and technological innovation in colleges and universities in northwest China is the lowest (0.344).

Table4The efficiency of scientific and technological innovation in colleges and universities after the revision by bootstrap

Provinces & Regions	2009	2010	2011	2012	2013	2014	2015	2016	2017	Average Value
Beijing	0.687	0.743	0.755	0.736	0.744	0.732	0.745	0.794	0.764	0.744
Tianjin	0.503	0.577	0.567	0.518	0.583	0.608	0.671	0.702	0.642	0.597
Hebei	0.626	0.651	0.643	0.696	0.691	0.647	0.657	0.763	0.799	0.686
Shandong	0.837	0.857	0.776	0.813	0.804	0.869	0.875	0.851	0.831	0.835
Northern Coast	0.663	0.707	0.685	0.691	0.705	0.714	0.737	0.777	0.759	0.715
Liaoning	0.761	0.886	0.843	0.89	0.823	0.837	0.894	0.930	0.902	0.863
Jilin	0.604	0.666	0.657	0.6	0.659	0.602	0.704	0.851	0.748	0.677
Heilong -jiang	0.591	0.729	0.776	0.803	0.749	0.715	0.783	0.888	0.882	0.768
Northeast	0.652	0.760	0.759	0.764	0.744	0.718	0.794	0.89	0.844	0.769
Shanghai	0.839	0.831	0.869	0.878	0.81	0.812	0.846	0.924	0.891	0.856
Jiangsu	0.832	0.815	0.784	0.767	0.774	0.807	0.819	0.85	0.8	0.805
Zhejiang	0.879	0.782	0.763	0.723	0.729	0.830	0.844	0.902	0.836	0.810
Eastern Coast	0.850	0.809	0.805	0.789	0.771	0.816	0.836	0.892	0.842	0.824
Fujian	0.458	0.46	0.465	0.499	0.425	0.458	0.477	0.494	0.508	0.472
Guangdong	0.947	0.943	0.956	0.929	0.908	0.802	0.830	0.831	0.802	0.883
Hainan	0.170	0.298	0.331	0.358	0.487	0.393	0.362	0.356	0.375	0.348
Southern Coast	0.525	0.567	0.584	0.595	0.607	0.551	0.556	0.560	0.562	0.568
Shanxi	0.408	0.455	0.481	0.500	0.450	0.492	0.513	0.672	0.703	0.519
Shaanxi Province	0.776	0.747	0.852	0.793	0.761	0.758	0.875	0.906	0.878	0.816
Henan	0.775	0.896	0.880	0.846	0.818	0.823	0.811	0.815	0.778	0.827
Inner Mongolia	0.322	0.361	0.459	0.456	0.482	0.456	0.765	0.769	0.593	0.518
Middle Reaches of the Yellow River	0.570	0.615	0.668	0.649	0.628	0.632	0.741	0.791	0.738	0.670
Anhui	0.578	0.725	0.645	0.633	0.622	0.694	0.689	0.689	0.665	0.660
Jiangxi	0.496	0.600	0.598	0.594	0.623	0.593	0.486	0.570	0.582	0.571
Hubei	0.901	0.854	0.886	0.894	0.858	0.874	0.875	0.856	0.915	0.879

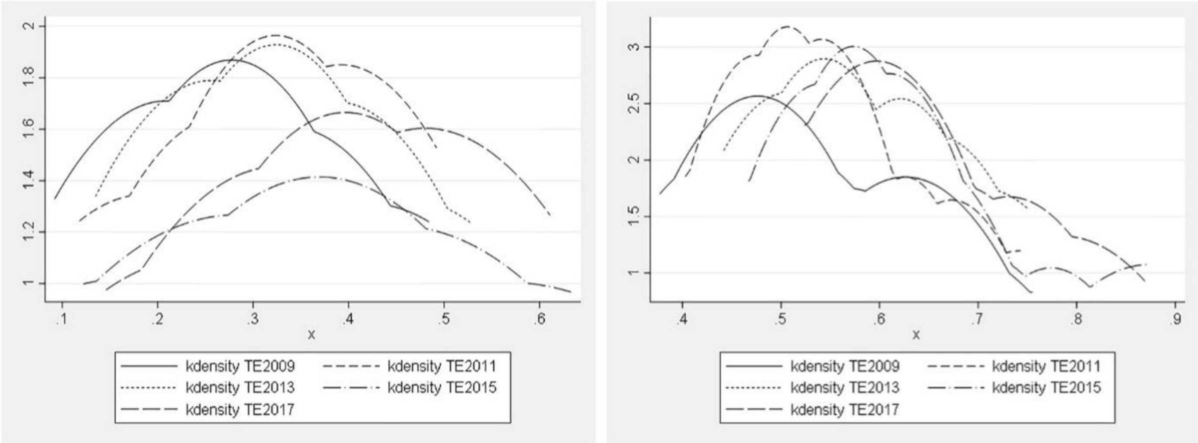
ISSN: 0010-8189

Hunan	0.794	0.878	0.826	0.765	0.784	0.769	0.839	0.885	0.912	0.828
Middle Reaches of the Yangtze River	0.693	0.764	0.739	0.721	0.722	0.733	0.722	0.750	0.768	0.735
Guangxi	0.572	0.518	0.533	0.547	0.566	0.560	0.545	0.572	0.524	0.549
Chongqing	0.551	0.649	0.603	0.723	0.655	0.603	0.674	0.703	0.702	0.651
Sichuan	0.755	0.742	0.743	0.759	0.751	0.773	0.874	0.903	0.869	0.797
Guizhou	0.377	0.437	0.403	0.407	0.442	0.424	0.467	0.546	0.541	0.449
Yunnan	0.405	0.476	0.487	0.577	0.512	0.601	0.608	0.699	0.621	0.554
Southwest China	0.532	0.564	0.554	0.602	0.585	0.592	0.633	0.684	0.651	0.600
Gansu	0.484	0.574	0.492	0.533	0.529	0.559	0.633	0.655	0.611	0.563
Qinghai	0.092	0.093	0.118	0.124	0.135	0.108	0.122	0.166	0.146	0.123
Ningxia	0.172	0.238	0.256	0.235	0.24	0.249	0.228	0.288	0.342	0.25
Xinjiang	0.362	0.38	0.429	0.407	0.393	0.447	0.495	0.547	0.488	0.439
northwest China	0.278	0.321	0.324	0.325	0.324	0.341	0.37	0.414	0.397	0.344
Whole country	0.585	0.629	0.629	0.633	0.627	0.63	0.667	0.713	0.688	0.645

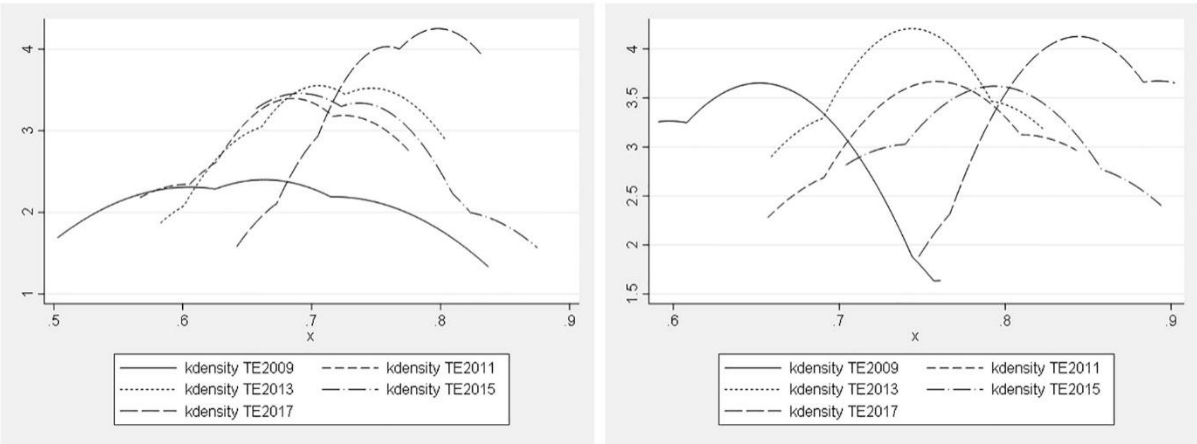
4.5 Dynamic evolution analysis of efficiency change

In this paper, the non-parametric kernel density estimation is used for further observation, and the density distribution trend map of the mean value of scientific and technological innovation efficiency of universities in China over the years is drawn, as shown in Figure 1.It shows that: (1) in the national sample period, with the increase of years, the distribution of University Science and technology innovation efficiency shifts to the right, indicating that the overall efficiency of University Science and technology innovation is in a state of growth;(2)The nuclear density curve of the regional economic comprehensive area moves to the right, which indicates that the efficiency of scientific and technological innovation in colleges and universities in Northwest China is gradually improving. The efficiency of scientific and technological innovation in colleges and universities in the northern coastal comprehensive economic zone shows a "bimodal" distribution, and there is a trend of polarization. The distribution of nuclear density curve in the economic comprehensive area of southwest China shows that the trailing on the right side is becoming more and more significant, which indicates that the efficiency gap of scientific and technological innovation in colleges and universities in southwest China is widening. The nuclear density curve of the economic comprehensive area in northeast China has shifted to the right, indicating that the efficiency of scientific and technological innovation in colleges and universities has gradually increased, and the number of peaks has not changed obviously. The wave peak of nuclear density curve in the eastern economic comprehensive area moves to the left at first and then to the right, which indicates that the efficiency of scientific and technological innovation in colleges and universities has decreased sharply and increased sharply. The change in 2015 is particularly prominent, the efficiency of the internal provinces is the closest, and the efficiency difference is large in other years. The width of nuclear density curve in the comprehensive economic zone of the middle reaches of the Yellow River gradually decreases, and the hidden wave peaks begin to have gradient effect, indicating that polarization or multipolarization begins to appear. The peak height of nuclear density curve increases gradually and the width decreases, which indicates that the regional difference of scientific and technological innovation efficiency of colleges and universities in the southern coastal provinces is decreasing.

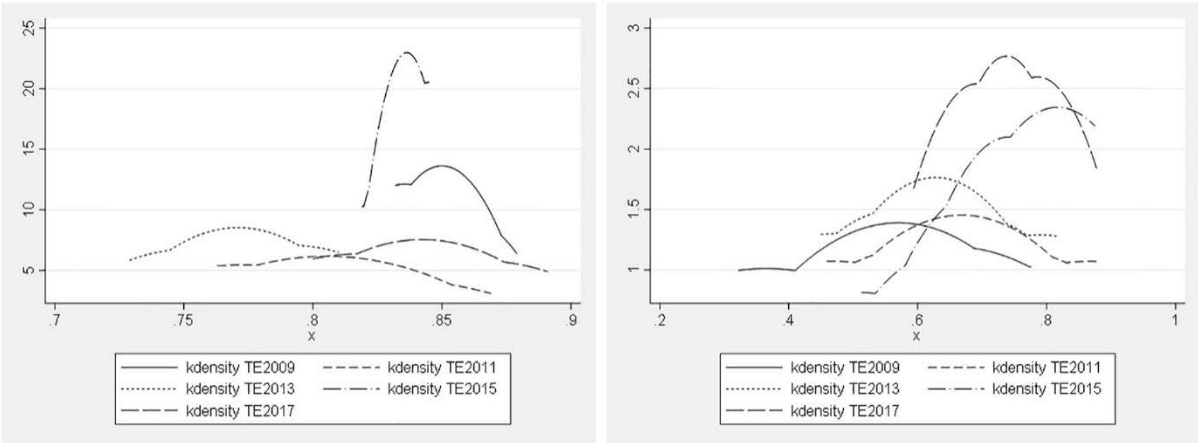
The peak height of the comprehensive economic zone in the middle reaches of the Yangtze River increases at first and then decreases, and the width gradually widens, indicating that the differences in the efficiency of scientific and technological innovation in colleges and universities in internal provinces and cities are gradually widening.



(a) Great northwest comprehensive economic zone (b) North coastal comprehensive economic zone

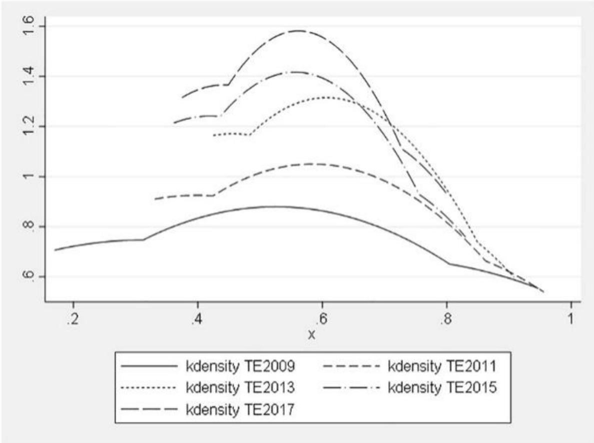


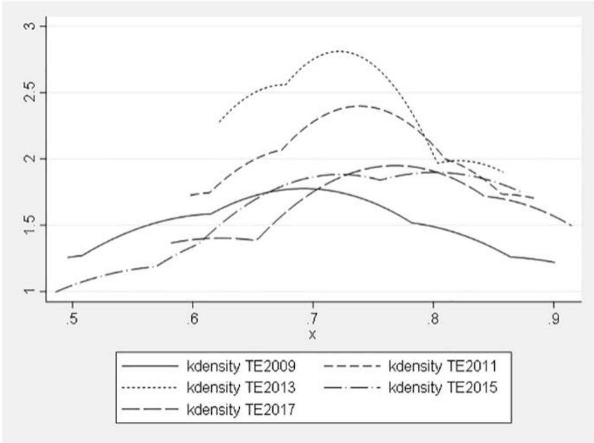
(c) Greater southwest comprehensive economic zone (d) Northeast comprehensive economic zone



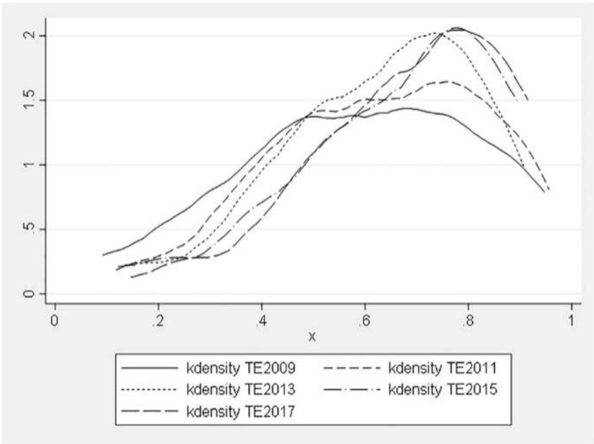
(e) Eastern comprehensive economic zone (f) Comprehensive economic zone in the middle reaches of the yellow river

ISSN: 0010-8189





(g) Southern coastal comprehensive economic zone (h) Comprehensive economic zone in the middle reaches of the Yangtze river



(i) Whole country

Fig 1: Nuclear density estimation of scientific and technological innovation efficiency of universities in china and eight regions from 2009 to 2017

4.6 Discussion

According to the above results, it can be seen that the level of regional economic development produces redundancy in the input of elements of scientific and technological innovation in colleges and universities. The reason is that the higher the level of economic development, the more investment in science and technology, but the less the output of science and technology is increased correspondingly. The level of economic development has not been organically combined with university innovation, which also verifies Wang Xiaozhen's [18] point of view Government expenditure on education funds has increased the utilization rate of R&D funds in colleges and universities, but it is not conducive to the reduction of R&D personnel and scientific and technological subject elements. The reason is that education funds are the main source of R&D funds in colleges and universities, and the use of funds is planned reasonably and effectively, which also verifies Shen Neng's point of view [19]. It is observed that after eliminating environmental factors, interference items and Bootstrap rectification, the efficiency of scientific and technological innovation in the eastern coastal universities is the highest, while that in the northwest is the lowest. This conclusion partially validates the view of Zhou et al. [20]. The reason is that the eastern coastal comprehensive economic zone has better material conditions, faster social and economic development, better infrastructure and more attraction for high-level scientific research talents than parts of Northwest China. Adequate R&D funds can stimulate the innovative power of university researchers, and the number of subjects above provincial level in Eastern universities is much higher than that in Northwest areas. Although in recent years, the national projects have a certain tilt to the west, the gap still exists. Taking the

National Natural Resources Fund in 2018 as an example, the number of projects in the eastern coastal areas was 9 981, while only 1 214 in the Greater Northwest.

V. Conclusion and Suggestions

Firstly, three-stage DEA is used to eliminate the influence of external environmental factors and random factors. On this basis, Bootstrap-DEA is used to filter the impact of random shocks, and the final value of scientific and technological innovation efficiency of universities in various provinces and cities is obtained. The results show that: (1) Without considering the interference of external environment and random factors, the efficiency of scientific and technological innovation of Chinese universities is in the non-DEA efficiency as a whole from 2009 to 2017, and the difference of efficiency values among regions is small. Beijing, Jiangsu, Shaanxi and other provinces and cities are in the frontier of innovation efficiency. Colleges and universities in Anhui, Guangdong and other provinces and cities have the lowest scientific and technological innovation, with the highest average efficiency in the eastern coast and the lowest average efficiency in the southwestern coast. (2) Among the external environmental factors, per capita GDP is not conducive to improving the efficiency of scientific and technological innovation in colleges and universities, while the number of colleges and universities is conducive to improving the efficiency of scientific and technological projects. Educational expenditure is conducive to reducing the redundancy caused by internal expenditure of R&D funds, but not to promoting the innovation efficiency of full-time personnel and scientific and technological projects. (3) The efficiency of scientific and technological innovation in colleges and universities in various regions of China is generally not high, the average efficiency of scientific and technological innovation in 30 provinces and cities has not reached the frontier and there are great differences among provinces and cities. The efficiency value of scientific and technological innovation in colleges and universities in the eastern coastal economic comprehensive area is the highest, and the efficiency value of scientific and technological innovation in colleges and universities in northwest China is the lowest. (4) Through Bootstrap correction, the average efficiency of scientific and technological innovation in colleges and universities from 2009 to 2017 is 0.645, which shows that if the level of scientific and technological innovation output is kept unchanged, the level of innovation output can be increased by 35.5% on average by improving management level, or by maintaining the current level of factor input, the level of innovation output can be increased by 35.5%. (5) The estimation of nuclear density shows that the efficiency of scientific and technological innovation in colleges and universities is increasing. The northern coast, the central part of the Yellow River, the middle reaches of the Yellow River and the middle reaches of the Yangtze River show obvious polarization of it. The nuclear density curve in Southwest China is quite right-tailed.

On the basis of the above conclusions, the following suggestions are made: Firstly, change the mode of scientific and technological research and development in colleges and universities and rationally allocate their structure of resource allocation. Secondly, expand financing channels for R&D funds, promote multi-channel and diversified scientific and technological investment system, and form the linkage mechanism of “government-enterprise-society”. Thirdly, in view of the problems of great regional differences, we should reduce the redundancy of R & D personnel and funds in colleges and universities in eastern colleges and universities, northeast and other regions. In addition to monographs and papers, more attention should be paid to the improvement of quality. The fourth is to enhance the popularity and attractiveness of colleges and universities, stimulate the vitality of scientific and technological innovation in colleges and universities, and reduce the brain drain of scientific and technological innovation talents in colleges and universities in northwest China.

ACKNOWLEDGEMENTS

The authors acknowledge Research Start-up Funds of North China University of Technology (110051360002）and General Project of Beijing Municipal Natural Science Foundation — " Research on the Bidirectional Optimal Adaptation of Water Resources and Industrial Structure Under the Coordinated Development of Beijing-Tianjin-Hebei Region" (No.: 9202005).

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