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Comparison of R&D Input-Output Efficiency in 31 Provinces and Cities in China

Zejiong Zhou, Yuting Jiang *

School of Economics, Anhui University of Finance and Economics, Bengbu, China

*** Corresponding author:** Yuting Jiang (Email: 1433562844@qq.com)

Abstract: In today's globally competitive economic environment, R&D is the source and internal power of economic growth, and its quantitative scale and innovation momentum directly affect the development of scientific and technological undertakings and the realization of high-level scientific and technological self-reliance and self-improvement. Based on the construction of regional R&D input-output efficiency evaluation index system, the article measures the R&D input-output efficiency and its yearly changes in 31 provinces and cities in China from 2017 to 2021 using CCR-DEA, BCC-DEA and Malmquist-DEA models. Based on the above conclusions, relevant recommendations are put forward to improve regional R&D input-output efficiency.

Keywords: R&D Input-output; DEA; Efficiency.

1. Introduction

With the advent of globalization and the knowledge-based economy, the concept of science and technology as the first productive force has been given increasing attention. Science and technology innovation has become the focus for enhancing international competitiveness and an important means of realizing coordinated, balanced and sustainable regional economic development. In recent years, Chinese governments and enterprises at all levels have continuously increased their investment in science and technology innovation, and both scientific and technological human capital and financial capital have enjoyed sustained and rapid growth. The report of the 20th CPC National Congress promotes and deploys education, science and technology, and human resources as a whole, pointing out that education, science and technology, and human resources are the basic and strategic support for building a socialist modernized country in a comprehensive manner, and that it is necessary to adhere to the idea that science and technology is the first productive force, human resources are the first resource, and innovation is the first driving force.

R&D input-output efficiency is an important indicator reflecting regional scientific and technological resource allocation and operation ability, which can be obtained through evaluation and measurement. Foreign research on the evaluation of R&D input-output efficiency is mainly promoted along the aspects of improving the efficiency evaluation method and extending the evaluation object level. In terms of evaluation methods, there are mainly two types of non-parametric Data Envelopment Analysis (DEA) and parametric Stochastic Frontier Approach (SFA), and the DEA method also develops CCR-DEA, BCC-DEA, cross-efficiency DEA, and so on. In terms of evaluation objects, there are mainly studies oriented to industrial sectors such as manufacturing, services, agriculture, etc. There are also studies oriented to regions, such as the 32 cities in Mexico. Domestic research on the evaluation of regional R&D innovation efficiency basically shows a similar development line with foreign research. Some scholars are devoted to the construction of regional R&D innovation efficiency index system, such as Yan Liand Wang Liqi. Some scholars pay attention to the empirical analysis of regional R&D innovation efficiency while improving the evaluation methodology, such as Wang Ruiqi et al., Gao Xia et al., Jiang Xinghua, and Tong Jixin et al., etc. These studies are useful to understand the level of R&D innovation efficiency in the empirical regions and advance the research on the evaluation of R&D innovation efficiency. Therefore, this paper evaluates China's regional R&D input and output efficiency from both static and dynamic aspects by establishing the index system of R&D input and output with certain theoretical value, which is of practical significance for the improvement of regional R&D input and output efficiency and the in-depth implementation of the national innovation-driven strategy.

2. DEA Model Design

2.1. Modeling

Data Envelopment Analysis (DEA) is a method proposed by the famous American operations researchers A. Charnes and W. W. Cooper for comparing and evaluating the relative effectiveness between similar Decision-Making Units (DMU) with multiple inputs and multiple outputs. Because the method directly uses input and output data to construct a nonparametric DEA model to compare the relative efficiency of input and output of decision making units, it does not need to determine the form of the function and the weights of the input and output indicators in advance when dealing with the input and output problems, and the decomposition of the efficiency of the input and output is more objective, based on this advantage, this paper adopts the Data Envelopment Analysis (DEA) evaluation model for assessment. The expression is:

$$\min[\theta - \varepsilon(\sum_{i=1}^{m} si^- + \sum_{r=1}^{n} si^+)]$$

$$\sum_{j=1}^{I} xij\lambda j + si^- = \theta xik$$

$$\sum_{j=1}^{I} yrj\lambda j - sr^+ = yrk$$

$$\sum_{j=1}^{I} \lambda j = 1$$

$$\lambda j, si^-, sr^+ \geq 0,\ j = 1,2,\cdots,n$$

Where, the BCC model is assumed to have multiple decision-making units (DMU), where x_{ij} is the i-th input of a certain decision unit j, and $x_{ij} \geq 0$;y_{rj} is the r-th output of a certain decision unit j,$y_{rj} \geq 0$, the θ is the target planning value, and λ_j is the planning decision variable, ε is the non-Archimedean infinitesimal, si^- and sr^+ are vectors of slack variables. If $\theta = 1, s^- = 0$, and $s^+ = 0$, the decision-making unit DEA is valid; if $\theta < 1$, the DMU is DEA invalid; if $\theta = 1$, and $s^- \neq 0$ or $s^+ \neq 0$, the DMU is weak DEA valid.

The Malmquist index method is widely used to measure productivity change and is expressed as:

$$M(x^{t+1}, y^{t+1}, x^t, y^t) = [\frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \times \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)}]^{\frac{1}{2}}$$

$$Effch = \frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)}$$

$$Tech = [\frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)}]^{\frac{1}{2}}$$

$$Tfpch = Effch \times Tech = (Pech \times Sech) \times Tech$$

Where, (x^t, y^t) and (x^{t+1}, y^{t+1}) denote the input-output vectors for period t and period t+1, respectively, where an M-index >1 indicates an increase in efficiency and an M-index <1 indicates a decrease in efficiency.

2.2. Sample Selection and Data Sources

R&D activity is a complex system with multiple inputs and outputs, and making a comprehensive, systematic and objective evaluation of it is a comprehensive evaluation problem with multiple criteria. Based on the current situation of R&D scale and taking into account the availability and validity of data, this paper measures and analyzes the R&D input-output efficiency of 31 provinces in China from 2017 to 2021, and selects the full-time equivalent of R&D personnel and the internal expenditure of R&D funds as the input indexes, and the number of patent authorizations and technology market turnover are selected to measure the output level of R&D in each region of China. The research design of R&D input and output indicators is shown in Table 1.

Table 1. R&D Input-Output Indicator System

Standardized layer	Indicator layer
Input indicators	Full-time equivalent of R&D personnel
	Internal expenditure on R&D funds
Output indicators	Number of patents granted
	Technology market turnover

The study takes 31 provinces and cities (excluding Hong Kong, Macao and Taiwan) as sample decision-making units, and carries out sample statistical analysis using the 2017-2021 China Statistical Yearbook, China Science and Technology Statistical Yearbook, and provincial and municipal statistical yearbooks as data sources to ensure the correctness and completeness of the data sources.

3. Empirical Analysis of R&D Input-Output Efficiency

3.1. Static Analysis of DEA Models

Using DEAP2.1 software to analyze the R&D input-output efficiency of the input-output indicators of 31 provinces in China in 2017 and 2021, we obtained the comprehensive efficiency value, pure technical efficiency value and scale efficiency value of R&D, and the results are shown in Table 2.

(1) From the comprehensive technical efficiency index, R&D input and output efficiency did not reach DEA efficiency in 2017 and 2021, and the supply efficiency was 0.41 and 0.386 respectively, which is in the lower category. From an inter-provincial perspective, there are still some differences in the R&D input-output efficiency of different regions, except for Beijing, Tianjin, Hebei, Heilongjiang, Shanghai, Shandong, Hunan, Guangxi, Hainan and Shaanxi, where the efficiency has improved, and the supply efficiency of most of the regions is gradually decreasing. Four and three regions reach the production frontier surface in 2017 and 2021 respectively, and the region that is effective in both study periods is Xinjiang, indicating that the R&D inputs and outputs in this region have realized the optimal allocation, the input structure is reasonable, and the inputs and outputs reach the best effect under different combinations. In 2021, three provinces, Beijing, Guangxi and Xinjiang, are on the production frontier, and the rest of the provinces have different degrees of room for improvement in the pure technical efficiency and scale efficiency, and the provinces in the last three places are Fujian, Guangdong and Chongqing, and these 3 provinces should focus on strengthening the level of R&D input and output and designing a reasonable incentive system to achieve the optimal scale.

(2) The pure technical efficiency of R&D input and output shows a downward trend. In 2021, the pure technical efficiency of national R&D input and output is 0.61, reflecting that there is more room for progress in the management level, and the scale efficiency of R&D input and output is lower than the pure technical efficiency, which indicates that the scale of R&D is the main factor restricting the efficiency of China's R&D input and output. The number of regions with effective pure technical efficiency is more than the number of regions with effective scale efficiency, and the number of provinces with effective pure technical efficiency in 2017 and 2021 is 8 and 9 respectively, indicating that these provinces are more advanced in management and technology, etc., and the established inputs maximize output, and the lower scale efficiency is the main reason for the lower comprehensive efficiency, and the investment scale should be adjusted to further improve the scale efficiency. The pure technical efficiency values of Hainan, Guizhou and Ningxia are at a lower level, 0.261, 0.294 and 0.386 in 2017, and 0.318, 0.318 and 0.176 in 2021, which are much lower than the national average, and must further improve the level of R&D technology.

(3) The scale efficiency of R&D input and output can reflect whether the regional R&D input and output is at the optimal scale, as can be seen from Table 2, the scale efficiency has slightly decreased from 0.589 in 2017 to 0.532 in 2021. The only region with scale efficiency of 1 in both years is Xinjiang. The scale efficiency values of Jiangsu and Guangdong are at a low level, and they should further expand their investment in R&D to achieve the optimal scale. Regions with increasing returns to scale, such as Hainan, Tibet and Gansu, should reasonably increase their R&D inputs, while regions with decreasing returns to scale have obvious efficiency loss problems due to the ineffective utilization of funding expenditures, and special attention should be paid to improving the direction of funding

utilization.

Table 2. R&D Input-Output Efficiency Values for 31 Provinces and Municipalities, 2017 and 2021

Provinces	2017				2021			
	Combined technical efficiency	Pure technical efficiency	Scale efficiency	Scale gains	Combined technical efficiency	Pure technical efficiency	Scale efficiency	Scale gains
Beijing	0.896	1	0.896	drs	1	1	1	-
Tianjin	0.298	0.604	0.494	drs	0.344	0.562	0.612	drs
Hebei	0.215	0.719	0.299	drs	0.393	1	0.393	drs
Shanxi	0.336	0.531	0.633	drs	0.273	0.596	0.458	drs
Inner Mongolia	0.552	0.552	0.999	-	0.397	0.587	0.677	drs
Liaoning	0.408	0.726	0.561	drs	0.226	0.422	0.535	drs
Jilin	0.558	0.581	0.961	drs	0.18	0.314	0.574	drs
Heilongjiang	0.315	0.628	0.501	drs	0.444	0.629	0.706	drs
Shanghai	0.299	0.609	0.49	drs	0.344	0.698	0.493	drs
Jiangsu	0.181	0.875	0.206	drs	0.094	1	0.094	drs
Zhejiang	0.254	1	0.254	drs	0.124	1	0.124	drs
Anhui	0.257	0.745	0.345	drs	0.19	0.484	0.393	drs
Fujian	0.175	0.541	0.323	drs	0.053	0.358	0.147	drs
Jiangxi	0.233	0.676	0.344	drs	0.085	0.273	0.31	drs
Shandong	0.177	0.475	0.373	drs	0.203	1	0.203	drs
Henan	0.233	0.738	0.315	drs	0.131	0.663	0.197	drs
Hubei	0.3	0.439	0.684	drs	0.221	0.443	0.498	drs
Hunan	0.136	0.436	0.312	drs	0.173	0.287	0.605	drs
Guangdong	0.139	1	0.139	drs	0.074	1	0.074	drs
Guangxi	0.761	1	0.761	drs	1	1	1	-
Hainan	0.213	0.261	0.814	drs	0.289	0.318	0.909	irs
Chongqing	0.236	0.644	0.366	drs	0.074	0.27	0.273	drs
Sichuan	0.223	0.605	0.368	drs	0.183	0.453	0.404	drs
Guizhou	0.214	0.294	0.726	drs	0.201	0.318	0.632	drs
Yunnan	0.52	0.882	0.589	drs	0.195	0.532	0.366	drs
Tibet	1	1	1	-	0.324	1	0.324	irs
Shaanxi	0.309	0.403	0.766	drs	0.373	0.42	0.888	drs
Gansu	1	1	1	-	0.521	0.524	0.994	irs
Qinghai	1	1	1	-	0.428	0.591	0.724	irs
Ningxia	0.29	0.386	0.751	drs	0.158	0.176	0.895	irs
Xinjiang	1	1	1	-	1	1	1	-
National average	0.41	0.689	0.589		0.313	0.61	0.532	

3.2. Dynamic Analysis of the Malmquist Index

Malmquist index can dynamically reflect the trend of R&D efficiency in each region, so DEAP2.1 software was used to analyze the R&D data of 31 provinces in China from 2017 to 2021, and then examine the dynamic changes and heterogeneity of total factor productivity.

(1) Analysis of overall efficiency changes. As can be seen from Table 3 and Table 4: the average value of China's R&D productivity index in 2017-2021 is 1.154, which is basically rising overall, and the total factor productivity index is greater than 1 in each year of the study period, indicating that the R&D efficiency is in a steadily rising stage. Decomposition, technical efficiency decreased by 8.3%, and the average value of technical progress increased by 25.9%, indicating that the drive of R&D technical progress plays a major role, reflecting that although the technical progress of China's R&D is very fast, the technical efficiency is still to be improved, and there is still more room for realizing the effective inputs and outputs of R&D by improving the technical efficiency. Sub-annually, the technical efficiency index during 2018-2019 and 2020-2021 is 0.927 and 0.617 respectively, and the technical progress index is 1.201 and 1.815 respectively, reflecting that the technical progress index makes a major contribution to the improvement of the total factor productivity of R&D, and the technical efficiency index has a greater impact on the change of the total factor productivity during the period of 2019-2020. In 2017-2021, the total factor productivity of R&D in China is greater than 1, and only the technical progress in each year is less than 1 in 2019-2020, and the value of the rest of the years is slightly larger, reflecting that technical progress is the main factor driving the growth of total factor productivity.

(2) Comparison of efficiency changes among provinces. From Table 4, it can be seen that: except for Jilin, Yunnan and Tibet, the R&D productivity index of which is less than 1 in 2017-2021, the R&D total factor productivity index of the other 28 provinces is greater than 1, indicating that the input-output efficiency of R&D in the vast majority of China's regions is constantly improving and developing in a better way. In terms of growth drivers, the technical efficiency of Shanxi, Inner Mongolia, Jilin, Liaoning and other regions has been reduced, and the improvement of R&D input-output efficiency mainly originates from the improvement of technological progress, whereas the changes in the technical efficiency of R&D input-output in Beijing, Hebei, Shanghai and other regions and the technological changes are synchronized, i.e., the technical efficiency and the factor of technological progress synergistically play a role in promoting the development.

Table 3. R&D Malmquist index and its decomposition, 2017-2021

Year	Technical efficiency	technological progress	Pure technical efficiency	Scale efficiency	Total factor productivity
2017-2018	1.126	1.169	1.019	1.105	1.317
2018-2019	0.927	1.201	0.946	0.979	1.113
2019-2020	1.096	0.985	1.048	1.046	1.079
2020-2021	0.617	1.815	0.835	0.739	1.120
average value	0.917	1.259	0.958	0.956	1.154

Table 4. R&D Malmquist index and its decomposition by region

Provinces	Technical efficiency	technological progress	Pure technical efficiency	Scale efficiency	Total factor productivity
Beijing	1.028	1.064	1	1.028	1.094
Tianjin	1.036	1.165	0.982	1.055	1.206
Hebei	1.164	1.239	1.086	1.071	1.442
Shanxi	0.949	1.313	1.029	0.922	1.247
Inner Mongolia	0.921	1.42	1.015	0.907	1.308
Liaoning	0.863	1.214	0.873	0.988	1.048
Jilin	0.754	1.226	0.858	0.879	0.925
Heilongjiang	1.09	1.17	1	1.089	1.275
Shanghai	1.036	1.186	1.035	1.001	1.229
Jiangsu	0.849	1.302	1.034	0.821	1.105
Zhejiang	0.836	1.305	1	0.836	1.091
Anhui	0.927	1.26	0.898	1.033	1.168
Fujian	0.741	1.43	0.902	0.822	1.06
Jiangxi	0.777	1.299	0.797	0.974	1.009
Shandong	1.034	1.28	1.205	0.858	1.324
Henan	0.866	1.293	0.974	0.889	1.119
Hubei	0.926	1.146	1.003	0.924	1.061
Hunan	1.063	1.195	0.9	1.18	1.27
Guangdong	0.854	1.323	1	0.854	1.129
Guangxi	1.071	1.28	1	1.071	1.371
Hainan	1.08	1.337	1.05	1.028	1.443
Chongqing	0.748	1.394	0.805	0.929	1.043
Sichuan	0.952	1.183	0.93	1.024	1.127
Guizhou	0.985	1.227	1.019	0.966	1.208
Yunnan	0.782	1.236	0.881	0.888	0.967
Tibet	0.755	1.252	1	0.755	0.945
Shaanxi	1.048	1.092	1.01	1.038	1.145
Gansu	0.85	1.176	0.851	0.998	1
Qinghai	0.809	1.249	0.877	0.922	1.01
Ningxia	0.858	1.395	0.822	1.045	1.198
Xinjiang	1	1.484	1	1	1.484
National average	0.917	1.259	0.958	0.956	1.154

4. Conclusion and Suggestions

4.1. Conclusion

This paper draws the following conclusions from an empirical study of R&D input-output efficiency in 31 provinces in China from 2017 to 2021:

Based on the DEA model measurement, it can be seen that the comprehensive efficiency of R&D inputs and outputs in 2017 and 2021 have not reached the DEA effective, and the efficiency of R&D inputs and outputs of different provinces varies greatly, and most of the provinces have different degrees of pure technical efficiency and scale efficiency improvement space, which should be focused on improving the level of R&D inputs and outputs, designing a reasonable incentive system, and Expanding inputs to achieve the optimal scale; Dynamic analysis based on Malmquist index shows that the average value of China's R&D input-output efficiency productivity index is 1.154 in 2017-2021, indicating that the overall supply efficiency is on the rise. The change of technological progress in R&D input-output plays an important role in the improvement of comprehensive efficiency.

4.2. Suggestions

First, increase support for high-tech industries. High-tech industries are an important driving force for economic development and innovation. The government should improve its support for scientific and technological innovation, increase investment in R&D funding and policy support, adjust the layout of R&D according to national strategic needs and industrial development direction, strengthen basic and applied research, improve original innovation capability, and establish a more flexible and efficient funding mechanism for scientific research projects, so as to attract more enterprises and scientific research institutes to participate in R&D in the field of high technology, in order to enhance the R&D output efficiency of each province.

Secondly, provinces are encouraged to strengthen cooperation between industry, universities and research institutes. It promotes in-depth cooperation among enterprises, universities and scientific research institutions, forms an integrated innovation system of industry-university-research, establishes a good cooperation mechanism, promotes the flow of knowledge and the allocation of resources, improves the efficiency of the R&D process and the innovation capacity, and accelerates the research, development and transformation of new technologies and new products. At the same time, the cooperation among industries, universities and research institutes provides enterprises with more support for scientific and technological talents, improves the overall quality and innovation ability of R&D teams, and promotes the efficiency of R&D input and output in each province.

Finally, strengthening inter-provincial synergy and cooperation is also an important way to improve the efficiency of R&D inputs and outputs. Different provinces have unique industrial characteristics and resource advantages, and provinces can work together to establish an inter-provincial R&D alliance dedicated to promoting knowledge sharing and technological cooperation. Through regular seminars, workshops and training courses, R&D personnel from different provinces will be provided with opportunities to communicate and cooperate, and to collaborate in sharing experiences and resources. At the same time, special funds should be set up to finance collaborative R&D projects, provide R&D equipment and technical support, and offer incentives to high-level R&D personnel to encourage the sharing of resources and experience among provinces, thereby accelerating the iteration and transformation of technological innovations and improving the efficiency of R&D inputs and outputs across the country.

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