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# Analyzing R&D Input-Output Efficiency by Industry Across Provinces: A Case Study of Listed Companies in Henan Province

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## Abstract

**This paper obtained the innovation input-output information of Henan Province from 2015 to 2019 from the CSMAR database, and used two DEA models, the DEA-BCC model and the Malmquist model, to construct a science and technology input-output evaluation index system to analyse the efficiency of urban areas, industries and enterprises in Henan Province respectively.**

## Keywords

**Science and Technology; Input-output; Data Envelopment Analysis.**

## 1. Introduction

In the context of economic globalization, the proposition that science and technology is one of the first productive forces has been increasingly recognized and accepted by people. The State has further increased its investment in science and technology, vigorously developed high technology and continuously accelerated the pace of industrialisation of science and technology, and science and technology has become a strategic policy for the economic and social development of many provinces and cities. The role of science and technology input and output on socio-economic development has been emphasized by government departments at all levels, and localities have formulated science and technology strategies and policies suitable for their own development according to their natural conditions, human resources, scientific and technological strength, economic base and geographical conditions, etc. Science and technology input has played a positive role in the development of society and economy. Therefore, the evaluation of science and technology inputs and outputs is of great practical significance for the rational use of resources and the improvement of the efficiency of the use of funds. In recent years, China has achieved many promising results in scientific research on the evaluation of science and technology inputs and outputs, but the evaluation methods are still too much bound to conventional methods, and the application and innovation of new methods need to be further strengthened. This paper attempts to use the idea of system operation research to establish a DEA evaluation model and propose a new method for evaluating science and technology inputs and outputs.

## 2. Model

Data Envelopment Analysis (DEA) is a new approach to systems analysis developed by renowned operational researchers such as A. Charnes and W.W. Cooper on the basis of the concept of "relative efficiency evaluation"[1]. The first DEA model, the C2R model, has been playing a vital role since its inception in 1978 and has further become an important and effective analytical tool in the field of management science and systems engineering. Decision units are evaluated by comparing the relative efficiency between them using a mathematical planning model[2]. In addition, the DEA evaluation model is particularly suitable for complex systems with multiple input and output variables, where the scale effectiveness and technical effectiveness of the decision units are evaluated simultaneously. Using this model not only

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economic efficiency indicators can be evaluated, but also some social efficiency indicators can be evaluated objectively, although the unit of measurement and nature of these indicators are different. It is undoubtedly desirable to use the DEA evaluation model to evaluate a systemic issue such as the efficiency of an enterprise's technological innovation, which has both economic and social benefits.

## 3. Indicator Construction

To evaluate the science and technology inputs and outputs, the selected indicators must objectively reflect the quantitative process in the inputs and outputs, and can reflect the evaluation purpose and evaluation content[3]. Therefore, the scientific establishment of the indicator system is the basis for the success of the evaluation. The establishment of the evaluation index system generally follows three principles, namely, the principle of scientificity, comparability and feasibility[4]. The principle of scientificity means that the evaluation index system should objectively reflect and describe the whole process and activity law of the evaluated thing or system as far as possible, and correctly reveal the essential characteristics of the evaluated object. The principle of comparability refers to the comparability of the evaluation index system among the evaluated objects, requiring clear definitions of evaluation indexes, in line with the norms, and consistent statistical caliber and statistical scope. The principle of feasibility refers to the collectability of the evaluation index data and the operability of the evaluation method to ensure the realizability of the evaluation work[5]. Finally, this paper takes the number of patents of enterprises as the index of science and technology output, and constructs the index of science and technology input from two perspectives of human resources and financial investment respectively, and finally selects the number of R&D researchers and the amount of R&D capital investment as the index of science and technology input.

## 4. Empirical Analysis

### 4.1. Static Efficiency Analysis of Innovation Inputs and Outputs in Henan Province based on BCC Model

The combined technical efficiency values of innovation inputs and outputs for 2015-2019 for five firms in Henan Province can be derived by using an input-oriented variable payoffs of scale model (BCC model) analysis through Deap 2.1 software.

**Table 1.** Combined efficiency values of innovation inputs and outputs of five enterprises in Henan Province from 2015 to 2019

| Company | 2015 | 20216 | 2017 | 2018 | 2019 | Mean |
|---|---|---|---|---|---|---|
| 1 | 0.660 | 1.000 | 1.000 | 1.000 | 0.831 | 0.898 |
| 2 | 1.000 | 0.613 | 0.377 | 0.477 | 0.410 | 0.575 |
| 3 | 0.980 | 0.784 | 1.000 | 0.775 | 0.593 | 0.826 |
| 4 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1 |
| 5 | 0.938 | 1.000 | 0.805 | 0.864 | 0.705 | 0.862 |
| Mean | 0.916 | 0.880 | 0.836 | 0.823 | 0.708 | |

The results of the empirical analysis are shown in Table 1, and the mean values of the combined technical efficiency of innovation inputs and outputs of the five enterprises in Henan Province from 2015 to 2019 are 0.916 in 2015, 0.880 in 2016, 0836 in 2017, 0.823 in 2018, and 0.708 in 2019, respectively, and according to the results of the DEA data analysis, we can know that the five enterprises in The combined technical efficiency of innovation inputs and outputs in all five

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years did not reach 1 and were in a non-effective state. However, by comparing these five enterprises, we find that only the fourth enterprise's innovation input-output integrated efficiency is equal to 1, which means that only the fourth enterprise has the highest innovation input-output efficiency in this five-year period and is on the frontier of effective technical efficiency, while the other four enterprises' innovation input-output integrated efficiency is not on the frontier of effective technical efficiency, and the least efficient one is the second enterprise. Through the above analysis, we can also know that except for the fourth enterprise, the rest of the enterprises generally have the phenomenon of inefficient resource allocation and wasteful technological innovation inputs. Therefore, based on the DEA input-oriented model, the remaining four enterprises have room to improve their input-output efficiency and optimize their resource allocation efficiency.

**Table 2.** Comprehensive efficiency values of innovation inputs and outputs of provincial cities in Henan Province from 2015 to 2019

| Province | 2015 | 2016 | 2017 | 2018 | 2019 | Mean |
|---|---|---|---|---|---|---|
| Jiaozuo | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1 |
| Kaifeng | 0.942 | 1.000 | 1.000 | 0.890 | 1.000 | 0.966 |
| Zhengzhou | 1.000 | 1.000 | 0.648 | 1.000 | 0.312 | 0.792 |
| Mean | 0.981 | 1.000 | 0.883 | 0.963 | 0.771 | |

After analyzing the comprehensive efficiency of innovation inputs and outputs of five enterprises in Henan Province through micro perspective, in order to further analyze the comprehensive efficiency of innovation inputs and outputs in Henan Province, this paper has further analyzed the comprehensive efficiency index of innovation inputs and outputs of each urban area in Henan Province from macro perspective, and then formed a complete analysis system from point to surface. Table 2 reports the comprehensive efficiency values of innovation input-output of each city in Henan Province from 2015 to 2019, and according to the results of the analysis we can intuitively see that the comprehensive efficiency values of innovation input-output of three urban areas in Henan Province from 2015 to 2019 are 0.981 in 2015, 1 in 2016, 0.883 in 2017, 0.963 in 2018 and 0.771 in 2019, among which the combined innovation input-output efficiency values of the three urban areas in Henan Province were equal to 1 in 2016 and fluctuated down in the following three years, indicating that the combined innovation input-output efficiency of the three urban areas in Henan Province was on the frontier of effective technical efficiency only in 2016. In addition, the cross-sectional comparison among municipalities reveals that the innovation input-output combined efficiency of Jiaozuo City reaches 1 in five years, followed by Kaifeng City at 0.966 and Zhengzhou City at 0.792, which indicates that the input-output efficiency of Kaifeng City and Zhengzhou City is low except for Jiaozuo City, which is on the frontier of effective technical efficiency, and therefore, there is a need and space for further optimization.

Based on the above analysis of the comprehensive efficiency of innovation inputs and outputs in three urban areas of Henan Province, we found that the comprehensive performance of innovation inputs and outputs in Zhengzhou City, the capital city of Henan Province, is not on a technically effective frontier, but in Jiaozuo City, a relatively backward and non-capital city in terms of economic development, the comprehensive efficiency values of innovation inputs and outputs are on a technically effective frontier. Combining with this data, this paper further analyzes the composite efficiency index of four industries in Henan Province, and tries to evaluate the intrinsic differences of innovation input-output efficiency in Henan Province more objectively from the perspective of industries. As shown in Table 3, four industries in Henan Province are compared in terms of innovation input-output efficiency according to DEA-BCC

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model, including: non-metallic mineral products industry, chemical raw materials and chemical products manufacturing industry, computer, communication and other electronic equipment manufacturing industry, and instrumentation manufacturing industry, which are chosen because, on the one hand, the above four industries have higher R&D These three factors can make the measurement of innovation output indicators in this paper appear more three-dimensional, and can highlight the quality and effect of innovation output. On the other hand, for the consideration of data availability, these four industries are selected as the sample for comparison in order to maintain the smoothness of the data of each year. According to the results of the returns we can see that the mean values of the combined efficiency of innovation input and output of the four industries in Henan Province from 2015 to 2019 were once: 0.908, 0.934, 0.866, 0.845, and 0.761, and the mean values of the combined efficiency of innovation input and output for five years were less than 1, which shows that the combined technical efficiency of Henan Province did not reach the effective state. The average value of the comprehensive efficiency of these four industries is between 0.667 and 1. Analyzing from the persistent state, only the comprehensive technical efficiency of chemical raw materials and chemical products manufacturing industry is located at the highest level, which is on the frontier of effective technology, while the comprehensive efficiency of innovation input and output of the remaining three industries still needs to be improved, and the allocation efficiency of resources needs to be further enhanced.

**Table 3.** Comprehensive efficiency values of industry innovation inputs and outputs in Henan Province from 2015 to 2019

| Industry | 2015 | 2016 | 2017 | 2018 | 2019 | Mean |
|---|---|---|---|---|---|---|
| Non-metallic mineral products industry | 0.973 | 0.736 | 1.000 | 0.850 | 1.000 | 0.912 |
| Chemical raw materials and chemical products manufacturing | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1 |
| Computer, communications and other electronic equipment manufacturing | 0.660 | 1.000 | 1.000 | 1.000 | 0.700 | 0.872 |
| Instrument manufacturing | 1.000 | 1.000 | 0.462 | 0.529 | 0.344 | 0.667 |
| Mean | 0.908 | 0.934 | 0.866 | 0.845 | 0.761 | |

## 4.2. Dynamic Analysis based on Malmquist Index Model

The DEA-BCC model analyzes the input and output of cultural industry in Henan Province from a static perspective, while the Malmquist index analyzes the input and output of cultural industry in Henan Province from a dynamic perspective. The general assumption is that the number of decision units to be analyzed is n and the time interval is t. The number of decision units in this paper corresponds to three prefecture-level cities and the time interval is the five-year observation period from 2015 to 2019.

Table 4 reports the Malmquist decomposition data of the combined efficiency of innovation inputs and outputs in Henan Province from 2015 to 2019, and it can be seen that the value of total factor productivity change of innovation inputs and outputs in Henan Province from 2015 to 2016 is 1.104, specifically, the efficiency of innovation inputs and outputs in Henan Province increased by 10.4% in that year. By further decomposing the technical efficiency, it is found that the change of pure technical efficiency is 1.020 and the change of scale efficiency is 1.259, thus indicating that the increase of total factor productivity in that year is mainly driven by the growth of scale efficiency; observing the results in the period from 2016 to 2017, it can be found that both pure technical efficiency and scale efficiency have a corresponding magnitude of decline, and the technical progress index has an increased increase, and finally the total factor productivity rises due to the improvement of technical progress, however, during 2018~2019, the total factor productivity change value of innovation input-output in Henan Province is 0.382,

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which is 61.8% lower compared to the base period, and further decomposition of technical efficiency reveals that the change of pure technical efficiency is 0.706, the change of scale efficiency is After further decomposition of technical efficiency, we find that the change in pure technical efficiency is 0.706, the change in scale efficiency is 0.386, and the change in technical progress is 1.402, so it shows that the decrease in total factor productivity in this year is mainly due to the decrease in scale efficiency. Combined with the results of DEA analysis, it shows that the allocation efficiency of resources in the innovation process in Henan Province is low, the resource allocation ability is poor, and the utilization efficiency of innovation inputs is also low, and there is the phenomenon of redundancy of innovation inputs, so Henan Province should reasonably increase the scale of innovation inputs to improve the efficiency of overall innovation inputs and outputs.

**Table 4.** Mean values of Malmquist index decomposition of innovation inputs and outputs from 2015 to 2019 in Henan Province

| Year interval | Technical Efficiency Index | Technological Progress Index | Pure Technology Efficiency Index | Pure Technology Efficiency Index | Total Factor Productivity Index |
|---|---|---|---|---|---|
| 2015~2016 | 1.284 | 0.860 | 1.020 | 1.259 | 1.104 |
| 2016~2017 | 0.786 | 1.579 | 0.865 | 0.909 | 1.241 |
| 2017~2018 | 1.109 | 0.620 | 1.111 | 0.997 | 0.687 |
| 2018~2019 | 0.273 | 1.402 | 0.706 | 0.386 | 0.382 |
| Mean | 0.743 | 1.042 | 0.912 | 0.815 | 0.775 |

Table 5 reports the reported results of the decomposition values of Malmquist index of innovation inputs and outputs in Henan province from 2015 to 2019, the total factor productivity indices of Jiaozuo city, Kaifeng city and Zhengzhou city are negative, among which Jiaozuo city decreases the slowest at 0.4% and Kaifeng city decreases the fastest at 45.2%, from the perspective of technical efficiency, the technical efficiency shows a decreasing trend overall. After further decomposition of total factor productivity, we can more clearly find that the main trigger for the decrease of total factor productivity in these three urban areas in Henan Province is still the decrease of scale efficiency, which verifies the above conclusion that there is redundancy of innovation input in Henan Province, and it is urgent to improve the efficiency of resource allocation. As a whole, there is an uneven regional distribution of the overall scale development of innovation inputs in the urban areas of Henan Province.

**Table 5.** Malmquist index decomposition values of innovation inputs and outputs in urban areas of Henan Province, 2015-2019

| Province | Technical Efficiency Index | Technological Progress Index | Pure Technology Efficiency Index | Pure Technology Efficiency Index | Total Factor Productivity Index |
|---|---|---|---|---|---|
| Jiaozuo | 1.000 | 0.996 | 1.000 | 1.000 | 0.996 |
| Kaifeng | 0.496 | 1.105 | 1.015 | 0.489 | 0.548 |
| Zhengzhou | 0.828 | 1.029 | 0.748 | 1.107 | 0.852 |
| Mean | 0.743 | 1.042 | 0.912 | 0.815 | 0.775 |

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## 5. Conclusion

The analysis of innovation input-output efficiency in Henan Province from 2015 to 2019 through DEA-BCC model and Malmquist index model can be concluded that the resource allocation efficiency of innovation inputs in Henan Province is low, and the lack of effective utilization of resources leads to the widespread phenomenon of redundancy of innovation inputs; therefore, the scale of innovation inputs should be reasonably controlled to improve the resource allocation efficiency of innovation inputs, and then promote the improvement of innovation input-output efficiency to promote the progress of local science and technology development.

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