Evaluation of the Efficiency of Science and Technology Innovation in National Central Cities Based on Patent Analysis

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Abstract. The national central city is the "spire city" in China's urban system planning, which plays an important role in leading regional scientific and technological innovation. In this paper, DEA-Queens model is used to analyze the efficiency of science and technology innovation in 9 National Central Cities in China from 2013 to 2017. The results show that the overall level of science and technology innovation efficiency in national central cities is increasing year by year, but the average value is only 0.7369, and there is still a large space for improvement; in terms of spatial differences, 4 cities, Beijing, Chengdu, Chongqing and Wuhan, had effective status in the calculation period, while the other cities had no effective status, and the efficiency of scientific and technological innovation was also significantly different in 9 cities.

Keywords: National Central City, Dea-Queens, Efficiency Evaluation

1. Introduction

In 2005, the Ministry of construction of China proposed to set up the highest level "National Central City" of China's urban system in accordance with the urban planning law. Since 2010, the state has proposed to build nine national central cities, namely Beijing, Shanghai, Tianjin, Chongqing, Guangzhou, Chengdu, Wuhan, Zhengzhou and Xi'an, to become the "spire city" in China's urban system. Scientific and technological innovation ability is the core power to promote regional economic development and social progress, and the most important component of regional competitiveness [1]. With the government 's understanding of the importance of innovation deepening, the input of innovation resources is also increasing rapidly. As the direct output of innovation, patents can scientifically and reasonably evaluate the efficiency of regional scientific and technological innovation. Therefore, this paper chooses to analyze the innovation efficiency of National Central cities based on patents[2,3].

In view of the fact that regional scientific and technological innovation is a complex problem with multiple inputs and multiple outputs, Scholars at home and abroad have studied the measurement of regional innovation efficiency from multiple perspectives. Data envelopment analysis (DEA) is the
most popular method to measure the efficiency of innovation. DEA was proposed by A. Charnes and W.W. Cooper. It is a mathematical programming method to evaluate the relative efficiency of homogeneous decision-making units with multiple inputs and multiple outputs. It don t need to consider the nonparametric evaluation method of production function relationship between input and output [4]. Nasierowski and Arcelus first used DEA to analyze the efficiency of innovation among countries [5]; Carayannisa and others pointed out that DEA is also feasible in the study of national science and technology innovation efficiency through further combing previous studies [6]. Cuitláhuac Valdez Lafarga used DEA model to analyze the efficiency of regional innovation in Mexico [7]; Thomas, Sharma and Jain use DEA model to measure the innovation efficiency of science and technology innovation in each region based on the data of American States and Colombia region from 2004 to 2008. The research results show that 14 of the 50 regions analyzed have significantly positive changes [8].

Most of the above studies adopt DEA static model, which is prone to errors, because the input and output of regional scientific research activities are distributed in different stages, and the output period lags behind the input period. Some scholars put forward DEA model to evaluate dynamic efficiency, such as Malmquist productivity index method and DEA-Window analysis method. There are Ungkyu Han, et al. use Malmquist productivity index to evaluate R&D performance changes in 15 regions of South Korea in 2005-2009 [9]. But Malmquist productivity index method can only analyze the data of two years, therefore this paper selects the input-output data of innovation in national central cities from 2013 to 2017, and uses DEA-Window analysis model to conduct dynamic analysis, aiming to analyze the efficiency of scientific and technological innovation in national central cities more accurately.

2. Research Design

2.1. DEA-Window Analysis Method

DEA windows analysis was first proposed by Charnes to evaluate the efficiency of panel data [10]. It can not only evaluate the efficiency of different decision making units (DMUs) in the same period, but also reflect the efficiency changes of different DMUs in different time windows.

DEA-Window analysis can not only realize the comparison of different decision-making units on the cross section, but also carry out the longitudinal analysis on the time series of the efficiency change of the same decision-making unit, that is, it can effectively use all the information of panel data. Suppose that there are n existing decision-making units, t periods, and w (1 ≤ w < T − t) window width. For each decision-making unit, t periods correspond to m inputs and g outputs, as shown in formula (1).

\[ X_j^t = (x_{1j}^t, x_{2j}^t, \ldots, x_{nj}^t)^T, j = 1, 2, \ldots, n, k = 1, 2, \ldots, m \]

\[ Y_j^t = (y_{1j}^t, y_{2j}^t, \ldots, y_{sj}^t)^T, j = 1, 2, \ldots, n, s = 1, 2, \ldots, g \]

Then the first window is composed of data from 1 to W, the second window is composed of data from 2 to w+1, and so on. The t-w+1 window is composed of data from t-w+1 to t, then the input-output variables of the R window are shown in formula (2).

\[ I_n^t = (X_n^t, X_n^{t+1}, \ldots, X_n^{t+w-1})^T, j = 1, 2, \ldots, n \]

\[ O_n^t = (Y_n^t, Y_n^{t+1}, \ldots, Y_n^{t+w-1})^T, j = 1, 2, \ldots, n \]

Then the input-output variables are introduced into the traditional data envelopment analysis model to get the DEA - Windows analysis results.
2.2. Index System
An important premise of DEA model is that the input-output index is required to have "co expansion", so it is necessary to test the Pearson correlation between the input and output index to determine whether the selected index meet the requirements. The results show that the 4 input-output indicators have a high correlation, and all of them have a significant positive correlation at the 1% significance level, which conforms to the "co expansion" required by DEA model. The Pearson correlation results are shown in Table 1, and the constructed index system is shown in Table 2.

Table 1. Pearson correlation of input-output index

| Pearson correlation | Input intensity of scientific research funds | Input intensity of scientific research personnel | Output of academic achievements | Economic benefit output |
|---------------------|---------------------------------------------|-----------------------------------------------|---------------------------------|------------------------|
| Input intensity of scientific research funds | 1                                           |                                               |                                 |                        |
| Input intensity of scientific research personnel | .710**                                     | 1                                             |                                 |                        |
| Output of academic achievements | .576**                                     | .906**                                       | 1                               |                        |
| Economic benefit output | .747**                                     | .855**                                       | .834**                          | 1                      |

Note: "**" means significant correlation at 0.01 level (bilateral).

Table 2. Evaluation index system of innovation efficiency of National Central City

| Variable type | Variable name | Variable description |
|---------------|---------------|----------------------|
| Input variables | Input intensity of scientific research funds | The ratio of RRD investment to GDP (%) |
| | Input intensity of scientific research manpower | Full time equivalent of R&D personnel (person year) |
| | Output of academic achievements | Number of patent authorizations (piece) |
| Output variables | Economic benefit output | Technical contract turnover (100 million yuan) |

2.3. data Sources
The research data is mainly the relevant data of four indicators included in the evaluation index system of innovation efficiency of national central cities. Based on the availability and accuracy of the data, the relevant data of science and technology innovation of nine national central cities in 2013-2017 are selected. The data sources are the statistical yearbook (2014-2018) of nine cities, the statistical yearbook of science and technology of nine cities (2014-2018), and the statistical bulletin of nine cities (2013-2017), and some of the data are from the city Provincial statistical yearbook. Part of patent data comes from Incopat, one of the largest patent databases in the world.
3. Empirical Analysis

DEA-Windows analysis method is used to evaluate the efficiency of innovation in national central cities. Based on the hypothesis of output orientation and constant returns of decision-making scale, DEA-SOLVER Pro5.0 software is used to calculate.

There is no consensus on the ideal window width of DEA-Windows analysis in academic circles. This paper uses the setting principle of window width (D. B.Sun(1988)) for reference to set the window width [11], as the formula (3).

\[ w = \begin{cases} 
\frac{t + 1}{2}, & \text{t is odd} \\
\frac{t + 1}{2} \pm \frac{1}{2}, & \text{t is even}
\end{cases} \tag{3} \]

W is the window width, t is the number of periods, The period selected in this paper is 5 years, so the window width of this paper is determined to be \( w = 3 \), and the innovation efficiency of the national central city is calculated, as shown in Table 3 and Figure 1.

**Table 3.** Science and technology innovation efficiency of National Central Cities (2013-2017)

|          | 2013   | 2014   | 2015   | 2016   | 2017   | average value |
|----------|--------|--------|--------|--------|--------|---------------|
| Beijing  | 0.8379 | 0.8698 | 0.9387 | 0.9847 | 1.0000 | 0.9262        |
| Chengdu  | 0.9174 | 0.7611 | 1.0000 | 0.9179 | 0.8646 | 0.8922        |
| Chongqing| 0.7766 | 0.8940 | 1.0000 | 1.0000 | 0.7413 | 0.8824        |
| Wuhan    | 0.5092 | 0.5806 | 0.8905 | 0.9719 | 1.0000 | 0.7904        |
| Guangzhou| 0.5959 | 0.5953 | 0.7721 | 0.8226 | 0.8569 | 0.7286        |
| Shanghai | 0.6233 | 0.6206 | 0.6861 | 0.7386 | 0.7766 | 0.6890        |
| Xi’an    | 0.4546 | 0.5384 | 0.7557 | 0.9403 | 0.7213 | 0.6821        |
| Tianjin  | 0.4210 | 0.4342 | 0.5544 | 0.5987 | 0.7406 | 0.5498        |
| Zhengzhou| 0.3775 | 0.4109 | 0.5285 | 0.5129 | 0.6293 | 0.4918        |
| average  | 0.6126 | 0.6339 | 0.7918 | 0.8319 | 0.8145 | 0.7369        |
The analysis results show that the average efficiency of innovation in national central cities from 2013 to 2017 is 0.7369, which shows that the overall level of innovation efficiency in national central cities is not high.

From the perspective of dynamic change trend, the average value of innovation efficiency in national central cities basically shows an upward trend. The average value of innovation efficiency rose from 0.6126 in 2013 to 0.8319 in 2016. In 2017, the average value of innovation efficiency slightly decreased, mainly due to the sharp decline of the average value of scientific and technological innovation efficiency in Xi'an and Chongqing. Based on the analysis of the original data, it is found that, with the increase of input, the patent authorization amount in the output index of scientific and technological innovation of Xi'an in 2017 is far lower than that in 2016, and the patent authorization amount and technical contract turnover amount in the output index of scientific and technological innovation of Chongqing in 2017 are far lower than that in 2016.

4. Conclusions
The national central city is the top city in China's urban system. It is the core driving force to coordinate regional development, narrow regional development gap and enhance China's international competitiveness. This paper analyzes the input-output efficiency of innovation in the National Central City from the perspective of time evolution and space difference by using DEA-Windows. The main conclusions are as follows:

In terms of time evolution trend, the average value of innovation efficiency of national central cities basically shows an upward trend, but the overall level of innovation efficiency is not high, and there is still a lot of room for improvement. While each city pays more and more attention to scientific and technological innovation, it will help the government to allocate resources reasonably and promote urban development better [12].

In terms of spatial differences, 4 cities, Beijing, Chengdu, Chongqing and Wuhan, have experienced the situation that the efficiency value of scientific and technological innovation has reached 1, which shows that these cities have advantages in innovation management level and management mode. However, other cities have never appeared in the forefront and are always in an invalid state. Among them, Tianjin and Zhengzhou have low investment intensity in science and technology, low management level, and low efficiency of scientific and technological innovation, which needs to be changed. These local governments should formulate scientific and reasonable innovation incentive policies, improve the management level, optimize the innovation mode, and improve the efficiency of scientific and technological innovation [13-15].
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