Analysis on the Efficiency of Science and Technology Resources Utilization in the Provinces along the Belt and Road

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Abstract. With the proposal of the "Belt and Road Initiatives for Science and Technology Innovation" in May 2017, science and technology resources show great value in many areas along the Belt and Road. It is necessary to correctly describe the status and analyze utilization efficiency of science and technology resources in a region, then scientific suggestions for improvement can be put forward. This article choose Guangdong province and Jiangsu province as comparative objects, which are important areas along the Belt and Road. After collecting data from 2002 to 2013, this paper analyze the efficiency of input and output in science-tech in these two provinces by using Data Envelopment Analysis. Problems in utilization of science and technology resources and suggestions are put forward in this paper. This article aims to offer great reference for improving the utilization of science and technology resources along the Belt and Road.

1. Introduction
"The Belt and Road Initiative for Science and Technology Innovation" is a plan of action proposed by President Xi Jinping at the International Belt and Road Summit Forum on "The Belt and an Road Initiative" in Beijing on May 14. In-depth analysis of the input-output efficiency of science and technology resources in a region is of great significance to the formulation of science and technology industrial policies. As the important parts of areas along the Belt and Road, Guangdong province and Jiangsu province implement the strategies of science and technology actively.

Although these two provinces gradually become the mainstay of the scientific and technological strength in the "Belt and Road" project, they still face problems such as low self-innovation capability[1], low utilization rate of science and technology resources[2]. For now, most of the researches about science and technology in Guangdong province and Jiangsu province focus on the character descriptions and the efficiency evaluation in technology input-output. Zeng Q, Xuan Z H(2017) analyzed seven core indexes in science and technology of Guangdong province, and clearly pointed out that the combination between economy and technology needs to go further[3]. Zou G M, Tang Y F(2014) analyzed the changes of main indexes in Guangdong technology and pointed out that Guangdong needs to strengthen scientific and technological innovation ability[4]. Zhang Xiufeng, Chen Guanghua (2016) used the collaborative R&D projects of some manufacturing institutes in Guangdong Province as an example to analyze the efficiency of R&D projects led by enterprises with different ownership styles[5]. Li Senlin, Zhong Zhou(2017) claim that market should take the decisive role in allocating human resources and innovative elements. Although these studies are intuitive, they still
lack the support of related theory and quantitative model. When it comes to the quantitative research, many scholars focus on evaluating the input-output efficiency. Most scholars use Data Envelopment Analysis research the input-output efficiency of science and technology in Guangdong quantitatively: Yang W M, Song S W(2013) measured the efficiency of science and technology input-output of 20 cities by using models in DEA and pointed out that the huge technological investment is a drive force to the development of technology. While such studies provided a macro judgment in the efficiency of technological input and output in a specific area, they still lack accurate identification of the most significant input index which affects one specific output index. Quantitative studies in this research field lack comparative study, but the advanced experiences in other provinces may be very useful. This paper compares and analyzes some input indexes and output indexes in Guangdong and Jiangsu provinces to provide some great reference for improving the utilization of science and technology resources along the Belt and Road.

2. The building of measure index system

2.1. Input and Output Indexes Selection

The input indexes and output indexes in this paper are chosen on the basis of relative literature. Considering the authenticity of data and the difficulties in collection, local financial allocation for sci-tech in Guangdong province(code X₁), the quantity of science and technology personnel in Guangdong province(code X₂) and the number of research institutions in Guangdong(code X₃) are chosen as the input indexes. Same input indexes are chosen in Jiangsu province, and they are coded by X₄,X₅,X₆ correspondingly.

Quantity of patent authorization (code Y₁) and national technology reward (code Y₂) in Guangdong are chosen as direct technology output indexes. Volume of business in technology market in Guangdong (code Y₃) is chosen as an indirect technology output index. These indexes aims to judge the level of the development of science and technology in Guangdong. Same output indexes are chosen in Jiangsu province, and they are coded by Y₄, Y₅, Y₆ correspondingly.

2.2. Data Selection

Statistic data analyzed in this article needs to be approved by Statistical Bureau, so the data will be overt several years later. The latest data we can get is the data of 2013.

By searching overt data in Technology Bureau and Statistical Bureau of these two provinces, data of indexes from 2002 to 2013 are summarized in the Table 1.

Table 1. Data of Science and Technology Input and Output Indexes in Two Provinces(2002-2013)

| Year | Quantity of patent authorization (item) Guangdong | Jiangsu | Volume of business in technology market (billion yuan) Guangdong | Jiangsu | National sci-tech award (item) Guangdong | Jiangsu | Local financial allocation for sci-tech (billion yuan) Guangdong | Jiangsu | Quantity of sci-tech personnel (000 people) Guangdong | Jiangsu | Number of research institutions (item) Guangdong | Jiangsu |
|------|---------------------------------|---------|--------------------------------------------------|---------|----------------------------------------|---------|--------------------------------------------------|---------|--------------------------------|---------|--------------------------------------------|---------|
| 2002 | 22761                           | 7595    | 68.45                                            | 59.45   | 13                                     | 13      | 57.70                                            | 9.86    | 8.69                                        | 30.73   | 2907                                       | 2907    |
| 2003 | 29235                           | 9840    | 80.57                                            | 76.52   | 14                                     | 19      | 56.58                                            | 17.79   | 9.38                                        | 33.18   | 2726                                       | 2726    |
| 2004 | 31446                           | 11330   | 57.27                                            | 89.79   | 21                                     | 24      | 65.37                                            | 26.79   | 9.52                                        | 33.55   | 2994                                       | 3765    |
| 2005 | 36894                           | 13580   | 112.47                                           | 100.83  | 15                                     | 31      | 83.77                                            | 35.68   | 12.21                                       | 38.17   | 3181                                       | 3751    |
| 2006 | 43516                           | 19352   | 107.03                                           | 68.83   | 19                                     | 35      | 104.10                                           | 54.41   | 14.71                                       | 38.11   | 3414                                       | 3620    |
| 2007 | 56451                           | 31770   | 133.86                                           | 78.42   | 29                                     | 52      | 119.26                                           | 68.73   | 20.00                                       | 43.79   | 3678                                       | 3898    |
| 2008 | 62031                           | 44438   | 184.78                                           | 94.02   | 30                                     | 47      | 132.52                                           | 91.52   | 24.00                                       | 53.59   | 4200                                       | 4761    |
| 2009 | 83621                           | 87286   | 247.93                                           | 108.22  | 26                                     | 51      | 168.50                                           | 117.02  | 28.37                                       | 67.17   | 4280                                       | 7521    |
| 2010 | 119343                          | 138382  | 242.50                                           | 249.34  | 36                                     | 47      | 214.44                                           | 150.35  | 34.47                                       | 73.69   | 4452                                       | 6798    |
| 2011 | 128413                          | 199814  | 286.62                                           | 333.43  | 34                                     | 56      | 203.92                                           | 213.4   | 41.08                                       | 81.62   | 4535                                       | 9061    |
| 2012 | 153598                          | 269944  | 369.75                                           | 400.91  | 26                                     | 53      | 246.71                                           | 257.24  | 49.23                                       | 98.23   | 4756                                       | 17776   |
3. The analysis of sci-tech input and output efficiency

3.1. Introduction of Data Envelopment Analysis
Data Envelopment Analysis (DEA) is a widely used method for efficiency rating, which is founded by famous American scholars, such as Charnes. This method develops the traditional concept of the engineering efficiency of single input and single output into the efficiency rating of decision making unit (MMU) of multi-input and multi-output, which plays an important role in enriching production function theory and its application technology. With the strength of simplifying calculation and reducing error, DEA has been a vital implement in scientific research of management, decision analysis and technical evaluation.

The models of BC², C²R and FG are all common in the usage of empirical research. In this paper, the C²R model is chosen to evaluate the efficient of sci-tech input and output in two provinces.

3.2. The basic principle of DEA and C²R model
Supposing the number of the DMU is m and the number of the evaluating indicator is n, p+q=n. P means the types of the input to each DMU, and q means the types of the output. Input index coded \( x_{ij} \) represents the quantity of the NO. i input to the NO. j DMU, and the output index coded \( y_{sj} \) represents the quantity of the NO. s input to the NO. j DMU (\( x_{ij} \geq 0, y_{sj} \geq 0; i=1,2,3,\ldots,p; s=1,2,3,\ldots,q \)).

The vector \( X_j = (x_{1j}, x_{2j}, \ldots, x_{pj}) \) represents the quantity of the input to the NO. j DMU; vector \( Y_j = (y_{1j}, y_{2j}, \ldots, y_{qj}) \) represents the quantity of the output to the NO. j DMU. Based on the above definition, two models can be constructed by DEA. The DMU in the following models is \( Y_{j0} \).

Model 1: Analyzing the efficiency of input on the viewpoint of constant output and decreased input.

\[
\begin{align*}
\min \theta = V_D \\
\text{s.t.} \sum_{j=1}^{m} \lambda_j X_j &\leq \theta X_{j0} \\
\sum_{j=1}^{n} \lambda_j Y_j &\geq \theta Y_{j0} \\
\lambda_j &\geq 0, j = 1,2,3,\ldots, m
\end{align*}
\]

Model 1.1

\[
\begin{align*}
\min \left[ \theta - \varepsilon (E^S - E^S^S) \right] = V_{D(c)} \\
\text{s.t.} \sum_{j=1}^{m} \lambda_j X_j + S^- = \theta X_{j0} \\
\sum_{j=1}^{n} \lambda_j Y_j - S^- = Y_{j0} \\
\lambda_j &\geq 0, j = 1,2,3,\ldots, m
\end{align*}
\]

Model 2: Analyzing the efficiency of input on the viewpoint of increased output and constant input.

\[
\begin{align*}
\min \alpha = V_D \\
\text{s.t.} \sum_{j=1}^{m} \lambda_j X_j &\leq X_{j0} \\
\sum_{j=1}^{n} \lambda_j Y_j &\geq \alpha Y_{j0} \\
\lambda_j &\geq 0, j = 1,2,3,\ldots, m
\end{align*}
\]

Model 2.2

\[
\begin{align*}
\min \left[ \alpha - \varepsilon (E^S^S + E^S^S^-) \right] = V_{D(c)} \\
\text{s.t.} \sum_{j=1}^{m} \lambda_j X_j + S^- = X_{j0} \\
\sum_{j=1}^{n} \lambda_j Y_j - S^- = \alpha Y_{j0} \\
\lambda_j &\geq 0, j = 1,2,3,\ldots, m
\end{align*}
\]
Both model 1.1 and model 2.2 are non-Archimedean infinitesimal C²R model converted from model 1 and model 2 respectively. According to the dual theory of linear programming, definition of $S^{+}$ and $S^{-}$ can be described as $S^{+}=(s_{1}^{+}, s_{2}^{+}, s_{3}^{+}, \ldots, s_{q}^{+}), i=1,2,3,\ldots,q$ is the remainder variable.

$S^{-}=(s_{1}^{-}, s_{2}^{-}, s_{3}^{-}, \ldots, s_{q}^{-}), i=1,2,3,\ldots,p$ is the slack variable. The following transition models are utilized to accomplish the conversion respectively.

\[
\begin{align*}
\min \theta &= V_{D} \\
\text{st} \sum \lambda_{j} Y_{j} + S^{+} &= \theta X_{j_{0}} \\
\sum \lambda_{j} Y_{j} - S^{-} &= Y_{j_{0}} \\
\lambda_{j} &\geq 0, j=1,2,3,\ldots,p \\
S^{+} &\geq 0, S^{-} \geq 0
\end{align*}
\]

Transition Model 1

\[
\begin{align*}
\min \alpha &= V_{D} \\
\text{st} \sum \lambda_{j} Y_{j} + S^{+} &= \theta X_{j_{0}} \\
\sum \lambda_{j} Y_{j} - S^{-} &= \alpha Y_{j_{0}} \\
\lambda_{j} &\geq 0, j=1,2,3,\ldots,p \\
S^{+} &\geq 0, S^{-} \geq 0
\end{align*}
\]

Transition Model 2

Define $E'=(1,1,\ldots,1)^{T}_{p}$ and $E=(1,1,\ldots,1)^{T}_{q}$ as unit column vectors of p dimensions and q dimensions.

3.3. Data Envelopment Analysis of sci-tech input and output

Analyzing the original data of sci-tech input indexes and output indexes in two provinces by utilizing C²R model and the DEAP 2.1, and then complete the further research of the input-output efficiency, input redundancy and output deficiency.

3.3.1. Analysis of sci-tech input and output efficiency. As is shown in the following Table 2, in Guangdong province, the sci-tech input and output efficiency in both 2006 and 2009 are in a low level. The comprehensive efficiency in 2006 is only 0.889, and the pure technical efficiency is 0.906. In 2009, the comprehensive efficiency is 0.996, and the pure technical efficiency is 0.998. In recent three years, the three types of sci-tech input and output efficiency have achieved the DEA efficiency, which shows that the development of science and technology in Guangdong is getting stable and steady.

The sci-tech input and output efficiency in Jiangsu province is in a low level when the year comes to 2006, 2008 and 2009. Comprehensive efficiency in 2006 is only 0.860, and the pure technical efficiency is 0.994. In 2008, the comprehensive efficiency is 0.837 and the pure technical efficiency is 0.985. The numerical value of comprehensive efficiency in 2009 is 0.939. The pure technical efficiency is 0.952 in 2009. In recent three years, the three types of sci-tech input and output efficiency have achieved the DEA efficiency, which shows that the development of science and technology in Jiangsu is on the right track.

| Year | Guangdong Province | Jiangsu Province |
|------|--------------------|------------------|
|      | Comprehensive efficiency (crste) | Pure technical efficiency (vrste) | Scale efficiency (scale) | Comprehensive efficiency (crste) | Pure technical efficiency (vrste) | Scale efficiency (scale) |
| 2002 | 0.961 | 1.000 | 0.961 | 1.000 | 1.000 | 1.000 |
| 2003 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2004 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2005 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2006 | 0.889 | 0.906 | 0.981 | 0.987 | 0.994 | 0.987 |
| 2007 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2008 | 1.000 | 1.000 | 1.000 | 0.837 | 0.875 | 0.956 |
| 2009 | 0.996 | 0.998 | 0.998 | 0.939 | 0.952 | 0.987 |
| 2010 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
3.3.2. Analysis of input redundancy and output deficiency. As is shown in the following Table 3., the input redundancy existed in local financial allocation for sci-tech, the quantity of sci-tech personnel and the number of research institutions in 2006. The input redundancy of the number of research institutions in 2006 is as much as 322.232, and meanwhile, the slack movement is 3.999. While there is still input redundancy items in 2009, the amount of input redundancy is in dramatic decline. And input redundancy of the number of research institutions still occupied a large amount. Obviously, the year in which there are input redundancies matches the time when slack movements appear, and it means that the input redundancies and the slack movements are main reasons for the low efficiency of sci-tech input and output. Which deserves to be valued is the redundancy of research institutions leading to the low efficiency of sci-tech input and output in Guangdong province.

| Year | Local financial allocation for sci-tech | Quantity of science and technology personnel | Number of research institutions | Volume of business in technology market | Slack movement |
|------|----------------------------------------|---------------------------------------------|--------------------------------|----------------------------------------|---------------|
| 2006 | -9.826                                  | -1.388                                      | -322.232                      | 399.9                                  |               |
| 2009 | -0.304                                  | -0.051                                      | -7.734                         |                                        |               |

The following Table 4. shows that there are small redundancies in local financial allocation for sci-tech, the quantity of sci-tech personnel and the number of research institutions during 2006. And meanwhile, slack movements exist in the quantity of patent authorization and the volume of business in technology market. Although there are still redundant items in the sci-tech inputs in 2008 and 2009, the redundancies are small. Little slack movement of the volume of business in technology market exists in the same time. The year in which there are input redundancies matches the time when slack movements appear, and it means that the input redundancies and the slack movements are main reasons for the low efficiency of sci-tech input and output. The redundancy of research institutions should be valued either in Jiangsu province.

| Year | Local financial allocation for sci-tech | Quantity of science and technology personnel | Number of research institutions | Volume of business in technology market | National sci-tech award | Slack movement |
|------|----------------------------------------|---------------------------------------------|--------------------------------|----------------------------------------|-------------------------|---------------|
| 2006 | -0.319                                  | -0.223                                      | -21.210                        |                                        |                         | 472.785       |
| 2008 | -11.398                                 | -6.674                                      | -592.922                       |                                        |                         | 9.015         |
4. Conclusions and Suggestions

Mass redundancy of research institutions can be found in the progress of science and technology in both Guangdong province and Jiangsu province by data envelopment analysis. In 2006, the redundancy of research institutions in Guangdong is 322.232. While the redundancy reduced to 77.34 in 2009, it is still a large number. The redundant research institutions lead a series of problems, such as low-level research achievement and poor capacity of innovation. Besides, the redundant research institutions themselves are huge wastes of scientific and technological personnel, research equipment and the research funding.

To the existing various kinds of scientific research institutions in Guangdong, the supervision of the government should rely on a scientific and effective evaluation system. Firstly, formulating the corresponding grade assessment standard to different levels of scientific research institutions.

Secondly, inspecting the research institutions according to the standards in the evaluation system. The unqualified institutions can exist only if they timely adjust themselves to reach the corresponding scientific research ability. But they still need to be paid close attention to the efficiency of scientific research activities. Research institutions which still has no change after the inspection should be cut or be merged to the other scientific research institutions which in the same category.

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