Research on the Science and Technology Collaborative Innovation Demonstration Zone Evaluation Based on Data Envelopment Analysis

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Abstract. In recent years, studies on the Science and Technology Collaborative Innovation Demonstration Zone have increased notably. However, there were few works dedicated to the evaluation method, and our study was to fill in the blank. In this paper, the evaluation model based on Data Envelopment Analysis was built, 6 input and 4 output evaluation indexes were introduced, and a case analysis was conducted. The research result provides reference for objectively evaluating the construction effect of the Science and Technology Collaborative Innovation Demonstration Zone.

1. Introduction

The Science and Technology Collaborative Innovation Demonstration Zone is considered a pathway to accelerate the science and technology innovation process, also serve as a collaborative innovation platform, it refers to an area that promotes domestic and national defense science and technology independent innovation, It is also the promotion and driving force of regional high-tech development, industrialization, industrial structure upgrade, and national defense technology development, plays a significant role in improving military, economic and social benefits. The development of the Science and Technology Collaborative Innovation Demonstration Zone focusing on military-civil basic technologies, as well as cutting-edge or disruptive technologies, to establish a mechanism that adapts to the domestic and national defense scientific and technological collaborative innovation, and promote the production of high-level and high-value technological achievements and products[1-3]. Based on the data envelopment analysis method, this paper introduces the input and output evaluation indexes of the Science and Technology Collaborative Innovation Demonstration Zone and conducts a case analysis. Aiming for objectively evaluating the construction effect and discovering the problems of the demonstration zone.

2. Overview of the Science and Technology Collaborative Innovation Demonstration Zone Evaluation Based on Data Envelopment Analysis

2.1. Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a cross-cutting field of mathematics, operations research, mathematical economics, and management science. It is a systematic analysis method based on the concept of "relative efficiency" proposed by scholars such as A.Charnes and W.W.Cooper. The DEA method has the following characteristics: (1) Strong objectivity: this method does not need to subjectively judge the evaluation index weights, effectively eliminating the interference and subjective
intentions of experts on the evaluation index weights. (2) Dimensionless. Effectively avoiding the impact of seeking the same indexes on the evaluation results and effects. (3) Calculation details. This method can obtain the evaluation conclusion without giving the relationship function and internal connection between the evaluation input and output.\textsuperscript{[4-6]}

Till now, some domestic scholars have already used the DEA method to carry out the demonstration zone construction effect evaluation. Jia Yongfei et al. (2020)\textsuperscript{[7]} built up a demonstration zones innovation capability evaluation index system and processed them using factor analysis methods. Based on this, the technological innovation efficiency of six independent innovation demonstration zones in Shandong Peninsula were evaluated using the DEA model. Yang Jie and Qin Yuanjian (2020)\textsuperscript{[8]}, using the three-stage DEA analysis method, evaluated the innovation efficiency of 146 national high-tech zones in China, and divided the national high-tech zones into five echelons according to innovation efficiency. Li Xuhui, Zheng Lilin, Cheng Jingjing (2019)\textsuperscript{[9]}, built an innovation-driven development level evaluation index system of the national independent innovation demonstration zone composed of 6 first-level indexes and 23 second-level indexes from the three aspects of innovation environment, innovation input and innovation output, And use the twice-weighted “horizontal” pull-out dynamic evaluation method to evaluate the innovation-driven development level of the demonstration zone dynamically.

2.2. Evaluation Model of the Science and Technology Collaborative Innovation Demonstration Zone Based on DEA

There are $n$ science and technology collaborative innovation demonstration zones $DMU_j$ ($1 \leq j \leq n$). The demonstration zone has $m$ types of input evaluation indexes and $s$ types of output evaluation indexes. The input and output evaluation vectors are: $x_j = (x_{1j}, x_{2j}, ..., x_{mj})^T > 0, j = 1, ..., n$; $y_j = (y_{1j}, y_{2j}, ..., y_{sj})^T > 0, j = 1, ..., n$. In order to integrate each input and each output evaluation index into one input and one output, it is necessary to assign weights to each input and output index, so that the input and output weight vectors are: $v = (v_1, v_2, ..., v_m)$, $u = (u_1, u_2, ..., u_s)$.

Based on DEA, the evaluation model of the scientific and technological collaborative innovation demonstration zone will use the C2R model of data envelopment analysis:
The non-Archimedean infinitesimal $\varepsilon$ is a number less than any positive number and greater than zero (such as $10^{-6}$). Set $\varepsilon$ as the non-Archimedes infinitesimal, and the optimal solution of the model (D$_{\varepsilon}$) is $\lambda^*_+, s^*_-, s^*+, \theta^*$. If $\theta^*=1$, the k-th DMU is weak DEA effective. If $\theta^*=1$, and $s^*-=0$, $s^*+=0$, the k-th DMU is DEA effective. When $\theta^*<1$, the k-th DMU is non-DEA effective.

3. Evaluation indexes of the Science and Technology Collaborative Innovation Demonstration Zone

The evaluation indexes of the Science and Technology Collaborative Innovation Demonstration Zone are mainly used to measure the effectiveness of demonstration zone construction and provide decision support for discovering problems as well as improving and perfecting the construction of demonstration zone. Evaluation indexes including input evaluation indexes and output evaluation indexes. The input evaluation index is mainly used to measure the overall input demonstration zone; the output evaluation index is mainly used to measure the output effect of demonstration zone\cite{10,11}.

3.1. Input Evaluation indexes of the Science and Technology Collaborative Innovation Demonstration Zone

Input indexes mainly include scientific and technological talent input, scientific and technological funding input, scientific and technological infrastructure input, scientific and technological input, scientific and technological policy input and other evaluation indexes.

3.1.1. Talent input. It mainly evaluates whether the innovation demonstration zone has invested a large number of outstanding talents around the collaborative innovation of science and technology. The value ranges from 0 to 1. The input value of science and technology talents in the i-th demonstration zone $x_1(i)$ is calculated as follows:

$$x_1(i) = \frac{\text{talents input number of the } i\text{-th demonstration zone}}{\text{ideal talents input number}}$$ (2)

3.1.2. Funding input. It mainly evaluates whether the innovation demonstration zone has invested a lot of money around the collaborative innovation of science and technology. The value ranges from 0 to 1. The value of the funding investment in the i-th innovation demonstration zone $x_2(i)$ is calculated as follows:

$$x_2(i) = \frac{\text{funding input of the } i\text{-th demonstration zone}}{\text{ideal funding input}}$$ (3)

3.1.3. Infrastructure input. It mainly evaluates whether the innovation demonstration zone has provided a lot of facilities and other conditions for the construction of scientific and technological collaborative innovation. The value is 0 to 1. The value of the investment in science and technology infrastructure in the i-th innovation demonstration zone $x_3(i)$ is calculated as follows:

$$x_3(i) = \frac{\text{infrastructure input of the } i\text{-th demonstration zone}}{\text{ideal infrastructure input}}$$ (4)

3.1.4. Science and technology input. It mainly evaluates whether the innovation demonstration zone has invested a large number of technologies with independent intellectual property rights around the
collaborative innovation of science and technology, with values ranging from 0 to 1. The value of science and technology input in the i-th innovation demonstration zone $x_4(i)$ is calculated as follows:

$$x_4(i) = \frac{\text{science and technology input of the } i\text{-th demonstration zone}}{\text{ideal science and technology input}}$$

(5)

3.1.5. Policy input. It mainly evaluates whether the innovation demonstration zone has formulated a scientific and technological collaborative plan, and whether the related financial, achievement transformation, talent introduction, intermediary service and other supporting policies are complete. The value ranges from 0 to 1. The input value of the science and technology policy of the i-th innovation demonstration zone $x_5(i)$ is calculated as follows:

$$x_5(i) = \frac{\text{policy input of the } i\text{-th demonstration zone}}{\text{ideal policy input}}$$

(6)

3.2. Output evaluation indexes of the Science and Technology Collaborative Innovation Demonstration Zone.

Output evaluation indexes include technical benefits, economic benefits, military benefits and social benefits.

3.2.1. Technical benefits. It mainly evaluates the technological achievements produced by the innovation demonstration zone. The value ranges from 0 to 1. The technical benefit value of the i-th innovation demonstration zone $y_1(i)$ is evaluated by experts.

3.2.2. Economic benefits. It mainly evaluates the output value of the innovation demonstration zone, the value ranges from 0 to 1, the value of the economic benefit of the i-th innovation demonstration zone $y_2(i)$ is calculated as follows:

$$y_2(i) = \frac{\text{output value of the } i\text{-th demonstration zone}}{\text{ideal output value}}$$

(7)

3.2.3. Military benefits. It mainly evaluates the contribution of the technological products produced by the innovation demonstration zone to national defence and army building, with value ranges from 0 to 1. The military benefit value of the i-th innovation demonstration zone $y_3(i)$ was evaluated by experts.

3.2.4. Social benefits. It mainly evaluates the innovation demonstration zone to promote industrial development, employment, and personnel training, etc. The value ranges from 0 to 1. The social benefit value of the i-th innovation demonstration zone $y_4(i)$ is evaluated by experts.

4. Application

There are 8 input-output evaluation data (simulation data) in the scientific and technological collaborative innovation demonstration zone, as shown in Table 1.
Table 1. Science and technology collaborative innovation demonstration zone data.

| Zone | Talent input | Funding input | Infrastructure input | Scientific and technological | Policy input | Technical benefits | Economic benefits | Military benefits | Social benefits |
|------|--------------|--------------|----------------------|-----------------------------|--------------|---------------------|-------------------|------------------|------------------|
| A    | 0.25         | 0.38         | 0.12                 | 1                           | 0.15         | 0.32                | 0.25              | 0.15             | 0.11             |
| B    | 0.35         | 0.58         | 0.32                 | 0.26                        | 0.45         | 0.36                | 0.26              | 0.3              | 0.36             |
| C    | 0.50         | 0.75         | 0.60                 | 0.65                        | 0.78         | 0.48                | 0.56              | 0.42             | 0.53             |
| D    | 0.56         | 0.78         | 0.78                 | 0.54                        | 0.75         | 0.68                | 0.72              | 0.65             | 0.65             |
| E    | 0.88         | 0.90         | 0.92                 | 0.8                         | 0.88         | 0.60                | 0.65              | 0.7              | 0.7              |
| F    | 0.80         | 0.85         | 0.72                 | 0.25                        | 0.88         | 0.71                | 0.25              | 0.82             | 0.82             |
| G    | 0.83         | 0.82         | 0.68                 | 0.22                        | 0.90         | 0.33                | 0.23              | 0.2              | 0.11             |
| H    | 0.89         | 0.86         | 0.92                 | 0.9                         | 0.82         | 0.80                | 0.89              | 0.85             | 0.91             |

4.1. Constructing the Science and Technology Collaborative Innovation Demonstration Zone Evaluation DEA basic model

Construct the DEA model of the demonstration zone A (similar to other demonstration zones):

\[
\min \left[ \theta - 10^{-6} \times (s_1^+ + s_2^+ + s_3^+ + s_4^+ + s_5^+ + s_6^+ + s_7^+ + s_8^+) \right]
\]

\[
0.25\lambda_1 + 0.35\lambda_2 + 0.53\lambda_3 + 0.56\lambda_4 + 0.88\lambda_5 + 0.82\lambda_6 + 0.83\lambda_7 + 0.89\lambda_8 + s_1^+ = 0.25
\]

\[
0.38\lambda_1 + 0.58\lambda_2 + 0.75\lambda_3 + 0.56\lambda_4 + 0.88\lambda_5 + 0.82\lambda_6 + 0.83\lambda_7 + 0.89\lambda_8 + s_1^+ = 0.38
\]

\[
0.12\lambda_1 + 0.32\lambda_2 + 0.66\lambda_3 + 0.78\lambda_4 + 0.92\lambda_5 + 0.72\lambda_6 + 0.68\lambda_7 + 0.92\lambda_8 + s_1^+ = 0.12
\]

\[
0.15\lambda_1 + 0.26\lambda_2 + 0.65\lambda_3 + 0.54\lambda_4 + 0.84\lambda_5 + 0.25\lambda_6 + 0.92\lambda_7 + 0.92\lambda_8 + s_1^+ = 0.15
\]

\[
0.32\lambda_1 + 0.45\lambda_2 + 0.78\lambda_3 + 0.75\lambda_4 + 0.88\lambda_5 + 0.82\lambda_6 + 0.83\lambda_7 + 0.92\lambda_8 + s_1^+ = 0.32
\]

\[
0.25\lambda_1 + 0.36\lambda_2 + 0.48\lambda_3 + 0.66\lambda_4 + 0.64\lambda_5 + 0.71\lambda_6 + 0.33\lambda_7 + 0.82\lambda_8 - s_1^+ = 0.25
\]

\[
0.15\lambda_1 + 0.26\lambda_2 + 0.56\lambda_3 + 0.72\lambda_4 + 0.65\lambda_5 + 0.25\lambda_6 + 0.89\lambda_7 - s_1^+ = 0.15
\]

\[
0.11\lambda_1 + 0.34\lambda_2 + 0.42\lambda_3 + 0.65\lambda_4 + 0.72\lambda_5 + 0.85\lambda_6 + 0.24\lambda_7 + s_1^+ = 0.11
\]

\[
0.21\lambda_1 + 0.36\lambda_2 + 0.53\lambda_3 + 0.65\lambda_4 + 0.37\lambda_5 + 0.82\lambda_6 + 0.11\lambda_7 + s_1^+ = 0.21
\]

4.2. The Effectiveness and Scale Returns Analysis of the Science and Technology Collaborative Innovation Demonstration Zone

Table 2 shows the analysis results of scale returns of the demonstration zone.

Table 2. Analysis Results of Scale Return of the Science and Technology Collaborative Innovation Demonstration Zone.

| Zone | DEA Effectiveness | Scale returns index(\(\sum\)) | Scale returns |
|------|------------------|-------------------------------|--------------|
| A    | DEA Effective    | 1                             | Same         |
| B    | DEA Effective    | 1                             | Same         |
| C    | Non-DEA Effective| 1.16                          | Decrease     |
| D    | DEA Effective    | 1                             | Same         |
| E    | Non-DEA Effective| 0.827                         | Increase     |
| F    | DEA Effective    | 1                             | Same         |
| G    | Non-DEA Effective| 0.475                         | Increase     |
| H    | DEA Effective    | 1                             | Same         |

It can be seen from the table that the demonstration zone A, B, D, F, and H are DEA effective, and C, E, and G are non-DEA effective. From this, it is clear that the input and output matching of demonstration zone A, B, D, F, and H is ideal, and the current trend can be maintained. For demonstration zone A, although the output indexes score is relatively low, however, its input indexes are also very low, indicating that the input-output ratio of this demonstration zone is ideal, so DEA in
demonstration zone A is effective. It can be seen from the table that the decreasing returns scale of zone C indicate that the demonstration zone has poor input and output effects, and a low input-output ratio. The increasing returns scale of zone D and G indicate that the input effect of these two-demonstration zone is ideal, but the output effect is not.

4.3. Improvement Strategies Analysis for the non-effective Science and Technology Collaborative Innovation Demonstration Zone

Non-DEA effective Science and Technology Collaborative Innovation Demonstration Zone can be compared with its "projection" on the relatively effective surface of DEA to find out the reason and degree of non-effectiveness (deficiency in each evaluation index), so as to change the situation. Table 3 shows the improvement strategies analysis for the non-effective Science and Technology Collaborative Innovation Demonstration Zone.

| Non-DEA effective zone | Index | Projection value | Gap/value% | Non-DEA effective zone | Index | Projection value | Gap/value% |
|------------------------|-------|-----------------|------------|------------------------|-------|-----------------|------------|
| X1                     | 0.5   | 0.491           | 0.0180     | X1                     | 0.83  | 0.323           | 0.6108     |
| X2                     | 0.75  | 0.697           | 0.0707     | X2                     | 0.82  | 0.387           | 0.5280     |
| X3                     | 0.6   | 0.589           | 0.0183     | X3                     | 0.68  | 0.356           | 0.4765     |
| X4                     | 0.65  | 0.623           | 0.0415     | X4                     | 0.22  | 0.187           | 0.1500     |
| X5                     | 0.78  | 0.651           | 0.1654     | X5                     | 0.920 | 0.387           | 0.5793     |
| Y1                     | 0.48  | 0.322           | 0.3292     | Y1                     | 0.33  | 0.33            | 0          |
| Y2                     | 0.56  | 0.56            | 0          | Y2                     | 0.23  | 0.23            | 0          |
| Y3                     | 0.42  | 0.495           | 0.1786     | Y3                     | 0.2   | 0.349           | 0.7450     |
| Y4                     | 0.53  | 0.536           | 0.0113     | Y4                     | 0.11  | 0.349           | 2.1727     |
| E                      | X5     | 0.88            | 0.727      | 0.1739                 | X1     | 0.88            | 0.727      |
| X2                     | 0.9   | 0.71            | 0.2111     | X2                     | 0.9   | 0.71            | 0.2111     |
| X3                     | 0.92  | 0.74            | 0.1957     | X3                     | 0.92  | 0.74            | 0.1957     |
| X4                     | 0.8   | 0.675           | 0.1563     | X4                     | 0.8   | 0.675           | 0.1563     |
| E                      | X5     | 0.88            | 0.742      | 0.1568                 | Y1     | 0.667           | 0.1117     |
| Y2                     | 0.65  | 0.668           | 0.0277     | Y2                     | 0.65  | 0.668           | 0.0277     |
| Y3                     | 0.7   | 0.7             | 0          | Y3                     | 0.7   | 0.7             | 0          |
| E                      | X5     | 0.88            | 0.743      | 0.0614                 | Y4     | 0.7             | 0.743      |

It can be seen from the table that the main reason for the non-efficiency of the demonstration zone C is that the index technical benefits \( y_1 \) and military benefits \( y_3 \) do not match the input index score, that is, ideal input does not produce ideal output. The reason why the demonstration zone E is not effective is that although it has a high funding input \( x_2 \) and infrastructure input \( x_3 \), its technical benefits \( y_1 \) is relatively low. Therefore, the demonstration zone must maintain the existing funding input and infrastructure input, on the basis of it, improve the technological innovation capability. The reason why the demonstration zone G is not effective is mainly because that although the it has a high talents input \( x_1 \), funding input \( x_2 \), infrastructure input \( x_3 \) and policy input \( x_5 \), its military benefits \( y_3 \) and social benefits \( y_4 \) are much lower, so the improvement strategy for demonstration zone G is to increase the output, especially military and social benefits.

4.4. Ranking of the Science and Technology Collaborative Innovation Demonstration Zones

Table 4 shows the ranking the Science and Technology Collaborative Innovation Demonstration Zones. It can be seen from the table that the ranking of the demonstration zones is: H > F > D > B > A > C > G > E > G.
Table 4. Ranking the Science and Technology Collaborative Innovation Demonstration Zones.

| Zone No. | Effective coefficient θ | rank | Zone No. | rank |
|----------|--------------------------|------|----------|------|
| A        | 0.753                    | 5    | H        | 1    |
| B        | 0.821                    | 4    | F        | 2    |
| D        | 0.856                    | 3    | D        | 3    |
| F        | 0.977                    | 2    | B        | 4    |
| H        | 1                        | 1    | A        | 5    |
|          | Virtual zone             | 0.345|          |      |

Ranking of non-DEA effective zone

| Zone No. | Effective coefficient θ | rank |
|----------|--------------------------|------|
| C        | 0.982                    | 1    |
| E        | 0.844                    | 3    |
| G        | 0.852                    | 2    |

5. Conclusion

The analysis lead us to following countermeasures and solution to the problems of the Science and Technology Collaborative Innovation Demonstration Zone. The effect of the innovation environment and atmosphere on the demonstration zone is significant. The development of the innovation level in the demonstration zone requires the improvement of the “soft” and “hard” environment of innovation-driven development and the cultivation of a good innovation atmosphere.

In terms of “hard” environment, the demonstration zone must first strengthen the IT infrastructure construction. In the era of big data, artificial intelligence and cloud computing, the implementation of innovation-driven strategies is inseparable from the support of a sound IT infrastructure. The demonstration zone should strengthen and continuously expand network construction. Then, must strengthen the construction of R&D institutions (including universities and research institutes, etc.), especially talent, so as to improve the innovation performance of R&D institutions.

In terms of “soft” environment construction, must first cultivate a good "mass entrepreneurship and innovation" atmosphere, encourage the public to participate in innovation, and develop crowdfunding and inspire creativity. Then, the government must take the lead and use “market-oriented” method to achieve the optimal allocation of resources, especially educational resources and corporate R&D resources. Finally, the government should take the initiative to complete relevant policies on innovation subsidies and incentives, promote the commercialization of scientific and technological innovations, and strengthen the connection between innovation and productivity.

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References

[1] Zongguo M and Chenhui D 2019 Construction and Evaluation of Innovation Ecosystem in National Independent Innovation Demonstration Zone——Based on the research consortium perspective (Economic reform) pp 60-67
[2] Zongguo M and Hui Z 2019 Strategic Thinking on Promoting High-Quality Development of National Independent Innovation Demonstration Zone (Macroeconomic Management) pp 47-54
[3] Zongguo M 2019 Research on the Mechanism of Innovation Ecosystem in National Independent Innovation Demonstration Zone Based on Research Consortium vol 37 (Scientific Management Research) pp 102-107
[4] Ya W and Jiaofeng P 2020 Assessing the Technological Innovation Efficiency of China’s High-Tech Industries with A Two-Stage Network DEA Approach (Elsevier Ltd)
[5] Liu L 2020 *Measuring the Innovation Efficiency of The Chinese Pharmaceutical Industry Based on a Dynamic Network DEA Model* vol 27 (Routledge)

[6] Na L and Changqing Y 2019 *Evaluation of Innovation Efficiency of Listed Companies in Environmental Protection Industry Based on DEA Method* vol 39 (Science and Technology Management Research) pp 45-50

[7] Yongfei J 2020 *National Independent Innovation Efficiency Evaluation Based on Factor Analysis and Cross DEA* (Science and Technology Management Research) pp 39-45

[8] Jie Y and Yuanjian Q 2020 *Comprehensive Analysis of the Innovation Efficiency of National High-Tech Zones——Based On DEA Model Research* (Technology Economics and Management Research) pp 3-8

[9] Xuhui L and Lilin Z 2019 *Research on the Dynamic Evaluation System of Innovation-driven Development in National Independent Innovation Demonstration Zones——Based on the Second Weighted Dynamic Evaluation Method* vol. 33 (East China Economic Management) pp 79-85

[10] Huimin B and Jianghua W 2018 *Research on the Countermeasures to Promote the Construction of a Military-Civilian Integration Innovation Demonstration Zone* (Chinese Administration) pp 76-79

[11] Weiwei D and Yusheng C 2018 *Evaluation of Innovation Ability of National Independent Innovation Demonstration Zones in China* (Industrial Technology and Economy) pp 78-85