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# Performance Evaluation for Provincial Key Laboratories Based on Three Dimensions of Quantity Quality and Effectiveness

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## Abstract

**It is significant for provincial key laboratories to summarize experiences, discover problems, bridge the gap and weakness, and improve sci-tech strength through assessment and evaluation. However, the current evaluation indicator system still has obvious "four-only" tendency, which is difficult to objectively evaluate the development of key laboratories. In this context, how to construct a new evaluation system and access its performance more scientifically is particularly important. Based on the principle of whole process management, this paper constructed an evaluation indicator system for disciplinary, enterprise established and provincial-municipal co-constructed provincial key laboratories from three dimensions of "quantity", "quality" and "effectiveness" and used best-worst method (BWM) to determine the weight of indicators at all levels. The "quantity", "quality" and "efficiency" indicator system can scientifically reflect the performance of provincial key laboratories, improve the shortcomings of the previous "four-only" evaluation, and provide reference for its subsequent development optimization.**

## Keywords

**"Four-only"; quantity quality and effectiveness; provincial key laboratories performance evaluation.**

## 1. INTRODUCTION

Provincial key laboratories are the important parts of national science and technology innovation system and the construction of innovation platform and the important platform to research common key technologies and enhance technical radiation capabilities and promote deep integration of industry-university-research [1]. The scientific evaluation of provincial key laboratories is conducive to the provincial key laboratories to see their own strengths and weaknesses in the development process, and implement targeted improvement measures to promote their development to a high level of quality.

In July 2018, the general office of the CPC central committee and the general office of the state council issued "opinions on deepening the reform of project evaluation, talent evaluation and institutional evaluation", which clearly pointed out that we should overcome the tendency to only rely on papers, professional titles, academic degrees and awards, and promote the representative work evaluation system, focusing on the quality, contribution and impact of landmark achievements [2]. At present, the existing evaluation indicator systems of most key laboratories at the provincial level still have disadvantages such as "only papers" and "only awards", which ignore the influence and contribution of landmark achievements, thus leading to the top of key laboratories with more scientific achievements but lower quality. On the contrary, key laboratories with little output but significant impact of landmark achievements

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lag behind. In addition, the related researches pay less attention to the comprehensive evaluation of key laboratories and neglect the systematic evaluation of the whole process of input, operation process and outcome output. Although the four indicators of thesis, professional title, academic degree and award can reflect the staff composition, academic level and operation development of key laboratories to some extent, they cannot be taken as the only evaluation indicator. The evaluation of provincial key laboratories depends not only on the quantity but also on the quality. Therefore, according to the assessment thought of "quantity", "quality" and "efficiency" standards[3], this study comprehensively evaluated the input, operation process and output of key laboratories in the whole process, and focused on the quality and impact of landmark results for the problem of "four only".

## 2. LITERATURE REVIEW

In recent years, scholars have carried out relevant research on key laboratory evaluation from multiple perspectives. One is to conduct a single performance evaluation from a single perspective, such as the scientific research achievements, innovation ability, operational performance and open sharing performance of key laboratories. For example, Tian Yajuan, Yang Zhiping, Zhou Tao and etc[4] evaluated the scientific research achievements of state key laboratories. Li Xuyan, Yang Xiaoqiu and Song Yinghua[5] focused on the influence evaluation of key laboratories to evaluate different state key laboratories. Wang Wanjuan and Wei Huaian[6] focused on the collaborative innovation ability of key laboratories to evaluate the state key laboratories. Yang Fangjuan, Liang Zheng, Xue Lan[7] evaluated state key laboratories from the perspective of operational performance. Chen Qi, Zeng Xiaosi and Lin Jian[8] and Hong Fan[9] evaluated open sharing performance of key laboratories.

Two is to evaluate the comprehensive performance of key laboratories. For example, Li Miaomiao and Li Yun[10] evaluated the efficiency of the jointly built key laboratory of Beijing by selecting four input indicators: laboratory area, total amount of equipment, number of fixed staff and funds allocated, as well as four output indicators: total number of papers, number of patents granted, number of students cultivated, and total number of domestic and foreign communication. Xin Duqiang[11] chose research funds, published papers, awarded achievements and cultivated postgraduates to evaluate the input-output efficiency of the state key laboratory. Cheng Ping, Lu Fan, Tang Gaofei and etc. [12] selected three input indicators of fund inputs, personnel inputs and equipment inputs and three output indicators of monograph and paper outputs, invention patent outputs and achievements transformation to evaluate the scientific research efficiency of the enterprise's state key laboratory. Comprehensive evaluation methods of previous studies are use DEA to calculate the input-output efficiency of key laboratories.

The existing researches on the evaluation indicator system of key laboratories present the following characteristics:①When evaluating the performance of key laboratory from a single perspective, some scholars have begun to pay attention to the phenomenon of "four-only". The evaluation indicators constructed such as "cited frequency" and "publication journal" reflect the quality of the paper, but the output indicators considered to reflect its influence are not comprehensive.② When evaluating comprehensive performance of key laboratories, some indicators that have been studied such as the number of papers[4-6,10-12], the number of patents[6,10,12], the number of monographs[12], and the number of awards[6,12] focused only on the number of outcomes but ignoring the quality and impact of the landmark achievements. ③The existing studies have classified different indicator values into one category, ignoring the differences in different indicator values, such as the journal level of published paper, the level of awarded achievements, the level of patents and works and etc. Therefore, considering different indicator values of different levels and categories, this study introduces the concept of

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"relative score". Relative scores are scores that determine meaning by comparing each other with indicators at different levels and in different categories. In summary, in the context of “breaking four-only limitations”, this paper constructs evaluation indicator systems to measure their performance levels for disciplinary, enterprise established and provincial-municipal co-constructed provincial key laboratories based on three dimensions of “quantity”, “quality” and “effectiveness”. The influential indicatores are classified as "effectiveness", focusing on the quality and impact of the landmark achievements.

## 3. CONSTUCTIOIN OF THE “QUANTITY”, “QUALITY”, “EFFECTIVENESS” PERFORMANCE EVALUATION INDICATOR SYSTEM OF PROVINCIAL KEY LABORATORIES

### 3.1. Indicator Selection

Based on relevant studies[3-14] and the current evaluation indicator system of provincial key laboratories and combined with the current national policy guidance and the characteristics of provincial key laboratories, the performance evaluation indicator system of provincial key laboratories was established for disciplinary, enterprise established and provincial-municipal co-constructed provincial key laboratories. The quality and influence of landmark achievements were highlighted.

3.1.1. “Quantity”—— inputs of provincial key laboratories

The indicators in "quantity" dimension mainly considers the input of key laboratories. Due to the lag in the output of scientific research achievements, it is difficult for key laboratories to obtain financial returns in the short term when conducting basic research. In this process, there should be sufficient fund guarantee, advanced scientific research equipment and professional scientific researchers to provide corresponding support. Thus, this paper selects fund inputs, equipment inputs and personnel inputs [6,10,12] to measure the input of three types of key laboratories. In the aspect of fund inputs, based on the central financial allocation[7] and the funds for scientific research projects[7,13] for existing research, considering that every key laboratory has its supporting institution, the laboratory itself will raise funds to support its own operation and development. The supporting funds for supporting institution, the funds raised by the laboratory itself and other funds are added. In the aspect of equipment inputs, the total value of equipment [6,10,12] has been selected as the evaluation indicator. In the aspect of personnel inputs, based on fixed staff and floating staff for existing research, considering that the painstaking research of researchers is the core strength for key laboratories to produce scientific research achievements and the efficient management of managers is a necessary condition for key laboratories to improve the output of scientific research achievements and operate efficiently, the input indicator of fixed researchers and fixed full-time managers were added.

3.1.2. Quality——operation process and general outputs of provincial key laboratories

The indicators in "quality" dimension focus on operation process and general outputs. Open communication reflects the influence of key laboratories in their related fields. This paper selects open communication [8,10] to evaluate the operation of three types of key laboratories. Evaluation indicators on open communication for the existing studies mainly included the total number of domestic and foreign communication [10], the number of international conferences or seminars hosted or co-organized [9,14] and the number of participants at international academic conferences [14]. General outputs indicators include intellectual property and talent cultivation [7,10,11]. Intellectual property reflects the achievements of key laboratories in basic research. Talent cultivation reflects the situation that key laboratories cultivated professionals in related fields for the society. This paper selects intellectual property and talent cultivation to

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measure general outputs of three types of key laboratories. Evaluation indicators on scientific research achievements for the existing studies mainly included the number of papers [4,5,10,11,12], the number of national three science and technology awards [6,7,14], the number of invention patents granted [6,8,10,12,14], and the number of published works [12]. Talent cultivation indicators mainly include the number of cultivated postgraduates [7,10,11]. But these indicators ignored the difference between indicators of different levels and categories. Therefore, this paper assigns different relative scores to papers, monographs and patents of different levels, academic conferences, international scientific research programs and open topics of different categories. The second-level indicator "open communication" of the three types of key laboratories includes academic conference scores, international cooperation scores and open topic scores. "Talent cultivation" all includes "talent cultivated by one hundred people", but there are differences in the indicator of "intellectual property".

The disciplinary key laboratories mainly focus on the frontier of discipline and major scientific and technological issues to carry out basic research and provide advanced technical theories. The provincial-municipal co-constructed key laboratories are mainly aimed at cities where the building of scientific research bases is relatively weak, so as to give full play to local resource advantages and improve the source innovation capacity of relevant regions. Thus, the second-level indicator "intellectual property" of disciplinary and provincial-municipal co-constructed key laboratories both includes "patents invented by one hundred people" and "works and papers published by one hundred people". However, the enterprise established key laboratories mainly focus on the key generic technologies of the industry, carry out applied basic research and key technology research and attach importance to the application and authorization of invention patents and the formulation of industry standards. Thus, the second-level indicator "intellectual property" of the enterprise established key laboratories include "patents invented by one hundred people", "standards formulated by one hundred people" and "works and papers published by one hundred people".

3.1.3. Effectiveness——Influential achievements of provincial key laboratories

The indicators in "effectiveness" dimension focus on the quality and impact of landmark achievements. The high-level achievements and the cultivation of high-level talents reflect the leading role of key laboratories. Thus, this paper selects "leading of intellectual property" and "leading of talents" to measure influential achievements of three types of key laboratories. To some extent, the return on investment brought by the achievement transformation reflects the ability of the key laboratory to translate the scientific research achievements. As the development orientation of enterprise established key laboratories focuses on key technology research and transformation of scientific and technological achievements and the development orientation of provincial-municipal co-constructed key laboratories focuses on promoting local economic development, the indicator "effectiveness" of enterprise established and provincial-municipal co-constructed key laboratories include "return on investment". Although the influence of the achievements has been considered in previous studies, the indicators of the achievements are not comprehensive. In the aspect of paper, based on the existing indicators such as cited frequency [4,5,7], publication journal [4], H index [4,5] and etc., the citation rate of high-level papers is selected. In the aspect of patent, PCT reflects the importance of the technology contained in the application for patent, and is an important indicator to measure the ability of independent innovation and international market competitiveness. Thus, proportion of PCT is selected. In the aspect of awarded achievements, based on the three science and technology awards in previous studies, this paper assigns different scores to awards in different levels, and selects the leading scores for the awarded achievements. Based on the development orientation of enterprise established, participation in the formulation of national and industry standards reflect the capability of the key enterprise established laboratories to lead the technological progress of the industry. Thus, the leading rate of standards is added. In the aspect

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of leading of talents, as a kind of academic honor, the title of talents is to commend and reward the talents who have made great achievements, such as the recruitment program of global experts, Chang Jiang scholars program and so on. Thus, the leading scores of talent titles is selected. In the aspect of return on investment, based on the return from transformation of achievements [12] and the production value of innovative products [6] in previous studies, the proportion of sales revenue of new products in supporting units reflects the ability of scientific and technological achievements to promote market, thus increasing the proportion of sales revenue of new products in supporting units.

### 3.2. Indicator Selection

Based on the preliminarily selected indicators, in order to evaluate the performance of provincial key laboratories more effectively, 15 experts and scholars from provincial key laboratories were selected to seek advice through offline visits and questionnaires. Likert scale 5 was adopted to evaluate the rationality of all indicators. First, membership conversion algorithm [16] was used, excluding “other funds”, “floating personnel input” of three key laboratories, " works and papers published by one hundred people " and “production value of innovative products”. Second, the reliability and validity of the remaining indicators is tested. By judging Cronbach’s $\alpha$, Cronbach's $\alpha$ of the three key laboratory performance evaluation were 0.815, 0.841 and 0.823, respectively, which passed the reliability test. Through KMO and Bartlett's spherical test, the KMO values of the three key laboratories were 0.785, 0.816 and 0.834, respectively, indicating that the scale has good structural validity. The evaluation indicator system of three key laboratories after indicator selection is shown in table 1. $A_1, A_2, A_3$ represents the first-level indicator “quantity”, “quality” and “effectiveness” respectively; $B_1, B_2, B_3, \ldots, B_9$ represents the second-level indicator respectively; $C_1, C_2, C_3, \ldots, C_{21}$ represents the third-level indicator respectively.

**Table 1.** Three kinds of key laboratory evaluation indicator selection

| First-level indicator | Second-level indicator | Third-level indicator | Indicator explanation |
|---|---|---|---|
| Quantity $A_1$ | fund input $B_1$ | actually received project funds $C_1$ | The research funds, operating subsidies and equipment renewal fees incurred by the laboratory. |
| | | supporting funds for supporting institution $C_2$ | The supporting institution of the laboratory provide the laboratory with certain economic support expenses in accordance with the supporting proportion. |
| | | financial allocation $C_3$ | The state allocates funds to support the operation and development of the laboratory. |
| | | funds raised by the laboratory itself $C_4$ | The laboratory itself raises funds for the development and operation of laboratory. |
| | equipment input $B_2$ | total value of equipment $C_5$ | The total value of dedicated instruments and equipment "in use" in the laboratory |
| | talent input $B_3$ | fixed researchers input $C_6$ | The person who conducts scientific research around the direction of laboratory research. |

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|---|---|---|---|
| | | fixed full-time managers input $C_7$ | The administrative person who mainly engaged in the daily affairs and open operation of the laboratory. |
| Quality $A_2$ | intellectual property $B_4$ | patents invented by one hundred people $C_8$ | The sum of the relative scores obtained by each one hundred fixed members of the laboratory who participated in the foreign or domestic invention patents applied or granted. |
| | | works and papers published by one hundred people $C_9$●▲ | The sum of the relative scores obtained by each one hundred fixed members of the laboratory who participated in and signed the name of the key laboratory for the publication of academic papers and academic works. |
| | | standard formulated by one hundred people $C_{10}$■ | The sum of the relative scores obtained by each one hundred fixed members of the laboratory who participated in published standard. |
| | talent cultivation $B_5$ | talent cultivated by one hundred people $C_{11}$ | The sum of the relative scores obtained by each one hundred fixed members of the laboratory who cultivated doctoral and master graduate and candidate. |
| | open communication $B_6$ | scores of academic conference $C_{12}$ | The sum of the relative scores of domestic and foreign academic conferences hosted, undertaken or attended by fixed members of the laboratory. |
| | | scores of international cooperation $C_{13}$ | The sum of relative scores of various international scientific research programs in which the laboratory participates |
| | | scores of open project $C_{14}$ | The sum of the relative scores of the research projects set up by the laboratory for domestic and foreign scientific and technological workers related to the main research direction of the laboratory. |
| Effectiveness $A_3$ | leading of intellectual property $B_7$ | the proportion of PCT $C_{15}$ | The proportion of the cumulative PCT of laboratory inventions in the cumulative invention patents. |
| | | leading scores of awarded achievements $C_{16}$ | The sum of the relative scores of provincial and ministerial awards obtained by the laboratory. |
| | | citation rate of high-level papers $C_{17}$●▲ | The total number of papers published in JCR area 1 and ESI high cited papers accounted for the proportion of total papers published in the laboratory. |

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| | | |
|---|---|---|
| | leading rate of standards $C_{18}$■ | The formulation of national and industry standards in which the laboratory participated account for the proportion of all the standards in which it participated. |
| leading of talents $B_8$ | leading scores of talent titles $C_{19}$ | The sum of the relative scores obtained from the cultivation of talents with various titles in the laboratory. |
| return on investment $B_9$ | return from transformation of achievements $C_{20}$■▲ | The economic benefits of the transformation of achievements in production or application. |
| | the proportion of sales revenue of new products in supporting units $C_{21}$■ | The proportion of sales revenue of new products developed by the laboratory to the total revenue of supporting units. |

Note: Evaluation indicators which labeled●are included only in disciplinary key laboratories; Evaluation indicators which labeled■are included only in enterprise-established key laboratories; Evaluation indicators which labeled▲are included only in provincial-municipal co-constructed key laboratories; Unlabeled indicators are included in all three types of key laboratories.

### 3.3. Weight Determination of Indicator Based on BWM

There are many weighting methods for evaluating indicators in key laboratories, including entropy weight method, factor analysis method, AHP-entropy weight method, data envelopment analysis method and AHP, among which AHP is the most frequently used method. The evaluation of key laboratories is a complex multi-attribute decision-making problem. Moreover, the calculation process of AHP is complex. Best-worst method is a multi-objective decision making method proposed by Professor Jafar Rezaei in 2015. Compared with AHP, the comparison of n (2n-1) /2 times is required, the comparison frequency between indicators at the same level is only 2n-3 times, which is easier to calculate. N is the number of indicators. BWM uses the consistency ratio to test the reliability level [17], making it more practical [18-23].

By offline visits in the form of issuing questionnaire, 10 experts and scholars from provincial key laboratory scored disciplinary, enterprise-established, provincial-municipal co-constructed provincial key laboratories in accordance with the BMW digital scale. The comparative judgment value given by 10 experts was used to calculate the weight of each indicator. Each indicator weight weighted average to get the final weight. $\lambda_i$ is the weight of expert i. Equal weight is used, that is to say, $\lambda_1 = \lambda_2 = \cdots = \lambda_{10} = 0.1$. The specific weight distribution is shown in figure 1.

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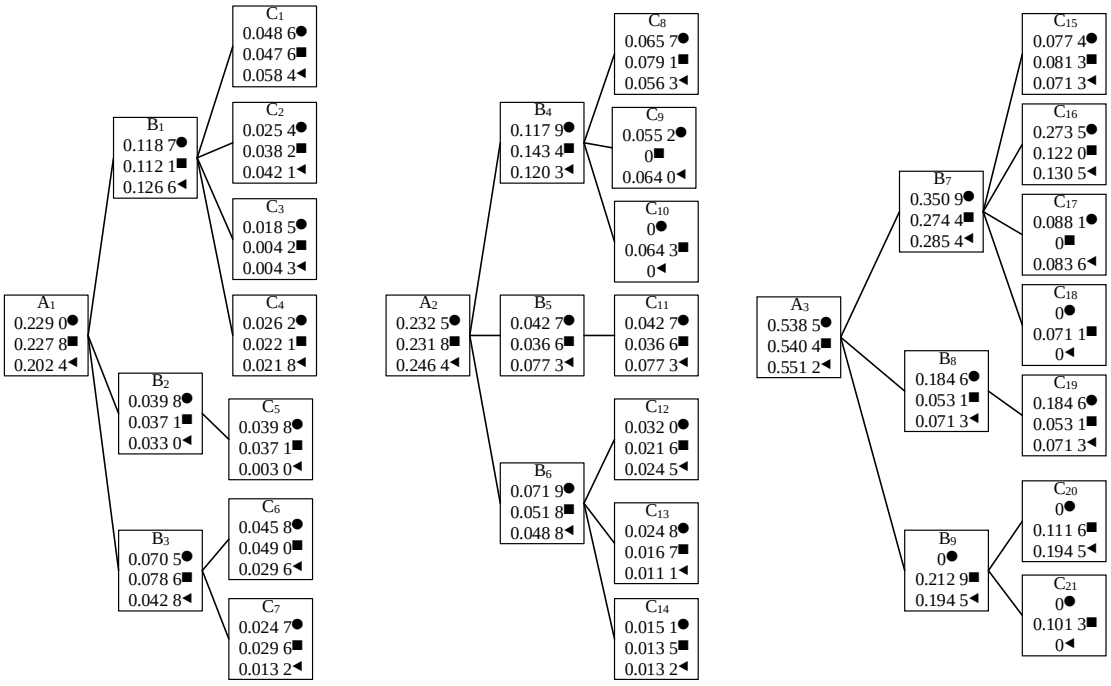


**Figure 1.** The weight distribution of quantity, quality, effectiveness and the corresponding two and three-level indicator

Note: Weight of indicators which labeled●are included in disciplinary key laboratories; Weight of indicators which labeled■are included only in enterprise-established key laboratories; Weight of indicators which labeled▲are included only in provincial-municipal co-constructed key laboratories.

## 4. CONCLUSION

As an important base for carrying out high-level research, only constantly improving the quality of their landmark achievements and accelerate the transfer and transformation of their achievements, can provincial key laboratories enhance their scientific and technological competitiveness. In this study, under the background of "breaking the four-only limitation", the evaluation index system was constructed from the three dimensions of "quantity", "quality" and "effectiveness" according to the characteristics of different types of provincial key laboratories, focusing on the quality, contribution and effect of landmark achievements, making up for the shortcomings of previous evaluation of key laboratories. However, there are some limitations in this study. For example, relatively few experts are selected, and the geographical coverage is not comprehensive enough. Due to space limitation, the evaluation index system of enterprise established and provincial-municipal co-constructed key laboratories co-built has not been tested. In the following research, we will further enrich the sample data, optimize the research methods, and more accurately evaluate the performance level of provincial key laboratories.

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