

Performance Evaluation of Collaborative Innovation of Industry, University and Research Institute in China

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Abstract: As an important form of technological innovation, the collaborative innovation of industry-university-research institute has attracted more and more attention from the business circles, science and technology management departments and academic circles in China. Against this background, the performance evaluation model of industry-university-research collaboration innovation was established on the basis of the input-output perspective, and the factor analysis was used to scientifically assess the performance of industry-university-research collaboration innovation in 29 provinces and cities in China. The scores and rankings were analyzed in detail.

1 Literature review

Regarding the evaluation of the collaborative innovation performance of industry-university-research institutes, the research direction of domestic and foreign scholars mainly focuses on the measurement and the improvement path of collaborative innovation performance of industry-university-research institute. In the late 1980s, Grander (1982), an American economist, first adopted the method of mathematical analysis to conduct a detailed mathematical description and process analysis of the industry-university-research cooperation behavior from the perspective of universities and commercial activities. Fritsch and Slavtchev (2006) used the knowledge production function method to evaluate the efficiency of the regional innovation system by taking the R&D expenditure of a specific region as the input, and the number of patents obtained as the output. In addition, Khodabakhshi (2010) and other researchers verified the random and fuzzy data envelope models, which provided a method for the DEA method to estimate the benefits in proportion.

It has to be admitted that Chinese scholars are relatively late to study the performance of industry-university-research collaboration innovation. In 1999, Li Daguang and Cui Yingde used the analytic hierarchy process to conduct the earliest research on the performance evaluation of industry-university-research integration. Subsequently, Fan Decheng and Tang Xiaoxu

(2009) evaluated the innovation performance of industry-university-research in 30 provinces and cities in China. Based on the application of data envelopment analysis, Zhu Lili (2012) analyzed the performance of industry-university-research collaborative innovation in Anhui Province, and put forward suggestions for performance improvement. These studies are of great significance to promote collaborative innovation between industry-university-research institutes. However, due to the complexity and uncertainty, there are still many difficulties in grasping and elaborating industry-university-research collaborative innovation in a comprehensive and accurate way, which requires more scholars to do further in-depth research.

2 Construction of indicator system

Under the framework of system theory, industry-university-research collaborative innovation belongs to an “input-output” system. Subject to the external environment, innovative subjects invest in human resources, material resources and financial resources. The interplay of the three parties reinforces the cooperation and facilitates the transition of innovation effects to the collaborative innovation output of industry-university-research institutes. Consequently, the paper divides collaborative innovation assessment indicators for industry-university-research institutes into input and output. Assessment indicator system is as shown in Table 1.

Table 1 Performance Evaluation System of Industry-University-Research Collaborative Innovation

Target	Primary indicator	Secondary indicator
Performance Evaluation of Industry-University-Research Collaborative	Industry-University-Research Collaborative	X1: Number of university R&D personnel / person X2: Internal expenditure of university R&D funds / 10,000 yuan X3: Number R&D personnel of R&D institution personnel / person

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rsity-Research Collaborative Innovation	Innovation Input	X4: Internal expenditure of R&D institutions / 10,000 yuan X5: Number of R&D personnel of industrial enterprises above designated size/ person X6: Internal expenditure of R&D funds of industrial enterprises above designated size / 10,000 yuan X7: Internal expenditures for R&D cooperation between R&D institutions and enterprises / 10,000 yuan X8: Internal expenditures for R&D cooperation between R&D institutions and government / 10,000 yuan X9: Internal Expenditure for R&D Expenditure of industrial enterprises above designated size and government/ 10,000 yuan X10: Proportion of university R&D funds from corporate funds / % X11: Proportion of university R&D funds from government funds / % Y1: Number of scientific papers of universities / articles Y2: Number of effective inventions in university / pieces Y3: Number of scientific papers of research institutions/ articles Y4: Number of effective inventions in R&D institutions / pieces Y5: Number of new product development projects of industrial enterprises above designated size / items Y6: Number of effective inventions of industrial enterprises above designated size / pieces Y7: Sales revenue of new products of industrial enterprises above designated size / 10,000 yuan Y8: Technology market turnover / 10,000 yuan
Industry-Univer sity-Research Collaborative Innovation Output		

In the input indicator of industry-university-research collaboration innovation, the number of R&D personnel in universities, R&D institutions, and industrial enterprises above designated size refers to the number of personnel involved in the innovation-research collaboration among the various innovation subjects, reflecting their input capabilities and potential for personnel involved in collaborative innovation. The internal expenditures of R&D funds of universities, R&D institutions, and industrial enterprises above designated size refer to the funds invested by various innovation entities in the collaborative innovation of industry-university-research institutes, which reflects their capital investment capacity and potential to participate in collaborative innovation. According to the amount and proportion of cooperation funds, the indicators X7, X8, X9, X10, and X11 reflect the closeness of cooperation between innovation entities.

There exist eight indicators suggesting the collaborative innovation output of industry-university-research institutes. Among all of these factors, the quantity of technical papers issued by universities, research institutes reflects the fruits of academic innovation. The abundance of inventions in universities, research institutes also reflects the ownership and innovative values of intellectual property and research results. Moreover, the Number of new product development projects of industrial enterprises above designated size, as the most straightforward outputs throughout corporate collaborative innovation process, shows the activity degree and direct outcome of collaborative innovation. As mentioned above, the number of inventions owned by industrial enterprises above designated size on the other hand proves the research and development intensity of the organization. The sales volume brought about by new products in industrial companies above scale demonstrates the

benefits gained by industry-university-research institutes from collaborative innovation. This is the foremost impetus of collaborative innovation and also industrialization among industry-university-research institutes. The turnover in the technology market indicates the degree of commoditization and industrialization of the collaborative innovation of industry, university and research institute.

3 Empirical analysis

The statistical data in this article comes from China Statistical Yearbook and China Science and Technology Statistical Yearbook. Given that there exists a time lag between the input of innovation resources and the output of innovation achievements, and referring to the research of existing scholars, the lag period is determined as one year in this paper. That is to say, the input of the collaborative innovation of industry-university-research institutes uses the data of relevant statistical yearbook in 2017, and the output indicators of collaborative innovation of industry-university-research institutes use the data of relevant statistical yearbooks in 2018, which is more practical and objective. Because of the lack of some index data in Tibet and Ningxia, they were excluded from the study.

Software SPSS20.0 was selected to process the indicator data. First, the original data is standardized to eliminate the effects of dimensions and orders of magnitude. As shown in Table 2, the KMO value of the data in this article is 0.707, and the partial correlation between variables is strong, which meets the requirements of factor analysis. At the same time, the significance of the data in this paper has passed the Bartlett sphericity test with a level of 0.05, indicating that factors can be used for analysis in this paper

Table 2 KMO and Bartlett's test

Kaiser-Meyer-Olkin measure of sample adequacy.	0.707
Bartlett's sphericity test	Approximate chi-square df
	1194.354 171

The maximum rotation of variance is adopted to perform factor rotation. Table 3 shows the total variance interpreted by the extracted factors and their proportions. According to the principle that the eigenvalue is greater

Sig. 0.000

than 1, three common factors were extracted after dimensionality reduction, with contribution rates of 46.634%, 32.950% and 13.019%, respectively. There is 92.602% of the information in the indicator, and the loss of information is small.

Table 3 Total variance explained

Ingredients	Initial eigenvalue			Extract square sum load			Rotated square sum loading		
	total	variance %	accumulation%	total	variance %	accumulation%	total	variance %	accumulation%
1	10.955	57.866	57.866	10.995	57.866	57.866	8.860	46.634	46.634
2	4.766	25.085	82.581	4.766	25.085	82.581	6.260	32.950	79.583
3	1.834	9.651	92.602	1.834	9.651	92.602	2.474	13.019	92.602

In the process of factor analysis, factor rotation is often carried out to better name and account for the extracted common factor. The processed rotation component matrix reflects the degree to which each

factor explains the original variable after rotation. Factors are more practical and convenient to analyze practical problems. In this paper, the maximum variance method is adopted for factor rotation. Table 4 presents the factor load matrix after rotation:

Table 4 Rotation component matrix

	ingre dient		
	1	2	3
Y4: Number of effective inventions in R&D institutions / pieces	0.990		
X4: Internal expenditure of R&D institutions / 10,000 yuan	0.982	0.126	
Y3: Number of scientific papers of research institutions / articles	0.981		
X3: Number of R&D personnel of R&D institution personnel / person	0.977	0.151	
X8: Internal expenditures for R&D cooperation between R&D institutions and government / 10,000 yuan	0.976	0.120	
Y8: Technology market turnover / 10,000 yuan	0.970	0.112	
X7: Internal expenditures for R&D cooperation between R&D institutions and enterprises / 10,000 yuan	0.919	0.180	0.228
X2: Internal expenditure of university R&D funds / 10,000 yuan	0.775	0.517	0.232
Y2: Number of effective inventions in university/pieces	0.752	0.471	0.276
Y1: Number of scientific papers of universities / articles	0.689	0.567	0.362
X1: Number of university R&D personnel / person	0.659	0.616	0.311
Y7: Sales revenue of new products of industrial enterprises above designated size / 10,000 yuan	0.989		
X5: Number of R&D personnel in industrial enterprises above designated size/ person	0.976	0.103	
X6: Internal expenditure of R&D funds of industrial enterprises above designated size / 10,000 yuan	0.968		
Y5: Number of new product development projects of industrial enterprises above designated size/ items	0.968		
Y6: Number of effective inventions of industrial enterprises above designated size / pieces	0.113	0.914	
X9: Internal Expenditure for R&D Expenditure of industrial enterprises above designated size and government/ 10,000 yuan	0.324	0.589	0.473
X10: Proportion of university R&D funds from government funds / %			0.950
X11: Proportion of university R&D funds from corporate funds / %		0.217	0.945

As can be seen from Table 4, the indicators Y4, X4, Y3, X3, X8, Y8, X7, X2, Y2, Y1, and X1 have a larger load on the common factor 1, which jointly reflects the input and output of universities and R&D institutions. Therefore, the common factor 1 is referred to as the innovation capacity factor of universities and R&D institutions.

In the common factor 2, the factors with higher factor load are Y7, X5, X6, Y5, Y6, and X9, which reflect the ability of enterprises to participate in collaborative innovation. As a result, the common factor 2 is called as the enterprise's innovation capability factor.

In the common factor 3, the indicators X10 and X11 reflect the closeness of cooperation between universities, governments, and enterprises. Therefore, the common factor 3 is called the industry-university-research collaboration innovation synergy factor.

The contribution rate of each common factor was divided by 92.602% of the total factor contribution rate to obtain the weight of each common factor. For convenience, the common factors 1, 2, and 3 are expressed as F1, F2, and F3, respectively. The weight coefficients of F1, F2, and F3 are 50.36%, 35.58%, and 14.06%, respectively. The comprehensive evaluation model of the collaborative innovation performance of

various provinces and cities is as follows:

$$F = 50.36\% * F1 + 35.58\% * F2 + 14.06\% * F3$$

By substituting the scores of each common factor into the above formula, the comprehensive evaluation scores

of the innovation performance of industry-university-research cooperation of all provinces and cities in China can be calculated. The specific situation is shown in Table 5:

Table 5 Comprehensive evaluation scores of collaborative innovation performance of industry, university and research in various provinces and cities in China

Provinces and cities	F1 score	Ranking	F2 score	Ranking	F3 score	Ranking	overall ratings	total ranking
Beijing	4.885	1	-0.611	26	-0.592	22	2.160	1
Jiangsu	0.396	5	2.568	2	0.528	7	1.187	2
Guangdong	-0.060	7	3.469	1	-0.812	25	1.090	3
Shanghai	0.976	2	0.178	6	0.618	6	0.642	4
Zhejiang	-0.268	13	1.413	3	0.467	8	0.433	5
Shandong	-0.164	9	1.397	4	-0.247	17	0.380	6
Sichuan	0.406	3	-0.415	16	2.158	1	0.360	7
Hubei	0.174	6	0.123	7	0.462	10	0.196	8
Shaanxi	0.397	4	-0.364	13	0.826	5	0.187	9
Liaoning	-0.087	8	-0.376	14	1.812	2	0.077	10
Hunan	-0.305	17	0.101	8	0.423	12	-0.058	11
Anhui	-0.165	10	0.319	5	-0.842	26	-0.088	12
Tianjin	-0.203	12	-0.242	12	0.464	9	-0.123	13
Henan	-0.335	20	-0.029	10	0.246	13	-0.144	14
Heilongjiang	-0.462	26	-0.600	24	1.711	3	-0.206	15
Fujian	-0.306	18	0.064	9	-0.688	24	-0.228	16
Hebei	-0.367	23	-0.222	11	0.153	15	-0.242	17
Chongqing	-0.535	29	-0.377	15	1.003	4	-0.263	18
Jilin	-0.168	11	-0.468	18	-0.542	20	-0.327	19
Jiangxi	-0.523	27	-0.463	17	0.207	14	-0.399	20
Guangxi	-0.321	19	-0.469	19	-0.643	23	-0.419	21
Yunnan	-0.276	14	-0.567	22	-0.566	21	-0.420	22
Shanxi	-0.359	22	-0.548	20	-0.530	19	-0.450	23
Gansu	-0.428	24	-0.839	29	0.446	11	-0.451	24
Guizhou	-0.443	25	-0.611	25	-0.502	18	-0.511	25
Inner Mongolia	-0.529	28	-0.642	27	-0.206	16	-0.524	26
Xinjiang	-0.276	15	-0.565	21	-1.591	27	-0.564	27
Hainan	-0.350	21	-0.644	28	-1.600	28	-0.630	28
Qinghai	-0.304	16	-0.581	23	-2.164	29	-0.664	29

4 Conclusion

The performance evaluation system of collaborative innovation of industry-university-research institutes constructed in this paper is universal, which conforms to the actual situation in various regions of China. There are three parts in the performance evaluation system of collaborative innovation of industry-university-research institutes, that is, the innovation capabilities of universities and R&D institutions, the innovation capabilities of enterprises, and the industry-university-research collaboration innovation synergy factor. The positive and negative scores of the common factor scores and comprehensive evaluation scores in Table 5 have no practical significance, which only reflects the relative relationship between the collaborative innovation performance of

industry-university-research institutes in various provinces and cities in China. The collaborative innovation performance of provinces and cities with a comprehensive score greater than 0 is higher than the national average, while that of provinces and cities with a comprehensive score less than 0 is lower than the national average. In general, the performance of industry-university-research collaborative innovation in China is not satisfactory, and only 10 provinces and cities have higher collaborative innovation performance than the national average. In addition, the provinces and cities have obvious regional characteristics. There is an obvious gap between the economically backward western region and the economically developed eastern region. For example, Beijing's comprehensive score is 2.160, which is much higher than other provinces and cities in China. Finally, with the exception of Beijing and Jiangsu, there was little difference in total scores for the neighboring regions in the remaining ranks.

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