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Research on the Evaluation Method of Innovation Capability of Colleges and Universities Combining Expert Judgment Method and Weighted Average Method

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Abstract As a core component of the comprehensive strength of colleges and universities, innovation ability is an important basis for the formulation and improvement of educational policies of colleges and universities. This paper takes the scientific evaluation of innovation ability of colleges and universities as the research purpose, analyzes the calculation and standardization method of some colleges and universities' innovation ability evaluation index data, and selects the shapiro-wilk test method as the screening method of the indexes. By using the quantitative screening method to assist the selection of indicators, it breaks through the limitations of the existing methods that are too subjective. Based on the quantitative screening method, a set of evaluation index system of innovation ability of colleges and universities is initially proposed from four perspectives: input of science and technology foundation, input of science and technology research and development, output of scientific and technological achievements, and effectiveness of science and technology. The gray statistical method is introduced to evaluate the various layers of influence factors of the indicators, so as to further screen the indicators and establish the final evaluation index system of innovation ability of colleges and universities. Meanwhile, it combines the improved CRITIC assignment method with the weighted average method as the method of assigning weights to the indicators. In the form of evaluating the scientific research projects of students in colleges and universities to reflect the overall competence level of the university's innovation ability, a number of randomly selected groups of 10 scientific research projects of H colleges and universities were rated 75 points and above.

Index Terms evaluation of innovation ability of colleges and universities, improved CRITIC assignment method, quantitative screening, weighted average method

I. Introduction

With the in-depth implementation of the innovation-driven development strategy, China has gradually entered the stage of high-quality development, and the construction of international and regional scientific and technological innovation centers has become a strategic focus for creating regional competitive advantages in the new era [1], [2]. Higher education institutions have innovative talents, teams, achievements and other advantageous resources, is the main force of scientific and technological innovation, and its scientific and technological innovation ability to a certain extent reflects the entire region and even the country's science and technology and economic and social development level [3]-[5]. At the same time, university innovation has a broad and far-reaching impact on industrial transformation and upgrading, economic development and change of production mode [6]. Therefore, in the context of regional economic development, it is necessary to scientifically assess the innovation capacity of universities in the region, identify the gaps, tap the potential, make up the short boards, and strengthen the advantages in order to create a world-class science and technology innovation center [7]-[9].

At present, China's universities and colleges of science and technology innovation evaluation of the phenomenon of homogenization, convergence is more serious, in the distribution system of scientific and technological resources, as well as the “double first-class construction” and discipline assessment, there is still a reliance on academic papers, project funding and other monolithic evaluation indexes phenomenon [10]-[13]. If local universities take this as a criterion, it is difficult to objectively reflect the whole picture of science and technology innovation activities, and also cannot reflect the quality of science and technology innovation and service contribution [14], [15]. With the construction of regional S&T innovation centers becoming one of the strategic focuses of China's competitive advantage in the new era, modern S&T activities are diversified and complex, and the knowledge structure of S&T talents also reflects composite and applied nature [16]-[18]. Therefore, the evaluation system of science and technology innovation ability for multi-type local universities should be constructed to enhance the ability of local universities to support and lead the regional economic development.

This paper firstly elaborates in detail the calculation and standardization process of evaluation index data of innovation ability of colleges and universities, adopts the shapiro-wilk test method, screens the indexes suitable for evaluating the innovation ability of colleges and universities from the massive data, and initially proposes the evaluation index system of innovation ability of colleges and universities. Then, we explain the steps of index analysis and screening based on gray statistical method. In the form of expert questionnaire, the content and structure of the index system are further adjusted to determine the final index system for evaluating the innovation ability of colleges and universities. Then analyze the steps of calculating the weights of the indicators by improving the CRITIC assignment method and the weighted average method, and determine the weights of the indicators of the evaluation system. Finally, taking university H as the experimental object, the overall innovation ability level of university H is evaluated by assessing the innovation ability performance of university H's research project team.

II. Index System for Evaluation of Innovation Capability of Colleges and Universities

II. A. Data preparation for quantitative screening

II. A. 1) Calculation of data for selected indicators

(1) Calculation of the Contribution Rate of Scientific and Technological Progress of Colleges and Universities

The principle of calculation of the contribution rate of scientific and technological innovation of universities: the contribution rate of scientific and technological innovation of universities refers to the proportion of economic growth caused by the scientific and technological innovation activities of universities in the region to the value of the economic growth of the region, which reflects the degree of influence and coordination of scientific and technological progress of universities on the development of the local economy. The scientific and technological innovation of colleges and universities is an important part of regional scientific and technological innovation, and the part of the contribution of regional scientific and technological innovation to economic growth that belongs to the contribution of scientific and technological innovation of colleges and universities to economic growth is separated separately, which is the contribution rate of scientific and technological progress of colleges and universities in the region. The region here is the province as the basic unit.

Regional S&T progress is realized through the activities of personnel in universities, research institutes, enterprises and other sectors. Talents play a decisive role in the science and technology innovation system, both practical and dynamic, and are the most active factors. According to Marx's complex labor simplification idea, the ratio of the change of personnel in colleges and universities to the change of personnel in the region is the proportion of scientific and technological progress in colleges and universities in the contribution rate of scientific and technological progress in the whole region. Assumption: scientific and technological progress relies on the activity of personnel. College personnel and non-college (enterprises, research institutions) research personnel activities have the homogeneity of various scientific and technological activities in colleges and universities (basic research, applied research, experimental development, etc.) on scientific and technological progress in the short-term utility of the difference is not obvious.

The contribution rate of scientific and technological progress in universities is calculated as follows:

After taking the logarithm of the Cobb-Douglas (C-D) production function $Y_t = A_i K_i^{\alpha} L_i^{\beta}$, the derivative with respect to t is given in equation (1):

$$\frac{dY_t}{Y_t} = \frac{dA_t}{A_t} + \alpha\frac{dK_t}{K_t} + \beta\frac{dL_t}{L_t} \tag{1}$$

Let $\frac{dA_r}{A_r} = a, \frac{dY_r}{Y_r} = y, \frac{dK_r}{K_r} = k, \frac{dL_r}{L_r} = l$ correspond to the the average annual growth rates of technological progress, GDP, capital investment, and labor force. a, β is the coefficient of elasticity of capital and labor output, respectively, then the equation is the same divided by y as in equation (2):

$$E_a = \frac{\alpha}{y} = 1 - \frac{\alpha k}{y} - \frac{\beta l}{y} \tag{2}$$

The economic meaning of equation (2): after deducting capital inputs and labor, the contribution rate brought by scientific and technological progress in economic growth. Where E_a represents the contribution rate of scientific and technological progress.

Calculated by the level method y,k,l. Y_0- GDP of the base period. Y_t- GDP of the t th year. k,t are all obtained by equation (3).

$$y=\left[\sqrt[1]{\frac{Y_t}{Y_0}}-1\right]\times 100\% \tag{3}$$

Let $\Delta L^g,\Delta L^q$ be the change value of university research full-time staff and regional research full-time staff, respectively, with equation (4).

$$E_a^t=\frac{\Delta L^g}{\Delta L^q}E_a \tag{4}$$

The economic meaning of formula (4): the proportion of full-time personnel changes in university research in the whole region and the product of regional contribution rate of scientific and technological progress. Where, E_a^t - universities and colleges of science and technology progress contribution rate, α,β are capital and labor output elasticity coefficients, respectively, under the condition of constant returns to scale, $\alpha+\beta=1$, and α and β are constants. In some developed countries, the capital output elasticity α is between 0.25-0.35. China's State Planning Commission and the National Bureau of Statistics pointed out that China's geographic area is wide, and the output structure of each province is not the same, in the use of the whole society caliber calculation of the contribution rate of scientific and technological progress of the 31 provinces, autonomous regions and municipalities directly under the Central Government, on the basis of the recommended value of $\alpha=0.35$, to α,β to be corrected, so as to make it more close to the objective reality, with the formula (5):

$$\alpha_0=\alpha\ln\left[e-1+\left(\frac{1}{N}\sum_{i=1}^{N}\frac{K_i}{L_i}\right)/\left(\frac{1}{N}\sum_{i=1}^{N}\frac{K_{ti}}{L_{ti}}\right)\right] \tag{5}$$

where, K_i - Region's i th year capital input. L_i - i th year labor input in the region. K_{ti} - i th year capital input in the country. L_{ti} - i th year labor input in the country. N -year span.

(2) Calculation of doctoralization rate of scientific researchers

Doctoralization rate of scientific researchers refers to the ratio of the number of researchers with doctoral degrees in universities within a region to the number of researchers as in equation (6). Set: r - doctoralization rate of scientific research personnel. a -Research with doctoral degree. b -Number of scientific researchers.

$$r=a/b \tag{6}$$

(3) Calculation of Research Intensity of Universities

The intensity of university research investment is the proportion of university research investment in the current year's regional GDP, which is used to measure the scale of scientific and technological investment and scientific and technological activities of universities in a country or region. Let e -intensity of university research input. y_1 -regional university research funding. y_2 -regional GDP, then there is equation (7):

$$e=y_1/y_2 \tag{7}$$

(4) Calculation of the share of investment in scientific research in the regional GDP of the current year

Set g - regional scientific research input intensity. z_1 -value of regional scientific research investment. z_2 -regional GDP value, then there is equation (8):

$$g=z_1/z_2 \tag{8}$$

II. A. 2) Standardization of indicator data

In order to eliminate the influence of indicator order of magnitude and outline on the data, the data of the evaluation indicators of scientific and technological innovation capacity of universities are standardized. Positive indicators, i.e., the larger the value of the indicator, the stronger the scientific and technological innovation capacity of universities.

Let: x_{ij} -the value of the i th indicator after the standardization of the j th region data. r_i -value of the indicator in the j th region for the i th indicator.

$\min_{i\le j\le n}(r_{ij})$ - Minimum value of the i th indicator data. $\max_{1\le j\le n}(r_{ij})$ - i th indicator data maximum. n -number of regions, with equation (9):

$$x_{ij} = \frac{r_{ij} - \min_{i\le j\le n}(r_{ij})}{\max_{1\le j\le n}(r_{ij}) - \min_{i\le j\le n}(r_{ij})} \tag{9}$$

II. A. 3) shapiro-wilk test for the overall distribution of different indicators

The reason for selecting the shapiro-wilk test to test the distribution of indicator data: there are many methods for quantitative screening of indicators, but each method has certain conditions of application. If the specific distribution of the indicator data is normal, then some parametric statistical methods can be applied to construct the indicator system, otherwise the non-parametric statistical model should be used to realize the screening of the indicator system. Therefore, it is necessary to test whether the indicator data obey the normal distribution to reflect the real situation of data distribution. The sample used in this paper is the provincial scope, the sample capacity of each indicator is 31, according to the conditions for the use of normality test, for a single indicator sample capacity between 3 and 50, belongs to the small sample test with small sample capacity, the shapiro-wilk method is used to carry out the normality test of the indicator data.

Let: W_x -value of the statistic for the shapiro-wilk test for indicator X . $\bar{X}$ - sample mean. n -sample capacity of indicator X . $X_{(1)}...X_{(i)}...X_{(n)}...X_{(n)^-}$ -Statistics of the observations $X_1,...X_i,...X_n$ of indicator X ranked from largest to smallest. $\alpha_i(W)$ - the statistical empirical coefficient of this test, $i\in(1,n)$. Then W_X is calculated as equation (10):

$$W(X) = \frac{\left[\sum_{i=1}^{K} a_i(W)[X_{(n+1-i)} - X_{(i)}]\right]^2}{\sum_{i=1}^{n}\left[X_{(i)} - \bar{X}\right]} \tag{10}$$

where $K=\frac{n}{2}$ when n is even and $K=\frac{n-1}{2}$ when n is odd.

Taking the significance level $\alpha = 0.05$, the quantile W_α of the statistic p is obtained from the sample size n. Compare W_x with W_α to determine whether the overall of indicator X obeys normal distribution.

Statistical test determination criteria: If $W_x < W_a$, then it can be assumed that the overall population from which the indicator data come does not obey a normal distribution. If $W_x > W_\alpha$, then it is considered that the indicator sample data from the aggregate obeys a normal distribution. Taking the significance level $\alpha = 0.05$, the comparison of W_X with the quantile W_α is transformed into a probability value determined by SPSS versus 0.05. If the test probability $P > 0.05$, the indicator X obeys a normal distribution, and if $P < 0.05$ the indicator X does not obey a normal distribution.

The empirical part reveals that the vast majority of the data of the 88 preliminary indicators remaining after the qualitative screening of the sea-selected indicators do not obey normal distribution, so non-parametric statistical methods are chosen to quantitatively screen the evaluation index system of scientific and technological innovation capacity of universities.

II. B. Preliminary establishment of the evaluation index system of innovation capacity of colleges and universities

Combined with the existing literature research and the actual situation, the evaluation index system of innovation ability of colleges and universities is proposed from four perspectives of science and technology basic input, science and technology research and development input, science and technology achievement output, and science and technology effectiveness, which is shown in Table 1.

Table 1: Indicators of scientific and technological innovation

Primary index	Secondary index	Three-level index
(A)Investment in technological infrastructure	(A1)Human Resources	(A11)Science and technology activity personnel
		(A12)The proportion of senior professional titles among personnel engaged in scientific and technological activities
	(A2)Funding input	(A21)Total funds for science and technology
		(A22)Per capita scientific and technological funds for personnel engaged in scientific and technological activities
		(A23)From government funds
		(A24)Government funds/Total funds for science and technology
(B)Investment in scientific research and developmen	(B1)Research investment	(B11)The number of scientific research projects
		(B12)Research project funds
	(B2)Academic Exchange	(B21)The number of international academic conferences hosted
		(B22)Exchange the number of academic papers
		(B23)The number of people attending international academic conferences
(C)Output of scientific and technological achievements	(C1)Papers and monographs	(C11)The total number of published papers
		(C12)The number of published papers/personnel engaged in scientific and technological activities
		(C13)The number of scientific and technological publications
	(C2)Scientific and technological achievements	(C21)The number of national awards
		(C22)Provincial and ministerial-level achievement awards
(D)Achievements in scientific and technological innovation	(D1)Patent effectiveness	(D11)The number of patent applications
		(D12)Number of patent authorizations
		(D13)Number of patent authorizations/number of patent applications
		(D14)The number of invention patent applications
		(D15)The number of authorized invention patents
		(D16)The number of authorized invention patents/the number of invention patent applications
		(D17)The number of authorized invention patents/personnel engaged in scientific and technological activities
	(D2)Technical achievements	(D21)Funds for technical service projects
		(D22)The number of patent sale contracts
		(D23)The actual amount of patent sales
		(D24)The number of technology transfer contracts
		(D25)Actual income from the transfer of achievements

III. Determination of the indicator system based on the gray statistical method

III. A. Gray statistical method for counting significant impact factors

According to the principle of gray statistics, the first step: the gray statistical method is used to whitening function data processing and gray class statistics on the importance degree of each influence factor of the recovered questionnaire. The second step: the degree of importance of the influence factors of online course evaluation is set into three gray classes: high, medium and low, and the gray class whitening function of each class is constructed. The third step: the gray class decision coefficient $\{H_{\text{low}}, H_{\text{medium}}, H_{\text{high}}\}$ is calculated, and the class corresponding to the maximum value of the gray class coefficient in the decision vector is selected, and only the influence factors with the degree of importance of the high class are selected in the process of analysis. The opinions of the experts are grouped into several categories, and the decision on the weight category to which an indicator belongs is made by obtaining the gray weights of all the experts who judge an indicator to be a certain weight category.

III. A. 1) Constructing the gray class whitening function

Let I = fraction $J = 1*, 2*, 3*...$ Indicators $K = 1, 2, 3...$ Category d_{ij} is the value assigned by the experts of the i th group to the weight of the j th indicator $i \in \{I, II, IIII...\}$ $j \in \{i^*, , 2^*, 3^*...\}$, d_{ij} is the score of the j th influencing factor whose importance level is i, let $f_k(ij)$ be the value of the whitening function of the j th influencing factor whose importance level is i, and k is the number of grey categories, $k=1,2,3$, $i=1,2,.....7, j=1,2,..7$.

$k=1$, first class (high): the whitening function is equation (11).

$$f_k(ij)=\begin{cases} 1 & d_{ij}=7 \\ d_{ij}-4/7-4 & 4<d_{ij}<7 \\ 0 & d_{ij}=4 \end{cases} \tag{11}$$

$k=2$, Type II (middle): the whitening function is Eq. (12).

$$f_A(ij)=\begin{cases} 0 & d_{i,j}<1 \\ d_{i,j}-1/4-1 & 1<d_{i,j}<4 \\ 1 & d_{i,j}=4 \\ 7-d_{i,j}/7-4 & 4<d_{i,1}<7 \\ 0 & d_{i,j}=7 \end{cases} \tag{12}$$

$k=3$, Type III (low): the whitening function is Eq. (13).

$$f_k(ij)=\begin{cases} 1 & d_{ij}=1 \\ 4-d_{ij}/4-1 & 1<d_{ij}<4 \\ 0 & d_{ij}=4 \end{cases} \tag{13}$$

III. A. 2) Determination of the coefficient of determination of the ash type

Let $h_k(j)$ denote the category to which the decision-making coefficient of the j th indicator belongs, and $f_k(ij)$ be the value of the whitening function of the j th influencing factor whose degree of importance is i, and then calculate the decision-making coefficient of the gray category according to the formula of the grey statistical method (14) by counting the scores that the experts have given to the degree of importance of the various indicators $hk(j)$.

$$n_K(j)=\sum n_{(ij)}f_K(ij) \tag{14}$$

III. A. 3) Determining decision vectors

The gray decision coefficients of each influencing factor are calculated by equation (14), $h_1(j),h_2(j),h_3(j)$, and the largest of the three coefficients is selected. This is the class to which the decision coefficient of the indicator belongs. This further determines the importance of each indicator.

III. B. Screening of evaluation indicators

III. B. 1) Questionnaire design

Gray systems theory is an applied mathematical discipline that studies the phenomenon of partially known and partially unknown information with uncertainty. Due to the uncertainty of risk, partially known and partially unknown, it has a high degree of grayness. The whitening weight function is a triple-fold line in right-angle coordinates, or S-curve, which quantitatively describes the degree to which a particular assessment object belongs to a certain gray category (called the weight function), i.e., the relationship that varies with the magnitude of the assessed indicator or sample point value. The role of the whitening weight function is to transform the scoring value of each indicator into the preference tendency value of each class, which is a semi-qualitative and semi-quantitative evaluation and description of the state of each indicator of the system.

In order to ensure the objectivity and authority of the established evaluation index system, this paper chooses to first issue a seven-level scale (the value of the scale is 1-7) questionnaire to 50 experts in the field for screening, experts in the importance of the value of 1-7 to select the importance of three-level indicators of the degree of importance of the appropriate score, a total of 50 questionnaires were issued, 50 valid questionnaires were recovered, and the questionnaire validity rate is 100%. Calculated by the gray statistical method, screening out the score value is not high, the number of indicators under the importance of the numerical value represents the number of experts who choose this score, the results of the expert rating is shown in Table 2.

Table 2: The importance of indicators of scientific and technological innovation

Index	Significance							Total
	1	2	3	4	5	6	7	
(A11)	0	0	15	17	14	1	3	210
(A12)	0	1	12	12	11	8	6	231
(A21)	0	0	16	14	19	0	1	206
(A22)	0	0	16	14	15	2	3	212
(A23)	0	0	8	12	17	7	6	241
(A24)	0	0	14	12	17	6	1	218
(B11)	0	0	3	16	19	10	2	242
(B12)	0	0	13	11	16	9	1	224
(B21)	0	0	10	12	11	8	9	244
(B22)	0	0	8	11	15	7	9	248
(B23)	0	0	9	16	17	6	2	226
(C11)	0	1	13	14	15	4	3	217
(C12)	0	0	9	15	20	6	0	223
(C13)	0	0	12	14	18	1	5	223
(C21)	0	0	7	12	17	4	10	248
(C22)	0	0	10	22	15	3	0	211
(D11)	0	0	0	19	20	10	1	243
(D12)	0	0	5	18	17	10	0	232
(D13)	0	0	13	15	12	10	0	219
(D14)	0	2	10	12	19	7	0	219
(D15)	0	0	4	16	19	5	6	243
(D16)	0	0	8	16	16	2	8	236
(D17)	0	2	12	14	17	5	0	211
(D21)	0	1	11	13	15	3	7	229
(D22)	0	0	12	10	15	9	4	233
(D23)	0	0	7	11	18	5	9	248
(D24)	0	0	3	13	20	8	6	251
(D25)	0	2	11	25	10	2	0	199

III. B. 2) Calculating decision vectors by the gray data statistics method

After obtaining the evaluation data of experts on the degree of importance of each indicator, the gray class decision coefficients are calculated according to equation (14). The gray class decision vector of each evaluation indicator is composed of three gray classes of decision coefficients $h_1(j), h_2(j), h_3(j)$ calculated by equation (14), and the decision vector represents three categories of high, medium and low importance. By applying the above gray statistical method to organize and calculate the expert rating data, the importance degree of each index can be obtained as shown in Table 3.

Table 3: Grey statistical analysis of the evaluation index system

Index	Significance			Degree of importance	Whether to select
	$h_1(j)$	$h_2(j)$	$h_3(j)$		
(A11)	11.52	12.72	5.76	Medium	Yes
(A12)	15.53	12.64	1.83	High	Yes
(A21)	19.38	10.62	0	High	Yes
(A22)	10.29	16.94	2.77	Medium	Yes
(A23)	16.17	13.83	0	High	Yes
(A24)	6.66	13.62	9.72	Medium	Yes
(B11)	5.79	23.17	1.04	Medium	Yes
(B12)	5.66	21.55	2.79	Medium	Yes
(B21)	5.83	13.14	11.03	Medium	Yes
(B22)	18.09	11.79	0.12	High	Yes

(B23)	13.03	16.97	0	Medium	Yes
(C11)	17.45	8	4.55	High	Yes
(C12)	2.45	3.34	24.21	Low	No
(C13)	6.28	17.28	6.44	Medium	Yes
(C21)	16	12.23	1.77	Medium	Yes
(C22)	11.35	13.87	4.78	Medium	Yes
(D11)	14.95	5.88	9.17	High	Yes
(D12)	24.43	4.49	1.08	High	Yes
(D13)	5.97	23.86	0.17	Medium	Yes
(D14)	11.14	13.12	5.74	Medium	Yes
(D15)	13.94	14.46	1.6	Medium	Yes
(D16)	14.06	10.47	5.47	High	Yes
(D17)	1.88	11.64	16.48	Low	No
(D21)	9.01	9.39	11.6	Low	No
(D22)	7.9	21.51	0.59	Medium	Yes
(D23)	16.51	7.09	6.4	High	Yes
(D24)	4.11	18.68	7.21	Medium	Yes
(D25)	7.42	11.97	10.61	Medium	Yes

III. B. 3) Determination of the system of evaluation indicators

Through the combination of Delphi method and gray statistical method, the three-level indicators were deleted: (C12) number of published papers/scientific and technological activities personnel, (D17) number of invention patent authorization/scientific and technological activities personnel and (D21) technical service subject funding, and the final evaluation index system was obtained as shown in Table 4.

Table 4: The final indicator system for scientific and technological innovation

<table>
<tr><th>Primary index</th><th>Secondary index</th><th>Three-level index</th></tr>
<tr><td rowspan="6">(A)Investment in technological infrastructure</td><td rowspan="2">(A1)Human Resources</td><td>(A11)Science and technology activity personnel</td></tr>
<tr><td>(A12)The proportion of senior professional titles among personnel engaged in scientific and technological activities</td></tr>
<tr><td rowspan="4">(A2)Funding input</td><td>(A21)Total funds for science and technology</td></tr>
<tr><td>(A22)Per capita scientific and technological funds for personnel engaged in scientific and technological activities</td></tr>
<tr><td>(A23)From government funds</td></tr>
<tr><td>(A24)Government funds/Total funds for science and technology</td></tr>
<tr><td rowspan="5">(B)Investment in scientific research and developmen</td><td rowspan="2">(B1)Research investment</td><td>(B11)The number of scientific research projects</td></tr>
<tr><td>(B12)Research project funds</td></tr>
<tr><td rowspan="3">(B2)Academic Exchange</td><td>(B21)The number of international academic conferences hosted</td></tr>
<tr><td>(B22)Exchange the number of academic papers</td></tr>
<tr><td>(B23)The number of people attending international academic conferences</td></tr>
<tr><td rowspan="4">(C)Output of scientific and technological achievements</td><td rowspan="2">(C1)Papers and monographs</td><td>(C11)The total number of published papers</td></tr>
<tr><td>(C13)The number of scientific and technological publications</td></tr>
<tr><td rowspan="2">(C2)Scientific and technological achievements</td><td>(C21)The number of national awards</td></tr>
<tr><td>(C22)Provincial and ministerial-level achievement awards</td></tr>
<tr><td rowspan="7">(D)Achievements in scientific and technological innovation</td><td rowspan="6">(D1)Patent effectiveness</td><td>(D11)The number of patent applications</td></tr>
<tr><td>(D12)Number of patent authorizations</td></tr>
<tr><td>(D13)Number of patent authorizations/number of patent applications</td></tr>
<tr><td>(D14)The number of invention patent applications</td></tr>
<tr><td>(D15)The number of authorized invention patents</td></tr>
<tr><td>(D16)The number of authorized invention patents/the number of invention patent applications</td></tr>
<tr><td>(D2)Technical achievements</td><td>(D22)The number of patent sale contracts</td></tr>
</table>

		(D23)The actual amount of patent sales
		(D24)The number of technology transfer contracts
		(D25)Actual income from the transfer of achievements

IV. Determination and application of indicator weights

IV. A. Improvement of the CRITIC empowerment methodology

Based on the Improved CRITIC Assignment Method, the indicators at each level are assigned a hierarchical weighting. Considering that the indicators at all levels of innovative capacity allow for uneven development, they are synthesized using the arithmetic average method. The calculation steps are as follows:

Step 1: Construct a raw data matrix. Suppose there are n evaluation objects in the second-level indicator S_k subsystem, and p_{s_k} evaluation indicators are formed to form the original data matrix of the third-level indicators in the S_k subsystem, where $X_{S_k} = (x_{ij})_{n \times p_{S_k}}$, where x_{ij} is the first i The observed values of the first j indicators of the evaluation objects, p_{s_k} are the number of the third-level indicators in the second-level indicators S_k.

Step 2: Positive processing of the original data of the third-level indicators. Referring to the positive processing method of Shang Liqun (2014), all the negative indicators and moderate indicators in the original data matrix of the third-level indicators were positiveized to form the positive data matrix of the third-level indicators in the S_k subsystem $X_{S_k}^{+} = (x_{ij}^{+})_{n \times p_{S_k}}$. The value of the forward indicator X_j is $x_{ij}^{+} = x_{ij}$. The value of the negative indicator X_j is given by equation (15):

$$x_{ij}^{+} = M_j - x_{ij} \tag{15}$$

For the fitness indicator X_j the values of $x_{ij}^{+} = M_j - | x_{ij} - m_j |$ are taken. Where M_j is a suitably large positive number and m_j is the ideal value of the indicator X_j, in this paper, we take $M_j = \max(x_{ij})$.

Step 3: Homogenization of data indicators after normalization. The indicators in the normalized data matrix are homogenized to form the dimensionless data matrix of the third-level indicators in the S_k subsystem $Z_{S_k} = (z_{ij})_{n \times p_{S_k}}$ in Eq. (16):

$$z_{ij} = \frac{x_{ij}^{+}}{\overline{x}_j^{+}} \tag{16}$$

In equation (16) $\overline{x}_j^{+} = \frac{1}{n}\sum_{i=1}^{n} x_{ij}^{+}$. In this paper $z_{ij} = 0.999999 \times \frac{x_{ij}^{+}}{\overline{x}_j^{+}} + 0.0000001$, to prevent the calculation of the code in the event that the mean appears to be 0, the calculation of the code is wrong.

Step 4: Calculate the contrast of indicators expressed as coefficients of variation.

The coefficient of variation of the third-level indicator X_j in the S_k subsystem is equation (17):

$$CV_{S_{kj}} = \frac{\sigma_j}{z_j} \tag{17}$$

In Eq. (17) $\overline{z}_j = \frac{1}{n}\sum_{i=1}^{n} z_{ij}, \sigma_j = \sqrt{\frac{\sum_{i=1}^{n}(z_{ij} - \overline{z}_j)^2}{n-1}}$.

Step 5: Calculate the conflicting nature of the indicators expressed in terms of gray similarity correlation. The sequence of system behaviors consisting of X_j and indicator X_j^{*} in the subsystem of second-level indicators S_k are $X_j = (z_{1j}, z_{2j}, \cdots, z_{nj}), X_{j^*} = (z_{1j^*}, z_{2j^*}, \cdots, z_{nj^*})$), and the corresponding zeroed image of the starting point is $X_j^{(0)} = (z_{1j}^{(0)}, z_{2j}^{(0)}, \cdots, z_{nj}^{(0)}), X_{j^*}^{(0)}((z_{1j^*}^{(0)}, z_{2j^*}^{(0)}, \cdots, z_{nj^*}^{(0)})$ where $z_{ij}^{(0)} = z_{ij} - z_{1j}$, yielding Z_{s_k} corresponding to the gray similarity correlation matrix $G_{s_k} = (\varepsilon_{ij^s})_{p_{S_k} \times p_{S_k}}$, calculated as equation (18):

$$\varepsilon_{jj^*} = \frac{1}{1+|s_j - s_{j^*}|} \tag{18}$$

Eq. (18) in $s_j - s_{j^*} = \int_1^n (X_j^{(0)} - X_{j^*}^{(0)})dt$, the conflicting nature of tertiary metrics X_j in the S_k subsystem, has the equation (19):

$$C_{s_{kj}} = \sum_{j^*=1}^{pS_k} (1-\varepsilon_{jj^*}) \tag{19}$$

Step 6: Calculate the weights of the third-level indicators. The weights of the third-level indicators X_j in the S_k subsystem are shown in equation (20):

$$W_{s_k j} = \frac{U_{s_k j}}{\sum_{j=1}^{p_{S_k}} U_{s_k j}} \tag{20}$$

In equation (20) $U_{s_k j} = CV_{s_k j} \times C_{s_k j}$.

Step 7: Synthesize the composite score of the secondary indicators. Synthesize the composite score of the second-level indicator by the arithmetic mean method by synthesizing the third-level indicator X_j in the subsystem of S_k after dimensionless as in Equation (21):

$$V_{s_k} = \sum_{j=1}^{p_{S_k}} W_{s_k j} \times z_j \tag{21}$$

Step 8: analogous to the above calculation ideas, the calculation of the weight of the second-level indicators $W_{D_m S_k}$, based on the arithmetic average method to get a comprehensive score of the first-level indicators as formula (22):

$$V_{D_m} = \sum_{s_k}^{p_{D_m}} W_{D_k S_k} \times V_{S_k} \tag{22}$$

IV. B. Weighted average method

The weighted average method mainly takes into account the fact that factors (or indicators) have different positions or roles in the evaluation, and establishes a weight for each evaluation indicator to reflect this difference. Using the weighted average method, it is important to determine the weight of each evaluation indicator, and the method of determining the weight has three major types: subjective, objective and subjective-objective methods. The weights used in this paper are all derived from the hierarchical analysis method. The weighted average method is expressed by the formula as equation (23):

$$E_i = \sum a_i \cdot S_i \tag{23}$$

where, E_i - the total score after weighting the i th indicator, a_i - the weight taken by the i th indicator, which is generally required to be $\Sigma a_i = 1$, S_i - the rating of the i th evaluation indicator.

IV. C. Calculation and determination of indicator weights

According to the selected indicators, prepare a questionnaire on the weights of the evaluation index system of innovation capacity of colleges and universities, and distribute questionnaires to 10 experts in related fields through the combination of online and offline, 10 questionnaires were distributed, 10 valid questionnaires were recovered, and the questionnaire validity rate was 100%. Based on the recovered questionnaire data, the improved CRITIC assignment method was used to calculate the results of the relative and absolute weights of the indicators at all levels, and the comprehensive indicator weights of the indicators at all levels are shown in Table 5, taking expert 1 as an example.

Table 5: The comprehensive weight results of indicators at all levels (Expert 1)

Index	Index	Relative weight	Absolute weight	Index	Relative weight	Absolute weight
(A) (0.205)	(A1)	0.108	0.02214	(A11)	0.50	0.01107
				(A12)	0.50	0.01107
	(A2)	0.103	0.021115	(A21)	0.284	0.00599666
				(A22)	0.252	0.00532098
				(A23)	0.216	0.00456084
				(A24)	0.248	0.00523652
(B) (0.216)	(B1)	0.102	0.022032	(B11)	0.70	0.0154224
				(B12)	0.30	0.0066096
	(B2)	0.137	0.029592	(B21)	0.371	0.010978632
				(B22)	0.348	0.010298016
				(B23)	0.281	0.008315352
(C) (0.278)	(C1)	0.172	0.047816	(C11)	0.60	0.0286896
				(C13)	0.40	0.0191264
	(C2)	0.145	0.04031	(C21)	0.30	0.012093
				(C22)	0.70	0.028217
(D) (0.301)	(D1)	0.121	0.036421	(D11)	0.172	0.006264412
				(D12)	0.122	0.004443362
				(D13)	0.158	0.005754518
				(D14)	0.178	0.006482938
				(D15)	0.153	0.005572413
				(D16)	0.217	0.007903357
	(D2)	0.112	0.033712	(D22)	0.262	0.008832544
				(D23)	0.271	0.009135952
				(D24)	0.207	0.006978384
				(D25)	0.16	0.00539392

The degree of similarity between the ith expert's and the remaining 9 experts is calculated through the decision-making similarity measure, so as to calculate the decision-making weight coefficients of the 10 experts, and the final results of the indicator weights are obtained through the weighted average as shown in Table 6.

Table 6: The final index weight result

Index	Index	Weight	Index	Weight
(A) (0.250)	(A1)	0.105	(A11)	0.0392
			(A12)	0.0399
	(A2)	0.103	(A21)	0.0547
			(A22)	0.0517
			(A23)	0.0462
			(A24)	0.0378
(B) (0.250)	(B1)	0.12	(B11)	0.0391
			(B12)	0.0304
	(B2)	0.104	(B21)	0.0493
			(B22)	0.0567
			(B23)	0.0389
(C) (0.250)	(C1)	0.109	(C11)	0.0343
			(C13)	0.0413
	(C2)	0.141	(C21)	0.0388
			(C22)	0.0361
(D) (0.250)	(D1)	0.164	(D11)	0.039
			(D12)	0.0374
			(D13)	0.0329
			(D14)	0.0342

			(D15)	0.0366
			(D16)	0.037
	(D2)	0.154	(D22)	0.0655
			(D23)	0.0264
			(D24)	0.0236
			(D25)	0.033

IV. D. Application and assessment of the evaluation indicator system

University H was selected as the experimental subject, and 10 research project teams with different majors were randomly selected from freshman to senior years within University H. The project team members covered freshman to senior years. The selected majors are: (M1) Department of Art, (M2) Department of Vehicle Engineering, (M3) Department of Biological Sciences, (M4) Department of Business Administration, (M5) Department of Chinese Language and Literature, (M6) Department of Information Management, (M7) Department of Geographic Sciences, (M8) Department of History, (M9) Department of Materials and Energy and (M10) Department of English. Points are assigned to each three-level index of the evaluation index system of innovation capacity of universities, each index is full of 4 points, and the index system as a whole is full of 100 points. The results of assessing the innovation ability of 10 scientific research project groups using the evaluation index system of innovation ability of universities are shown in Table 7.On the whole, the innovation ability scores of the 10 scientific research project groups are all 50 points and above, which are initially judged to have certain scientific research and innovation ability. And there are obvious differences in innovation ability between majors, (M1) Department of Art, (M5) Department of Chinese Language and Literature, (M8) Department of History, (M10) Department of English, and other majors that are inclined to the liberal arts have a lower level of scientific research and innovation ability, which are all between 50 and 60. On the other hand, science and technology majors such as (M2) Department of Vehicle Engineering, (M3) Department of Biological Sciences, (M7) Department of Geographic Sciences, and (M9) Department of Materials and Energy have a higher level of scientific research and innovation ability, reaching 75 and above. Accordingly, it can be seen that the level of scientific research and innovation ability is not low in University H as a whole, but there are obvious differences in scientific research and innovation ability among majors. Because of the limitations of liberal arts majors in scientific research and innovation, it is suggested that University H should focus on the development of scientific research and innovation in science and technology majors, and provide sufficient support and guidance for their scientific research and innovation, so as to promote the improvement of the overall level of the university's innovation ability.

Table 7: The innovation ability scores of 10 scientific research project teams

Major	Score
M1	555
M2	79.25
M3	77.5
M4	61.5
M5	57.5
M6	71.25
M7	78.5
M8	59.75
M9	81.75
M10	58.5

V. Conclusion

Combining quantitative screening method and gray statistical analysis, this paper proposes a set of evaluation index system of innovation ability of colleges and universities containing 8 secondary indicators and 25 tertiary indicators from 4 perspectives, including scientific and technological basic input, scientific and technological research and development input, scientific and technological achievements output and scientific and technological effectiveness. And using the improved CRITIC assignment method and the weighted average method to calculate and determine the weights of the indicators, a set of more scientific and objective evaluation method of innovation ability of colleges and universities was formed.

Taking university H as the experimental object, the 10 randomly selected scientific research project groups were evaluated by using the improved university innovation ability evaluation index system. The research project groups as a whole obtained innovation ability scores of 50 and above, but the difference between liberal arts majors and science and technology majors is obvious, reflecting that University H has a certain level of scientific research and innovation ability. It is suggested that the development strategy of innovation ability of University H should focus on the development of scientific and technological majors' research project teams, and provide sufficient support and guidance to them.

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