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An Evaluation Model of Higher Education Based on 3E Evaluation System and Entropy Weight Method

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Abstract: *As the era of knowledge economy coming, education contributes a lot to the development of a country. However, the development of higher education in different countries is uneven. For the sake of numeric measurement of the health and sustainability of higher education, we introduce 9 indicators from three aspects primarily, which are based on CIPP model and 3E evaluation system. Furthermore, combining Principal Component Analysis (PCA) with entropy weight method (EWM), the weight of classified subsystems is obtained and the health and sustainability evaluation model was established. Finally, K-means cluster analysis (KCA) is employed to clarify the higher education level of different countries into four: the first echelon, the second echelon, the third echelon and the fourth echelon.*

Keywords: *higher education, sustainable development, EWM*

1. Introduction

As we look around the world, many countries in the world have establishing a variety of national approaches to higher education, especially the developed countries, such as United States, Germany and so on. However, when every approach applied to practice, each of these national systems of higher education has its strengths and weaknesses. Therefore, changes are needed, which are undoubtedly full of hardship. So it is essential for us to develop a model to measure and assess the health of a system of higher education at a national level, with the aim of better promoting the higher education system and make it healthier and more sustainable.

2. The Health Measurement of Higher education

2.1 Construction of Quality Evaluation Index System of Higher Education

CIPP model is one of the most widely used evaluation systems. It includes four parts: background evaluation, input evaluation, process evaluation and result evaluation. **3E evaluation system** is a method of recognizing and dealing with complex problems, which is proposed by Professor Checkland from the perspective of SSM. It is widely used when soft factors such as society, politics, culture and human behavior are involved, and the traditional hard system analysis loses its advantages and sometimes even fails.

Based on the two models, we construct the analysis framework of the health and sustainability of higher education. After referring to the relevant educational evaluation indicators from the international and universities, we finally choose nine indicators of higher education development quality evaluation from three dimensions: the basis of higher education, the process of higher education and the performance of higher education.

2.2 Determination of Index Weight

Firstly, we choose principal component analysis method to determine the weight of evaluation indicators. We use it to recombine multiple indexes into a new group of unrelated comprehensive indexes. Then, according to the actual needs, we select as few comprehensive indexes as possible, so as to reflect the original index information as much as possible. Specific steps are as follows.

2.2.1 Definite Variable

There are nine factors that affect the quality of higher education. We assume that each influencing

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factor is $x_1, x_2, \ldots, x_p$, and their comprehensive index principal component is $z_1, z_2, \ldots, z_m$.Thus, we have

$$\begin{cases} z_1 = l_{11}x_1 + l_{12}x_2 + \ldots + l_{1p} \\ \ldots \\ z_m = l_{m1}x_1 + l_{m2}x_2 + \ldots + l_{mp}x_p \end{cases} \tag{1}$$

2.2.2 Standardize the Original Data

Because the dimensions of the original data are different, in order to make the data of different dimensions can be calculated, we standardize the original data.

There are random variables $x_1, x_2, \ldots, x_p$, their average of sample are $\overline{x_1}$, $\overline{x_2}$, …, $\overline{x_p}$. And we definite their sample standard deviation as *S1*, *S2*, …, *Sp*. Then, we do a standardized transformation of variables:

$$x_i = \frac{X_i - \overline{X}_i}{S_i} \tag{2}$$

2.2.3 Calculation of Correlation Coefficient Matrix

After standardization, we calculate the correlation coefficient matrix and the corresponding eigenvalues (arranged from small to large) and their corresponding eigenvectors.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ \cdots & \cdots & \cdots\cdot & \cdots \\ r_{p1} & r_{p2} & \cdots & r_{pp} \end{bmatrix} \tag{3}$$

$$r_{ij} = \frac{\sum_{k=1}^{n}(x_{ki} - \overline{x_i})(x_{kj} - \overline{x_j})}{\sqrt{\sum_{k=1}^{n}(x_{ki} - \overline{x_i})^2 \sum_{k}^{n}(x_{kj} - \overline{x_j})^2}} \tag{4}$$

2.2.4 Calculation of Principal Component Contribution Rate

We use the formula 5 to calculate principal component z_i contribution rate.

We use formula 6 to calculate cumulative contribution of principal component z_i .

$$\frac{\lambda_i}{\sum_{k=1}^{p}\lambda_k}(i = 1,2,\ldots,p) \tag{5}$$

$$\frac{\sum_{k=1}^{i}\lambda_k}{\sum_{k=1}^{p}\lambda_k}(i = 1,2,\ldots,p) \tag{6}$$

Generally, we often choose $\lambda_1, \lambda_2, \ldots, \lambda_m$ as the eigenvalues, when the cumulative contribution rate is about 85%. And the eigenvalues $\lambda_1, \lambda_2, \ldots, \lambda_m$ correspond to the first, second and the m-th principal components. Then, by using the above evaluation indicators, we further determine the weight of these indicators, so as to get the combination of the main indicators.

Secondly, we use the regression entropy weight method to standardize, so that the optimal value and the worst value of each variable after alternation are 1 and 0 respectively. Afterwards, we set the evaluation index as X_1, X_2, $X3$, ··; X_k.

We set X = {X_{il}, Xi_2..., X_{in}}. where k and n are the evaluation indexes and the number of sovereign states in the world. where k = 9.

Then we have:

$$y_{ij} = \frac{x_{ij} - \min(x_i)}{\max(x_i) - \min(x_i)}$$
$$y_{ij} = \frac{\max(x_i) - x_{ij}}{\max(x_i) - \min(x_i)} \tag{7}$$

Where y_{ij} is the standard value of each country, max (X_i) and min (X_i) are the maximum and minimum values of the evaluation value X_i.

After standardization, we successfully use yij instead of X_{ij} to express the quality of higher education in a country.

Then we definite

$$P_{ij} = y_{ij}/\sum_{j=1}^{n} y_{ij} \tag{8}$$

After that, according to the concept of information entropy in information theory, follow the formula 9, and the information entropy of each evaluation index can be calculated, and the information entropy E_i of each evaluation index can be obtained.

$$E_i = -\ln(n^{-1})\sum_{j=1}^{n} p_{ij}\ln(p_{ij}) \tag{9}$$

Since we have got information entropy, the weight of each index can be further calculated, according to the formula 10.

$$w_i = \frac{1 - E_i}{k - \sum_i E_i} \quad i=1,2,\ldots\ldots,k \tag{10}$$

2.3 Establishment of Higher Education Quality Evaluation System

After the calculation process, we get the weight of each index, as shown in Table 1.

Table 1: The weight of each index

	Indicators	Weights	Indicators	Weights
Higher education Coupling Model (BPP)	Basic of Higher Education	52.31%	GDP per capita	24.67%
			Proportion of total higher education to GDP	52.10%
			The proportion of R & D expenditure in GDP in Colleges and Universities	23.23%
	Process of Higher Education	27.74%	Ratio of students to teaching staff	19.75%
			The ratio of the total population to the number of Universities	59.36%
			Enrollment rate of Higher Education	20.89%
	Performance of Higher Education	19.95%	Number of papers in sci tech Journals	39.00%
			Number of papers introduced	33.76%
			Number of Top 1000 universities in QS	27.24%

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3. Model Test

3.1 Model Test on 3 Countries

Given that our evaluation model is a generalized model whose parameters cannot be determined until the target state is chosen, we test it on 3 countries respectively so as to certify its robustness and validity. And the 3 countries are Germany, Mexico and Indonesia.

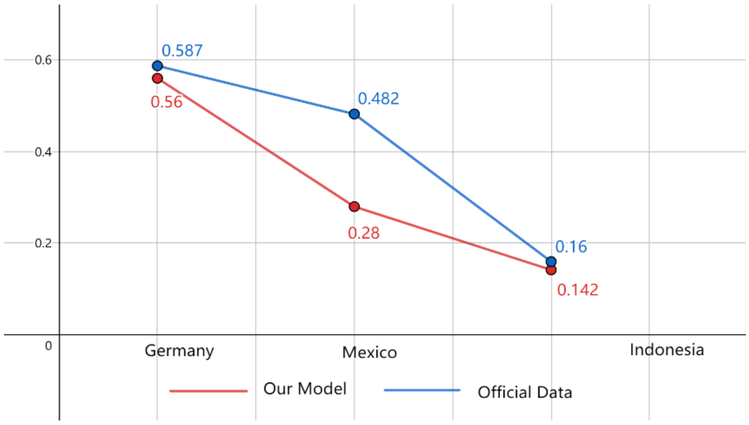

Figure 1: Comparison of the rank based on our model and official data

From Figure 4 above, it can be interpreted that the rank of higher education quality according to the evaluation from our model differs from that according to Official Data, but in a reasonable range. The tendency of the two lines is similar.

Thus, we could come to the conclusion: Countries with a good foundation of higher education, especially those with higher total investment in higher education, are more likely to show excellent quality of higher education. For example, compared with Mexico, there is a big gap in Indonesia's investment in the foundation of higher education, especially in higher education. AS a result, the quality of higher education in Mexico is better.

3.2 Classification of Four Level

Based on the outcome of 15 countries, we then work on obtaining a relatively accurate range of four levels of higher education. Here, we adopt K-means cluster analysis (KCA), a statistical analysis to assign the most concentrated and least dispersed cluster labels to the input training samples.

We divide the data into three groups, and then randomly select three objects as the initial clustering centers. Cluster groups are significant for all research items ($p<0.05$), which means that there are obvious differences in the characteristics of research items (comprehensive scores) among the three groups obtained by cluster analysis, and the specific differences can be compared through the average value, and finally combined with the actual situation.

Table 2: The analysis results of Cross (chi square)

	Title	cluster1	cluster2	cluster3	Total	χ^2	p
Region	China	0(0.00)	0(0.00)	1(16.67)	1(7.69)	26	0.353
	India	0(0.00)	1(25.00)	0(0.00)	1(7.69)		
	Brazil	0(0.00)	1(25.00)	0(0.00)	1(7.69)		
	Singapore	1(33.33)	0(0.00)	0(0.00)	1(7.69)		
	Japan	0(0.00)	0(0.00)	1(16.67)	1(7.69)		
	Chile	0(0.00)	1(25.00)	0(0.00)	1(7.69)		
	Saudi Arabia	0(0.00)	0(0.00)	1(16.67)	1(7.69)		
	France	0(0.00)	0(0.00)	1(16.67)	1(7.69)		
	Thailand	0(0.00)	1(25.00)	0(0.00)	1(7.69)		
	Australia	1(33.33)	0(0.00)	0(0.00)	1(7.69)		
	The United States	1(33.33)	0(0.00)	0(0.00)	1(7.69)		
	The United Kingdom	0(0.00)	0(0.00)	1(16.67)	1(7.69)		
	The Netherlands	0(0.00)	0(0.00)	1(16.67)	1(7.69)		
Total		3	4	6	13		

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Then, we classify the quality of higher education into four levels, as shown in Table 3.

Table 3: Classification of higher education level

Level	Range
the first echelon	0.56(±0.11) - 1
the second echelon	0.36(±0.05) - 0.56±(0.11)
the third echelon	0.17(±0.06) - 0.36(±0.05)
the fourth echelon	0 - 0.17(±0.06)

4. Strengths and Weaknesses

4.1 Strengths

Based on CIPP evaluation mode and 3E evaluation system, we constructed our model. We can use our model measure its own output, and reflect the system's utilization of resources, and reflect the effect of the system's output on its superior system. By widely collecting data and literature, we transformed the evaluation of higher education into three aspects: foundation of higher education, process of higher education and performance of higher education.

Meanwhile, we modified some secondary indicators, such as the total investment in higher education to the ratio of higher education and national GDP, which can be used to more reasonably evaluate the countries, whose development status is not so advanced.

Moreover, our model uses principal component analysis and entropy weight method to reduce the interaction between multiple secondary indicators. At the same time, the weight of indicators created by this way is objective and reasonable, which has higher credibility and accuracy than the subjective weight.

4.2 Weaknesses

We use the CIPP model to construct the quality evaluation index system of higher education development, however, because the variance of the first principal component of this method is the largest among all the original variables, the variance of the comprehensive evaluation function will not exceed the variance of the first principal component, so this method has some defects.

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