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Evaluate Higher Education Systems By Principal Component Analysis and Fuzzy Comprehensive Evaluation

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Abstract

This paper focuses on measuring and assessing the health of the nation's higher education system, developing a model to assess the health of the higher education system based on principal component analysis and fuzzy integrated evaluation methods. We derived the five most important indicators and arrived at a ranking of the health status of higher education systems in 30 countries. Then, the model is applied to evaluate the higher education systems of the United States, China, and Japan.

Keywords

Principal Component Analysis; Fuzzy Comprehensive Evaluation; Higher education system sustainability index.

1. Introduction

The universalization of higher education has become a mainstream trend in the development of global higher education. In terms of theory, existing studies have mainly adopted interdisciplinary perspectives such as sociological theory, institutional theory, and economic theory to construct and explain the changes of the higher education system by quantitative and qualitative research methods, strengthen the comparative study of differences among different countries, and actively explore the development path of non-elite higher education, and pay attention to various issues such as equity and development of higher education.

We developed a model to assess the health of the higher education system in any country and tested it.

2. Model Establishment and Solution

2.1. Principal Component Analysis

The assumption is that the matrix before standardization Z is the matrix after standardization zj is the statistics of indicator j for each country; u is the main component to be assessed, so the objective function can be as:

$$\begin{cases} u_1 = l_{11}z_1 + l_{12}z_2 + \cdots + l_{1p}z_p \\ u_2 = l_{21}z_1 + l_{22}z_2 + \cdots + l_{2p}z_p \\ \cdots\cdots\cdots\cdots \\ u_m = l_{m1}z_1 + l_{m2}z_2 + \cdots + l_{mp}z_p \end{cases} \quad (1)$$

where u_1, u_2, ...um is called the 1st, 2nd, ...mth principal components of the indicators z_1, z_2, z_p; l is the load of the original indicator z_j (j=1,2,...,p) in each principal component.

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2.2. Fuzzy Comprehensive Evaluation

The fuzzy integrated evaluation model established is:

$$B(b_1, b_2, \cdots, \mathrm{b_m}) = (a_1, a_2, \cdots, a_n)\begin{bmatrix} r_{11} & \cdots & r_{1m} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{nm} \end{bmatrix} \tag{2}$$

A fuzzy comprehensive evaluation is to quantify the fuzzy indicators reflecting the evaluated things by constructing hierarchical fuzzy subsets (i.e., determining the affiliation degree), and then synthesizes each indicator by using the principle of fuzzy change. There are three main parts: determination of weights, determination of fuzzy relationship matrix, and selection of operators.

If we set $u=\{u_1,u_2,..., u_n\}$ as the set of factors of the evaluation object, which represents the set of factors of the evaluation model, for this question, then un (n=1,2,3,4,5,6) represents the five indicators of the number of disabled people going on to higher education, the state financial investment, the average annual salary of graduates, the proportion of female students, and the number of international papers published, respectively.

Then let $v=\{v_1,v_2,...,v_m\}$ be the set of judgments, representing the set of decision objectives. In this problem, we set v_m to represent the health level of the higher education system, and set it to 3 levels: poor, reasonable, and good, i.e., corresponding to m=3.

Since the influence of each fuzzy factor in the set of factors on the thing being judged is different, there exists an influence distribution, i.e., weight distribution, for each influential factor on the judged target. Let $A = \{a_1, a_2, ..., a_n\}$ represent the set of weight assignments, where ai denotes the degree of influence of the ith factor in u. However, this amount of relative weight belongs to a fuzzy concept, which is a fuzzy vector belonging to a fuzzy vector on u, with $A \in F(u)$.

Similarly, m judgments in a fuzzy setting are not positive or negative. So the result of the fuzzy comprehensive evaluation model can be viewed as a fuzzy set on v, which is written as $B=\{b_1,b_2,..., b_m\} \in F(v)$. where b_j denotes the status of the jth middle evaluation in the overall v of the evaluation target.

Construct $R=(r_{ij})_{n*m}$ matrix to react from u to v and use it to obtain a fuzzy transformation T_R.

2.3. Education Evaluation Model

After 2010, the United Nations Development Program uses the following formula to calculate the Education Index.

$$\mathrm{EI{:}\ EI} = \frac{\sqrt{\mathrm{MYSI} \cdot \mathrm{MYSI}} - 0}{\mathrm{EI}_{ob} - 0} \tag{3}$$

Where MYSI is the average years of schooling index for the population. $MYSI=MYS/MYS_{ob}$. MYS is the average number of years of schooling of the population, is the expected number of years of schooling (including repetition) for children born in the current year, and is the sum of age-specific enrolment at all levels of education (Primary education, secondary education, higher education, etc.). MYS_{ob} is the reference value of the expected number of years of schooling of the population in that year (up to 18 years, which is the sum of the time needed to obtain a master's degree in most countries). EI_{ob} is the reference value of the education index for that year.

Here we creatively propose the sustainability index X by replacing the UNDP's education index equivalently with the rubric derived from the fuzzy evaluation algorithm:

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$$X = \frac{\sqrt{\mathrm{KCX} \cdot \mathrm{KCX}} - 0}{\mathrm{IKCX} - 0} \tag{4}$$

Where KCX is the sustainability index expectation. KCX=I_a / I_c. I_a is the first parameter derived for one of the years in the fuzzy algorithm. I_c is the third parameter in the fuzzy algorithm. IKCX is the second parameter in the fuzzy algorithm, i.e. the standard value of continuous development. IKCX= I_b.

2.4. Results

We obtained a ranking of 30 countries with comprehensive valid data according to the Sustainability Index, as shown in **Table. 1**.

Table. 1 Sustainability Index

Nation	KCX	IKCX	X	Nation	KCX	IKCX	X
Canada	11.857	0.1	118.6	American	1.322	0.27	4.896
New Zealand	9.875	0.13	75.9	Italia	1.267	0.32	3.959
Finland	8.667	0.13	66.7	Britain	1.186	0.30	3.953
Denmark	7.091	0.11	64.5	German	1.179	0.39	3.023
Norway	7.600	0.14	54.3	Japan	0.846	0.28	3.021
Korea	8.625	0.23	37.62	Switzerland	1.01	0.43	2.35
Ireland	6.273	0.20	31.362	Russian	0.907	0.45	2.016
Netherlands	7.333	0.25	29.332	Portugal	0.676	0.38	1.779
Greece	3.353	0.26	12.896	Brazil	0.658	0.37	1.778
Iceland	2.895	0.26	11.135	Thailand	0.644	0.37	1.741
Cuba	2.500	0.23	10.87	China	0.923	0.50	1.846
Luxembourg	2.000	0.25	8.0	Singapore	0.852	0.50	1.704
Belgium	1.840	0.29	6.345	Viet Nam	0.885	0.51	1.732
Sweden	1.586	0.25	6.344	Iran	0.852	0.50	1.690
Spain	1.518	0.32	4.744				

We loaded the ranking of all 30 member countries for 2018 from the official website, as shown in **Figure. 1**.

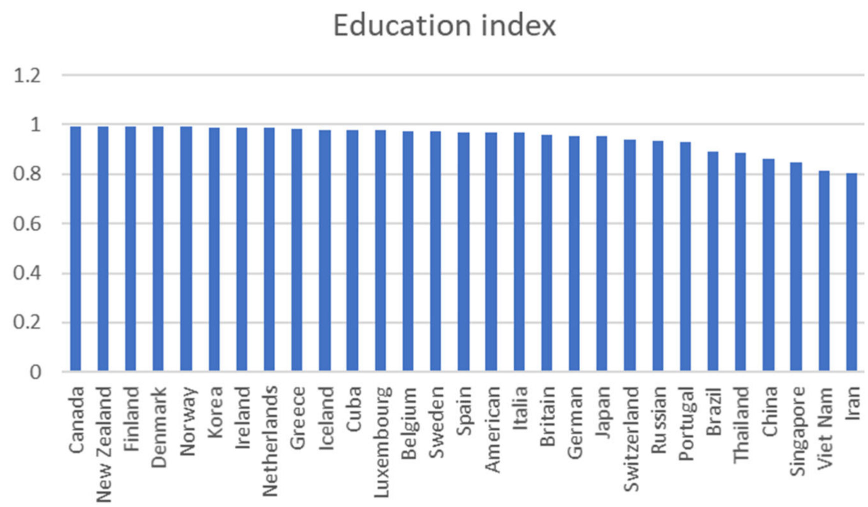

Figure. 1 Education Index Rank [1]

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The reliability and usefulness of our model can be tested to some extent by comparing our ranking with the 2017 UNESCO Education Index ranking. **Figure. 2** clearly shows the relationship between them.

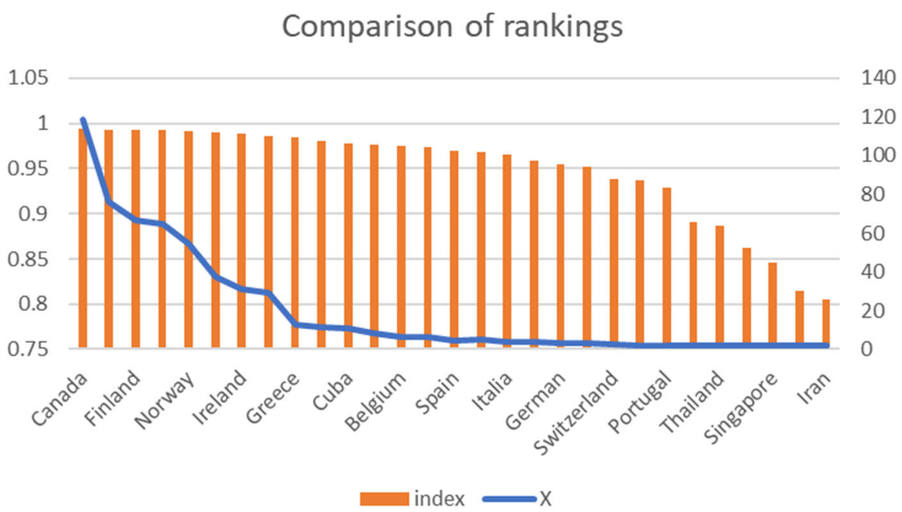

Figure. 2 Comparison of rankings

We can see that the rankings of the 30 countries match very well. This means that the results of our model are very consistent with the official results. Therefore, we can conclude that our model is practical and reasonable.

3. Model Application

We first selected the 10 countries from the 30 countries that had data on these 5 components. The calculated feature roots are shown in **Table. 2**.

Table. 2 The top 5 components

Rank	Characteristic value	Contribution rate (weighting)	Cumulative contribution rate
1	3.4746	0.69492	0.69492
2	1.0738	0.21476	0.90968
3	0.3659	0.07318	0.98286
4	0.0466	0.00932	0.98286
5	0.0391	0.00782	0.99068

As can be seen from Table 2, the cumulative contribution from the second subcomponent is 81.5%, which means that most of the main subcomponent is involved, so these five components are our composite indicators. We renamed these five composite indicators as indicators A, B, C, D, and E to reflect the health of each country's higher education system.

Taking China as an example, the development trend of each indicator is analyzed as follows.

Indicator A is proportional to time.

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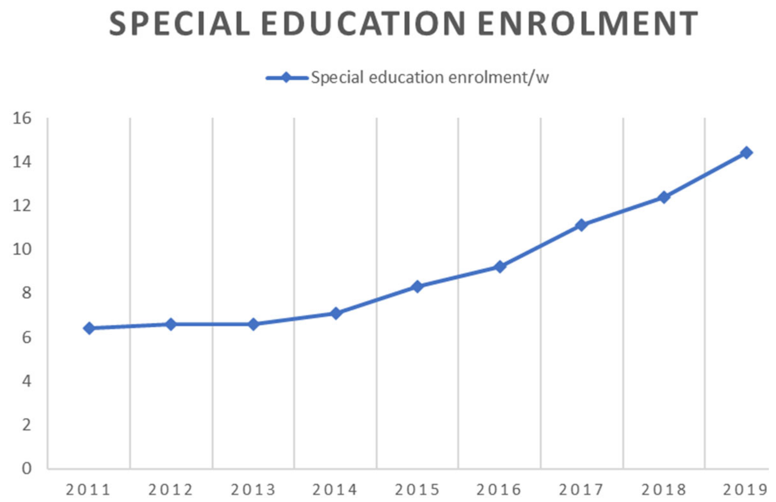

Figure. 3 Indicator A

Indicator B has been fluctuating with a decreasing trend over the period 2011-2019.

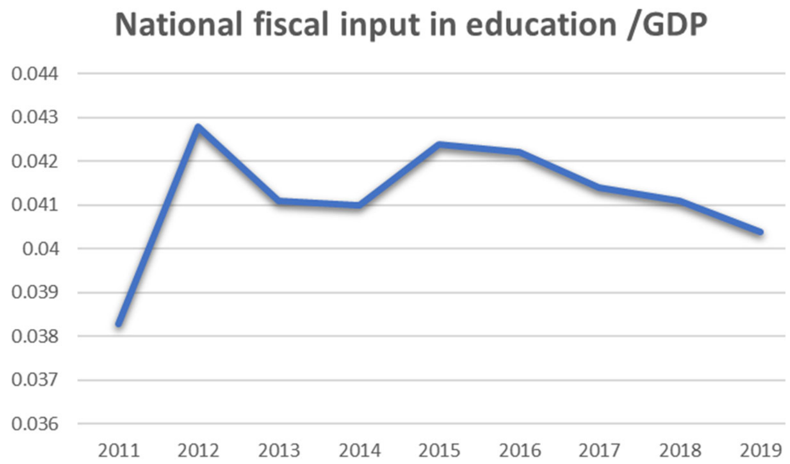

Figure. 4 Indicator B

Indicator C is proportional to time.

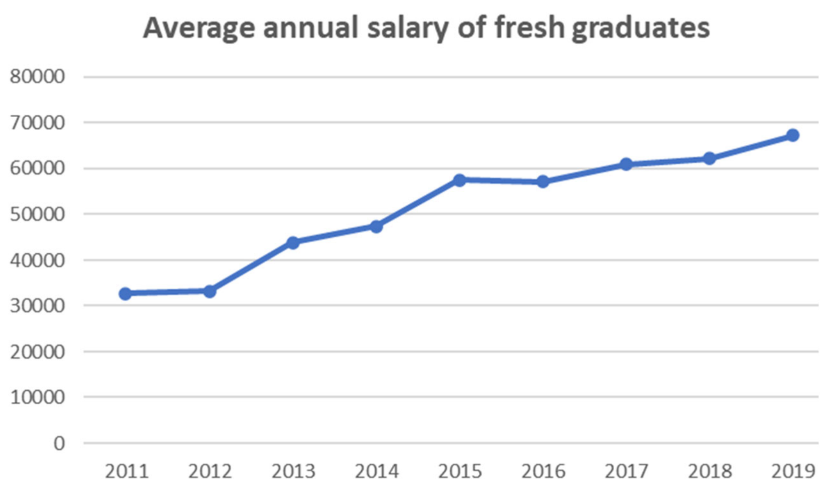

Figure. 5 Indicator C

Indicator D has fluctuated and stabilized over the period 2011-2019.

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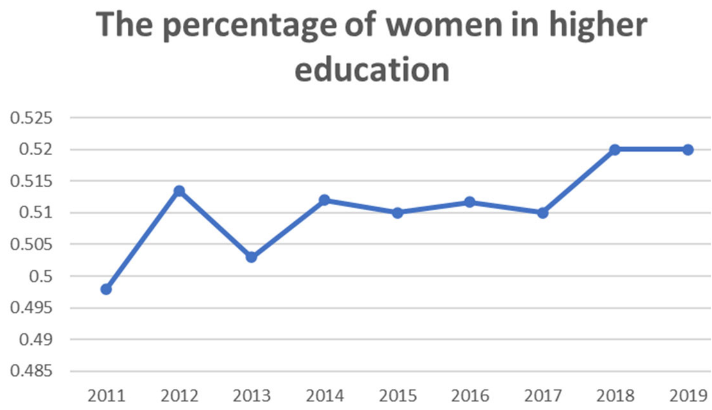

Figure. 6 Indicator D

Indicator E is proportional to time and grew rapidly in 2015

Figure. 7 Indicator E

A fuzzy comprehensive evaluation algorithm to calculate the weights of five indicators was implemented. And a comprehensive evaluation table and sustainability index for three complete statistical countries, the United States, Japan, and China were derived.

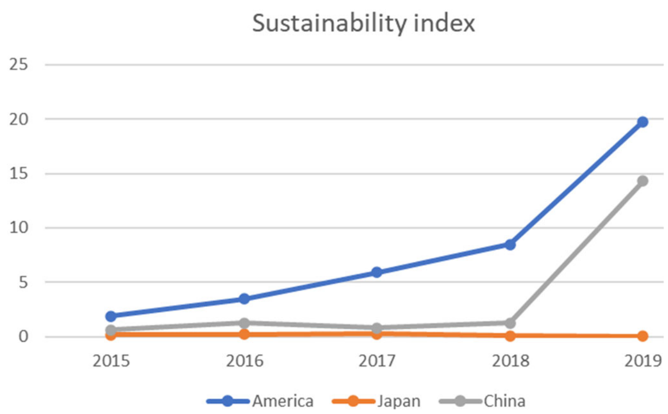

Figure. 8 Sustainability index

The sustainability indexes of the U.S. and China are generally on the rise, and the higher education system is healthy and sustainable; the sustainability index of Japan tends to be stable, and the higher education system is relatively healthy and stable.

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4. Sensitivity Analysis

According to our analysis of the problem, all five indicators have an impact on the health of the higher education system, so it is necessary to know the magnitude of the impact of changes in the indicators on the final benefit. This requires a sensitivity analysis of satisfaction first. In the model application above we obtained the fuzzy evaluation results and sustainability index for China for the period 2015-2019, and the corresponding fuzzy evaluation results and sustainability index are calculated and compared graphically below by changing the indicators as follows.

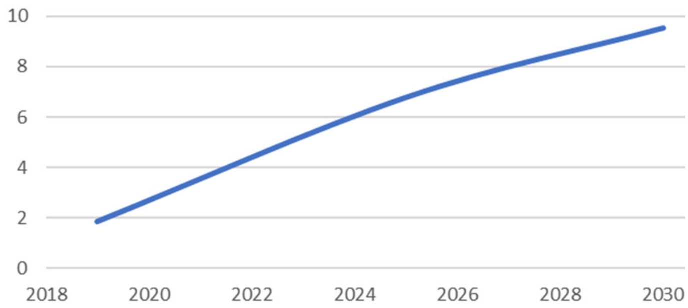

Figure. 9 Sensitivity analysis

Figure 9 is drawn by changing the number of special education enrollment, national financial investment in education/GDP, the average annual salary of fresh graduates in higher education, the proportion of women in higher education, and the number of international papers published in each country, and it can be seen from the graph that the sustainability index changes by a relatively large amount, so our model is more sensitive.

5. Conclusion

In this paper, we applied the interpolation method to the data, the principal component analysis, and the fuzzy evaluation algorithm to evaluate the higher education system of several countries for each year. Finally, we creatively cited UNESCO's education index and brought in the data of each country we obtained in the evaluation to obtain the higher education sustainability index X. We also ranked the sustainability index of 30 countries and focused on the data of China from 2015 to 2019. The following conclusions were obtained.

The criteria for judging the sustainability system of higher education were constructed.

The data of the United States, China, and Japan from 2015 to 2019 were brought into the model to solve, and it was found that the overall sustainability index of the United States and China showed an increasing trend, and the higher education system was healthy and sustainable; the sustainability index of Japan tended to be stable, and the higher education system was more healthy and stable.

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