Health Evaluation System of National Higher Education Based on Improved Entropy Weight Method Combined with GE Matrix

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ABSTRACT

In order to measure whether a country's higher education system is healthy and sustainable, the higher education system (hereinafter referred to as HES) is divided into three aspects: input, environment, and output. These three aspects are analyzed and refined respectively, which are used as indicators to quantify the HES and establish the evaluation framework of HES. Based on the entropy weight method improved by normalizing data collected from various countries of the world, the weight of three aspects and the scores of the health degree and sustainability of HES can be determined. Finally, after integrating results into GE matrix, a system is established to measure the health status of any country's HES. Based on the National Higher Education Evaluation System (hereinafter referred to as NHEES) established in this paper, further discussion is made to analyze and verify the effectiveness of the system. The application of the system can evaluate the health status of higher education in any country of the world, make relevant decisions and innovations to specific countries.

CCS CONCEPTS

• **Computing methodologies**; • **Modeling and simulation**; • **Model development and analysis**;

KEYWORDS

Higher education, Evaluation system, Entropy Method, GE-Matrix

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1 INTRODUCTION

1.1 Background

For the continuation and rise and fall of human civilization, education is definitely a big deal. Higher education, as a social activity to cultivate senior professionals, has a profound impact on the development of science and technology, economy, and other aspects of society.

With the pursuit of human progress, the demand for the right [1] to enjoy good higher education is increasing. Statistics from UNESCO show that in the past 20 years, the total enrollment rate of global higher education has almost doubled, from 19% to 38% between 2000 and 2018 [2]. From the perspective of decision makers, whether the educational resources are sufficient, high-quality, fully utilized, and whether the system is efficient are the questions that need to be considered. Meanwhile, for the direct participants and beneficiaries, it's also notable to keep a watchful eye on whether the education system is fairly and open.

1.2 Motivation

Although the world attaches more and more importance to higher education, the fact is that the higher education system in all countries is unique, and closely related to the economic development, national history, and social environment of the country. Different countries have different systems of higher education, and each has its own merits and demerits.

At present, scientific research isn't perfect in evaluating the health level of higher education system of any country in the world. There is lack of a comprehensive evaluation system to assess the health of higher education in any country. For example, the number of universities in a country is small, but we can't simply say the country's higher education is unhealthy, perhaps because the country's geographical area is small, etc.

In order to learn from each other's strong points and master the health status of HES between countries, it is necessary to combine education with data to establish a comprehensive system for comprehensive evaluation of HES that can be applicable to any country of the world.

1.3 Paper Structure

This paper introduces the whole process of how to evaluate the health status of higher education in any country of the world. First, we establish a framework of HES as our evaluation system's organizing framework, which shows in Section 3.1. Then, referring to OECD education indicators [3], we determine the indexes participating evaluation in Section 3.2. Next, we collected data from 13 countries in the world for each indicator. Determine the weight of each indicator using entropy weight method improved by normalizing data in Section 4.1, and then we can calculate the score of each country as the health level of its higher education. Next in Section 4.2, we put forward health index (HI) and coordination index (CI) as the X-axis and Y-axis of GE Matrix respectively [4],

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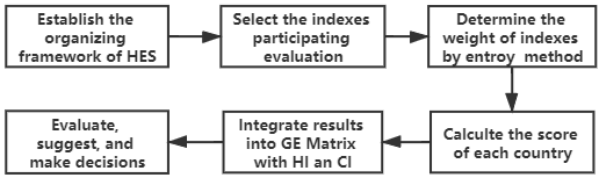

Figure 1: Paper Structure.

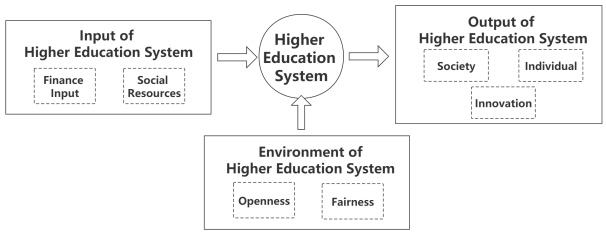

Figure 2: Framework of NHEES.

and use GE Matrix integrated the scores of each country as the evaluation method. Finally, in Section 5, we choose 13 countries around the world to apply and test the evaluation system proposed in this paper, and take Estonia as an example for in-depth evaluation and suggestions. The whole structure concisely shows in Figure 1

2 PREMISE

All the considerations and modeling in this paper are based on the following contents:

- We assume in foreseeable future analyzed in this article, education is still needed and its method won't be disruptively changed (for example no brain-computer interface).
- In the process of modeling, we won't consider the sudden impact on the input and operation of the education system caused by great changes outside the education system (such as the sudden civil war).

And to ensure that the evaluation system has some good attributes, we need to start with the following principles to select indicators and build the system.

- Systematic. As a complex system, higher education is multifactorial and hierarchical. The selection of indexes and the establishment of models need the internal laws and relations of the reaction system.
- Comparable and Operable. Each indicator used for evaluation should have a unified standard and measurement method, and from the perspective of implementation, the data used for the evaluation model needs to be easy to collect.
- Scientific. The indexes used in the evaluation should conform to the facts, have clear significance and representativeness, represent one aspect of the characteristics of the system, and reflect the connotation and essence of the higher education system. In addition, we should pay attention to the reliability and objectivity of the data while getting data.

3 EVALUATION FRAMEWORK

3.1 Organizing Framework

In the process of constructing the evaluation model framework of higher system, we draw on the experience of higher education evaluation in the UK [5]. According to the operation of the system, we divide the system into three parts: higher education system input, environment, and output. There is no direct comparability between the actual operation of the higher education system and the differences between different systems, so there is no index to quantify directly. Analyze the relevant aspects of the three, and complete the selection of indicators combined with the specific situation and significance and then establish the evaluation framework of higher education system, as shown in Figure 2

3.2 Index Selection

3.2.1 Input of Higher Education System. The normal operation of the higher education system and the completion of the mission need a certain amount of resources. It can be roughly divided into three aspects: human, material, and financial resources. In a broad sense, material resources are the embodiment of material assets and teaching resources that are inherent or uneasy to change, and can be used or maintained in the original form for a long time, such as land, teaching facilities, teaching knowledge materials, etc.; human and financial resources are the dynamic assets of education assets, or the dynamic input, which includes the flow elements into the system, and it is often reflected in the state's current investment in education (education budget expenditure).

In reality, the biggest impact on the existing system is capital inflow. We use four indicators to measure it, and three of them evaluate the direct education expenditure, while one evaluates the proportion of scientific research and development in the field of education, as shown in Table 1

At the same time, for human and material resources, we collectively referred to as social resources, and use four indicators shown in Table 2 to evaluate.

3.2.2 Environment of Higher Education System. Higher Education System Environment refers to the state of higher education system in the country or society, including national economic situation, government policy, social openness, access to educational participation and progress opportunities, etc. [6]

In this model, based on the idea that it is easy to quantify the indicators, we select openness and fairness to represent the environment. Openness can be understood as the opening up and development of a country, as well as the depth and breadth of exchanges and cooperation with the world. In the framework of this paper, we use the following two indicators shown in Table 3 to quantify it.

Fairness is understood as the fairness of education. There are educational equity problems all over the world. For example, individuals have different educational opportunities and gender imbalance. Two indicators showing in Table 4 are used to quantify it.

3.2.3 Output of Higher Education System. Output measures need to cover research, teaching and training. Research performance is measured by publications and their impact; education and training

Table 1: Indices of Finance Input

Finance Input	Explain
Expenditure on HE institutions as a percentage of GDP	Showing the overall level of investment in higher education at the systemic level
Public expenditure on HE as a percentage of total public expenditures	Indicating how much the government invests in education, relative to these other domains
Annual expenditure per student by higher education institutions	Showing the actual amount of resources available to higher education institutions, relative to the number of students
Annual expenditure per student by higher education institutions	Showing the investment of society in R&D

Table 2: Indices of Social Resources

Social Resources	Explain
Ratio of students to academic staff in higher education	Showing how resources for education are allocated
Full-time equivalent researchers per 1000 people	One way of comparing the supply of researchers to R&D systems is through measuring the numbers of researchers relevant to the size of the labor force
Total number of universities	Representing the quantity of higher education
Number of top 100 universities	Representing the quality of higher education

Table 3: Indices of Openness

Openness	Explain
Total number of international students	Reflecting the relative opening and development of the country
Rate of international collaboration	Showing the extent and breadth of international exchanges and cooperation measured by measured by examining coauthor ships on peer-reviewed articles.

Table 4: Indices of Fairness

Fairness	Explain
Access to education	Showing how much opportunity people in the country have for higher education and using entry rates to higher education to quantify it.
Absolute value of sex ratio among people with higher education	Indicating the difference in the number of men and women with higher education in the country.

Table 5: Indices of HES Output

	Society	Explain
Society	Education attainment	Showing that the higher education system has a long-term indirect impact on society.
	Employment rates of bachelor's graduates (25-34year-old)	Showing the efficiency of higher education system
Individual	Relative earnings of bachelor's graduates (25-34year-old)	Showing the quality of higher education and the ability to renew itself through innovation and creative thinking
Innovation	Number of citable documents including articles, reviews and conference papers	Indicating the difference in the number of men and women with higher education in a country.

Table 6: Three Level of HES

Level 1	Level 2	Level 3
Higher Education System Input (HESI)	Finance input	Expenditure on HE, % of GDP
		Public expenditure on HE, % of total public expenditures
		Annual expenditure per student by HE institutions
		HE R&D expenditure, % of GDP
	Social resources	Ratio of students to academic staff in HE
		FTE researchers per 1 000 people
		Number of top 100 universities
		Total number of universities
Higher Education System Environment (HESE)	Openness	The total number of international students
		rate of international collaboration
	Fairness	Absolute value of sex ratio among people with HE
		Access to education
Higher Education System Output (HESO)	Society	Education attainment
		Employment rates of bachelor's graduates (25-34year-old)
	Individual	Relative earnings of bachelor's graduates (25-34year-old)
	Innovation	Number of citable documents

are measured by student throughput. But if a large number of graduates can't meet the needs of the national economy, it may waste national resources. Therefore, the best measure of teaching and training should be the graduation rate of undergraduates. But on the other hand, from the perspective of hierarchy, we divide the output of higher education into three secondary indicators, namely, innovation, individual and society, to measure the output. The specific indicators of each level are shown in Table 5

In this section, we discuss the above three aspects of the evaluation framework, select indicators and analyze the reasons for the selection of each indicator, and finally form the three-level indicators of the evaluation framework, as shown in Table 6

4 ESTABLISHMENT OF EVALUATION SYSTEM AND EVALUATION METHOD

4.1 Scoring System Based on Improved Entropy Weight Method

4.1.1 Normalization. When evaluating the health status of higher education system in different countries, the indicators selected at different levels have different dimensions and dimensions. Therefore, it is necessary to standardize various indicators into a general-purpose scale, that is, the system should standardize all the data in the study before using it for the model. Firstly, the maximum minimum standardization method is considered to be used to deal with it. However, because the method is very sensitive to outliers, it isn't robust and the distribution isn't uniform enough, so we improve the entropy method by normalizing data using following method.

According to the nature of indicators, they can be divided into two categories: positive indicators and negative indicators. Collect the data of N indicators from M countries to construct the matrix $\boldsymbol{X}$, and x_{ij} represents the original value of the index of sample country j, where (i = 1, 2, ..., n) and (j = 1, 2, ..., m). For indicator I, the matrix $\boldsymbol{r}$ is constructed to represent the similarity level between the original data of indicator I and the optimal value of indicator I in all country data. As shown in formula (1), for positive indicators, the higher the value, the better the health status of higher education system.

$$r_{ij} = \frac{x_{ij}}{max_j(x_{ij})} \tag{1}$$

Where $max_j(x_{ij})$ is the best value of positive indicator I, which means the maximum value indicator I among all M sample countries.

For negative indicators, as shown in formula (2), the higher the value, the worse the health status of HES.

$$r_{ij} = \frac{min_j(x_{ij})}{x_{ij}} \tag{2}$$

Where $min_j(x_{ij})$ is the best value of negative indicator I, which means the minimum value of indicator I among all M sample countries.

After the matrix $\boldsymbol{r}$, it is specified that f_{ij} represents the final standardized value of index I of sample country j, and its calculation is shown in formula (3).

$$f_{ij} = \frac{r_{ij}}{\sum_{j=1}^{m} r_{ij}} \tag{3}$$

4.1.2 Entropy Weight Method to Determine the Weight and Calculate the Comprehensive Score [7]. Previous studies have successfully used this method to determine the weight of a group of indicators which are used for evaluation [7]. Entropy was first introduced into information theory by Shannon [8], whose basic idea is to determine the target weight according to the variability of the index. The smaller the information entropy of the index, the greater the variability of the index value and the more information it provides. Therefore, the greater the role and the greater the weight in the NHEES. Compared with the subjective assignment method, this method can better explain the results with higher accuracy and objectivity.

Through entropy weight method, the normalized data is processed into three main variables (dimension reduction), namely as above, input, environment, and output of HES.

First, calculate the information entropy of each index, the entropy value E_i of index I is obtained by equation 4).

$$E_i = -\ln(n)^{-1} \sum_{j=1}^{m} f_{ij} \cdot \ln f_{ij} \tag{4}$$

where $i = 1,2,3, \ldots, n; E_i \geq 0$, *and if* $f_{ij} = 0$, $E_i = 0$

According to the information entropy of each indicator E_1, E_2, . . ., the weight of each indicator can be calculated, and then the comprehensive score of each country can be obtained, that is, the comprehensive performance of sample country j from indicator 1 to N can be defined as shown in formula (5).

$$w_i = \frac{1 - E_i}{\Sigma_{i=1}^{n}(1 - E_i)}, \quad F_j = \sum_{i=1}^{n} w_i \cdot f_{ij} \tag{5}$$

Since our National Higher Education Evaluation System has three main aspects, we accordingly get three Fs to describe the comprehensive performance of a country (j omitted in the equation) on higher education system input (in), environment (en), and output (out) aspects.

$$\begin{aligned} F_{in} &= \sum_{i=1}^{n_{in}} w_{i(in)} \cdot f_{ij(in)} \ i = 1, 2, \ldots, n_{in} \\ F_{en} &= \sum_{i=1}^{n_{en}} w_{i(en)} \cdot f_{ij(en)} \ i = 1, 2, \ldots, n_{en} \\ F_{out} &= \sum_{i=1}^{n_{out}} w_{i(out)} \cdot f_{ij(out)} \ i = 1, 2, \ldots, n_{out} \end{aligned} \tag{6}$$

4.2 Evaluation Method

4.2.1 Health Index and Coordination Index. In this paper, health index (HI) is used to describe the overall health status of higher education system, and coordination index (CI) is used to describe the consistency and coordination of health status between higher education input (in) and higher education output (out). Following the above formulas, we define Health Index (HI) to be

$$HI = C \cdot F \tag{7}$$

$$\text{where} \quad \mathbf{C} = \begin{bmatrix} \boldsymbol{\gamma_{in}} \\ \boldsymbol{\gamma_{en}} \\ \boldsymbol{\gamma_{out}} \end{bmatrix}^T \quad \mathbf{F} = \begin{bmatrix} \boldsymbol{F_{in}} \\ \boldsymbol{F_{en}} \\ \boldsymbol{F_{out}} \end{bmatrix}$$

$$\boldsymbol{\gamma_{in}} = \sum_{i=1}^{n_{in}} w_{i(in)} \quad i = 1, 2, \ldots, n_{in}$$

$$\boldsymbol{\gamma_{en}} = \sum_{i=1}^{n_{en}} w_{i(en)} \quad i = 1, 2, \ldots, n_{en}$$

$$\boldsymbol{\gamma_{out}} = \sum_{i=1}^{n_{out}} w_{i(out)} \quad i = 1, 2, \ldots, n_{out}$$

And the Coordination Index (CI) is defined as [9]:

$$CI = 1 - \frac{S}{\bar{F}} \tag{8}$$

$$\text{where} \ S = \sqrt{\frac{1}{2}\left[(F_{in} - \bar{F})^2 + (F_{out} - \bar{F})^2\right]}$$

$$\bar{F} = \frac{1}{2}(F_{in} + F_{out})$$

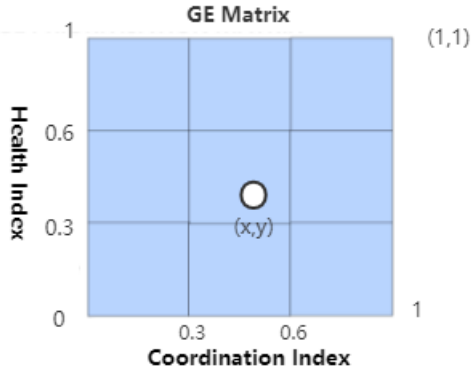

Figure 3: GE Matrix Diagram.

4.2.2 Using GE Matrix to Evaluate the Health Status of Higher Education System [10]. As shown in Figure 3, we can determine the position (x, y) in the GE Matrix if we use the GE Matrix if we use the GE Matrix with hi value as y and CI value as X of a country in any given year the distance between (x, y) and the best position (1,1) is regarded as the health score of a country's higher education system. So, the lower the score, the more similar it is to the best, and the healthier the higher education system that represents a country.

In this section, based on the evaluation framework proposed in Section 3, we discuss that how to improve entropy weight method by normalizing collected data, and how to use entropy as a weighting mechanism. Finally, applying GE matrix with HI and CI we proposed, the complete evaluation system is established. Then, below is about how to apply the NHEES.

5 APPLICATION OF NATIONAL HIGHER EDUCATION EVALUATION SYSTEM

5.1 Practical Application

The NHEES is applied to 13 countries to assess the health status of their HES. The selected countries are highly representative, including developed countries and developing countries, involving six continents. Collect and integrate data of the selected indicators from The World Bank Database [11], UNESCO Database [12], OECD Database [13], and other authoritative organizations by our own, obtain HI and CI, and then score the health level of a country's HES, as shown in Table 7. The lower the score, the healthier a country's higher education system. As a result, the United States ranks the highest of all countries and Chile the lowest.

According to the HI value (Y-axis) and CI value (x-axis) of each country, display its coordinates in the GE Matrix, as shown in Figure 4. From the distribution of location (x, y), we can see that the health level of American higher education system is much higher than that of other countries. In some developed countries, such as Germany, Australia and Japan, their HI values are very close, ranging from 0.03 to 0.04, and their final scores are very close. China and India, the two largest developing countries, have higher HI values, but lower CI values, lagging most developed countries. For other developing countries, their current higher education system isn't a healthy and sustainable system.

Table 7: Score of 13 Countries

Rank	Country	Input	Env	Output	HI	CI	Score
1	U.S.	0.128797	0.024407	0.100947	0.097083	0.311087	1.13572
2	Germany	0.021682	0.008501	0.052141	0.03939	0.297344	1.190167
3	Australia	0.015465	0.012653	0.040261	0.030818	0.309089	1.19024
4	China	0.021279	0.005613	0.089302	0.062802	0.263669	1.191857
5	Japan	0.01506	0.005577	0.044775	0.032811	0.286131	1.202108
6	Russia	0.008766	0.007493	0.041362	0.029397	0.279969	1.208517
7	Brazil	0.014637	0.002964	0.047011	0.03385	0.273637	1.208739
8	Saudi Arabia	0.009347	0.004735	0.031131	0.022654	0.286374	1.210152
9	India	0.012716	0.001775	0.051854	0.036379	0.258757	1.215732
10	Estonia	0.007183	0.00344	0.029853	0.021189	0.273665	1.218865
11	South Africa	0.005973	0.004067	0.037066	0.02561	0.260028	1.223517
12	Indonesia	0.008296	0.001471	0.033749	0.023718	0.260864	1.22452
13	Chile	0.004312	0.002388	0.041949	0.028168	0.23541	1.236549

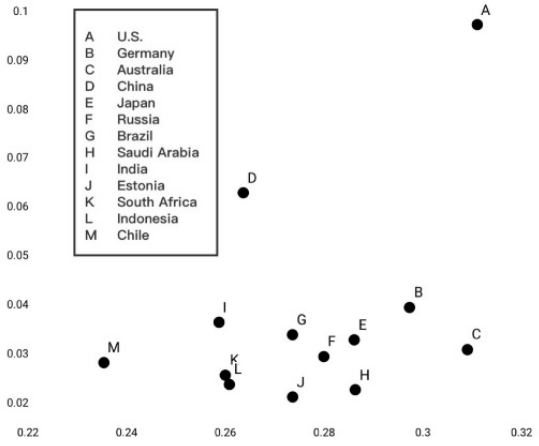

Figure 4: GE distribution in 13 Countries.

If you put the result in the real world, you can understand why it is. The U.S. is the only superpower in the world which owes to its science and technology, education, economic, etc. And with its state system, history and the longest development of modernization, its health status should be way ahead. And like Japan or Australia, as typical developed counties for a long time, they perform better in coordination owing to their stable long-term capitalism system development. As for China or India, their prominent point is the mass population. So, their health status is slightly higher right now because their resources are numerous. However, also due to their population, there is a huge gap between them with other developed countries. We don't explore why deeply, because that's not the point of this paper.

It should be pointed out that because the final selected countries are typical and extensive, the average scores of these countries can represent the average health status of higher education systems in the world and reflect the average level of health and sustainability of higher education systems.

Therefore, this paper chooses the average score as the evaluation criterion. The evaluation method is: when a country's score is higher than the average, it means that the health level of its higher education system is higher than the world average. On the contrary, if the score is lower than the average, it means that the health level of its higher education system is lower than the world average.

5.2 Typical Analysis - Estonia

5.2.1 Background and Prospect of Higher Education in Estonia. Since the restoration of independence in 1991, Estonia's economy has developed rapidly, especially in recent years. Although it is a developing country, its per capita GDP growth has exceeded the average level of OECD in the past decade (OECD, 2017 [14]). In the decades since independence, the education system has also changed. The government attaches great importance to education and investment in education. As a result, Estonia's higher education system has developed rapidly, ranking high in the skill level of the young population of OECD.

Based on the calculated data in Table 7, comparing and integrating the data of Estonia with the average values of 13 countries, it is found that many indicators are still below the average level. So, we set a vision for Estonia to reach the average by 2030. According to the evaluation system of higher education system proposed in this paper, users can analyze and put forward corresponding countermeasures to improve Estonian higher education system from three organizational frameworks of input, environment, and output of higher education system. Due to the limited space, this paper only takes financial input as an example to make in-depth analysis.

5.2.2 Analysis of Financial Investment in Higher Education in Estonia. Compare Estonian data with the average of 13 selected countries, as shown in Figure 5

After comparison, it can be found that: (1) Estonia spends 1.8% of its GDP on higher education, ranking in the top half of about 13 countries, but it is still below the average level; (2) higher education seems to be a high priority of Estonian public budget, and the Estonian government's expenditure on higher education accounts for 3.5% of the total public expenditure; (3) per capita expenditure of university students and per capita-expenditure GDP is closely related. Although the per capita GDP of Estonia is relatively low,

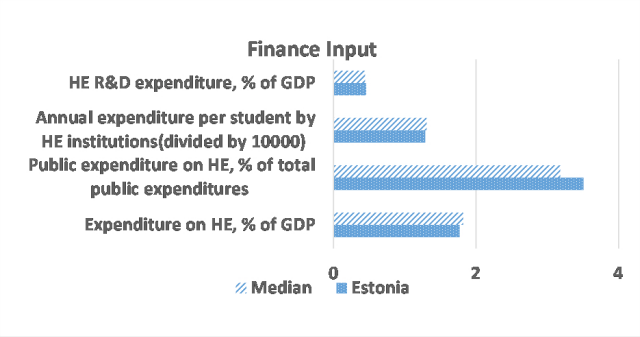

Figure 5: Comparing Estonian Financial Input with Average.

the per capita student expenditure of its universities is almost close to the average level.

5.2.3 Improvement measures and verification. According to the comparison, policy makers can make relevant improvement measures, such as paying attention to the proportion of higher education in GDP, making the ratio of higher education expenditure to GDP 0.0048, etc. When Estonia's lower than average indicators reach the average level, other indicators will remain unchanged, and other countries and indicators will remain unchanged, which will be re substituted into the calculation. The results showed that: HI = 10.032411, CI = 10.291247. Compared with the average value of HI = 10.031977 and CI = 10.29243414, the HI value is significantly higher, and the CI is slightly lower than the average level, but very close, indicating that the health status of Estonian higher education system has reached the world average level by 2030. At the same time, the results also verify the correctness of the model and the reasonability of the results.

6 CONCLUSIONS

This paper studies how to use a unified evaluation system to evaluate the health of higher education system in any country in the world under the existing world environment and education system. We can sum up the contributions of this paper into the following two points.

- Establish the National Higher Education Evaluation System. This paper proposes an organizational framework for evaluating higher education, and selects valuable indicators in the framework, improves the entropy weight method and takes it as a mechanism to determine the weight to calculate the weight of indicators and the health score of higher education system. Combined with GE Matrix, NHEES is finally established. Meanwhile, we present how to apply the evaluation system to 13 countries, analyzes the results and gives relevant measures.
- A general idea and way of evaluating a system. The idea establishing NHEES is that we consider the system as a black box [15], which means we care about its input, environment, and output rather than its internal structure. And the idea and the way to establish evaluation systems can expand to other applications and fields.

However, there still are many limitations need further research. And there are two problems that lead to the imperfection of NHEES.

- In Section 3, our index selection is based on comparability and operability, that is to select some representative and quantifiable indicators that can collect data. But we believe that these indicators aren't the most perfect, there must be some other or difficult to quantify indicators, but more valuable indicators. That's what we're going to do next.
- We believe when the system is perfect, there is a specific value to distinguish whether higher education is healthy or not. When it exceeds the value, the HES of a country can be considered healthy. We are committed to looking for the value.

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