Research on Higher Education Evaluation System Based on the 3E-R model

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Abstract. Globalization has created a higher education environment that is much more different than ever before. The level of higher education is related to a nation's comprehensive national power closely. Therefore, it is urgent and vital to building a healthy and sustainable higher education system that meets national development needs, which should also equip with an effective evaluation system that can be used widely. We use rigorous methods to build the 3E-R model to distinguish those two concepts and quantify them in the higher education system. In terms of the measurement of the heath of the higher education system, we employ 3E (Economics, Efficacy, Effectiveness) and "process" variables derived from them to measure the input, process, and output of a nation's higher system. We use the Average Weighted Method to measure just-in-time indicators (efficacy and effectiveness) and principal component analysis (PCA) to identify their weights on the basis of multi-country data. In terms of quantifying the sustainability of the system, we introduce risk factor R to measure the extent to which external factors influence the higher education system. Specifically, we measure external risk by a nation's fragility and market competition intensity of its higher education system and measure the level of resistance to external risks by the nation's economic strength. Since economic strength is historically relevant, we used the Time Cumulative Algorithm to calculate it. Finally, we use our model to analyze and evaluate the health and sustainability of the higher education systems of these 31 countries.

Keywords: PCA, Time Cumulative Algorithm, Higher Education Evaluation.

1. Introduction

Once upon a time, people in the higher education system were used to face-to-face learning. Thanks to modern transportation and technological advances, countless cross-campus, cross-country, and cross-ocean academic exchanges occur worldwide every day.[1] Globalization has created a higher education environment that is much more different than ever before. However, higher education systems in many countries have been severely hit by the sudden epidemic. The weaknesses of higher education systems have been magnified.[2] Nowadays, a country's level of education, especially higher education, is closely related to its comprehensive national power. Therefore, it is urgent and vital to building a healthy and sustainable higher education system that meets national development needs. [3]

Higher education, also called post-secondary education, third-level, or tertiary education, is an optional final stage of formal learning that occurs after completion of secondary education. Higher education includes teaching, research, exacting applied work, and social services activities of universities. [4] Moreover, a System of Higher Education is an organizational structure that consists of higher educational institutions (colleges, universities, etc.) and the personnel and infrastructure required to educate students beyond the secondary level. A higher education system's health reflects the ability to align around a common vision, execute against that vision effectively, and renew itself through innovation and creative thinking. The ability to maintain the system's effectiveness over time reflects its sustainability. [5]

We find that many international organizations have established national-level education evaluation systems and quality assurance systems for higher education. Institutions like UNESCO, International Institute for Educational Planning (IIEP), and OECD emphasize the rational allocation of educational

resources, educational equity, and internal and external quality assurance [6]. However, they almost do not consider the measurement of the system's resistance to shocks (like the sudden epidemic), in other words, the system's stability.

At the same time, after thorough research, we find that the Universitas 21 Ranking is the only one in the world to assess national higher education systems now, which is built based on resources, environment, connectivity, and output. However, it just ranks the higher education system but does not display the standard of measuring the health and sustainability of the nation's higher education system.[7]

2. Higher Education Evaluation Model Based on PCA

To measure the health and sustainability of the higher education system, we build an input-procedure-output-based model called the 3E-R model, which can measure the economy, efficacy, effectiveness, and risk in the future. In the model, we also use different reasonable methods to quantify the aforementioned significant indicators.

A) Economics

For the Economics indicator, we want to quantify how much importance a country attaches to its higher education system. We use economic strength and higher education system investment data to calculate how much importance a country attaches to its higher education system.[8]

a) Economic strength. Since the evaluated higher education system falls within a country, we use Gross Domestic Product (GDP) per capita (rather than GNP) to measure a nation's economic strength. We normalize this indicator ranging from 0 to 5. The World Bank provides the data.

The mathematical expression for economic strength indicators in the 3E-R Model equation forms.

$$E_{str} = 1 + \ln \frac{GDP_{pc\_i}}{GDP_{pc\_\max}} \tag{1}$$

Among then, E_{str} is economic strength, GDP_{pc} is the n Gross Domestic Product (GDP) per capita.

b) Importance a country attaches to its higher education system. We use Government expenditure on education, total (% of GDP) to measure the level that a country puts importance on its higher education system.

c) Higher Education System Investment. A country's investment in its education system represents the level of government support for the system and the level of private sectors support and attention to the education system. Hence, when calculating the education system investment, we should calculate government expenditures in higher education and the input of non-government organizations and students' families to the education system. Therefore, we determine a proportional index p to measure the ratio of non-government investment in education to government investment in a country. We assume p=1. The data on government expenditure on education is available at the World Bank.

$$p = \frac{I_{\text{non-gov}}}{I_{gov}} \tag{2}$$

$$E_{\text{invest}} = I_{gov} + p \cdot I_{gov} \tag{3}$$

Where p is the ratio of non-government investment in education to government investment, $I_{\text{non-gov}}$ is the non-government investment, I_{gov} is the government investment, E_{invest} is the investment in education.

The mathematical expression for Importance indicators in the 3E-R Model equation has a form of.

$$E_{\text{invest}} = \frac{E_{\text{gov}} \cdot (1 + p) \cdot GDP_{pc\_i}}{5} \tag{4}$$

$$\text{Importance } = E_{gov} \tag{5}$$

Where E_{gov} is the government expenditure on education.

B) Efficacy

In our model, the output of the higher education system (Efficacy) refers to some material resources produced by the input funds, such as the schools built, the level of educational teaching hardware and software, etc. We use the following indicators to measure it.

a) Quality. We use The QS World University Rankings to measure the quality of teaching output, including Research Quality, Teaching Quality, Graduate Employability, and International Outlook.

b) Quantity. In a country, we use Educational attainment, at least a Bachelor's (EA), and the Pupil-teacher ratio, tertiary (PTR) to measure the quantity of higher education system's output. Considering that the two factors are cumulative, we also consider the changing trend between the two factors. The World Bank provides the data.

We normalize this indicator ranging from 0-5 marks. The mathematical expression for efficacy indicators in the 3E-R Model equation has a form.

$$Efficacy = E_{qity} + E_{qtty} \tag{6}$$

$$Efficacy = \alpha_1 QS + \alpha_2 EA + \alpha_3 PTR + \alpha_4 \Delta EA + \alpha_5 \Delta PTR \tag{7}$$

Where E_{qity} is the quality to measure efficacy, E_{qtty} is the quantity to measure efficacy, QS is the QS World University Rankings.

C) Effectiveness

In terms of output effects, we divide them into direct effects and indirect effects.

a) Direct effects. The direct effect refers to the economic and social value brought by the industry. We use the Skillset of university graduates, University-industry collaboration in R&D, and Scientific publications to measure talent and economic and academic effectiveness.

We use the World Economic Forum's ratings for each country in 2019 as our basis for normalizing our indicators to a score ranging from 0-5.

The mathematical expression for direct effects indicators in the 3E-R Model equation has a form of

$$E_{\text{Direct}} = \beta_1 D_{\text{Skill}} + \beta_2 D_{R\&D} + \beta_3 D_{Pub} \tag{8}$$

Among then, E_{Direct} is the direct effects, D_{Skill} is the Skillset of university graduates, $D_{R\&D}$ is the University-industry collaboration in R&D, D_{Pub} is the scientific publications.

b) Indirect effects. The indirect effect refers to the benefits that the higher education system brings to the country in terms of society by producing highly qualified people. We know that the Literacy rate is a good indicator of the literacy level of society. Although cultural literacy is not part of higher education, we use the Literacy rate provided by World Bank to measure the social benefits since we assume that those who accept higher education would feedback into society.

The mathematical expression for effectiveness indicators in the 3E-R Model equation has a form of

$$\text{Effectiveness } = E_{\text{Direct}} + \beta_4 E_{\text{Indirect}} = \beta_1 D_{Skill} + \beta_2 D_{R\&D} + \beta_3 D_{\text{Pub}} + \beta_4 E_{\text{Indirect}} \tag{9}$$

We search for the data of the indicators related to efficacy, economic, and e effectiveness and operate the mass data with different methods based on data's attributes.

a) Just-in-time Indicators

Since we need to measure efficacy and effectiveness, which is the increment of input per year, we do not need to consider the cumulative effect of time. We only need to use the latest data to measure those related variables.

b) Cumulative Indicators

We believe that the Economic strength measured by per capita GDP has a cumulative effect on the country. We define this cumulative proportion as k. Therefore the equation is.

$$E_{Str}(n) = (1-k)GDP_{pc}(n) + kGDP_{pc}(n-1) + \cdots + k^{i}GDP_{pc}(n-i) + \cdots \quad (10)$$

By querying the data, we assume that $k = 0.3$ is acceptable.

In order to expand the difference between the data, we normalize them all with a score distribution domain of [0,5]. We calculate Absorption Efficiency and Transformation Efficiency by dividing the indicators and multiplying by 2.

$$\text{Importance degree } (ID) = E_{\text{invest}} \quad (11)$$

$$\text{Transformation efficiency } (TE) = \frac{Efficacy}{E_{\text{invest}}} \cdot 2 \quad (12)$$

$$\text{Absorption efficiency } (AE) = \frac{\text{Effectiveness}}{E_{\text{invest}}} \cdot 2 \quad (13)$$

Principal component analysis (PCA) is the process of computing the principal components and using them to perform a change of basis on the data,[9] sometimes using only the first few principal components and ignoring the rest [10]. We employ PCA to get the coefficients for Efficacy and Effectiveness. Results are listed in Table 1.

Table 1. The weight of indicators

Indicators	Weight (%)
QS	6.95
EA	10.04
PTR	16.50
ΔEA	11.35
ΔPTR	55.16
D_{Skill}	11.83
$D_{R\&D}$	22.95
D_{Pub}	25.41
E_{Indirect}	39.82

Now we have five factors which include the output part (efficacy and effectiveness) and the "process" part (Importance degree, Transformation efficiency, Absorption efficiency). Since it is difficult to compare those five indicators, we use the direct sum-up method to calculate the health of the system. We obtain the final scoring expression as.

$$\text{Health Index (ESHI)} = \text{efficacy} + \text{Effectiveness} + ID + TE + AE \quad (14)$$

$$\text{Efficacy} = 6.95\%QS + 10.04\%\,\text{EA} + 16.5\%PTR + 11.35\%\Delta EA + 55.16\%\Delta PTR \quad (15)$$

$$\text{Effectiveness} = 11.83\%D_{\text{Skill}} + 22.95\%D_{R\&D} + 25.41\%D_{\text{Pub}} + 39.82\%E_{\text{Indirect}} \quad (16)$$

3. Sustainability Evaluation System Considering Risk Factors

The assessment of the internal efficiency of the education system is included in the Education System Health Index (ESHI) uniformly. Therefore, the Sustainable Education System Index (SESI) is equal to the Education System Health Index (ESHI) divided by the risk factor R, that is.

$$SESI = \frac{\text{ESHI}}{R} \tag{17}$$

Risk factor refers to the external risks of the education system that can cause damage to the higher education system. It can be divided into two main aspects: domestic and international. For domestic risks, we use the country's fragility to measure. We consider the risks of competition in the international education market for global risks. In addition, since a country's economic strength will greatly affect the country's resistivity against external risk, we also take economic strength calculated into the calculation of the risk factor R.

Fragility is the quality or state of being easily broken or destroyed. We employ the Fragile States Index provided by Fund for Peace (FFP) to measure a nation's fragility. The Fragile States Index comprises several indicators, including Cohesion Indicators, Economic Indicators, Political Indicators, Social Indicators, and Cross-Cutting Indicators. Several subscales under each indicator, with higher ratings indicating a more fragile country.

We classify countries into five levels (from 1 to 5) using cluster analysis. The result is shown in Figure 1.

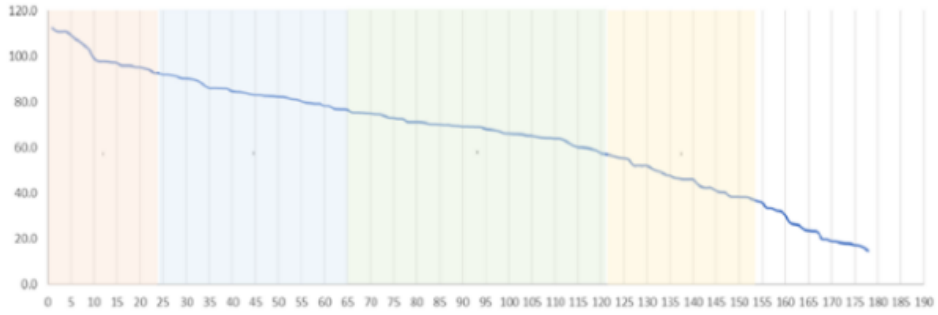

Figure 1 Cluster analysis of fragility

Market competition intensity refers to how competitive a national higher education system is in the international market. Because we assume that students can circulate freely between countries to obtain a better education, a country will face more brain drain when it is less competitive in education, which represents more risk.

Since direct data on educational competitiveness is not available, we use national competitiveness as a proxy, which is acceptable because students also focus on the country's overall strength in which the school is located when they receive higher education. Moreover, it is generally acknowledged that educational competitiveness and national competitiveness are strongly and positively correlated. The data on national competitiveness is available at World Economic Forum.

The mathematical expression for R in the 3E-R Model equation has a form.

$$R = \frac{\text{Fragility score } + \text{ competition intensity}}{E_{Str}} \tag{18}$$

So, the mathematical expression for SESI in the 3E-R Model equation has a form.

$$SESI = \frac{ESHI \times E_{Str}}{\text{Fragility score } + \text{ competition intensity}} \tag{19}$$

We have extensively selected 31 countries as our samples, collected data from all aspects, and applied our indicators to them.

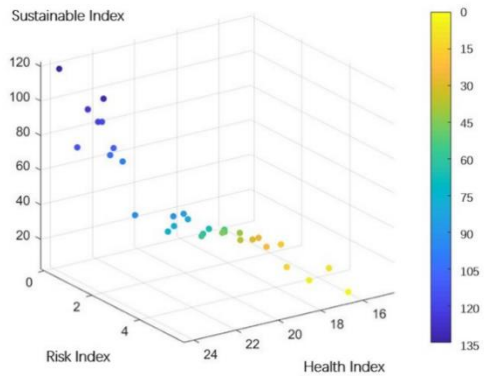

Figure 2 Relation among three indexes

Based on the data and indicators obtained and the Figure 2, we can divide these countries into three categories:

• Muscular. The country has a score area [50, 120], and we can consider it a "Muscular" higher education system. "Muscular" means that the country has a healthier education system but also faces a lower level of risk. We consider that their higher education system does not require additional improvements.

• Improvable. The level of sustainability in these countries is roughly between scoring [11, 30]. Those countries generally have low-risk levels but are not high on health indicators in the higher education system. So, there is room for those countries to improve.

• Vulnerable. This part of the country has a score below 11 points. They generally have high-risk factors, mainly reflected in the country's poverty, which we think is difficult to change over a long time.

We believe that countries in the "Improvable" level have specific problems and have more development space. The world map for SESI is shown in Figure 3.

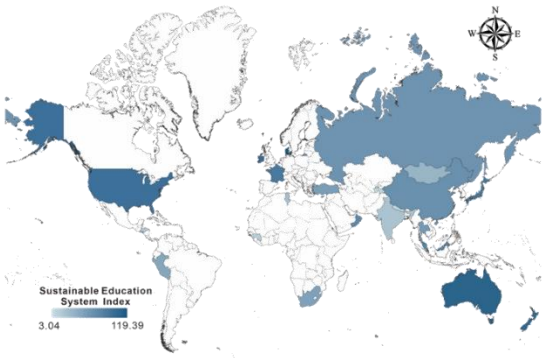

Figure 3 World map for SESI

4. Conclusion

We define the 3E indicators as economics, efficiency, and effectiveness. We calculate the ratio of inputs by calculating the ratio between the indicators to determine how much importance a country attaches to its higher education system, how efficiently the inputs are transformed, and how efficiently the inputs are absorbed. The calculated ratio is used as an indicator to assess the input-process-outcome of the higher education system, and we will mainly use the "process" factor to calculate the health index of the education system. Then, we introduced the concept of risk factor R to assess the sustainability of the education system in conjunction with the health index.

In the 3E-R model, we employ eight indicators of 3 aspects to measure the health of a nation's higher education system and introduce the risk factor R to measure the sustainability of the system. In this way, the 3E-R model can avoid the abrupt influence of a single indicator, and the results are integrated. Our indicators can systematically measure all aspects of the whole process of the education system, including all aspects of input-process-output indicators. We also consider the risk factors

faced by our indicator ESHI and the higher education system, including national fragility and the international competitive environment. In terms of the measurement of indicators, we adopt different scoring methods according to the different types of indicator data to ensure comparability between indicators so that the results are comparable. We use many visual information presentations to make our model results more intuitive and vivid.

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