

Policy Works! Energetic and Quasi-periodically Postive Higher Education System

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Abstract

As we step into the era of information explosion, higher education systems need to keep up with the times. In order to assess the health and sustainability of higher education and give effective policies, we establish the periodic positive-feedback optimization model and other models based on the theory of multivariate evaluation to higher education system. The paper begins by the Higher Education Health Assessment Model, a typical evaluation model, based on the AHP-EWM efficiency coefficient coupling principle. Then in order to extending this model to a sustainable assessment model, the modified data envelopment analysis (DEA) theory is used to establish education System sustainability assessment model (ESA). Through predictive analysis of the fluctuation characteristics of social factors, the stability of the investment efficiency is verified. For the relevance of the research model, a timeline optimization model (TOM) is developed using a Periodic Positive feedback genetic algorithm to obtain the targeted policies and the optimal schedule for their implementation. To further illustrate, the impact of unexpected factors on higher education are measured by impact quantifiers. For the purpose of quantitating the effectiveness of the policy, a target policy evaluation model is established based on the revised theory of intervention analysis. Therefore, the effectiveness of the policy can be verified intuitively.

Keywords

Higher Education System; Timeline Optimization Model; Intervention Analysis.

1. Introduction

1.1. Problem Background

A country with a healthy and sustainable higher education system means that the country's cultural and technological fields have unlimited development potential. The development of higher education systems in different countries is different. Countries with insufficient levels of higher education urgently need to reform their higher education system. These countries need to implement effective policies to enable the higher education system to develop healthily and sustainably, but this is difficult.

In order to measure and evaluate a country's higher education system, it is necessary to establish a health status evaluation and sustainable development evaluation model. Use this model to select the country to be improved, and evaluate the health and sustainability before and after the improvement. Develop a corresponding implementation plan for it, discuss the impact of the policy and verify its effectiveness.

1.2. Our Work

The workflow of this paper is shown in figure 1.

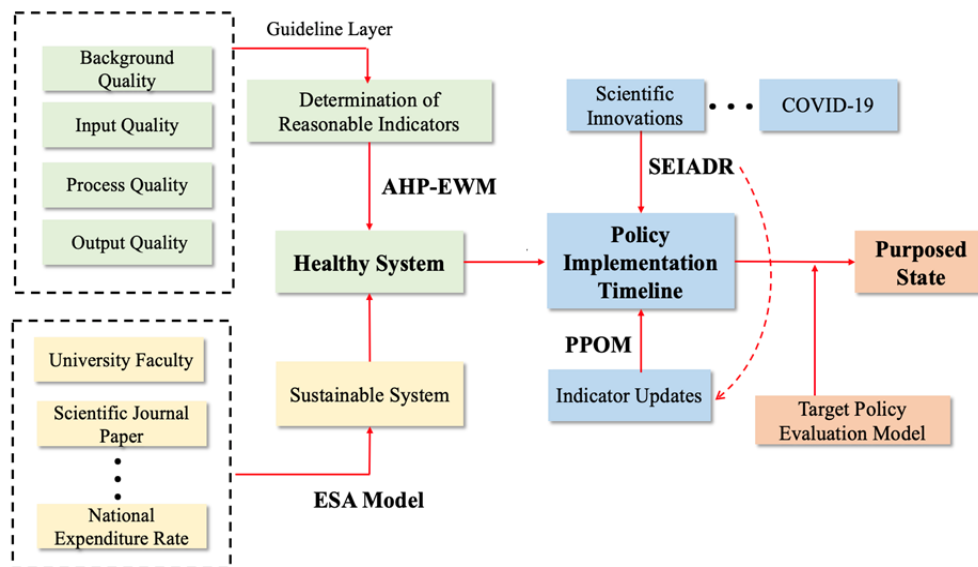


Figure 1. Technology route for the creation of our paper

2. Part I: Health status assessment in higher education

In order to evaluate the health status of the higher education system, we established a health status evaluation model based on the AHP-EWM efficiency coefficient coupling principle. First, we do a quantitative screening of the indicators that represent higher education. Secondly, this paper calculates the health index and defines the threshold of health status by solving the revised weight method and using Higher Education and Health Assessment Model. Finally, the model is applied to developed countries and developing countries respectively.

2.1. Higher Education Health Assessment Model (HAM)

2.1.1. AHP-EWM Health Indicator weights

The AHP method often uses the consistency matrix method when determining the weights between factors at each level, which have subjective errors. Therefore, we consider using entropy weight method (EWM) to correct the weight value. Coefficient Synthesis Analysis was used to couple AHP and EWM to calculate the weight of health indicators.

The calculation steps of AHP-EWM Health Index weights are as follows:

Step 1: we hierarchical screening represents 11 indicators of higher education and verify the rationality of the selected indicators.

Step 2: AHP and EWM were used to calculate the weight of indicators.

Step 3: we efficacy coefficient synthesis analysis was used to combine the two weights to determine the final weight.

(1) Indicator selection

The health of higher education can be divided into three dimensions: macro, meso and micro. Among them, the macro level mainly refers to the overall quality elements. The intermediate level focuses on the quality elements of the curriculum. The micro level focuses on the learning outcomes of individual students. According to this method, we selected 11 small indicators in 4 large fields. The specific stratification method is shown in figure 2:

BQI stands for Background Quality of higher education, IQI stands for Output Quality of Higher Education, PQI stands for Process Quality in Higher Education, OQI stands for Output Quality of higher education.

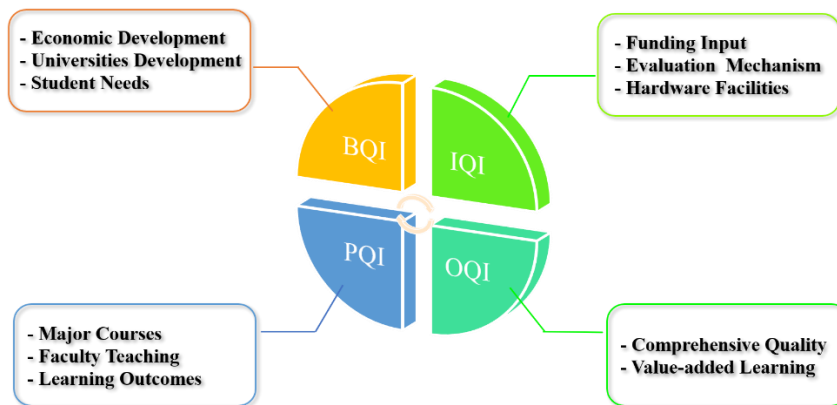


Figure 2. The classification schematic diagram

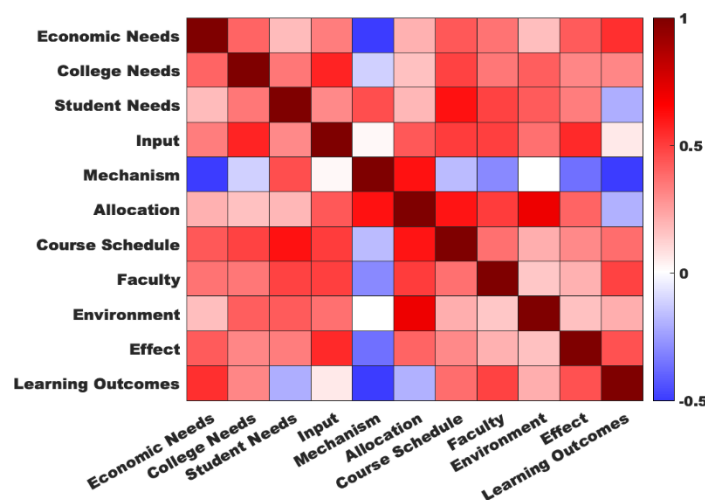


Figure 3. Indicator correlation coefficient heat map

We judge the reasonableness of the selected indicators by analyzing the magnitude of the correlation coefficients among the indicators. As can be seen from the figure, the correlation coefficient between any two indicators is very low, and the indicators are independent of each other. The selected indexes are reasonable.

(2) Calculation of index weights

Firstly, the weights a of 11 Health indicators was obtained by the AHP and then another weights b was obtained by the entropy weight method (EWM). The two were coupled, and the weights w of 11 Health indicators was revised by the method of composite analysis.

The specific formula of entropy weight method (EWM) is shown as follows:

$$\begin{cases} f_{ij} = \frac{y_{ij}}{\sum_{i=1}^n y_{ij}} & i = 1, 2, \dots, 11 \\ e_{ij} = -\frac{1}{\ln n} \sum_{i=1}^n f_{ij} \ln f_{ij} \\ b_i = \frac{1 - e_{ij}}{k - \sum e_{ij}} & i = 1, 2, \dots, 11 \end{cases} \quad (1)$$

Using the method of coefficient synthesis analysis, the formula for calculating the final weight w of the 11 indicators is:

$$w_i = [\max(a_i - b_i) + b_i \cdot (a_i + b_i)] / a_i \quad (2)$$

Where I represents the index serial number, standardize the weights: $w_i = w_i / \sum w_i$

Taking the United States as an example, the index weights of AHP-EWM obtained by solution are as table 1:

Table 1. The weights of the 11 index in the United States

guideline layer	sub-criteria layer	Weights
<i>BQI</i>	Economic development needs	0.0748
	Universities development needs	0.2314
	Student needs	0.0829
	Funding input	0.0695
<i>IQI</i>	Monitoring and evaluation mechanism	0.1206
	Hardware facilities and resource allocation	0.0624
	Major and course schedule	0.0724
<i>PQI</i>	Faculty teaching and support services	0.1041
	Learning and research environment	0.0666
	Comprehensive quality improvement effect	0.0300
<i>OQI</i>	Value-added learning outcomes	0.0854

2.1.2. The establishment of HAM

AHP-EWM Health Index can be obtained by multiplying the weight of the 11 divided little finger marks and their corresponding standardized data. The greater the weight of the index, the greater the influence of the index on higher education. The specific calculation formula is as follows:

$$HI_i = \sum_{j=1}^{11} w_{ij} \cdot y_{ij} \quad (3)$$

Where, HI_i represents the score of the i -th country, j represents the index number, w_{ij} represents the weight, and y_{ij} represents the index data.

Each country has its own set of 11 higher education indices, so that each country can get its own set of weighting coefficients. National health index can be obtained by using higher education health evaluation model. The health of a country's higher education can be assessed through a health index. Through the method of comprehensive analysis, it is concluded that higher education reaches the threshold of health. This is a way to gauge the health of a country's higher education.

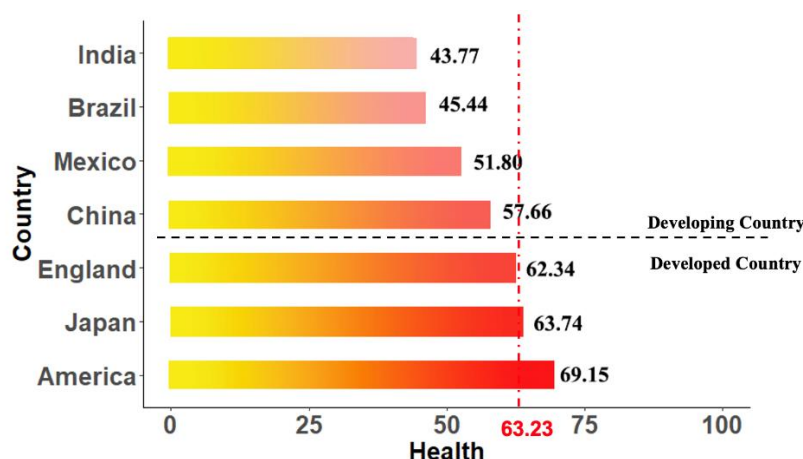


Figure 4. Health index score chart

2.2. AHP-EWM Health Index assessment

In order to make our model applicable to a wider range of countries, we divide countries into developing countries and developed countries. We selected 7 countries, and put all the data of 7 countries into the model to calculate the score of higher education health index of each country, which can be used as an indicator to evaluate the health status of higher education.

Higher education is generally healthier in developed countries than in developing countries. The calculation results of specific health degrees are shown in figure 4:

As shown in figure 4, there is room for improvement in education levels in both developed and developing countries, with the latter currently higher than the latter. According to the mutation synthesis analysis, a healthy higher education system should have a baseline score of 63.23. A health index higher than 63.23 is necessary for a healthy higher education system.

3. Part II: Sustainability Analysis

In this section, ESA, education system sustainability assessment model, is established based on data envelopment analysis, DEA method in economics and fluctuation model, which measures the stability of education system by the change of efficiency redundancy index over time. And by optimizing the model, with the goal of maximum efficiency, the method of adjusting education inputs is given to realize the vision of sustainable development of higher education system.

3.1. Education System Sustainability Assessment Model (ESA)

ESA, the abbreviation of education system sustainability assessment model, is a combination of DEA model and fluctuation prediction model. The ESA model predicts the social factors by their fluctuation over time and calculates the investment redundancy over time to assess the stability of the system.

3.1.1. Modified DEA theory for prediction

DEA is a method usually used to practice benchmarking exercise among a group of comparable observations and then find out optimizing results by changing both input and output values. In this paper the directional DEA model is utilized.

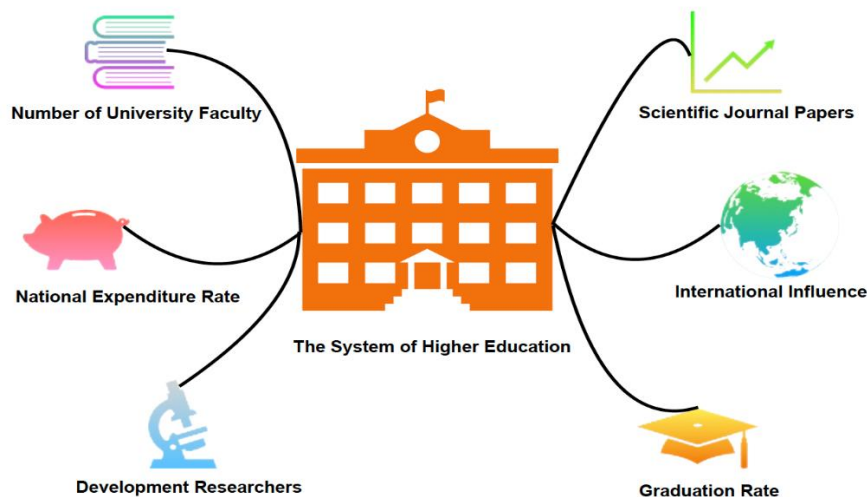


Figure 5. The relationship between input, output and the higher education system

Firstly, input and output parameters^[1] are supposed to be given. In this paper, the input parameters are: number of university faculty (x_1), national expenditure rate on higher education (x_2) and the number of development researchers (x_3). The output parameters are percentage of scientific and technical journal papers (y_1), international influence (y_2) and graduation rate (y_3). The relationship between the input and output parameters and the higher education system is shown in figure 5.

Then by giving a pre-assigned direction^[2]:

$$g = (-g_X^-, g_Y^+) \neq 0_{m+s} \quad (4)$$

And the associated linear program can be implemented as follow:

$$\begin{aligned} \max_{\beta, \lambda} \quad & \beta \\ \text{s.t.} \quad & \begin{cases} X\lambda \leq x_0 - \beta g_x^- \\ Y\lambda \geq y_0 + \beta g_y^+ \\ \lambda \geq 0 \end{cases} \end{aligned} \quad (5)$$

When the value of inputs and outputs are unable to change and $\beta_{CRS}^* = 0$, the efficient of inputs gets to the peak in the present pre-assigned direction. And also, the slack parameters are given to optimize the model further, which means that with further changes in input and output values can be made to obtain higher efficiency. In the Higher Education Sustainability Assessment Model, a higher efficiency represents less input of financial and human resources obtains more international educational impacts and outstanding students.

3.1.2. Efficiency redundancy index

In ESA model, the efficiency redundancy index^[3] can be illustrated as follow:

$$ERI = \beta_{CRS}^* - \beta_{VRS}^* \quad (6)$$

β_{CRS}^* and β_{VRS}^* represents the constant and variable returns to scale parameter. Therefore, *ERI* describe the size of the original parameter relative to the optimized variable. The smaller the value, the less redundant the investment is and the more sustainable the higher education system is.

According to the characteristics of natural and social environment development, consider each social factor fluctuates can be roughly considered in sine waves over time. Under such conditions, we can predict the changes of each input and output parameter for the next 15 years, using a high-order sine wave fit with available data from 1998 to 2018. The investment redundancy is then calculated by the DEA model.

3.1.3. Sustainable strategies and purposed vision

As stated above, a sustainable higher education system should have investment redundancy that decreases or remains consistently low over time. The DEA model can give slacks for different input and output values, which means the size of the input and output adjustments making them more efficient. The effectiveness of the adjustment strategy can be seen by giving the policy change to the input, i.e., the investment value, and comparing the investment redundancy before and after the adjustment.

3.2. Sustainability analysis and proposed vision

3.2.1. Sustainability evaluation

In the above, three developed and three developing countries are selected. The changes in investment efficiency of the three developed countries from 1998 to 2018 are shown in figure 6.

It can be concluded that the efficiency of all three parameters gradually increases. Moreover, the investment efficiency of Japan remains stable on top of the higher one. The U.S. and the U.K. also maintain high levels, although they are volatile. Therefore, the higher education systems of the three developed countries tend to be sustainable.

3.2.2. Healthy and sustainable status assessment after vision proposed

According to the ESA model, the number of university faculty, the national expenditure rate on higher education and the number of development researchers as input parameters, the percentage of scientific and technical journal papers percentage of students going abroad, and graduation rate as output parameters, and the maximum efficiency and decision adjustment values are obtained for the current situation with the maximum efficiency as the optimization objective. The specific results are shown in figure 7.

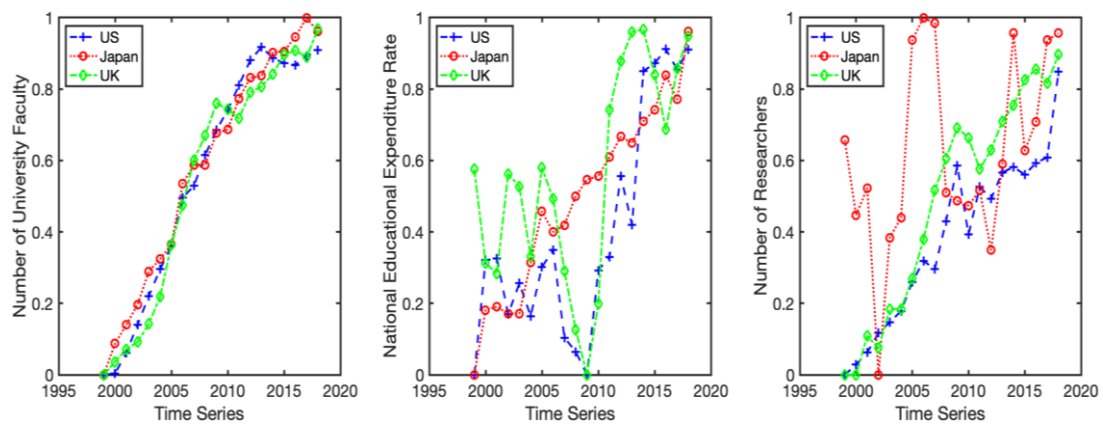


Figure 6. Investment efficiency changes of the three developed countries

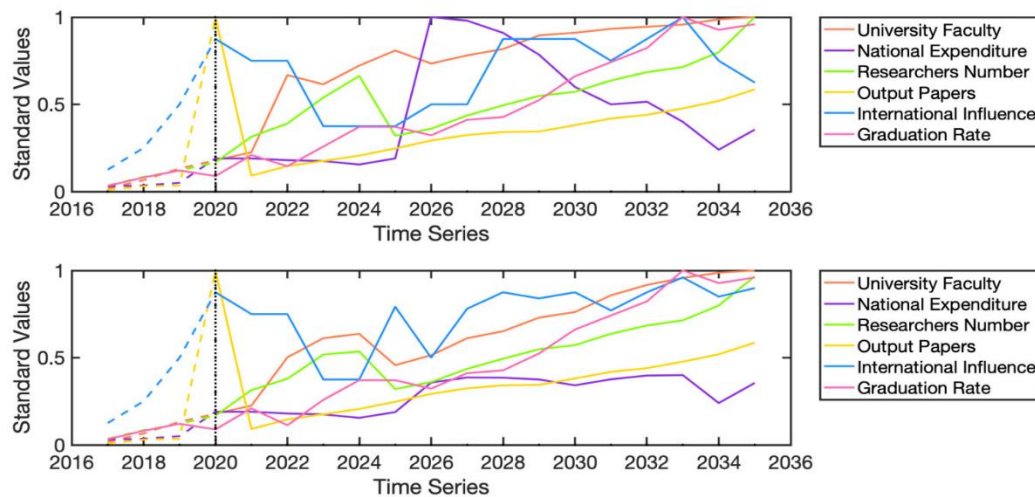


Figure 7. Contrast true and predicted values chart

After adjusting according to the ESA model results, efficiency redundancy index is shown in figure 8:

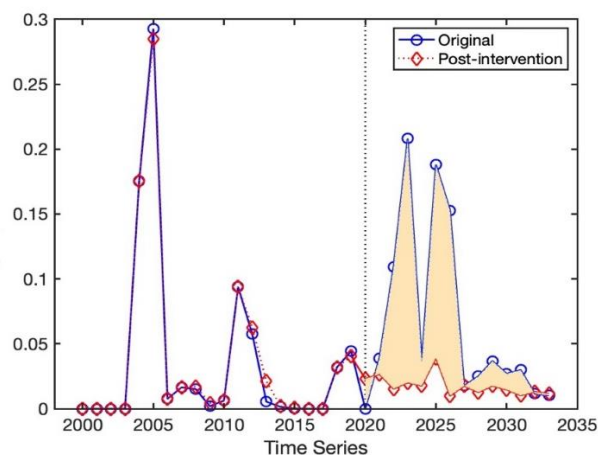


Figure 8. Efficiency redundancy index chart

The figure 8 shows that without adjustment, there will be a large redundancy in investment in education in 2022 and 2026, although it will decrease to a lower value by 2035, still less in line with the requirements of sustainable development. After adjustment, the investment

redundancy can be maintained at a lower state, which is ideal for a sustainable higher education system.

In order to evaluate the health status after the implementation of the above improvement measures, this paper quantified the impact of the improvement measures on 11 indicators representing the health status of higher education by solving the ESA model. Combined with Model I, the health index after the improvement measures was calculated. The specific steps are as follows:

Step 1: After the influence is visualized, it is applied to the index weights of Model I: Higher education health assessment model.

Step 2: The revised weight was combined with ESA model for index prediction, and the data was substituted back into Model I to solve the health status index.

Step 3: In order to compare and analyze the health status of the implementation of the improvement measures and keep the original weight coefficient unchanged, ESA model was used for index prediction and Model I was used to calculate the health index.

The comparison results are shown in figure 9.

Through comparative analysis, after the improvement measures, higher education health index score is expected to reach the baseline of health status of 63.23 in 2035, break through 63.23 in 2040, and maintain the health status. Without improvement measures, countries will not be able to maintain a healthy higher education system for the next 20 years.

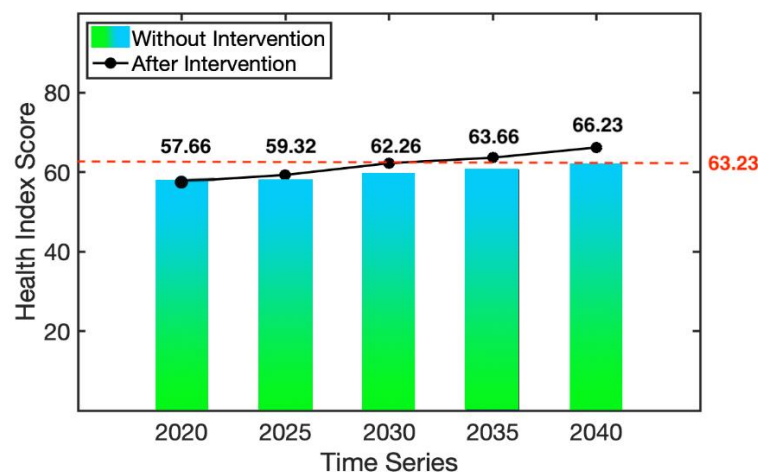


Figure 9. Comparison of health status with or without improvement measures

4. Part III: Timeline Optimization Model (TOM)

In this section, we are required to propose targeted policies and an implementation timeline with the purpose of maximizing educational health. In our model, we plan to transform this question into an objective optimization problem. In addition, as the higher education can be regarded as an industry together with its profitability and rivalry components [10], we introduce the SEIADR model to measure the magnitude of shocks from different events.

4.1. Periodic Positive Optimization Model (PPOM)

Genetic algorithm (GA) is an optimization algorithm that was once used to solve time planning type problems [4]. The genetic algorithm consists of three parts: selection, crossover, and mutation, which eventually filter out the optimized individuals. The optimization objectives and constraints are as follows:

$$\max HI = \sum(w_i \cdot I_i) \quad (i = 1, 2, 3, 4) \quad (7)$$

$$s.t. \begin{cases} w_i = \varepsilon_i \cdot \sin kt_i \\ w_1 + w_2 + w_3 + w_4 = 1 \\ I_i \geq 60 \\ 5(i-1) < t_i < 5i \end{cases} \quad (8)$$

where ε_i is impact factors of the various events on each indicator which will be quantified by SEIADR. $\sin kt$ are initial fluctuations. I_i is the four indicators in the guideline layer.

Step 1: Select the timing of the introduction of four policies as decision variables and select the indicator of the healthiness of higher education (HI) as fitness function.

Step 2: Perform the first genetic, crossover, and mutation to obtain the initial population.

Step 3: Superimpose evolutionary generation; perform selection, crossover, variation; merge two generations; calculate the fitness function.

Step 4: Judge the strengths and weaknesses of this generation of individuals. If the individuals are weak then return to step 3.

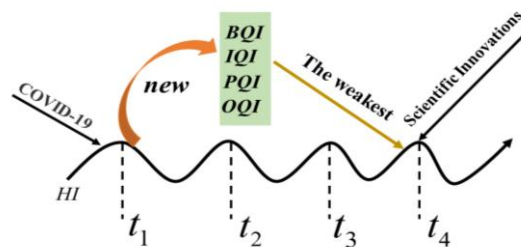


Figure 10. Timeline optimization model

In terms of the short-term policy, the most impactful factor on higher education will be the epidemic. According to the relevant literature [5], the epidemic will contribute significantly to reverse globalization. That means the indicators of higher education in BQI and IQI will be hit relatively hard. As a result, for the next five years, we focus on epidemic-related policies. At the time of reaching the next time node, the four indicators in the guideline layer will migrate to a new state which is closer to the proposed state. Then we choose the weakest indicator and the new policy will be proposed for this indicator. Keep repeating the above process and the purposed state will finally achieved. The specific process is shown in the figure 10.

4.2. The magnitude of shocks by SEIADR

The SEIR is a dynamics model which was once used to do research on the evolution of public opinion [6]. In this paper, the traditional SEIR model is improved to describe the evolution of the healthiness of higher education under the impact of various events. As universities affected by emergencies are not infectious, some of them will transform into transmitters after a period of delay.

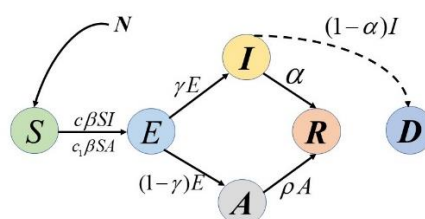


Figure 11. The virus propagation process of the SEIADR model

In the model, S is for susceptible population. E stands for exposed population. I represents infected population. R stands for rehabilitation population. However, under the effect of COVID-

19, a large number of asymptomatic infections will occur. As a result, we add **A** and **D** into the model, representing asymptomatic population and dead population respectively. The virus propagation process of the SEIADR model is shown in figure 11.

where c_1 is the average number of contacts of asymptomatic infected persons, $1 - \gamma$ is the conversion rate of asymptomatic population, ρ is the cure rate of asymptomatic infected patients, $1 - \alpha$ is the mortality rate, N is the total population.

After the introduction of asymptomatic infected population, the differential equations of the model is listed as:

$$\begin{cases} N(t) = S(t) + E(t) + I(t) + A(t) + R(t) + D(t) \\ \frac{dS}{dt} = -c\beta \frac{SI}{N} - c_1\beta \frac{SA}{N} \\ \frac{dE}{dt} = c\beta \frac{SI}{N} + c_1\beta \frac{SA}{N} - \gamma E - (1-\gamma)E \\ \frac{dI}{dt} = \gamma E - \alpha I \\ \frac{dA}{dt} = (1-\gamma)E - \rho A \\ \frac{dR}{dt} = \alpha I + \rho A - (1-\alpha)I \\ \frac{dD}{dt} = (1-\alpha)I \end{cases} \quad (9)$$

Through the above system of equations, our purpose is to solve for the variable I . Each equation depicts the transformation of the individual in the model shown in figure 11. By relative size of I in different countries we can qualify ε_i . Since parameters other than I do not need to be solved, we combine Iterative method of equation subsystem [7] directionally solving for I .

Based on the epidemic-related data from six different country, we obtain trends in the number of infections by country over the next five years. Among them, the trend which includes I is as figure 12.

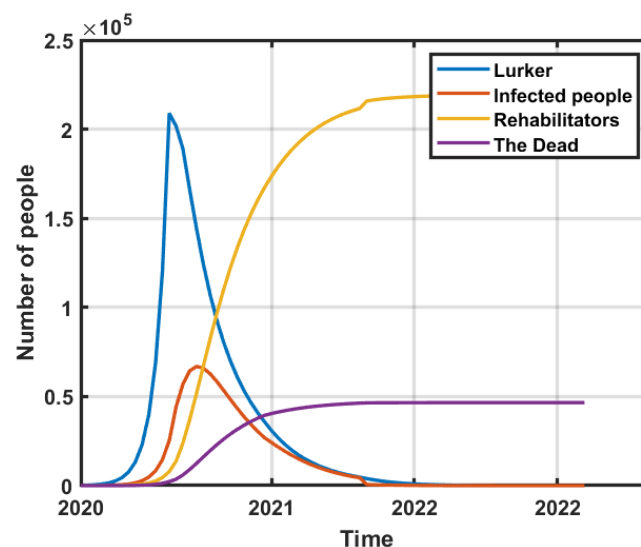


Figure 12. Trends in the number of infections

From figure 12, we can see that the epidemic is expected to subside around 2022. As a result, we have to consider the impact of the epidemic on higher education in the short-term.

In order to quantify the impact of the epidemic on countries, we introduce impact quantifiers ε ,

$$\varepsilon = 1 - \frac{\ln I - \min(\ln I)}{\max(\ln I) - \min(\ln I)} \times 100\% \quad (10)$$

where I represents infected population. Since the high order of magnitude of the number of infections is not conducive to in-depth analysis, logarithmizing the data can somewhat eliminate the effect of order of magnitude.

4.3. Results presentation

As we consider that the impact scale of the policy in time is mostly measured in months, floating-point values should be mapped to date forms:

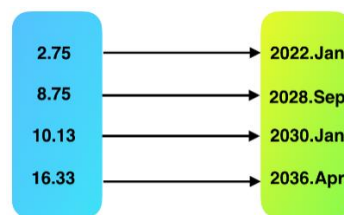


Figure 13. Numeric Type Mapping chart

The recursive schedule with the epidemic-related policies as initial values is as table 2.

Table 2. Policy implementation timeline

Policy	Time Node	HI
National Test Cancellations and Rescheduling	2022.9	58.45
Scientific Research Support Program	2028.9	60.16
Specialty Subject Strengthening Project	2030.1	62.31
Higher Education Infrastructure Improvement Program	2036.4	63.70

5. Part IV: Policy effectiveness assessment and impact analysis

In order to evaluate the effectiveness of policies and explore the realistic impact of policy implementation, this paper established a target policy evaluation model based on the prediction method of the revised intervention analysis model. This model evaluates the impact of higher education goal policies on students, teachers, schools and countries from the perspective of quantitative analysis. Finally, this paper evaluated the effectiveness of the policy from the perspective of post-intervention prediction through a controlled experiment.

5.1. Target Policy Evaluation Model

For different groups, we will implement the plan after classifying the realistic impact on the higher education system. This paper divides the influence of the policy into four aspects: students, teachers, schools and the country.

In this paper, 4 indicators related to the implementation plan are selected from the 11 indicators in Model I: enrollment rate of higher education, student-teacher ratio of higher education institutions, number of schools, and national education expenditure. These four indicators respectively represent the impact of the implementation of the corresponding policies on students, teachers, schools and the country. We standardized 4 data indicators to represent these real-world impacts.

Corresponding policies will always have an impact on the problem studied after implementation, so the 4 intervention variables in the model are continuous intervention variables^[8]. At this time, we can use the step function to express, and its form is:

$$S^T = \begin{cases} 0, & t < T \\ 1, & t \geq T \end{cases} \quad (11)$$

Where T is the time of policy implementation. Let y_t be some index value of the higher education system. x_t represents the index value when there is no intervention effect, z_t is the process value of intervention influence. The higher education index under the influence of target policy intervention can be expressed as:

$$y_t = x_t + z_t \quad (12)$$

Where x_t can be determined by regression method and ARMA, which are determined by the above intervention events.

The specific steps of intervention analysis model^[8] prediction method are as follows:

(1) The ARMA model is established by using the sequence (that's the first half of y_t) without intervention, and then extrapolated by using the model, the predicted value $\hat{x}_t$ is regarded as the value that is not affected by intervention.

(2) The actual value (that's the last half of y_t) after intervention is subtracted from the predicted value $\hat{x}_t$ to obtain the utility value z_t affected by the intervention. These results are used to estimate the parameters ω and σ of the intervention impact part z_t . The form of that part is as follows:

$$z_t = \frac{\omega}{1 - \sigma B} \quad (13)$$

Where ω is the unknown parameter of the intervention impact, and the estimated regression equation is $z_t = \sigma z_{t-1} + \omega$.

(3) Calculate purification series. Purification sequence refers to the series that eliminate the effect of intervention. It is obtained from the actual observation minus the actual effect, that is:

$$X_t = y_t - \frac{\hat{\omega}}{1 - \hat{\sigma}} S_t^T \quad (14)$$

(4) Establish an improved ARMA model by using purification series

(5) Establish the total intervention analysis model by using X_t and z_t :

$$\begin{cases} y_t = X_t + z_t, & t \leq T \\ y_t = X_t + \hat{\sigma}(y_{t-1} - X_{t-1}) + \hat{\omega}, & t > T \end{cases} \quad (15)$$

(6) Predict by the model.

5.2. Analysis of intervention prediction results

5.2.1. Impact degree analysis

This paper selects the data of four indicators affected by the policy in recent 20 years. These data were used to apply each indicator separately to the intervention analysis model. According to the analysis of the previous questions, the degree of influence on students, teachers, schools and countries is different after taking corresponding measures. According to the results of the model, the change rule of the index before and after the implementation plan is analyzed and predicted.

Four groups of data were substituted into the intervention analysis model to obtain the influence degree of the target policy on the four groups of people represented by the four indicators respectively^[11]. The standardized results of calculation are shown in the table 3.

Table 3. Influence scale table

Enrollment	Student-faculty Ratios	The number of schools	Education funding
0.3756	0.2154	0.1132	0.2954

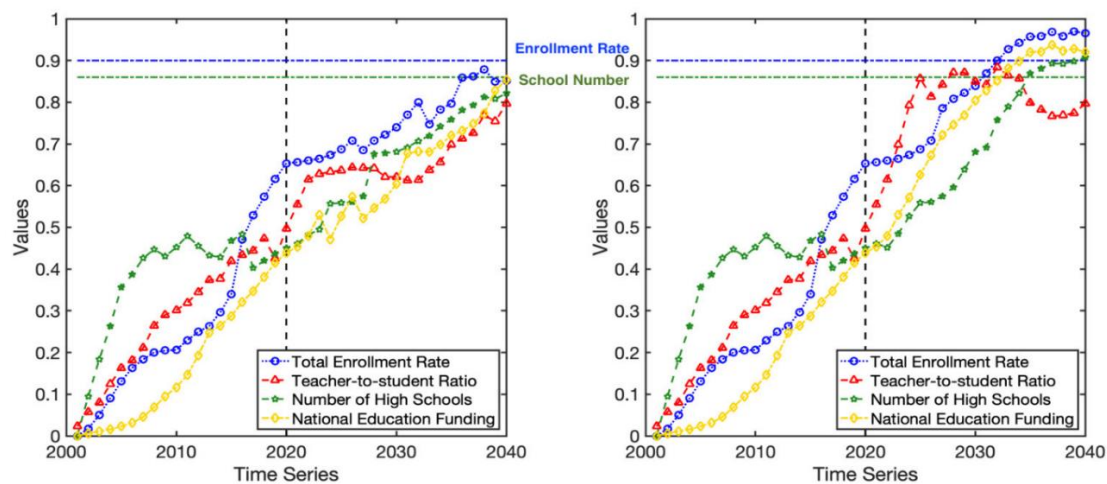
Based on the comprehensive analysis, the adoption of our target policies will have a greater impact on students and a smaller impact on schools in the next 20 years. This shows that the adoption of effective policies can make a big change in the enrollment rate so that students can benefit more.

5.2.2. Evaluation of policy effectiveness

There are 4 sets of indicator data, so there are 4 intervention analysis models. ω was substituted into the intervention analysis model to solve and predict, and the change rules of the four indicators from 2001 to 2040 were obtained. Among them, the data of 2001-2020 are the original data, and the data of 2021-2040 are the forecast data. The solution results of the intervention analysis model are shown in figure 14(b). To verify the effectiveness of the policy in the future, the predicted results of the time series model without any intervention were calculated, as shown in figure 14(a).

In the figure 14, the values are all between 0 and 1. The synthetic analysis of the coefficient of variation of these four indicators in all countries shows that in a healthy higher education system, the efficiency value of enrolment rate is at least 0.90, and the quantity benefit value of higher education is at least 0.86, which can be achieved in most developed countries.

As can be seen from the chart, with these measures taken, enrolment rates and the number of higher education institutions continued to rise in the short term and reached a healthy level in.



(a) Predictive plots without intervention (b) Intervention analysis prediction chart

Figure 14. Forecast comparison chart.

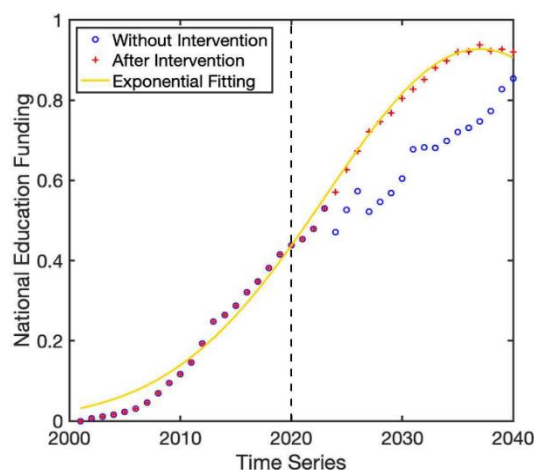


Figure 15. Comparison chart of education expenditure

The comparative analysis shows that the country's higher education system will not be healthy and sustainable in 20 years without any interventions or targeted strategies to reform the system. After the implementation of the target policy, the higher education system of the selected countries is expected to be in a state of healthy development in the next 20 years. Therefore, the target policy adopted in this paper is effective.

With the implementation of the policy, the national education expenditure will increase greatly in the short term, and then the growth rate will slow down and finally stabilize. After the implementation of the target policy, the national education expenditure will increase exponentially in the short term.

Further analysis shows that the implementation of the new policy requires a large amount of national capital investment, and the short-term benefits are low. Making the country's higher education system healthy will require long-term sustained investment, which will put considerable strain on the country's finances. In the near future, state funding needs to continue to increase, which is difficult to achieve.

6. Sensitivity Analysis

In general, the fluctuations in our model come mainly from disturbances related to sudden events like scientific innovation and COVID-19. Based on SEIADR, we have obtained a series of values of impact quantifiers ε . However, once the sudden event cause impact on several indicators in the very short term, the stability of the model may be reduced. As a result, we assign different extreme values to ε to evaluate the stability of the model under extreme conditions.

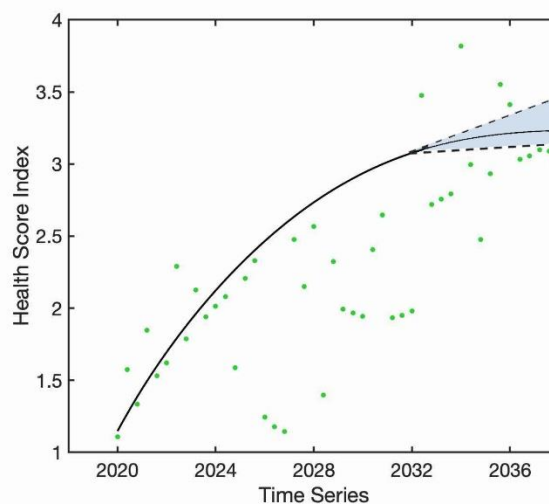


Figure 16. Convergence of health index score

As we can see from the figure 16, with the increase of ε , the fluctuation of HI is increasing, which is consistent with the definition of ε . In addition, when the value of ε is relatively small, the curve of HI is more smooth. That means when $\varepsilon \rightarrow 0$, our model has the ability to describe the health of higher education in the absence of external disturbances. Then the stability of the model is verified, where further promotion can be done.

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