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Health and Sustainability Indicators of Higher Education System

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Abstract: The aim of this research was to explore the critical indicators of evaluating higher education system. The data was obtained according to the available information from websites of relevant authoritative organizations like U.S. News and Universitas 21, etc. The national higher education system was evaluated by the analytic hierarchy process (AHP) model, then by further establishing the dual index evaluation model which includes the concepts of Health Index (H), Sustainability Index (S), finally, combined the two-index by Mckinsey matrix. This research ranked the sustainability and health of higher education systems from 10 countries in 2020 where it reflected that Unites States had the highest evaluation weight while India and Brazil still had room for improvement. Using India as the research subject, the health and sustainability degree of the improved higher education system were analyzed by Lanchester's equation. According to the results of the evaluation model, a policy implementation model was proposed to ensure the healthy and sustainable development of India's higher education system.

Keywords: Higher education system; AHP; McKinsey matrix; Lanchester's equation

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1. Introduction

Higher education system is one of the important aspects of the national education system, and it is the main social activity to cultivate senior professionals. It includes many factors such as different levels, disciplines, teachers structure, as well as internal and external environment as important structures. In recent decades, with the development of the modern society, the evaluation of higher education system has evolved and broadened. Therefore, exploring the sustainability of higher education system is of great significance to build a sustainable society. The purpose of this study was to analyze and establish a quantitative model for a comprehensive evaluation of the higher education system and to provide corresponding analysis as well as policy suggestions for a typical country.

When literatures related to the research subject were examined, many studies on higher education system, policy, reformation, management, educational resources, and education ecology were found. In addition, according to the available information, many organizations including US News and Universitas 21 had created various indicators of higher education systems to measure the progress of the countries in the field of higher education. Common indicators were divided into four categories which include scientific research, educational innovation, student learning, and cooperation as shown in **Figure 1**. Other studies had also considered more comprehensive social factors taking into account institutional strengths, openness, top universities, and education funding. However, it is not yet possible to define global standard indicators to measure the health and sustainability of higher education systems.

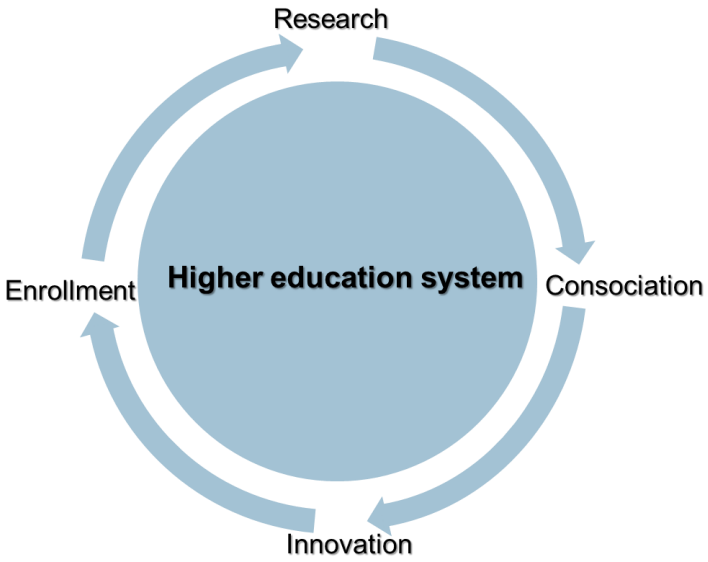

Figure 1. Four aspects of the higher education system evaluation model

Taking into account of existing research, this study focused on the measures of the health and sustainability of higher education systems, sustainability predictions, and the impact of environmental factors on system sustainability.

2. Research assumption

(1) The research subjects and institutions of this study were college students as well as professional colleges, using a statistical method to measure. Since it is difficult to define an accurate boundary of the higher education system and it contains many details that are difficult to accurately quantify, the main purpose of this model was to measure the health and sustainability of the higher education system rather than statistically accurate data.

(2) The selected national reference subject was relatively stable, that is to say, when measuring the sustainability of the country's higher education system and formulating policies, the social environment would not change dramatically. For example, serious natural disasters and destructive wars.

(3) The data of financial expenditure in the field of education, scientific research achievements of colleges and universities adding the composition of college students in the selected countries' higher education system were available. The higher education system is a huge and complex system which is difficult to analyze comprehensively so representative indicators were used to evaluate its health and sustainability.

(4) The statistics were valid and assuming that the truth value of each index was near the statistics.

(5) The operation mechanism and system attribute of the higher education system in the studied country were independent of the higher education system in other countries. The research subject of the higher education system chosen was not affected by other subjects but depended on the internal elements of the system.

(6) Assuming that time was numerically continuous in addition that the effect of novel coronavirus was short-term and would not have a long-term effect on the country.

3. Research

The purpose of this study was to establish an effective quantitative model to evaluate the higher education system of different countries as well as to verify and score. For the typical representative of participating countries; India, this paper provided feasible policy suggestions based on the model.

3.1. Measurement of health and sustainability

Analytic hierarchy process (AHP) is an evaluation method that decomposes the elements related to decision problems into goals, criteria, and plans (sub-goals and sub-criteria), as well as combines qualitative analysis and quantitative analysis on this basis. It was proposed by Professor T.L.Saaty from University of Pittsburgh in the 1970s. The main feature of this method is that it can use subjective judgment to quantify the decision-making process at different levels and provide a relatively simple comprehensive solution for complex evaluation problems that are difficult to quantify.

For the establishment of the national higher education system evaluation model, this study set the national higher education system as the target layer and further selected educational resources, openness, and educational output; the three level indicators as the standard layer. Five targeted countries (America, Brazil, China, Australia, and India) were evaluated for their higher education system as the scheme layer so as to build a hierarchical structure model as shown in **Figure 2**.

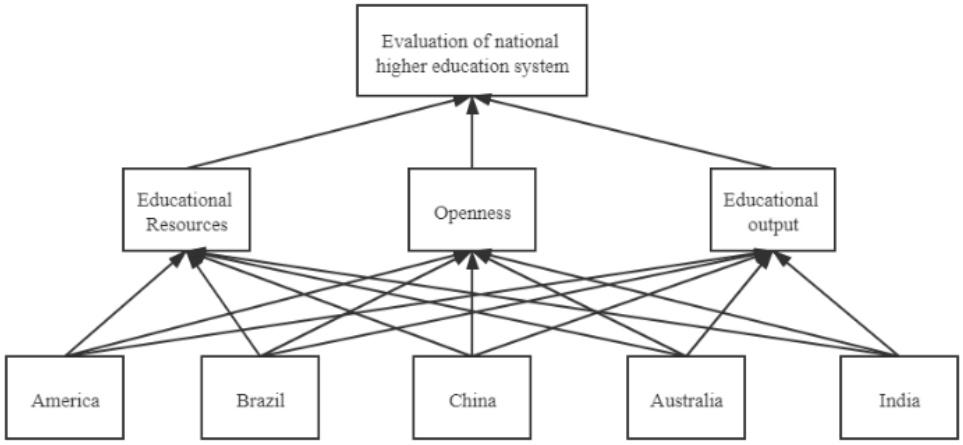

Figure 2. Hierarchical structure model

When AHP was used to evaluate the hierarchy structure, the strong and weak relationship of the superior indicators were judged according to the elements in the hierarchy starting from the criterion layer and the judgment matrix was assigned to the lower level successively while the odd judgment grade standard was adopted to determine.

For the judgment matrix groups that were obtained from subjective evaluation, the transitivity of the strong and weak relations were tested one by one, that is, the matrix consistency. In regard to this, according to the empirical judgment, the consistency test discriminant CR < 0.10 was calculated as the test passed standard.

The consistency index, $CI = \frac{\lambda_{max}}{n-1}$ where n is the order of the matrix, $\lambda_{\max}$ is the largest eigenvalue. The random consistency index RI takes the constant value when the ordinal number is the order of the corresponding matrix.

$$RI = [0, 0, 0.58, 0.90, 1.12, 1.24, 1.32, 1.41, 1.54]$$

This study used the level of single sort and deposition method, obtained the rule layer weight vector and plan layer for weight vector synthesis of weight matrix, and finally calculated based on the national higher education system for the target weight vector (high indicated system of perfect health; low indicated room for improvement).

$$W_t = (0.4004, 0.0711, 0.2418, 0.2208, 0.0658)$$

As can be seen from the overall ranking result, from the results of the comprehensive three factors, the higher education system of United States had the highest evaluation weight while the higher education systems of China and Australia ranked the second echelon. The higher education systems of Brazil and India were relatively backward, having large room for improvement.

3.2. Health degree and sustainable development indicators

In order to provide a comprehensive picture of the health and sustainability of higher education system, this study used a range of indicators. The indicators were selected based on the following principles:

(1) Indicators should be as comprehensive as possible to include most of the typical elements that can assess the health and sustainability of a higher education system.
(2) Indicators should preferably come from authoritative data institutions and facilitate government control and adjustment through feasible plans.
(3) Priority is given to indicators that have been reasonably tested in existing studies.

Based on these three principles, a set of metrics at two levels was built as shown in **Table 1**.

The first layer included three indicators which were educational resources, openness, and educational output. The second layer consisted of nine sub-levels; three for each layer. In selecting the sub-levels, this study considered three of the most pressing issues in the higher education system today in each sub-level. Finally, a higher education system for health degree and sustainability was constructed as the basis of the evaluation model.

Table 1. Indicator system for health degree and sustainability

Level 1 indicator	Level 2 indicator
Education resources	Ratio of the annual education expenditure to GDP
	Ratio of the number of universities to land area
	Number of top 100 professional disciplines
Openness	Proportion of international students
	Proportion of local students studying abroad
	Proportion of people with higher education
Educational output	Employment rate of higher education graduates
	Average annual income of higher education graduates
	Number of dissertations per capita in university

3.3. Dual index evaluation model

In the research, the evaluation criteria and evaluation factors were defined as follows:

Definition of evaluation criteria: healthy, H (static); sustainable, S (dynamic)

Definition of evaluation factor: educational resources, R; openness, O; educational output, P

The health level of higher education system was defined as $H = a_1R + a_2O + a_3P$ which indicated the linear weighted representation after the standardization of three factors. Its sustainability level was defined as $\frac{\frac{P}{R}+\alpha \cdot O}{2+2\alpha}$ which ensured the standardization of the range value. The progress of educational output relative to educational resources was regarded as the internal cycle factor of the national higher education system, supplemented by the degree of openness as the external cycle standard in which the regulating parameters $\alpha = a_1 \cdot a_2/a_3$ can be obtained according to the entropy weight method to determine the index weight.

The H and S levels of each country were calculated respectively and the McKinsey matrix concept chart of H-S was drawn to analyze the degree of the region of the higher education system level of each country.

3.4. Entropy weight method analysis

Standardization was first done for positive and negative indicators:

$$x_{ij}' = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}}, \quad x_{ij}' = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}}$$

The proportion of item j in country i:

$$y_{ij} = \frac{x_{ij}'}{\sum_{j=1}^{m} x_{ij}'}$$

Where x_{ij}' is the corresponding index value after standardization and the total number of countries is m. The index information entropy:

$$e_j = -K\sum_{j=1}^{m}\left(y_{ij} \ln y_{ij}\right)$$

In the formula, K is a constant, and K is 1/lnm. When $y_{ij} = 0$, the value is defined as $\lim_{y_{ij}\sim 0} y_{ij} \ln y_{ij} = 0$. The index information entropy:

$$d_j = 1 - e_j$$

Information entropy redundancy is the utility value which reflects the utility ability of index information evaluation. The index weight:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}$$

Where n represents the total number of evaluation indicators and according to the entropy additivity, the weight value of the upper level index is calculated proportionally by using the weight of the lower level second-level index.

3.5. GE matrix analysis

GE matrix method which is also known as the General Electric Company Law; the McKinsey matrix, a nine-box matrix method and industry attraction matrix is a new portfolio analysis method developed by GE in the 1970s. It is of great value and significance to select and position business for enterprises. GE matrix can be used to evaluate institutions based on their strength in the market and the attractiveness of the market they are in. GE matrix can also be used to describe a company's portfolio to determine their strengths and weaknesses. When broad and flexible definitions of industry attractiveness and business strength are required, strategic planning can be based on the GE matrix. The existing business (or institution) is evaluated according to the two dimensions which are market attractiveness and business strength. Each dimension is divided into three levels and nine grids to represent the combination of different levels on two dimensions. In the two dimensions, evaluation indexes can be determined according to different situations.

According to the weight obtained by the entropy weight method, the 10 countries were weighted and scored in whcih the American higher education system score was taken as the benchmark for standardized scoring.

In terms of the scores, the gaps between the countries were relatively large because of the level of the American higher education system. From the perspective of the economy, society, and environment of different countries, India, Brazil, and China which are developing countries with large populations have not achieved the same level of higher education penetration rate as developed countries. The scoring criteria in this model was not divided into an absolute pass or fail but it was used as a judgment of keeping up with and improving countries with high-level higher education systems.

Health Index (H)

0-0.55	Sub-health status
0.55-0.75	Basic health status
0.75-1.0	Full health status

Sustainability Index (S)

0-0.4	Poor sustainability
0.4-0.7	Generally sustainable
0.7-1.0	Sustainable development

Table 2. Score of the evaluation index weight

First-level indicator	Second-level indicator	Information entropy	Utility value	Secondary weight	First weight
Educational resources	Ratio of the number of universities to land area	0.8312	0.1688	0.14450	0.4497
	Ratio of the annual education expenditure to GDP	0.8527	0.1473	0.1265	
	Number of top 100 professional disciplines	0.7925	0.2075	0.1782	
Degree of openness	Proportion of international students	0.8335	0.1665	0.1431	0.2609
	Proportion of local students studying abroad	0.9259	0.0741	0.0636	
	Proportion of people with higher education	0.9368	0.0632	0.0542	
Educational output	Employment rate of higher education graduates	0.9021	0.0979	0.0841	0.2892
	Average annual income of higher education graduates	0.8800	0.1200	0.1031	
	Number of dissertations per capita in university	0.8813	0.1187	0.1020	

Table 3. Indicator scores of ten countries

Indicator \ Country	Brazil	India	Canada	Holland	Japan	Australia	China	Korea	Britain	America
H	0.38	0.45	0.50	0.57	0.59	0.65	0.61	0.66	0.80	0.87
S	0.31	0.26	0.47	0.57	0.71	0.67	0.65	0.64	0.78	0.84

Based on the above results, the McKinsey matrix from the perspective of education system evaluation can be obtained where countries with high comprehensive health and sustainability scores had reasons to believe that their higher education systems are perfect. **Figure 3** shows the matrix that was adopted.

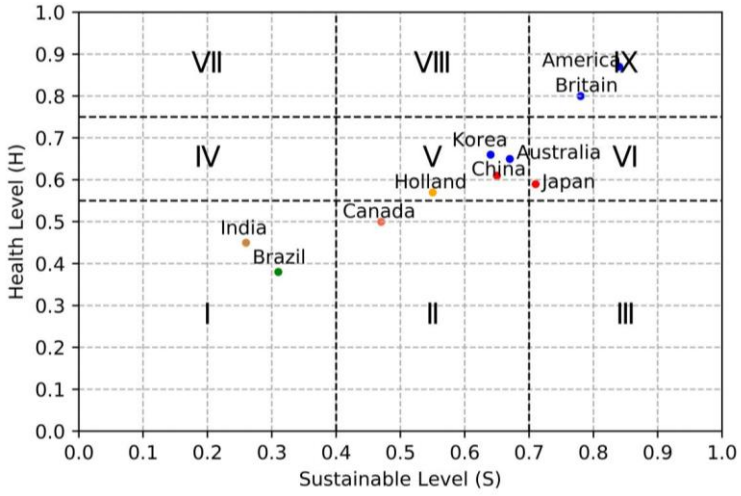

Figure 3. GE matrix in evaluating Health Index and Sustainable Index

3.6. Mechanism of Lanchester's equation

The Lanchester's equation was originally used in combat to assess the losses of soldiers on both sides. It is a nonlinear first order differential equation which can obtain the dynamic change of the system under different war strategies. The equation is described as:

$$\begin{cases} \dfrac{dx}{dt} = -ay - \alpha x + u(t) \\ \dfrac{dy}{dt} = -bx - \beta y + v(t) \end{cases}$$

Where a and b are the intensity of attack from side to side; α and β are the loss of soldiers due to reasons other than attack; u(t) and v(t) represent the complement of soldiers.

The Lanchester's equation provides a model for warfare where its use in this paper was to capture the dynamics of the sustainability of higher education systems and to predict changes in sustainability. The Lanchester's model does not only describe the influence on its own aspect but also the interaction of all aspects and the influence outside the system.

Taking the educational resources indicator for evaluating the health degree and sustainability of higher education system as an example, it includes three second-level indicators which are the ratio of the number of universities to land area, the ratio of the annual education expenditure to GDP, and the number of the top 100 professional disciplines. All secondary indicators reflect the input and allocation of resources in a country's higher education system. However, educational resources are also influenced by environment (GDP, the proportion of people in a country's higher education population, etc.). The interaction between environment and educational resources are clearly reflected in Lanchester's equation.

$$\begin{cases} \dfrac{dR}{dt} = \alpha_{11}R + \alpha_{12}O + \alpha_{13}P + U_1 \\ \dfrac{dO}{dt} = \alpha_{21}R + \alpha_{22}O + \alpha_{23}P + U_2 \\ \dfrac{dP}{dt} = \alpha_{31}R + \alpha_{32}O + \alpha_{33}P + U_3 \end{cases}$$

The policy functions for the three states are U1, U2, and U3, respectively with respect to time t.

4. Appraisal of the higher education system in India

Through the analysis, it can be seen that the higher education system in India currently has the following problems:

(1) Lack of government investment in public education resources
India has one of the largest number of higher education institutions in the world, largely because of the expansion of private higher education and state universities resulting in lagging infrastructure, high tuition fees, poor teaching methods, and a shortage of high-quality teachers.

(2) Low degree of openness of the national higher education system
It is affected by national policies, low degree of openness of colleges and universities, as well as unreasonable economic structure of the country.

(3) Unreasonable structure of educational output
The lack of high-quality teachers, scientific research, and innovation ability.

Due to the large gap between the health and sustainability of India's higher education system and that of the United States as well as other countries, this study specifically focused on three aspects which were

educational resources, openness, as well as educational output, and combined with the practical conditions of developing countries like India, the following vision was put forth:

(1) Increase the proportion of national fiscal expenditure on public education resources from the current 2.5% to 4%.
(2) Promote a more balanced distribution of higher education resources and increase the ratio of universities to land area from 3.02 to 5 per 10,000 square kilometers.
(3) Increase the internationalization of higher education, the proportion of international students from 0.8% to 1.5%, and the proportion of local students studying abroad from 28% to 40%.
(4) Enhance the scale of the national high-tech industry, increase the average annual income of higher education graduates from 10,317 US dollars to 20,000 US dollars, and issue incentive policies for innovative patents which is expected to increase the number of university papers per capita from 0.032 to 0.2.

The improved higher education system in India based on the above was scored by using the two index evaluation model where the American higher education system score was used as the benchmark for standardized scoring. The scores that were obtained this time were H = 0.53 and S = 0.42. Although there were still gaps between the current scores with the scores of the American higher education system, they significantly improved compared to H = 0.45 and S = 0.26 before the improvement. What is worth integrating is putting forward the vision from the comprehensive analysis of India's current higher education system situation which has stronger feasibility and effectiveness.

5. Policy validity analysis

This study used the Lanchester's model in the field of military warfare to evaluate the effectiveness of policy implementation. The differential equations in Lanchester's model do not only include the effects of each index factor itself but also the effects of their interaction and the effects of the external factors (such as policy) which fit well with the need to assess policy effectiveness.

For a series of targeted policies, this research used the following model to quantify them:

$$U(t) = \frac{(1+\alpha)t}{1+e^{-(1+\beta)t}}$$

This study used U(t) to represent U1, U2, and U3. Among them, α and β were the two parameters that were dynamically adjusted according to policy changes. The former represented active policy input and support such as increasing the investment of national financial funds in the construction of colleges and universities, improving the income level of college teachers, etc. The latter, on the other hand represented the reform and reshaping of the existing system such as increasing the support for public higher education institutions and guiding private schools to transform into social public facilities. When solving the model, this study discretized the changes of the two parameters; α and β in the policy model, respectively with a range of 0% to 25% at an interval of 5%. In practical test, the curves of α at 20% and 25% were quite similar. Hence, this research chose to substitute 50% for 25% as to the upper bound of α. After solving three of the first-level evaluation indexes in Lanchester's equation, the function curves of Health Index, H and Sustainability Index, S with respect to time, T under different policies were obtained according to the dual index evaluation model and the prediction and evaluation were then made.

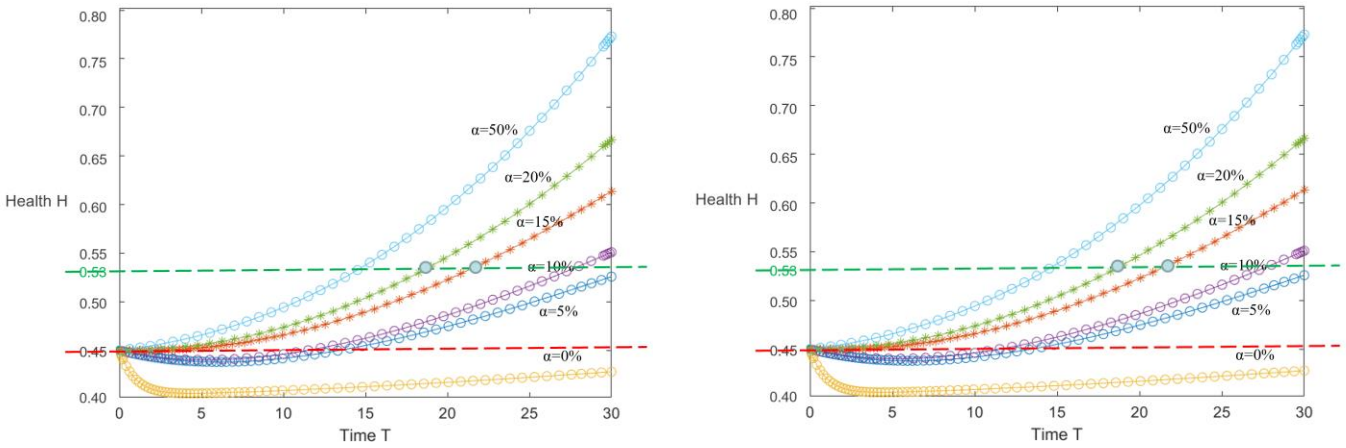

Figure 4. Curve of Health Index, H under the changes of α and time, T

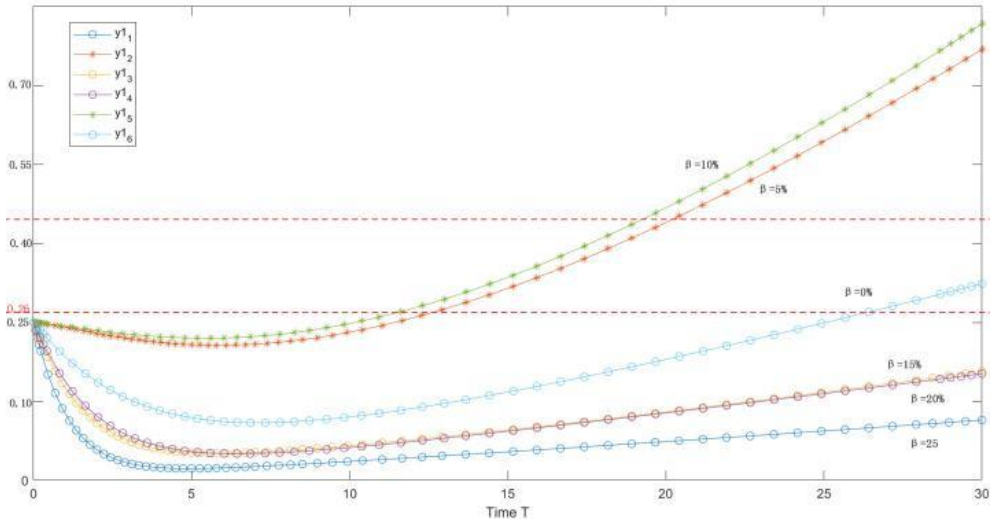

Figure 5. Curve of Sustainability Index, S under the changes of β and time, T

From **Figure 4**, it is not difficult to find that the Health Index, H and Sustainability Index, S of the improved system increase along with the policy's active input to education. Given the vision that was presented earlier and the practical effectiveness, α between 15% and 20% (two curves with *) is the best choice.

As can be seen from **Figure 5**, it is not true that more and faster policy investment in reform and institutional restructuring would lead to better results. The effect is best when β is between the two curves with *, that is, between 5% and 10% while the opposite effect occurs when β is higher. The same is true in the actual implementation of the means of education system reform. The interests of all parties should be taken into account. For some long-term problems, it is impossible to solve them once and for all and excessive efforts at the early stage would cause greater resistance.

6. Conclusion and recommendations

The improved higher education system in India was scored by using the dual index evaluation model while the American higher education system scores were used as the benchmark for standardized scoring. The scores obtained was H = 0.53 and S = 0.42. Although there were still large gaps between the scores, they significantly improved compared to H = 0.45 and S = 0.26 before the improvement. What is worth integrating is putting forward the vision from the comprehensive analysis of India's current higher education system situation which has stronger feasibility and effectiveness.

Based on the current problems of the higher education system in India, this study combined the enlightenment given by parameter α and β where the larger the positive based on resource allocation scheduling, the higher the Health Index and Sustainability Index scores of the system. The reform based on system improvement is logically continuous and there is an interval in which the system reaches an ideal state. Finally, this study proposes targeted policies with a 20-year cycle as follows:

Table 4. Policy schedule

Time	Policies					
	Positive			Reform		
	Education resources	Degree of openness	Educational output	Education resources	Degree of openness	Educational output
1	P1	P2		P3		P4
2	P1	P2		P3		P4
3	P1	P2		P3		P4
4	P1	P2		P3		P4
5	P1	P2		P3		P4
6	P5		P6	P7	P8	P9
7	P5		P6	P7	P8	P9
8	P5		P6	P7	P8	P9
9	P5		P6	P7	P8	P9
10	P5		P6	P7	P8	P9
11	P10	P11		P12	P13	P14
12	P10	P11		P12	P13	P14
13	P10	P11		P12	P13	P14
14	P10	P11		P12	P13	P14
15	P10	P11		P12	P13	P14
16	P10	P11		P12	P13	P14
17	P10	P11		P12	P13	P14
18	P10	P11		P12	P13	P14
19	P10	P11		P12	P13	P14
20	P10	P11		P4	P13	P14

Table 5. Policy implications

Policy	Specific content of policy
P1	Strengthen the construction of teaching staffs and improve the treatment toward teachers
P2	Begin the international teachers development project and select excellent teachers to further their studies abroad in order to expand their international vision
P3	Reform the undergraduate education and promote curriculum reform
P4	Reform the examination system and change the current annual examination system into the semester credit system
P5	Focus on the development of central affiliated institutions as well as the 20 research-oriented and innovative institutions
P6	Promote the coordinated development of state-owned and private universities, private enterprises, as well as central universities in addition to build a national innovation cluster

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Policy	Specific content of policy
P7	Establish local (state) higher education committee to plan and coordinate the development of higher education in the region
P8	Reform the system of affiliated colleges
P9	Improve the system and mechanism of higher education quality evaluation and monitoring
P10	Increase public financial expenditure and provide additional financial support for vulnerable students
P11	Differentiation to solve the problem of unbalanced development of higher education and implement the plan of equal opportunity in higher education
P12	Promote private capital injection into non-profit higher education and expand financial assistance to students in recognized private institutions
P13	Implement the reform of university classification and autonomy, abolish the single classification mode, and bestow more autonomy to universities
P14	Using the new PPP (public-private partnership) mode to create research and innovative universities

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Disclosure statement

The authors declare that there is no conflict of interest.

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