Diagnosis and Treatment of Higher Education

Mengfan Guo
Juncheng Ren
Zhuoying Li

Renmin University of China
Beijing, China
Advisor: Mengfan Guo

Summary

The higher education system is directly linked to the development potential of a country. Building a healthy and sustainable higher education system is of profound significance. We approach three problems: identify and measure the system's health, formulate policies towards better health, and evaluate the effectiveness of our policies.

To build models to assess the health of higher education systems in all countries, we build a Health Assessment (HA) indicator system based on the education indicator system proposed by the OECD. We use the Entropy Weight Method (EWM) to calculate weights for secondary indicators. We formulate an Education Power (EP) and a Sustainability Index (SI) to reflect the overall level and sustainability of a higher education system; and using the Analytic Hierarchy Process (AHP), we combine them to calculate a Health Degree (HD) score. We introduce the McKinsey matrix commonly used in management to compare the health of countries' higher education systems. We determine the classification range of EP and SI through k-means clustering and divide the McKinsey matrix into nine boxes. We use the coordinate $(\mathrm{EP}, \mathrm{SI})$ and the Health Degree to reflect the health status of higher education system in a country. We apply the Health Assessment (HA) model to countries with available data; and based on the results, we select for analysis Italy, where there is room for improvement in the higher education system.

Combining the results of the HA model and analyzing the scores of the secondary indicators, we propose a vision of migrating Italy's health state point from its current position to a better position. Specifically, we plan to increase the EP to 0.6 and to make the SI as close as possible to 0.41. In order to realize this vision, we put forward five policies, formulate a 12-year phased development plan from the perspectives of education inputs and education outputs, and set an implementation timetable.

The UMAP Journal 42 (3) (2020) 311–333.

To evaluate the effectiveness of the policies, we compare the health state of the higher education system in Italy 12 years from now with and without policy intervention. For the non-intervention situation, we use time series analysis to predict the changes of secondary indicators. For policy-intervention, we use a multiple linear regression model to reflect the interaction between indicators after analyzing the correlation of secondary indicators. We plot the results on the McKinsey matrix; they show that the policy intervention can achieve our vision. We also note the difficulties and specific impacts of policy implementation.

Finally, we carry out a sensitivity analysis of the evaluation model and an error analysis of the prediction model, demonstrating robustness and accuracy of our models.

Introduction

Problem Background and Restatement

With the rapid growth of modern technology, countries have laid great emphasis on their higher education development, which is an important manifestation of national competitiveness. Building a healthy, sustainable higher education system is of profound significance for a country's long-term development.

In the context of the covid pandemic, many problems in the higher education system arose, including lack of skilled health workers, lack of funds, and disruption of international exchange. Therefore, it is critical to reflect on our higher education system, identify its strengths and weaknesses, and renew strategies to strengthen it.

We attack the following problems:

- **Task 1:** Select proper indicators and build a model or a suite of models to evaluate the health of any nation's system of higher education. Apply the model to assess the health of several countries' higher education systems.
- **Task 2:** Choose a country which has room to improve its higher education system based on the analysis of Task 1. Describe an achievable and practical vision of the selected country's system that should meet the requirements of a healthy and sustainable higher education system. Measure the health of the newly proposed system and the current one. Propose necessary policies and a detailed implementation timeline to realize the vision.
- **Task 3:** Analyze the effectiveness of these policies with the model in Task 1. Discuss the implementation difficulties and their real-world impacts during the implementation and in the end state.

Literature Review

Since the middle and late 1980s, education indicators and education indicator systems have become hot topics in educational research all over the world. A comprehensive education indicator system can help decision-makers learn about the real state of a higher education system and support future planning.

Many international organizations have proposed indicator systems. A classical structure comprises education inputs, process, and products [Johnstone 1981]. UNESCO referred to Johnstone's approach to reflect the change in an educational system, using education supply, demand, enrollment and participation, internal efficiency, and output with a special concern for education equity and quality [Ling 2004]. Similarly, based on the CIPP evaluation model (Context, Input, Process, and Product), the Organization for Economic Cooperation and Development (OECD) put forward the framework of OECD Indicators of Education Systems (INES), which includes the inputs, participation, and outputs of education [OECD 2020].

In addition, many countries and regions have built their own education evaluation system. An example is the indicator system of the European Union, which involves the three European policy priorities (employability, matching of supply and demand, and accessibility) [Lassnigg , 81–86]. Focusing on actual education problems, the Special Study Panel on Education Indicators (SSPEI) from the U.S. National Center for Education Statistics advocated the construction of an educational index system from six major areas [National Center for Education Statistics 1991].

Despite the many evaluations to assess education systems, there is no system particularly built for higher education. We build a model to measure and assess the health of a system of higher education and give policy suggestions accordingly.

Our Work

We reviewed relevant literature and chose to use as our indicator system the education evaluation system based on the CIPP evaluation model proposed by OECD. We collect the required data and carry out data preprocessing. Next, we adopt EWM and AHP methods to evaluate the national higher education "power." Referring to the McKinsey matrix, we add a sustainability dimension and establish a health assessment model for higher education system.

We apply our model to analyze the health state of higher education systems in some representative countries and select Italy as our target. We put forward a reasonable development vision and a phased higher education promotion policy for Italy. We quantify the effectiveness of the policies, taking into account interaction of indicators. Then we compare the results with the predicted Italian health scores in the absence of policies.

Finally, we analyze the impact of policies on Italy during and after the implementation and point out the difficulties in improving the health of the higher education system.

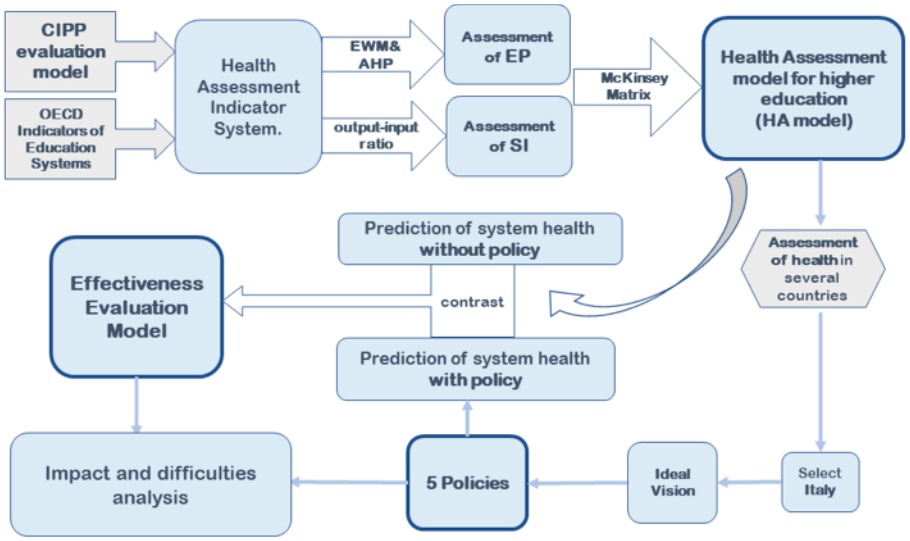

Figure 1. Our workflow.

Assumptions and Justifications

- **A country's environment is relatively stable**, so that the country will not undergo dramatic changes such as a major financial crisis or public health emergency over the next decade. Small-scale incidents that happen occasionally will not have a fundamental impact on the country's higher education.
- **The higher-education level of countries with better economic conditions can represent and reflect the development of global higher education**. This means that we can select representative countries to train our evaluation model, and the results of the model can be applied to all countries.
- **Any specific country can be regarded as a macroscopic unit**, whose development is relatively independent of other countries.
- **The health of a country's higher education system can be comprehensively and scientifically reflected through limited and reasonably selected indicators.** That health is determined by many factors. Because of interactions among these factors, some factors can be eliminated without affecting the evaluation effect, and a limited number of factors that can fully reflect the health status can be screened out.
- When the international environment is relatively stable and there is no policy intervention, **the indicators that we select show regularity in the**

short term. This regularity may be embodied in stability, linear changes, nonlinear changes, or periodic fluctuations.

Table 1.
Notations used.

Abbreviation	Concept
HA	Health Assessment
HD	Health Degree
EP	Education Power
SI	Sustainability Index
EC	Education Context
EPA	Education Participation
EI	Education Input
EO	Education Output

Health Assessment Model

System health is a measure of the ability of an organization or system to align around a common vision, pursue that vision effectively, and renew itself through innovation and creative thinking. If we consider a system healthy, the system should not only achieve a high level in various aspects, but also be sustainable and balanced in these aspects.

The health assessment model for a system of higher education that we build should meet the following requirements. The model should be...

- ...**universal**, so it can be applied to any nation in the world. So the indicators we select should be applicable for most countries.
- ...**comprehensive**, exhausting various aspects of higher education.
- ...**a proper measure** of the health state of the higher education system at a national level.
- ...**robust**. The evaluation results of the model are relatively stable, with the possible disturbance of uncertainties.

The HA Indicator System

Determination of Indicators and Data Collection

We need to select representative indicators. The framework of the OECD Indicators of Education Systems (INES) stands out for its universality and reasonability. It reflects a consensus among professionals on how to measure the current state of education. Therefore, we choose INES as the framework of our indicator system. However, INES is not closely related

to higher education and it doesn't focus on health assessment. So we make necessary modifications to the original framework to better address our purpose:

- We include the context into our system, covering not only economic and social factors that serve as the foundation of education improvement but also literacy rate, duration of compulsory education, etc., to reflect the basic education capacity of a country.
- We change some indicators in the original framework to focus on health assessment in higher education.

Our indicator framework is comprised as follows:

- **Education context:** the background information of higher education development, including economic and social situations and basic education capacity.
- **Education input:** the financial and human resources invested in higher education.
- **Education participation:** the gender difference of higher education access and the level of international exchange.
- **Education output:** higher education coverage, completion rate, and output of scientific research.

After identifying the indicator framework in **Table 2**, we collect data from authoritative sources, including World Bank Data [n.d.], UNESCO Institute for Statistics [n.d.], and the International Labour Organization ILOSTAT database [n.d.]. Considering that we are discussing the state of higher education, we mainly choose countries with a certain level of economic development.

We arrive at the 20 second-level indicators in **Table 2**.

The indicators requiring clarification are GPI, GPIA, the Net flow ratio of internationally mobile students, and PUB.

GPI and APIA represent the ratio of female-to-male gross enrollment rates at different levels of education, as a reflection of fairness in the education process.

The Net flow ratio of internationally mobile students shows the total number of foreign higher education students studying in a country (inbound students) minus the total number of domestic students studying at the same level of education in another country (outbound students) as a percentage of the country's total higher education enrollment.

To describe the output of scientific research, we adopt the adjusted PUB score as the indicator. The PUB score is the relative score of the number of papers included in the Science Citation Index-Expanded and Social Science Citation Index. To calculate a country's PUB score, we first find the PUB scores of the country's universities in the top one thousand world

Table 2.
The Health Assessment indicators.

Designation	Meaning	Unit
Education Context		
DCE	Duration of compulsory education	years
EET	Expenditure on education as % of total government expenditure	%
GDP	GDP per capita	USD
LR	Literacy rate in population 25-64 years	%
UR	Unemployment of total labor force	%
Education Input		
GEN	Government expenditure on post-secondary non-tertiary* education as % of GDP	%
GET	Government expenditure on tertiary education as % of GDP	%
GEPT	Government expenditure per student, tertiary % of GDP per capita	%
TN	Teachers in post-secondary non-tertiary education, both sexes	number
TT	Teachers in tertiary education programmes, both sexes	number
Education Participation		
GPIA	Gross enrollment ratio for tertiary education, adjusted gender parity index (GPIA)	−
GPI	Gross enrollment ratio, post-secondary non-tertiary, gender parity index (GPI)	−
NFR	Net flow ratio of internationally mobile students (inbound − outbound), both sexes	%
PTR	Pupil-teacher ratio, tertiary	−
Education Output		
ERT	Gross enrollment ratio for tertiary education	%
ERN	Gross enrollment ratio, post-secondary non-tertiary	%
GRT	Gross graduation ratio in tertiary	%
LF	% of labor force with advanced education	%
STEM	% of graduates from science, technology, engineering, and mathematics programs in tertiary	%
PUB	PUB	%

*Post-secondary non-tertiary education refers to higher-education institutions that do not give a bachelor's degree, such as some American community colleges.

universities; the country's PUB score is the average PUB score of the top 10 universities in the country.

Data Preprocessing

Data Filling: To deal with missing values in the data, we adopt the following approaches: If an indicator for a country...

- ... has rather few missing data of the years and the indicator has a relatively small variance, we use the average value of other years to fill the missing ones.
- ... has rather few missing data of the years but the indicator has a relatively strong correlation with the year indicator, we use regression interpolation.
- ... lacks data for all years, we fill in the data of this indicator with the mean of all countries. considering the specific meaning of the indicator.

After processing missing values, we obtain complete data for 49 countries for the past 20 years.

Handling Outliers: Through descriptive statistics and boxplots, we analyzed each indicator in all countries and found some outliers. We discarded data with impossible values (e.g., enrollment rate exceeding 100%) and data at a significance level of 0.01, and processed them as if they were missing values

Data Normalization

Having cleaned the data, we need to normalize the different indicators so that they can be compared on the same scale. The 20 indicators can be divided into three categories, for which we carry out different methods for normalization. We let j be the country and normalize the value x_{ij} on indicator i to $\tilde{x}_{ij}$.

- Benefit Attributes: the larger, the better.

$$\tilde{x}_{ij} = \frac{x_{ij} - \min\{x_i\}}{\max\{x_i\} - \min\{x_i\}}.$$

- Cost Attributes: the smaller, the better.

$$\tilde{x}_{ij} = \frac{\max\{x_i\} - x_{ij}}{\max\{x_i\} - \min\{x_i\}}.$$

- Interval Attributes: An interval attribute's optimal value lies in a certain interval $[a, b]$. Let

$$M = \max\{a - \min\{x_i\},\ \max\{x_i\} - b\},$$

$$\tilde{x}_{ij} = \begin{cases} 1 - \dfrac{a - x_i j}{M}, & x_{ij} < a; \\ 1, & a \le x_{ij} \le b; \\ 1 - \dfrac{x_{ij} - b}{M}, & x_{ij} > b. \end{cases}$$

For most indicators, it is quite clear whether they are benefit or cost attributes. Based on our belief that the more high-level a university means a higher teaching level, we conclude that STEM is an interval attribute. We specify its interval using the range of STEM of the top 11 countries in ranked list of the number of high-level universities in a country, which is [16.7, 32].

Calculating Education Power (EP)

We introduce Education Power (EP) as the overall description of a country's higher education level. The entropy weight method (EWM) is commonly used as a weighting method. It assumes that the higher the degree of dispersion of an index, the greater the degree of differentiation, the more information can be derived, and the greater weight should be given to the index, and vice versa [Zhu et al. 2020]. We use the entropy weight method to estimate the weight values of the second-level indicators.

Suppose that we have n indicators and m countries. We first standardize the measured values. We denote the standardized value of the indicator i for country j by p_{ij}, where

$$p_{ij} = \frac{\tilde{x}_{ij}}{\sum_{j=1}^{m} \tilde{x}_{ij}}.$$

In EWM, the entropy value E_i of the ith indicator is calculated as

$$E_i = \frac{\sum_{j=1}^{m} p_{ij} \ln p_{ij}}{\ln m}.$$

The larger E_i, the greater the differentiation degree of index i, and the greater weight should be given to index i. Therefore, the weight w_i of index i is calculated as

$$w_i = \frac{1 - E_i}{\sum_{i=1}^{n} (1 - E_i)}.$$

The comprehensive performance S_j of country j is the weighted total of all indicators:

$$S_j = \sum_{i=1}^{n} w_i p_{ij}. \qquad \textbf{(1)}$$

Our indicator system is divided into four dimensions (education context, input, participation, and output) with corresponding indicators n_{ec}, n_{ei}, n_{epa}, and n_{eo}. Thus, we apply EWM to each of the four dimensions and calculate four scores S, each via the corresponding version of **(1)**.

Then, we apply EWM to our data and get the weights of indicators for each dimension as shown in **Table 3**.

Table 3.
Weights of the indicators (rounded).

	Indicator	Weight		Indicator	Weight
Content			**Participation**		
	DCE	.01		GPIA	.25
	EET	.34		GPI	.31
	GDP	.51		NFR	.17
	LR	.06		PTR	.27
	UR	.08		ERT	.14
Inputs			**Outputs**		
	GEN	.53		ERN	.27
	GET	.15		GRT	.13
	GEPT	.23		LF	.09
	TN	.05		STEM	.06
	TT	.04		PUB	.30

Next, to find the respective weights of each of the four dimensions, we adopt the Analytic Hierarchy Process (AHP) method. The weight value vector (rounded) is

$$w = (.26, .11, .06, .57)$$

for respectively education context, input, participation, and output. The overall description of a country's higher education level Education Power is calculated as

$$\text{EP} = (S_{\text{ec}}, S_{\text{ei}}, S_{\text{epa}}, S_{\text{eo}}) \cdot w^{\intercal}.$$

Sustainability Index

We introduce another index—the Sustainability Index (SI)—to describe the sustainability and balance of the system of higher education. We will use the combination of EP and SI to assess the health of the system of higher education.

SI is defined as the education output-input ratio:

$$\text{SI}_0 = \frac{S_{\text{eo}}}{S_{\text{ei}}},$$

$$\text{SI} = \frac{\text{SI}_0 - \min\{\text{SI}_0\}}{\max\{\text{SI}_0\} - \min\{\text{SI}_0\}}.$$

SI reflects the conversion efficiency of educational resources. Higher SI means greater potential for future development and higher viability of current policies in the long run.

The McKinsey Matrix

To combine the impacts of EP and SI to assess the health performance of the higher education system, we adopt the McKinsey matrix.

The McKinsey matrix is a classic tool to help manage complex business portfolios. It puts the industry attractiveness on the Y-axis and the competitive strength of a business unit on the X-axis so that a business unit is assessed from the two dimensions. The McKinsey matrix has also been applied to evaluate sustainable urbanization [Wang and Jiang 2018].

We modify the McKinsey matrix method to our problem. We put EP on the X-axis and SI on the Y-axis to construct the McKinsey matrix. To identify the nine boxes in the McKinsey matrix, we adopt the k-means clustering algorithm to find the threshold values for each box. We cluster the selected countries into three categories according to EP and then according to SI. Then we use the average of the three sort centers as the two threshold values. The threshold values are 0.3 and 0.6 for EP and 0.14 and 0.41 for SI.

We plot a country "health state" point (EP, SI) on the plot and then calculate its euclidean distance to the ideal point (1,1) as the final assessment of the Health Degree (HD) of the higher education system:

$$HD = \sqrt{(1 - \text{EP})^2 + (1 - \text{SI})^2}.$$

The smaller HD, the healthier the higher education system.

Application of the HA Model

We apply our model to the United States, the United Kingdom, the Czech Republic, Italy, and Thailand to give an analysis of the health state of their higher education systems. The results are shown in **Table 4** and **Figure 2**.

Among the five countries, the United Kingdom has the highest score in both EP and SI and is in the optimal box of the matrix. The other countries all have room for improvement in their higher education systems. Italy was one of the earliest Western countries in the world to develop higher education and set up universities. To identify its problems and facilitate the future health development of its higher education system, we select Italy to do a case study.

Table 4.
Health assessment of selected countries.

Country	EC	EI	EPA	EO	SI	EP	**HD**
United Kingdom	.49	.11	.59	.71	.66	.66	.48
United States	.59	.12	.44	.56	.52	.58	.64
Italy	.21	.37	.51	.50	.19	.45	.98
Thailand	.41	.35	.00	.32	.14	.35	1.08
Switzerland	.90	.47	.87	.06	.01	.41	1.16

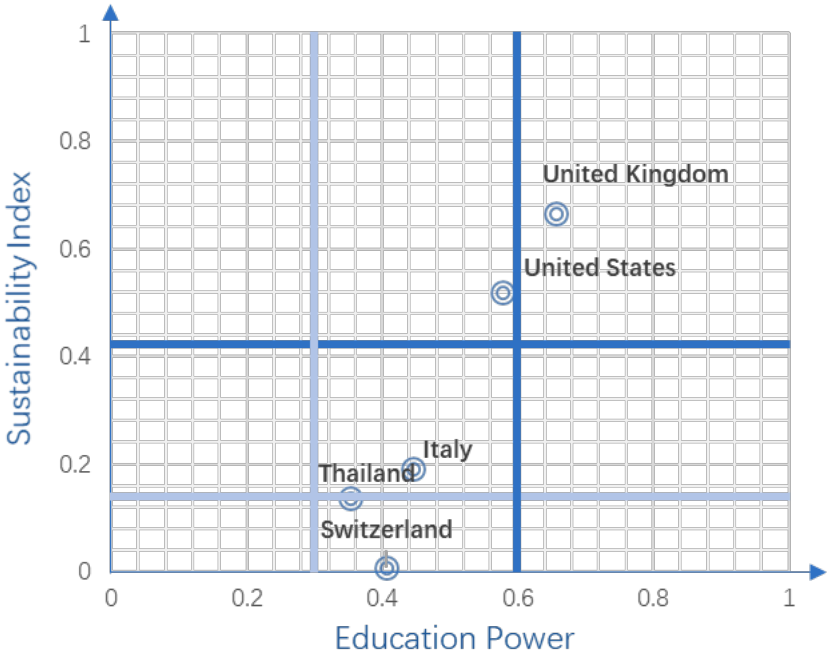

Figure 3. Plot of selected countries on the McKinsey matrix.

Migrate to a Healthy and Sustainable State

Analysis of Italy's Current Higher Education System

The health state point of Italy falls in the bottom box in the middle of the matrix, indicating that Italy's higher education system has medium power and a relatively low level of sustainability. Compared to the other countries, Italy is in the middle or lower reaches of each of the four dimensions. To clarify the deficiencies, we compare some second-level indicators between Italy and other European countries.

We discover the following:

- Italy, as a developed country, has a good economic and social foundation; but the poor education context is mainly due to the lack of government investment in education.
- The government's spending on tertiary education is inadequate but on post-secondary education is relatively reasonable.

Table 5.
Comparisons between Italy and other European countries.

Country	EC	EPA		EI		EO			
	EET	NFR	PTR	GET	GEPT	ERT	ERN	LF	STEM
United States	13	5	12	1.5	19	88	5.3	73	17
United Kingdom	14	16	16	1.4	38	60	2.3	84	24
Sweden	16	3	12	1.8	43	67	3.3	84	28
Norway	16	−3	9	2.1	40	82	3.2	84	22
Italy	**8**	**1**	**20**	**0.8**	**24**	**62**	**2.8**	**75**	**16**
France	10	7	17	1.2	32	66	1.5	77	27
Finland	12	5	20	1.7	34	88	6.4	74	27
Czech Republic	10	9	18	0.7	20	64	7.5	76	24
Austria	11	13	7	1.7	36	85	4.7	77	30

- The proportion of men and women participating in higher education is balanced; but the international attraction is weak, and the resources of teachers are relatively scant.
- Italy's overall performance in education output is far from satisfactory. The enrollment rate in higher education is relatively low, and higher education should be further popularized and encouraged.
- Italy has a low proportion of STEM graduates and a relatively low level of education of the labor force. This may be due to the more developed art and design industry in Italy and the lack of attention to science and technology.

The Vision for Italy

We describe a vision for the higher education system of Italy and prove its rationality and attainability.

We believe that the closer the health state point is to $(1, 1)$, the healthier the higher education system is. So we want Italy's health state point to migrate from the current position to an upper-right position.

Italy has a solid economic and social foundation and it's well-known for its long history in higher education. Besides, Italy has diverse higher education institutions. Also, Italy has always attached great importance to higher education and has made continuous reforms to stimulate the development of higher education, for example, promoting the decentralization of education and accelerating the Bologna Process (of ensuring comparability of European countries' standards for higher-education qualifications) [Huang 2005].

Considering practical difficulties, it is very hard to migrate to the upper-right box. Therefore, the vision we propose for Italy's higher education system is to migrate the health state point from the current position to the yellow area marked in **Figure 4**. Specifically, the EP score should reach .60, entering the optimal interval. As for SI, we hope to increase it as much as possible without explicitly requiring it to reach .41, the threshold value of the optimal interval.

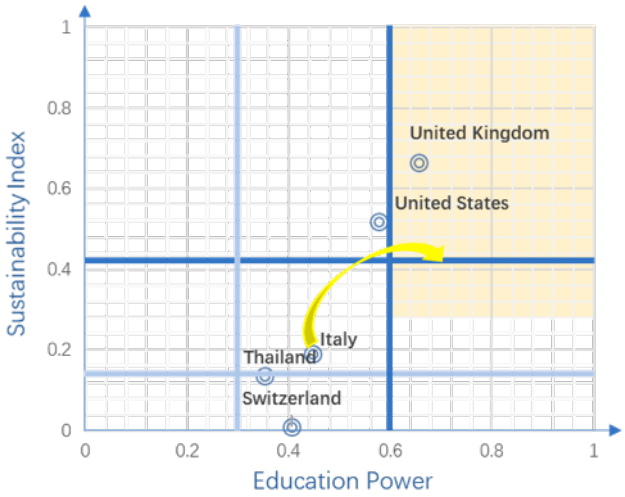

Figure 4. The vision for Italy.

To fulfill our vision, the higher education system must improve the four dimensions of EP but also improve the SI output-input ratio, so as to ensure the viability of policies in the long run. Relating to the HA indicator system we have built, we picture the ideal vision in the following aspects:

- **Education context:** The country's economic and social foundation provide guarantee and support for further development of higher education.
- **Education input:** Higher education becomes an important object of government investment, giving priority to the development of higher education.
- **Education participation:** All young people of school age enjoy equal access to higher education. A perfect international exchange mechanism and an open and inclusive academic environment is formed, and the integration of higher education in Europe is basically realized.
- **Education output:** All education resources are properly allocated. The coverage of higher education expands significantly. More universities reach world-class.

Policy for Italy

Based on the previous analysis, we propose a series of policies to achieve the ideal health state of Italy's higher education system.

- **Policy 1:** Increase government spending on education, especially on post-secondary education. In Italy, all public universities are almost free of tuition. But after 2000, the Italian Ministry of Education began to impose symbolic fees on public institutions due to the influx of foreign students [Jia and Wang 2008]. So the development of higher education is largely dependent on government support.
- **Policy 2:** Create an open and inclusive academic environment to improve international attraction and further expand international academic exchange. Facilitate and accelerate the Bologna Process [Bi 2008].
- **Policy 3:** Give greater autonomy to higher education institutions. Reduce policy restrictions on them. In this way, the institutions can decide independently how to allocate educational resources, which may improve the efficiency of the resources. These institutions can carry out more autonomous scientific research activities, thus promoting the progress of scientific research [Jia and Wang 2008].
- **Policy 4:** Publicize the importance of higher education, especially post-secondary, and encourage the public to pursue higher education. Increase the enrollment ratio of different levels of higher education.
- **Policy 5:** Improve the treatment of teachers. Attract more qualified people to become teachers, thus cut the pupil-teacher ratio to provide better education quality.

To implement these policies in detail, we built a timeline for the execution of the policies based on real-world constraints. We set the policy for the next 12 years and divide the 12 years into four phases. To achieve a healthy higher education system, the five targeted policies come from the four aspects: educational background, input, output, and process. They're not doing it all at the same time, given the realities and the national resource constraints, but they're doing it in different phases.

The Implementation Timeline

For convenient reference, we repeat in **Table 6** descriptions of the indicators mentioned below.

- **2021–2023:** As a result of the global pandemic, we face several serious problems, including a lack of skilled workers for the health profession and professional medical researchers, a lack of funding for the education system, and a disruption of international exchanges. We need to

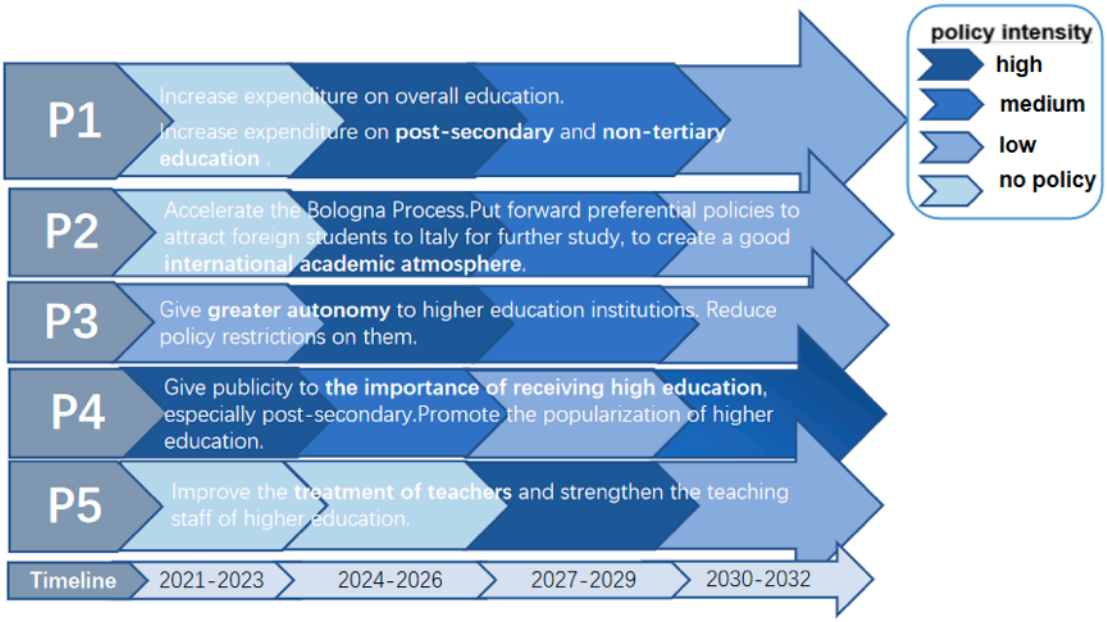

Figure 5. The implementation timeline for Italy.

Table 6.
Health Assessment indicators.

Designation	Meaning	Unit
Education Context		
EET	Expenditure on education as % of total government expenditure	%
Education Input		
GEN	Government expenditure on post-secondary non-tertiary education as % of GDP	%
Education Participation		
NFR	Net flow ratio of internationally mobile students (inbound − outbound), both sexes	%
PTR	Pupil-teacher ratio, tertiary	–
Education Output		
ERN	Gross enrollment ratio, post-secondary non-tertiary	%
PUB	PUB	%

increase the post-secondary enrollment rate as soon as possible to meet the needs of skilled health graduates; the metric implemented in our system is to increase the ERN by 8%. Meanwhile, in terms of higher education process and output, NFR will be increased by 3% and PUB score will be increased by 5%.

- **2024–2026:** After the outbreak, the economy will gradually recover. The government should give priority to the development of higher education, increase investment in higher education, and promote international exchanges. Corresponding indicators will be EET and GEN indicators increased by 5% and 8%. At the same time, the higher education enrollment rate will continue to increase, and ERN will increase by 6%. In terms of higher education process and output, increase NFR by 10% and PUB score by 4%.
- **2027–2029:** With the first two phases in place, most policy intensity diminishes. Start to increase the policy intensity on teachers, and reduce PTR by 2. International communication increases NFR by 8%, EET and GEN by 4% and 6%, ERN by 4%, and PUB by 3%.
- **2030–2032:** Confine policy implementation to support further the development of higher education institutions in a more academic and knowledge-based society. Increase ERN by 4%, while EET and GEN increase by another 3%, NFR by 6%, PUB by 3%, and PTR decreases by 1.

Effectiveness Evaluation of Our Policies

We evaluate the effectiveness of the policy recommendations and timeline in as intuitive a way as possible. To do this, we compare Italy's scores on Educational Power (EP), Sustainabilty Index (SI), and Health Degree (HD) with and without policy implementation.

Prediction with No Such Policy

We find that most of the indicators for Italy from 2000 to 2019 have long-term trends and volatility. The time sequence diagram for some indicators are shown in **Figure 6**.

Since the implementation cycle of the policy recommendations is not very long (12 years), we use autoregressive and moving average models to predict the indicators.

We want to focus on the change and improvement of the health state of the higher education system of Italy, so it's reasonable to keep the other countries' data unchanged in the period we are going to discuss and calculate the health scores of Italy. Otherwise, the assessment will be largely dependent on the performance of other countries and will not reflect real

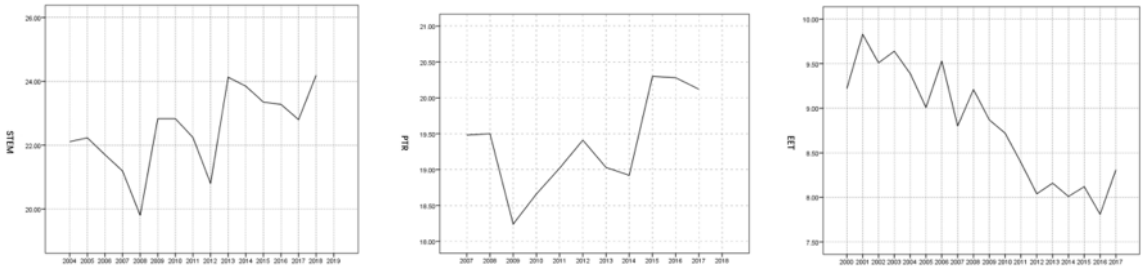

Figure 6. Time series graphs for STEM, PTR, and EET for Italy, 2000–2019.

progress of the higher education system of Italy, since the assessment model we have constructed measures the *relative* health level of a country.

Using the time series prediction models noted above, we predict the change of health status of Italian higher education system without new policy intervention in the next 12 years. We substitute these predicted data into the health assessment model that we built. We get Italy's scores on EP, SI, and HD without policy implementation.

Next, we need to quantify the impact of our policy on specific indicators. We have proposed improving indicators by stages, but the indicators often do not improve independently as might be expected. Because of correlation among the indicators in the rating system, an increase in one indicator often leads to a change in indicators associated with it. In order to scientifically evaluate the rationality of the policy, we first conduct correlation analysis on all indicators, and use multiple linear regression to build a linear relationship for indicators with strong correlation, so as to quantify the impact in the real world.

[EDITOR'S NOTE: We omit the details of the authors' investigation of correlations of the indicators.]

We predict the progress of the higher education system of Italy with policy intervention over the next 12 years and plot the results in **Figure 7**.

If these policies are not implemented, although the EP score will grow steadily, the SI score will fall sharply, resulting in a less healthy system. With policy intervention, EP score will increase steadily with time. At the same time, the SI shows an upward trend with fluctuations. At the end of 12 years, both EP and SI reach high scores compared with no intervention situation. EP has reached the optimal interval and SI has become really close to the threshold value of the optimal box. This is in line with our expectations that it is indeed very difficult to improve the SI score. But we still see a huge progress in SI. So we can consider that our policies can support the migration from the current state to the proposed state. Italy can realize its vision.

Figure 7 indicates that in the first few years of policy implementation, the SI, i.e., the output-input ratio, and EP score both increase. In the middle term, the SI score declines slightly. This is because after we invest more financial and human resources into the higher education system, the re-

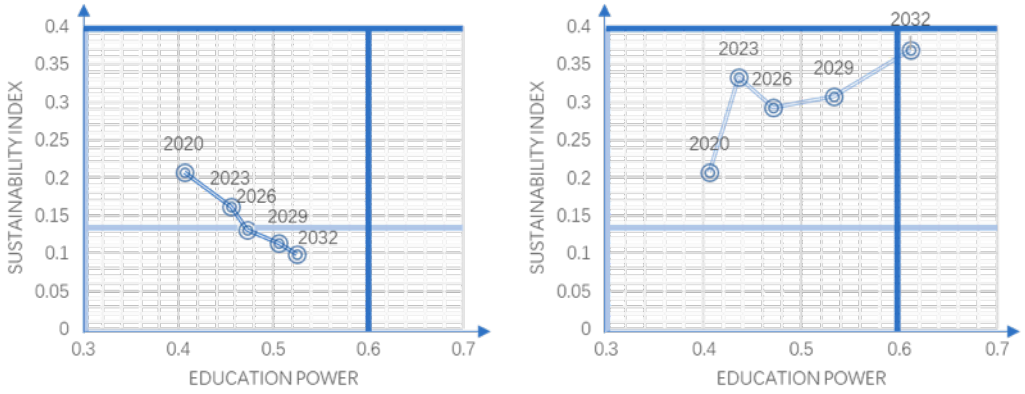

Figure 7. Predicted results for Italy: **a.** Without policy implementation. **b.** With implementation.

sources cannot be properly allocated and utilized in a timely manner, resulting in inefficient use of resources and a decline in the output-input ratio. In the later period, the two items increase synchronously and our system reaches a relatively stable state.

Figure 8 depicts the variations of EP, SI, and HD with and without policy implementation. It is obvious that implementation of our policies could ameliorate the system health.

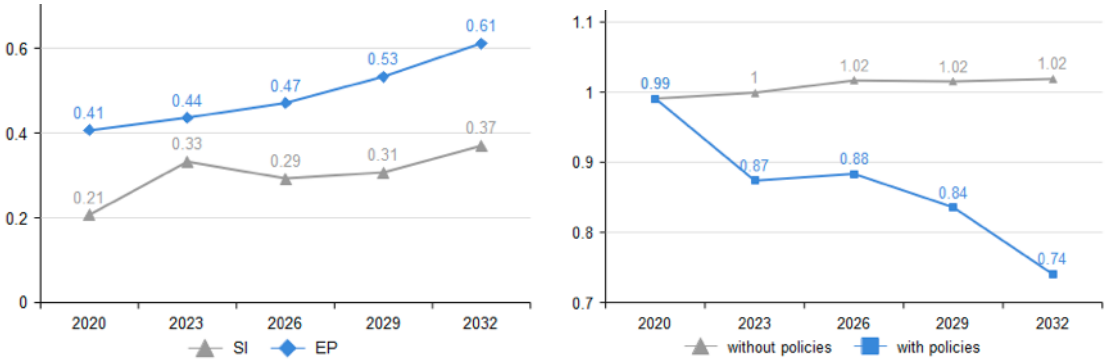

Figure 8. EP, SI, and HD with and without policy implementation.

Policy Difficulties and Impact Analysis

Our policy implementation has different emphases in different periods. We analyze the impact of policies on the transition process and the end state as follows.

Transition State

Prior to 2023, policy focused on tertiary education. At the national level, this will enhance the country's reserve of professionals to deal with the follow-up impact of the epidemic, to prevent the national unemployment

surge. This is an opportunity for development and a challenge for universities that are not well developed in Italy. For students, it can enhance their skills and enhance their competitiveness.

After 2023, the government's investment in institutions of higher learning has gradually increased. At the national level, this will increase the financial pressure of the government to some extent. But for institutions of higher learning, this will help them conduct more sophisticated scientific research. At the same time, the international academic exchange atmosphere in Italy will be freer, attracting more high-level talents to Italy and accelerating the Bologna Process. The number of teachers will increase, and the system management of university teacher mobility will gradually fade.

End State

The strength and sustainability of Italian higher education will reach a higher level. The state, society, and schools will gradually benefit from the returns of higher education. University research strength, in terms of world ranking, will increase. The talent gap in various disciplines will be supplemented. The overall academic quality of students will be improved.

Difficulties

The vision that we propose is to achieve coordinated progress in education strength and sustainability in Italy. But from the results, it is difficult to reach the level of the world-class higher education power such as in Britain and the United States. Italy's higher education has always been a national centralized management; to reach or even exceed the threshold in a short period of time requires greater national capital investment. For Italy, which suffered a serious economic setback in 1998 and whose economy is still in recovery period, huge capital investment is not realistic.

In the ecosystem of higher education, output reflects input with a time lag. This delay makes it impossible to get returns in the short term after the government increases its expenditure on higher education.

Sensitivity Analysis and Error Analysis

Assessment Model Sensitivity Analysis

We need to test whether our models' results are sensitive to changes in the input parameters. Data are often perturbed by artificial error and unpredictable factors. To simulate such perturbation, we calculate the variance of indicator x_i after normalization. The greater the variance, the greater the volatility of the indicator. It turns out that ERN has the largest

variance. So we add a stochastic disturbance term ε_i to the data of ERN. We assume that this stochastic disturbance fluctuates randomly in the range of 10% of the original data. Since the normalized data is located in the interval $[0, 1]$, we define the data after adding the stochastic disturbance as $0.9\tilde{x}_i + \varepsilon_i$, where ε_i is a uniformly distributed random number in the interval $[0, 0.1]$. Then we use the new data to calculate the weights using the entropy weight method. By comparing the weights with and without stochastic disturbance, we find that the changes of the weights are within 3%, which shows that the weights are not seriously affected by data error and pertrubation. Our health assessment model is relatively stable.

Prediction Model Error Analysis

We set the error of each index data element x_i to be u_i. We assume that u_i is a random variable that follows a normal distribution with mean 0 and a constant variance and is independent of the indicator data, which means $\text{Cov}(u_i, x_i) = 0$ for all i. After perturbation, the data are $x_i + u_i$.

We find that the predicted HD by 2032 is affected by less than 3%.

Model Evaluation and Further Discussion

Strengths

- **Selection of evaluation indicators.** The choice is scientific and comprehensive. We adopt the framework of the OECD Indicators of Education Systems for its universality and reasonability. We also make necessary modifications to better address our purpose, including involving the education context and adjustiing specific indicators.
- **Data preprocessing.** We have filled missing data and handled outliers in the acquired data. For different indicators, we have adopted different processing methods, and modified the processing results based on the actual meaning, and finally obtained a relatively complete data set.
- **Application of management thinking.** We regard each country as an independent functioning unit. We adopt the McKinsey matrix, commonly used in management, to creatively analyze the combined effects of EP and SI to give an overall description of the health state of a national higher education system.
- **Comprehensive application of multiple methods.** We use relatively objective methods—EWM and AHP—to identify the weights of the multiple indicators. Also, we use k-means clustering to find threshold values for the McKinsey matrix.

- **The evaluation model is robust.** We did a sensitivity analysis on the weights: We made the weight coefficients of several indicators fluctuate in a small range and found that the list of countries' sustainable development levels did not change significantly, indicating that our evaluation model has high stability.

Weaknesses

- **Sudden factors.** The model does not consider the impact of sudden factors. We assume that the international environment in which the country is located is relatively stable, but emergencies might take place.
- **Incomplete data.** We are unable to obtain data for all of the required indicators. Although we have dealt with missing values, the accuracy of model fitting is still affected to a certain extent.
- **Short-term only.** The model is suitable only for short-term forecasting and evaluation. We assume that the changes in various indicators over time show regularity in the short term.

References

Ahn, Taesik, Abraham Charles, and William W. Cooper. 1988. Some statistical and DEA [Data Envelopment Analysis] evaluations of relative efficiencies of public and private institutions of higher learning. *Socio-Economic Planning Sciences* 22 (6): 259–269.

Bi, Chaohui. 2008. The reform of the quality assurance system of higher education in Italy during the Bologna process. *Study on Higher Education in Heilongjiang Province* 3: 52–55. [in Chinese] http://www.cnki.com.cn/Article/CJFDTOTAL-HLJG200803017.htm.

Huang, Qibing. 2005. Review of the reform of higher education in italy. *Foreign Education Studies* 8: 38–40. [in Chinese] http://www.cnki.com.cn/Article/CJFDTOTAL-WGJY200508009.htm.

International Labour Organization Department of Staistics. n.d. ILOSTAT database. http://datalib.edina.ac.uk/catalogue/ilostat.

Jia, Shuli, and Yan Wang Yan. 2008. The characteristics and enlightenment of Italian higher education. *Contemporary Education Forum (Macro-Educational Studies)* 10: 112–114. [in Chinese] http://www.cnki.com.cn/Article/CJFDTOTAL-JYLT200810049.htm.

Johnstone, James N. 1981. *Indicators of Education Systems*. Paris: UNESCO.

Lassnigg, Lorenz. 2003. Indicators for quality in VET [vocational education and training]: European experience. https://ihs.ac.at/publications/soc/rs63.pdf.

National Center for Education Statistics. 1991. *Education Counts: An Indicator System to Monitor the Nation's Educational Health*. Washington, DC: Government Printing Office.

OECD. 2020. Education at a Glance 2020: OECD Indicators. https://www.oecd-ilibrary.org/education/education-at-a-glance-2020_69096873-en.

Shanghai Ranking Consultancy. 2020. Academic Ranking of World Universities. https://www.shanghairanking.com/rankings/arwu/2020.

UNESCO. n.d. UIS.Stat. http://data.uis.unesco.org/.

World Bank Data. n.d. Word Bank Open Data. http://data.worldbank.org.

Xu, Ling. 2004. Analysis and thinking of international educational index system. *Educational Science* 2: 18–21. [in Chinese] http://www.cnki.com.cn/Article/CJFDTOTAL-JYKO200402004.htm.

Yang, Wei, and Xiaoli Jiang. 2018. Evaluating sustainable urbanization of resource-based cities based on the McKinsey matrix: Case study in China [Datong city]. *Journal of Urban Planning and Development* 144 (1) (March 2018). https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29UP.1943-5444.0000423.

Zhu, Yuxin, Dazuo Tian, and Feng Yan. 2020. Effectiveness of entropy weight method in decision-making. *Mathematical Problems in Engineering* 2020, Article ID 3564835. https://downloads.hindawi.com/journals/mpe/2020/3564835.pdf.

About the Authors

Mengfan Guo

Jungcheng Run

Zhuoying Li