Measurement and Evaluation of Collaborative Development Level of Higher Education

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Abstract—With the aid of grey correlation theory and technique for order of preference by similarity to ideal solution (TOPSIS), this paper sets up a multi-dimensional evaluation index system (EIS) for the comprehensive development level (CDL) of China's higher education, and quantifies the state of collaborative development in 2005-2017 with an improved distance collaboration model. The results show that: Being the premises and bases of higher education, the supply subsystem develops much slower than the other subsystems (i.e., participation, output, and environment), and clearly pulls the development of the other subsystems. From 2012 onwards, the subsystems conformed to basically the same trend for the degree of collaboration: The degree of collaboration tended to be stable. There was even a slight dent in overall degree of collaboration between 2012 and 2016. Hence, the overall degree of collaborative development was far slower than the overall degree of development. After more than a decade of development, the degree of development, degree of collaboration, and degree of collaborative development reached basically the same level in 2017. The empirical results shed new lights on the focal points of higher education development in China.

Keywords—Higher education, collaborative development, evaluation index system (EIS), improved distance collaboration model

1 Introduction

Higher education is an important propeller of social progress and economic growth. Firstly, higher education blesses the educated with the knowledge and skills necessary for improving labor productivity and save production cost. Secondly, higher education trains modern high-tech professionals, providing a strong support to technological innovation. Thirdly, higher education helps to reform the social structure and optimize the cultural environment. Without higher education, it is impossible for a country to modernize science and technology, not to mention realizing social progress or economic growth.

Since reform and opening-up, China has made remarkable achievements in higher education. In the decade following 1999, the institutions of higher learning (IHLs) opened their doors wider, and shifted from elite education to mass education. On the scale of higher education, China has surpassed India and the United States (US), ranking first in the world for many years. At present, China is working hard to enrich the connotations of higher education, while maintaining the sustained growth of its scale. To coordinate the development and enhance the quality of higher education, all IHLs in China are obliged to optimize its structure, efficiency, and benefits, and adapt to the development of society, economy, and environment [1-5].

This paper aims to objectively evaluate the collaborative development level of China's higher education. Firstly, an evaluation index system (EIS) was designed for the overall development level of higher education. Next, an improved distance collaboration model was developed to measure the degree of development, degree of collaboration, and overall degree of collaborative development of China's higher education and its subsystems, drawing on the technique for order of preference by similarity to ideal solution (TOPSIS), and grey correlation theory.

2 Literature Review

Many scholars have explored the collaborative development of China's higher education. Through qualitative analysis, Zhang and Wang [6] suggested that competition is the key to the efficient allocation of higher education resources, but excessive competition will undermine the health and sustainability of higher education; the higher education reform in China calls for the paradigm shift from competition to collaborative development, which is widely adopted around the world for structural optimization of higher education. Inspired by the education index system of United Nations Educational, Scientific and Cultural Organization (UNESCO), Sun et al. [7] constructed an EIS and a comprehensive evaluation model for higher education level of Chinese provinces, and empirically evaluated the comprehensive level, demand, supply, enrollment, participation, performance, and output of higher education in each province.

Zhang et al. [8] designed a 7-dimensional EIS for comprehensive development level (CDL) of higher education, and statistically analyzed the CDL of higher education of each Chinese province through partial least squares (PLS)-structural equation modeling (SEM). The results show that the CDLs between the three regions of China have significant differences, i.e., the higher education CDLs of eastern provinces are generally higher than those of central and western provinces; the provinces within each region differ in terms of the CDL of higher education. Drawing on systems theory and synergetics, Liu [9] defined the concept of the collaborative development of regional higher education, empirically examined the collaborative development between the subsystems of regional higher education in China, including scale, structure, quality, and benefits, and divided the collaborative development of regional higher education in China into moderately collaborative development, weakly collaborative development, and weakly uncollaborative development [10-12].

From the perspectives of synergetics and systems theory, Liu and Wang [13] created a comprehensive EIS for higher education structure and industrial structure, and employed the collaborative coupling model to investigate the collaboration between the two factors in China; it is learned that the collaboration is precarious on the national level, and vastly different from region to region. Chen and Chen [14] conducted factor analysis on the coordination between higher education and economy in 31 Chinese provinces, and drew the following conclusions: The overall degree of coordination between higher education and economy was relatively low in 2005-2014, despite certain improvement; the degree of coordination varied significantly between provinces; each province has unique reasons for the change of coordination degree.

Xue and Liu [15] performed comprehensive integration of the spatial layout of higher education in Beijing-Tianjin-Hebei (BTH) region, and discovered problems in the balance of spatial layout, the rationality of hierarchical structure, and the scientificity of specialty design. Focusing on connotations, overall collaboration, and student experience, Huang and Sun [16] integrated subjective and objective indices into an EIS for provincial higher education in China, and implemented the EIS to measure and evaluate the CDL of provincial higher education, revealing the provincial imbalance and insufficiency of CDLs, the low CDLs in most provinces, as well as the stepped decline in CDL from eastern region, central region, to western region.

The above studies basically rely on the EIS and empirical analysis/model to quantify the current state or degree of coordination of inter- and intra-regional higher education in China, failing to tackle the overall collaborative development of the national higher education system. Taking the CDL of China's higher education as a whole, this paper quantitatively measures the collaborative development levels of the higher education system in China and its subsystems, with improved distance collaboration model based on TOPSIS and grey correlation theory [17-21].

3 Methodology

3.1 EIS construction

Before empirically analyzing the degree of collaboration of higher education, it is necessary to construct an EIS with indices that scientifically reflect the correlations and features of higher education and its subsystems. In general, the EIS for higher education should have functions like description, interpretation, evaluation, monitoring and prediction [22-24].

To build a pertinent, scientific, unified, comparable, and feasible EIS for China's higher education [22], this paper selects indices from four dimensions, namely, participation, supply, output, and environment, laying the basis for quantifying the collaborative development level of China's higher education and its subsystems. In total, the established EIS include 4 primary indices, which are supported by 10 secondary indices and 33 tertiary indices (Table 1).

Table 1. The EIS of the CDL of China's higher education

Primary indices	Secondary indices	Tertiary indices
Participation	Scale	Number of college students per 100,000 people
		Number of colleges per million people
		Number of students per college
		Gross enrollment rate of higher education
	Hierarchy	Proportion of undergraduates in college students
		Proportion of graduate students in college students
		Proportion of general undergraduate colleges in all colleges
Supply	Financial input	Higher education expenditure per student (RMB 10,000 yu-an/student)
		Proportion of national higher education input in gross domestic product (GDP)
		Research fund per teacher
	Human input	Total number of full-time teachers
		Total number of R&D personnel
		Proportion of full-time teachers with deputy senior titles and above in all teachers
	Material input	Area per college
		Area of school buildings per student
		Value of fixed assets per student
		Number of books per student
		Value of teaching and research instruments per student
Output	Research benefit	Number of technological service projects in colleges
		Number of awards for achievements in colleges
		Amount of technology transfer contracts in colleges
		Income of patent transfers in colleges
	Knowledge output	Number of papers published per teacher
		Number of monographs published per teacher
		Number of cited research and consultation reports
		Number of authorized intellectual property rights per teacher
	Talent output	Number of junior college graduates and above
		Proportion of junior college graduates and above in the employed population
Environment	Policy environment	Education fund in state budget
	Economic environment	Household consumption
		Real GDP per capita
		Urban unemployment rate
		Proportion of tertiary industry

1) Participation: This subsystem involves 2 secondary indices and 7 tertiary indices. Specifically, the secondary index of scale covers 4 tertiary indices, reflecting the opportunities for Chinese citizens to access higher education in general; the secondary index of hierarchy covers 3 tertiary indices, reflecting the opportunities for Chinese citizens to receive each level of higher education.

2) Supply: This subsystem describes the premises and bases for the operation and development of higher education. There are 3 secondary indices (i.e., human input,

financial input, and material input), plus 11 tertiary indices. To objectively reflect the level of each input, all indices were measured by per capita values or proportions, except the total number of full-time teachers and the total number of research and development (R&D) personnel under the secondary index of human input.

3) Output: This subsystem characterizes the achievements and benefits of higher education, and directly mirrors its operating efficiency and development quality. The 3 secondary indices and 10 tertiary indices fully demonstrate the research benefits, research and teaching results, as well as talent cultivation of higher education.

4) Environment: The health and sustainability of higher education hinge on the social and economic environment. To a certain extent, the society and economy could manifest the current state of higher education. In this subsystem, 2 secondary indices, namely, policy and economic environment, and 5 tertiary indices, were chosen to measure the environment of China's higher education.

3.2 Evaluation process

In essence, the distance collaboration model uses Euclidean distance to measure the deviation of the actual state of a system from the ideal state, and thus quantify the degree of collaboration of the system. Here, the improved distance collaboration model is coupled with TOPSIS and grey correlation theory to evaluate the collaborative development of China's higher education. The deviation between the current and ideal states of higher education was calculated, and used to derive the exact degree of collaborative development, facilitating the empirical analysis.

Based on the established EIS, the subsystems of the improved distance collaboration model covers four dimensions: Participation, supply, output, and environment. The historical statistics on the tertiary indices of each subsystem were imported to the model to obtain the development level of each subsystem, the degree of collaboration of each subsystem and pull factors between subsystems, as well as the CDL, overall degree of collaboration, and overall degree of collaborative development of higher education.

Standardization of evaluation indices: The indices in the established EIS need to be nondimensionalized to eliminate their dimensional differences. Different types of indices were standardized by different methods.

The benefit indices, whose quality is positively correlated with value, were standardized by:

$$g_{ist} = \frac{z_{ist} - \min\limits_{t} z_{ist}}{\max\limits_{t} z_{ist} - \min\limits_{t} z_{ist}} \tag{1}$$

The cost indices, whose quality is negatively correlated with value, were standardized by:

$$g_{ist} = \frac{\max\limits_{t} z_{ist} - z_{ist}}{\max\limits_{t} z_{ist} - \min\limits_{t} z_{ist}} \tag{2}$$

The intermediate indices, whose quality is positively correlated with the proximity to the intermediate value, were standardized by:

$$g_{ist} = \frac{\max_t |z_{ist} - z'_{ist}| - |z_{ist} - z'_{ist}|}{\max_t |z_{ist} - z'_{ist}|}$$ (3)

where, z_{ist} is the s-th index of subsystem i in period t; $z'_{ist} \in [\min_t z_{ist}, \max_t z_{ist}]$ is the ideal intermediate value or planned optimal value; g_{ist} is the dimensionless index after standardization, $i = 1, 2, \cdots, n$, $s = 1, 2, \cdots, m$, $t = 1, 2, \cdots, k$.

Calculation of Euclidean distance: The positive and negative ideal points of each index in each subsystem were determined based on the historical statistics. The set of positive ideal points and that of negative ideal points are denoted as $G^+ = (g_{i1}^+, g_{i2}^+, \cdots, g_{im}^+)$, and $G^- = (g_{i1}^-, g_{i2}^-, \cdots, g_{im}^-)$, respectively. Then, the Euclidean distances between each subsystem and its positive and negative ideal points can be respectively calculated by:

$$Q_{it}^+ = \sqrt{\sum_{s=1}^m (g_{is}^+ - g_{ist})^2}$$ (4)

$$Q_{it}^- = \sqrt{\sum_{s=1}^m (g_{is}^- - g_{ist})^2}$$ (5)

where, g_{is}^+ and g_{is}^- are the best and the worst values of the s-th index of in subsystem i over the years, respectively; Q_{it}^+ and Q_{it}^- are the Euclidean distances between subsystem i and the positive and negative ideal points in period t, respectively.

Degree of development of each subsystem and the overall degree of development of higher education: The degree of development of subsystem i in period t can be calculated by:

$$q_{it} = 1 - \frac{Q_{it}^+}{Q_{it}^+ + Q_{it}^-} = \frac{Q_{it}^-}{Q_{it}^+ + Q_{it}^-}$$ (6)

where, $\frac{Q_{it}^+}{Q_{it}^+ + Q_{it}^-}$ is the proximity of subsystem i to the positive ideal point. The closer the q_{it} value to zero, the lower the degree of development of the subsystem; the closer the q_{it} value to one, the higher the degree of development of the subsystem.

The overall degree of development of higher education in period t can be calculated by:

$$q_t = \sum_{i=1}^n \omega_i q_{it}$$ (7)

where, ω_i is the weight of each subsystem. Here, the value of ω_i is determined by entropy weighting, an objective weighting method.

Deng's degree of grey correlation and pull factors between subsystems: Taking the degree of development of each subsystem as the main sequence or the contrast sequence, this paper calculates the Deng's degree of grey correlation of each subsystem, and then determines the pull factors between the subsystems.

Deng's degree of grey correlation: Let the degrees of development of a subsystem $X_i = (q_{i1}, q_{i2}, \cdots, q_{it})$ be the main sequence, and those of another subsystem $X_j = (q_{j1}, q_{j2}, \cdots, q_{jt})$ be the contrast sequence, $i, j = 1, 2, \cdots, n$. First, the main and con-

trast sequences were nondimensionalized into $y_i(l)$ and $y_j(l)$, respectively, $l = 1, 2, \ldots, t$. Then, a grey correlation analysis model can be established as:

$$\Delta_j(l) = \left| y_i(l) - y_j(l) \right| \tag{8}$$

$$\gamma_{ij}(l) = \frac{m + \rho M}{\Delta_j(k) + \rho M} \tag{9}$$

On this basis, the Deng's degree of grey correlation γ_{ij} between sequences i and j can be calculated by:

$$\gamma_{ij} = \frac{1}{t} \sum_{l=1}^{t} \eta_j(l) \tag{10}$$

where, $\Delta_j(l)$ is the sequence of absolute differences; $\gamma_{ij}(l)$ is the correlation coefficient sequence between sequences i and j ; $m = \min_j \min_l \Delta_j(l)$ and $M = \max_j \max_l \Delta_j(l)$ are the minimum and maximum absolute differences, respectively; $\rho \in (0,1)$ is the correlation coefficient or resolution coefficient; t is the number of samples or periods.

Pull factors: If the development curve of subsystem j is higher than that of subsystem i (i.e., subsystem j develops ahead of subsystem i), then the pull factor of subsystem j to subsystem i is $\theta_{ij} = \gamma_{ij} < 1$, that is, the pull effect of subsystem j on subsystem i is less than 1. If the development curve of subsystem j is lower than that of subsystem i (i.e., subsystem j lags behind of subsystem i), the pull factor of subsystem j to subsystem i is $\theta_{ij} = 1/\gamma_{ij} > 1$, that is, the pull effect of subsystem j to subsystem i is greater than 1.

Degree of collaboration of each subsystem: The positive and negative ideal degrees of development of each subsystem can be respectively determined as:

$$q'_{it}{}^{+} = \sum_{j=1}^{n} \omega_i \, \theta_{ij} q_{jt} \tag{11}$$

$$q'_{it}{}^{-} = 0 \tag{12}$$

where, $i, j = 1, 2, \cdots, n$.

By the Euclidean distance formula, the deviations of the degree of development of each subsystem from the positive and negative ideal degrees of development can be calculated, and used to derive the degree of collaboration of that subsystem:

$$P_{it} = \frac{\sqrt{(q_{it} - q'_{it}{}^{-})^2}}{\sqrt{(q_{it} - q'_{it}{}^{-})^2} + \sqrt{(q_{it} - q'_{it}{}^{+})^2}} = \frac{|q_{it}|}{|q_{it}| + |q_{it} - q'_{it}{}^{+}|} \tag{13}$$

Overall degree of collaboration and overall degree of collaborative development: The overall degree of collaboration and overall degree of collaborative development of higher education in China can be respectively calculated by:

$$P_t = \sqrt[n]{\prod_{i=1}^{n} P_{it}} \tag{14}$$

$$PQ_t = \sqrt{P_t \cdot q_t}$$ (15)

4 Empirical Analysis

4.1 Data selection and measuring results

Table 2. The overall degree of development of higher education and the degree of development of each subsystem

Year	Degree of development of participation	Degree of development of supply	Degree of development of output	Degree of development of environment	Overall degree of development
2005	0.2354	0.3719	0.1651	0.1532	0.2394
2006	0.2600	0.3802	0.1998	0.2518	0.2653
2007	0.3731	0.3554	0.1801	0.3533	0.3270
2008	0.4754	0.2270	0.2896	0.2489	0.3902
2009	0.5114	0.2813	0.3635	0.2282	0.4362
2010	0.5541	0.3597	0.3444	0.3347	0.4722
2011	0.5709	0.4316	0.4279	0.4295	0.5142
2012	0.5700	0.4798	0.4874	0.5038	0.5360
2013	0.5763	0.4855	0.4931	0.5915	0.5439
2014	0.6030	0.5116	0.5470	0.6183	0.5765
2015	0.6688	0.5705	0.7092	0.7478	0.6641
2016	0.7425	0.6296	0.7883	0.8522	0.7374
2017	0.8373	0.6578	0.8412	1.0000	0.8136

The statistics on the tertiary indices in 2005-2017 were obtained from official sources, such as China Statistical Yearbooks, Educational Statistics Yearbooks of China, China Labor Statistical Yearbooks, and Statistical Bulletins on Education released by Chinese Ministry of Education. The data on some indices were directly extracted from these sources, and those on some indices were calculated from the data of these sources. In the environment subsystem, the real GDP per capita was calculated based on the constant price in 2005, aiming to eliminate the impact of inflation.

Based on the established EIS, the collaborative development situation of China's higher education was measured by processing the collected statistics through the above-mentioned methods. The measuring results are recorded in Tables 2-4. By entropy weighting, the weights of participation, supply, output, and environment subsystems were determined as 0.60, 0.16, 0.22 and 0.02, respectively. During the calculation of Deng's degree of grey correlation, mean normalization was performed on both the main and contrast sequences, that is, each data in the two sequences was divided by the arithmetic mean of the corresponding sequence, and the resolution coefficient ρ of formula (9) was set to 0.5.
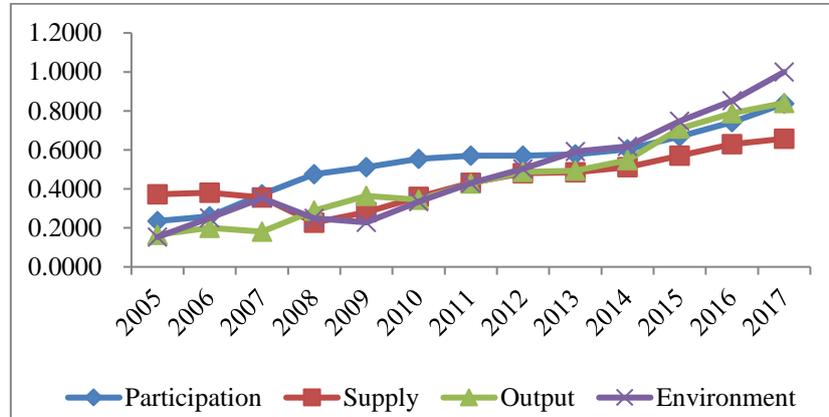
Table 3. The pull factors between subsystems

Subsystem	Participation	Supply	Output	Environment
Participation	1.0000	1.3533	1.4395	1.5736
Supply	0.6995	1.0000	0.6545	0.6377
Output	0.6258	1.6060	1.0000	0.7179
Environment	0.6087	1.5672	1.3344	1.0000

Table 4. The degree of collaboration of each subsystem and overall
degree of collaborative development of higher education

Year	Degree of collaboration of participation	Degree of collaboration of supply	Degree of collaboration of output	Degree of collaboration of environment	Overall degree of collaboration	Overall degree of collaborative development
2005	0.8464	0.6633	0.7469	0.6672	0.7273	0.4173
2006	0.8411	0.6799	0.8269	0.9952	0.8282	0.4688
2007	0.9887	0.7601	0.6548	0.8372	0.8012	0.5119
2008	0.9202	0.8096	0.9538	0.7767	0.8619	0.5799
2009	0.9601	0.8944	0.9563	0.6195	0.8446	0.6070
2010	0.9583	0.9566	0.9060	0.8369	0.9131	0.6566
2011	0.9754	0.8844	0.9924	0.9533	0.9505	0.6991
2012	0.9244	0.8454	0.9301	0.9574	0.9133	0.6997
2013	0.9199	0.8467	0.9322	0.8519	0.8869	0.6945
2014	0.9052	0.8498	0.8999	0.8645	0.8796	0.7121
2015	0.8637	0.8675	0.8298	0.8451	0.8514	0.7519
2016	0.8634	0.8711	0.8289	0.8302	0.8482	0.7908
2017	0.8862	0.9070	0.8410	0.7926	0.8556	0.8343

4.2 Result analysis

In 2005-2017, the degree of development of each subsystem exhibited a clear upward trend. From the level in 2005, the degree of development of participation, supply, output, and environment in 2017 increased by 2.56, 0.77, 4.09 and 5.53 times, respectively, with an annual mean growth rate of 11.72%, 6.29%, 15.83%, and 19.44%, respectively. Except for supply, all subsystems achieved a rapid annual growth faster than 10%. Besides, the degree of development curve of supply was lower than that of participation, output, or environment. The above results show that supply develops much slower than the other subsystems. Thanks to the balanced, sustained, and high-speed growth of the subsystems, the overall degree of development of higher education is bound to increase rapidly and continuously, and the collaborative development of higher education is promoted substantially.

Fig. 1. The degree of development of each subsystem

As shown in Table 3, supply had a significant pull effect on other subsystems of higher education. The pull factors of supply for participation, output and environment subsystem were 1.3533, 1.6060, and 1.5672, respectively, all of which were greater than 1. Being the premises and bases of higher education, the supply of fund, man-power, and material is a major driver of the participation, benefit, and environment of higher education. In return, the pull factors of supply, output, and environment for participation were 1.3533, 1.4395, and 1.5736, respectively, all of which were greater than 1. This means the participation, mainly characterized by scale and hierarchy, is clearly promoted by the other subsystems. Considering the pull factors and the annual growth rates of the subsystems, China should invest more fund, manpower, and material in higher education, to prevent resource bottlenecks, elevate the overall degree of collaborative development, and promote the all-round coordination of higher education.

During 2005-2017, the degree of collaboration of each subsystem changed in two phases: Before 2012, all subsystems witnessed significant fluctuations in the degree of collaboration, and differed greatly in the change direction of that degree. From 2012 onwards, the subsystems conformed to basically the same trend for the degree of collaboration: the degree of collaboration tended to be stable, with limited increase or decrease. The stable trend in the latter phase is attributable to the implementation of the Enhancement Plan for the Innovation Ability of IHLs (2011 Plan) and the emphasis on the connotations of higher education. Since 2011, the IHLs in China have maintained sustained growth in number and scale, while attaching greater importance to the supporting systems (e.g., supply, output, environment, and policies) of higher education.
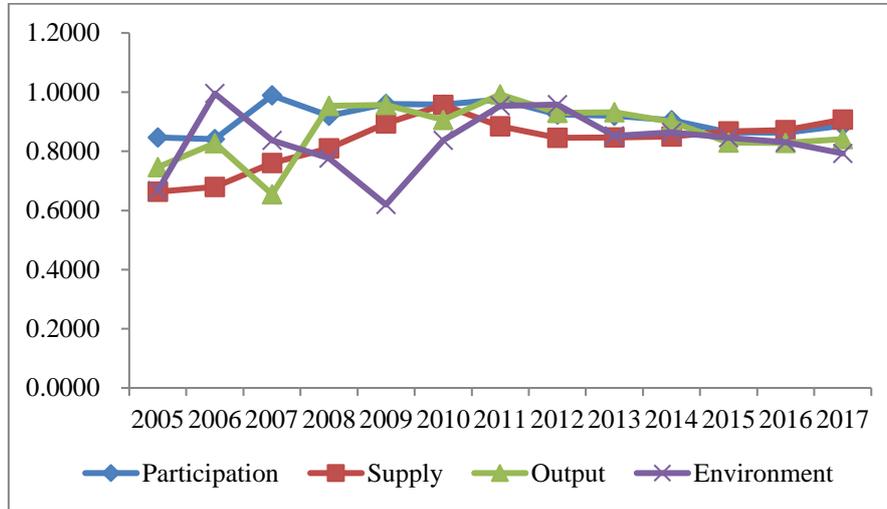
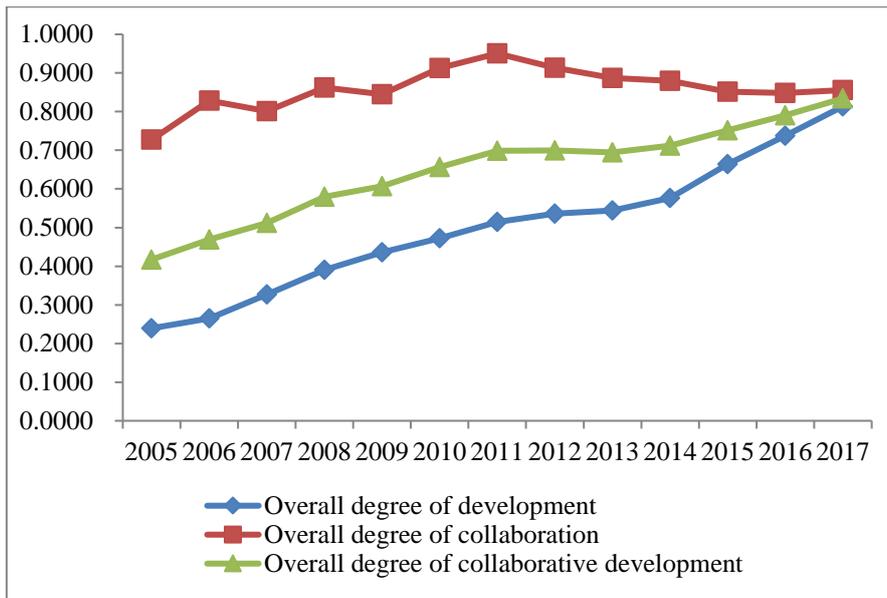**Fig. 2.** The degree of collaboration of each subsystem

Fig. 3. The trend of collaborative development

In 2005-2017, China's higher education saw obvious growth in the overall degree of development and the overall degree of collaborative development, which increased by 2.40 times and nearly 1 time, respectively. The annual mean growth rates of the overall degree of development and the overall degree of collaborative development were 10.88% and 6.02%, respectively.

By contrast, the overall degree of collaboration increased by only 17.64% in 2017 from the level of 2015, and remained basically stable through the sample period. There was even a slight dent between 2012 and 2016. Hence, the growth rate of the overall degree of collaborative development was far slower than that of the overall degree of development.

After more than a decade of development, the degree of development, degree of collaboration, and degree of collaborative development reached basically the same level in 2017, respectively 0.8136, 0.8556, and 0.8343. Apart from continued structural optimization, China should input more resources in higher education to pull the development of other subsystems, deepen the collaboration between subsystems, and thus enhance the overall degree of collaborative development of higher education.

5 Conclusion

To measure the development of China's higher education, this paper first designs a four-dimensional EIS, involving such subsystems as participation, supply, output, and environment, and then quantifies the state of collaborative development of China's higher education in 2005-2017, with improved distance collaboration model based on TOPSIS and grey correlation theory. The main conclusions are as follows:

Being the premises and bases of higher education, the supply of fund, manpower, and material is a major driver of the participation, benefit, and environment of higher education. From 2012 onwards, the subsystems conformed to basically the same trend for the degree of collaboration: the degree of collaboration tended to be stable. There was even a slight dent in overall degree of collaboration between 2012 and 2016. Hence, the overall degree of collaborative development was far slower than the overall degree of development. After more than a decade of development, the degree of development, degree of collaboration, and degree of collaborative development reached basically the same level in 2017.

At present, China is working hard to enrich the connotations of higher education. To promote the balanced and coordinated development of higher education, all IHLs in China are obliged to optimize its structure, efficiency, and benefits, and adapt to the development of society, economy, and environment. To improve the operation and allocation efficiency of manpower and resource of higher education, China should invest more fund, manpower, and material in higher education, reform the relevant personnel system and resource sharing mechanism, and establish resource sharing platforms between colleges in and beyond each region. These measures could promote the development of the supply subsystem, which pulls the advancement of the other subsystems, and boosts the overall degrees of collaboration and collaborative development of higher education.

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7 References

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