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Research on the Innovation of Undergraduate Education Model Driven by Industry-Teaching Integration and Smart Campus System under the New Quality Productivity Framework

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Abstract Education is the foundation for the development of national endeavors. As an important part of China's education system, undergraduate education is one of the sources that constitute new quality productivity. This study constructs a performance evaluation system for undergraduate education based on principal component analysis (PCA) and data envelopment analysis (DEA), and conducts a systematic research on the innovation of undergraduate education model driven by industry-teaching integration and smart campus system under the framework of new quality productivity. A multidimensional evaluation index system containing educational inputs and educational outputs was first constructed, and the PCA method was applied to downsize the original indexes, streamlining the input indexes into four principal components and the output indexes into three principal components, with the cumulative variance contribution rates reaching 76.37% and 77.59%, respectively. The CCR and BCC models of DEA were then applied to empirically analyze the undergraduate education performance of 12 comprehensive colleges and universities directly under the Ministry of Education. The results show that 6 colleges and universities reach the absolute efficiency of DEA, the average value of comprehensive efficiency is 0.923, and there is a waste of resources of 0.077; the analysis of scale efficiency shows that 2 colleges and universities are in the state of diminishing returns to scale, and 4 colleges and universities are in the state of increasing returns to scale. Through truncated regression modeling, it was found that physical resource inputs have a significant positive facilitating effect on the scale efficiency of undergraduate education in colleges and universities, while teaching and learning support services show a significant negative inhibiting effect. The findings of the study provide decision-making references for optimizing the allocation of undergraduate education resources, promoting the deep integration of industry and education, and improving education quality.

Index Terms New quality productivity, integration of industry and education, undergraduate education, principal component analysis, data envelopment analysis, performance evaluation

I. Introduction

A hundred years of planning, education for this, the country's prosperity comes from the support of talent, the growth of talent can not be separated from the role of education [1]. Education is the foundation of the development of the national cause, with a basic and overall position. In the process of economic and social development, education also plays an influential role, occupies a pivotal position, is the lifeblood of economic and social prosperity [2]-[4]. The quality of education has become a measure of the quality of education, and high-quality education can effectively promote the cultivation of talents. Therefore, the study of education quality improvement in the academic world is an unchanging topic.

Today, undergraduate education, as an important part of China's education system, is one of the types of higher education, and constitutes one of the sources of China's new quality productivity [5], [6]. The development of new quality productivity cannot be separated from highly skilled laborers and high-quality talents [7]. Undergraduate education, on the other hand, is the prerequisite for the cultivation of scientific and technological innovation, highly skilled laborers and high-quality talent team, and is an important combination of science and technology as the first productive force, talent as the first resource, and innovation as the first driving force [8], [9]. It plays a unique and important role in the integration of education, science and technology, and talent to promote the development of new productivity [10]. Vigorously advocating "deepening the integration of industry and education" is the key system for the high-quality development of undergraduate education, and the integration of industry and education shoulders the important responsibility of cultivating high-quality technical and skilled personnel, and the responsibility of cultivating talents to build a modernized country [11], [12]. The development of the effectiveness of industry-teaching integration in undergraduate education is concerned with the overall development of the undergraduate education system, but also with the process of social modernization and innovation.

Education is the foundation of the development of national endeavors, with a basic and overall status. In the process of economic and social development, education plays an influential role and occupies a pivotal position, which is the lifeblood of economic and social prosperity. The quality of education has become a measure of its superiority, and high-quality education can effectively promote the cultivation of talents. Today, undergraduate education, as an important part of China's education system, is one of the types of higher education and one of the sources of China's new productivity. The development of new productive forces cannot be achieved without highly skilled laborers and high-quality talents. Undergraduate education, on the other hand, is the prerequisite for the cultivation of scientific and technological innovation, highly skilled laborers and high-quality talent teams, and is an important combination of science and technology as the first productive force, talent as the first resource, and innovation as the first driving force. It plays a unique and important role in the integration of education, science and technology, and talents to promote the development of new quality productivity. Strongly advocating "deepening the integration of industry and education" is the key system for the high-quality development of undergraduate education, and the integration of industry and education shoulders the important responsibility of cultivating high-quality technical and skilled talents, and the responsibility of cultivating talents to build a modernized country. The development of the effectiveness of industry-teaching integration in undergraduate education is concerned with the overall development of the undergraduate education system, as well as the process of social modernization and innovation.

Based on this background, this study explores the innovation path of undergraduate education model driven by the integration of industry and education and smart campus system from the framework of new quality productivity. The study adopts a combination of quantitative and qualitative methods to construct an undergraduate education performance evaluation index system, uses principal component analysis to downscale the evaluation indexes, and then uses data envelopment analysis to conduct a comprehensive evaluation of undergraduate education performance. Through the empirical analysis of comprehensive colleges and universities directly under the Ministry of Education, the current situation of undergraduate education input and output efficiency is analyzed in depth, key factors restricting the improvement of the quality of undergraduate education are identified, and the differences between first-class colleges and universities and ordinary colleges and universities in terms of scale efficiency and their influencing factors are explored. The research results will provide theoretical support and practical guidance for optimizing the allocation of undergraduate education resources, improving the mechanism of industry-education integration and enhancing the quality of talent cultivation.

II. Innovative paths for undergraduate education models in the framework of new quality productivity

This chapter explores the innovation path of undergraduate education model based on industry-education integration and smart campus system under the framework of new quality productivity.

In essence, talent cultivation mode innovation of undergraduate education is the reorganization of elements in the talent cultivation system to promote the unity of talent quality and cultivation goals in an optimal form of organization and movement. In the process of reengineering the talent cultivation mode of undergraduate education in the new era, it is necessary to consider the optimal functioning of the whole elements such as people, resources, technology and methods, and its main paths are as follows:

(1) Relying on big data for scientific decision-making of talent cultivation

The Internet stores a wealth of educational resources and educational data, and the use of big data technology to mine and analyze these data can obtain a variety of very valuable information to help educational decision makers make scientific decisions.

First, to ensure the scientific nature of the enrollment decision of talent training. With the help of big data analysis technology to mine the data contained in the candidates, student registration changes, past enrollment and enterprise talent demand and other valuable information, to grasp the trend of industry and enterprise demand for talent, clear different characteristics of the student enrollment rate differences and professional development differences, and understand the employment situation of different professions, so as to scientifically and reasonably determine the structure of enrollment of professions, the number of people ratio and scale, improve the enrollment acceptance ratio and the future professional matching employment rate. Ratio and future professional matching employment rate, targeted enrollment decision-making.

Secondly, to ensure the scientific nature of the decision-making of talent cultivation and export. Utilizing Internet technology, various resources of undergraduate colleges and employers are integrated to help students of undergraduate colleges and universities conduct online career experience, which is conducive to helping graduates make good career planning decisions. Utilizing cloud computing and big data technology to integrate massive student job-seeking information and enterprise job demand information to provide graduates with personalized information push services. Dynamic tracking and monitoring of the employment situation of graduates, which in turn provides feedback and early warning information for the cultivation of talents in undergraduate colleges and universities. According to the major technical problems released by enterprises, successful cases of entrepreneurship and current areas suitable for entrepreneurship, provide entrepreneurship training services for graduates to improve the success rate of graduates' innovation and entrepreneurship.

(2) Establishing a perfect system of collaborative education between schools and enterprises

School-enterprise collaborative cultivation contains two levels. The first is the collaborative training of students. Taking the deep cooperation between schools and enterprises as a carrier, promoting the alliance between undergraduate colleges and enterprises, uniting with the industry and linking with the park, enterprises participate in the whole process of talent cultivation in undergraduate education. In the technical and practical specialties to implement modern apprenticeship system, the school enrollment and enterprise recruitment connected, the implementation of school and enterprise education “double subject”, student apprenticeship “double identity”, clear school, enterprise and student tripartite rights and obligations.

Second, teacher training. Promote undergraduate colleges and universities to cooperate with large and medium-sized enterprises to build “dual-teacher” teacher training bases, and support in-service teachers to practice and exercise in enterprises on a regular basis. Explore the industrial mentor system and encourage enterprises' technical and management talents to teach in schools. In the construction of the teacher training system, it is necessary to consider the differences in the training needs of teachers of different ages, specialties and genders, improve the pertinence of training, and carry out personalized training in combination with the needs of teachers of different levels. According to the characteristics of “Internet +” undergraduate education, we should seek the diversity of training methods, and adopt a variety of teaching methods to improve teachers' ability to apply Internet technology.

(3) Integrate teaching resources with the help of modern technology and tools

The use of Internet technology can integrate all kinds of scattered resources into a large-scale data resource platform, build a network teaching resource base, and construct a network learning space. In the modern education technology platform, VR, as a highly immersive media, is presented in an intuitive way so that students can recall their experience in the VR virtual scene at any time, which makes students' thinking become fine, thus obtaining better learning results.

(4) Construct networked course teaching system

1) Construct remote dynamic classroom teaching mode

The remote dynamic classroom teaching mode, in which the teaching process is docked with the production process, can realize the close connection between theoretical teaching and the real work scene of enterprises and improve the effectiveness of theoretical teaching.

2) Build virtual factory with the help of VR technology

With the help of VR technology, the real enterprise environment is integrated into the teaching, which enables students to master a variety of new technologies and complex production processes of enterprises in the virtual training process. Enterprises are able to play the function of improving students' professional skills mainly in professional core courses, professional platform courses, professional outreach courses and professional practice courses, as well as the function of improving students' comprehensive practical skills. The establishment of virtual factories through the integration of industry and education and the realization of networked collaboration between schools and enterprises can effectively reduce the risks in teaching and improve the internalization of knowledge and the enhancement of skills.

3) Building an intelligent management system for practical teaching

An important part of talent cultivation in undergraduate education is to improve the practical ability of talents through off-campus internship and practical training, so it is necessary to attach great importance to off-campus practical teaching.

Firstly, an intelligent management system of off-campus practice teaching network is established. The main functions include the management of practice teachers, the management of students' practice program, the management of students' practice effect evaluation and the management of practice bases. Adopting Internet of Things (IoT) technology, real-time tracking and positioning of off-campus practice teaching, realizing intelligent management of off-campus practice teaching data, and solving the problems of lagging update of practice teaching data.

Secondly, relying on new media technology, establish off-campus practice teaching quality monitoring platform. Undergraduate colleges and universities utilize the platform to collect and process dynamic data of off-campus practice teaching, and evaluate and monitor the quality of off-campus practice teaching from multiple perspectives. For the situation that may cause internship safety problems or even cause injuries, timely warnings are put forward, and the more concentrated problems encountered by students in the process of practice are analyzed and solved in a timely manner.

(5) Establishing an open talent training evaluation system

Utilizing big data and cloud computing technology for teaching evaluation can provide detailed and accurate evaluation data for teachers and students of undergraduate schools and enterprises. The teaching evaluation system includes all the students' evaluation of the whole teaching process, including every online course, every simulation training and every offline classroom teaching, as well as the students' evaluation of the teaching effect of online and offline teaching teachers, and the teachers' and enterprises' evaluation of the students' learning process, etc. The evaluation of different evaluation subjects is based on the virtual training system. The evaluation of different evaluation subjects is based on virtual network behavior and actual offline classroom behavior, using big data analysis results to timely adjust teachers' teaching and students' learning, real-time assessment and feedback on students' academic progress and learning level.

Table 1: Input-output index system for undergraduate education Performance evaluation

First-level indicator	Secondary indicators	Third-level indicators
Educational input	Financial resources	Per-student expenditure on educational undertakings
		Fixed assets
		Proportion of sources of funds
		The proportion of self-raised funds for the construction of first-class specialties
		The allocation rate of funds for the construction of first-class specialties
	Human resources	Investment in enrollment funds
		The proportion of full-time teachers at the senior professional level
		Teacher turnover rate
		The number of admissions staff
	Material resources	The per-student occupied area of school buildings
		Per-student campus area
		Fixed assets
	Talent management	Is there a clear enrollment process
		Is there a clear admission plan
Education output	Build a high-level teaching staff	Library utilization rate
		Multimedia classroom usage
		The average number of subjects taught by teachers
		Duration of after-class tutoring and Q&A sessions
		The average number of students per class
		The degree of students' satisfaction with teaching
		The number of self-compiled textbooks by the teachers of this school
		The ratio of administrative staff to teachers
	Optimize the discipline layout level	The project approval situation of first-class courses
	Mid-term results	Patent income
	Social influence	Alumni ranking and comprehensive quality score
	Talent cultivation	Standard graduate
		Graduate employment rate
	First-class scientific research achievements	National-level scientific research project
		The number of published scientific and technological works
		The number of academic papers published in science and technology
		Number of patent authorizations

III. Performance evaluation of undergraduate education based on PCA and DEA

This chapter proposes an undergraduate education performance evaluation method based on PCA and DEA, which utilizes principal component analysis (PCA) to downscale the constructed undergraduate education performance evaluation indicators, and then applies the DEA model to achieve a comprehensive evaluation of undergraduate education performance.

III. A. Construction of undergraduate education performance evaluation index system

According to analyze the relevant literature to index selection, this paper in order to establish the undergraduate college education performance assessment system, according to the logic model, the indicators are summarized, to get the specific index system as shown in Table 1.

III. B. Processing of PCA-based evaluation indicators

Given the importance of evaluation indicators to the evaluation results, further analysis is needed on the basis of input-output analysis to select the final evaluation indicator trade-offs. As a multivariate problem, undergraduate education performance evaluation will become complicated with the increase of variables, at the same time, in the case of more indicators, the information represented by the indicator variables may have overlapping parts, that is, there is a correlation, and this correlation will inevitably lead to an increase in the amount of computation and a waste of storage space. Therefore, it is necessary to replace the original indicator variables with as few as possible while ensuring that no information is lost, a process known as "dimensionality reduction".

From the point of view of computation and storage space, since the data involved in this paper is not large, there is no need for dimensionality reduction processing. From the requirement of the number of indicators, the evaluation model adopted in this paper is based on the Data Envelopment Approach (DEA), and the DEA method has strict limitations on the number of indicators, and in order to obtain a more accurate evaluation result with a higher degree of differentiation, it is necessary to make the number of Decision Making Units (DMUs) t as much as possible to satisfy the requirements of $t \geq \max(s \cdot m, 3 \cdot (s+m))$. Here s and m denote the number of input and output indicators respectively. Taken together, the original indicators need to be downscaled. Commonly used methods include synthesis method, analysis method, indicator attribute grouping method and cluster analysis method. In this paper, the principal component approach (PCA) is used for dimensionality reduction processing.

The PCA method is to remove the correlation of indicator variables by using orthogonal transformation, and replace the original variables with as few new variables as possible that have no correlation, and these new variables become principal components [13]. The steps of principal component analysis method are as follows:

In order to eliminate the effect of inconsistency in data magnitude, it is necessary to standardize the indicator data. Let the original data have n units to be evaluated, each unit to be evaluated has p indicators, and a_{ij} denotes the j dimensional attribute of the i th row of data. The standardized processing formula is shown in equation (1):

$$x_{ij} = \frac{a_{ij} - \mu}{\sigma} \tag{1}$$

where μ is the arithmetic mean and σ is the standard deviation, which is standardized to obtain the matrix $Z(x_{ij})_{n \times p}$, and the matrix of correlation coefficients $R(r_{ij})_{n \times p}$ can be built based on $Z(x_{ij})_{n \times p}$, where,

$$r_{ij} = \frac{\sum_{k=1}^{n}(x_{ki} - \overline{x}_i)(x_{kj} - \overline{x}_j)}{\sqrt{\sum_{k=1}^{n}(x_{ki} - \overline{x}_i)^2 (x_{kj} - \overline{x}_j)^2}} \tag{2}$$

Compute the eigenroots of $R(r_{ij})_{p \times p}$ and arrange them in ascending order to get $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_p \geq 0$, and then solve for λ_j corresponding to the feature vector $e_j = (e_{1j}, e_{1j}, \cdots, e_{1j})^T$. Then there is that the j th principal component of the i th unit to be evaluated is shown in equation (3):

$$F_{ij} = e_{1i}Z_1 + e_{2i}Z_2 + \cdots + e_{pi}Z_j \quad i = 1, 2, \cdots, n \tag{3}$$

The contribution rate of principal components reflects the ability of principal components to synthesize the information of original variables, and the contribution rate C_k of principal component k is calculated as shown in equation (4):

$$C_k = \frac{\lambda_i}{\sum_{k=1}^{p} \lambda_k} \quad i = 1, 2, \cdots, p \tag{4}$$

The cumulative contribution of principal component k, C_k', is calculated according to the formula shown in equation (5):

$$C_k^* = \frac{\sum_{k=1}^{i} \lambda_k}{\sum_{k=1}^{p} \lambda_k} \quad i = 1, 2, \cdots, p \tag{5}$$

III. C. DEA-based performance evaluation method for undergraduate education

III. C. 1) Basic concepts of DEA

Data Envelopment Analysis (DEA) is a special tool based on linear programming with the same relative effectiveness of organizational types [14]. This method focuses on the relative effectiveness of the production frontier forecast of the DEA by the decision making unit and the amount of deviation of the DMU from the DEA frontier. CCR can deal with the problem of constant returns to scale and BCC model is used to deal with the problem under the assumption of variable returns. DEA evaluates the relative effectiveness of the decision making unit if the decision making unit is evaluated at the corresponding production frontier this is known as DEA effective,. Otherwise it is called non-DEA effective.

In solving the DEA model, the efficiency can be obtained by analyzing the results of the solution, the main parameters such as scale income conditions, weights, slack variables and the values of the residual variables and the projected values. These data can reflect different information and can produce different functions in management decisions.

(1) Efficiency

This is the most important objective and function of solving the DEA model, and the input-output efficiency can reflect the comprehensive efficiency when the DMU is in the state of constant returns. Technical efficiency can reflect the input-output efficiency of the hypothetical DMU in the state of optimal returns to scale, while scale efficiency is a relative measure of the current state of DMU returns to scale and the optimal scale By analyzing the combination of comprehensive efficiency, technical efficiency and scale efficiency, the relative efficiency of DMUs of different sizes can be found out to provide targeted recommendations for management decisions.

(2) Scale Revenue

The situation is based on the specific revenue scale, the revenue scale includes increasing returns to scale, constant returns to scale, and decreasing returns to scale, which can provide a basis for decision-making for DMUs to reduce demand, maintain scale and scale expansion.

(3) Weights in the DEA model

The weight is mainly reflected in three major aspects: the sum of the weights is not equal to 1, instead of the generally accepted concept of weights in the assessment method, and the reference objects used to calculate the weights of each group are different. Most DEA assessment questions do not prioritize or standardize the data, and the relative magnitude of the weights is meaningless.

(4) Slack and residual variable values

These values can reflect the degree of inadequacy or redundancy of inputs and outputs, and their role is mainly to help propose management strategies and guide decision makers to make more accurate input-output revisions.

(5) Projected values

The projected values can clearly reflect the actual demand for the current input resources of the DMU and the maximum production that can be realized. On the other hand, it can also point out the future development potential of the DMU, which is characterized as helpful for solutions and guidance.

III. C. 2) Steps in the analysis of DEA

The specific steps of DEA analysis are as follows:

(1) Select decision-making units for evaluation. DEA has the following two requirements: first, all DMUs need to have the same type of function. Second, the relative number of decision-making units is greater than the total number of input and output indicators.

(2) Find a relevant and reasonable input-output item to evaluate the relative efficiency of the selected decision unit. In selecting input-output indicators, reflect the purpose and content of the evaluation. Secondly, from a technical

point of view, it is important to avoid strong linear relationships between indicators within the input-output set, and finally consider the importance and availability of the indicators.

(3) Applying the DEA method and analyzing the results of empirical studies. Several DEA methods can be selected in the case of different assessment purposes and contents. In the operation process, especially when the assessment and analysis results are not satisfactory, the input and output indicator system must be adjusted and resolved without deviating from the assessment purpose. Adjust the input and output indicator system and always perform different DEA assessments and analysis. We can observe which indicators are able to effectively influence DMUs and which ones do not have a significant impact.

III. C. 3) DEA methodology and CCR modeling

It is recognized that there are n Decision Making Units (DMUs), any one of which has m "inputs" and s "outputs", which represent the consumption of resources by the unit or department and the number of outcomes that occur as a result of the consumption of resources, respectively. The relationship between the two is shown in Figure 1.

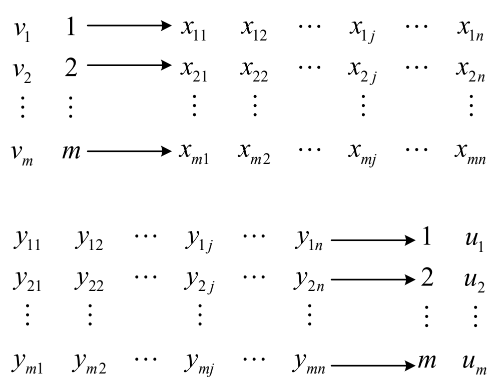

Figure 1: Relationship between Input and output quantities

where, x_{ij} represents the amount of inputs for the jth DMU to the inputs in i, $x_{ij} > 0$. y_{ij} represents as the amount of inputs from the jth DMU to the inputs in i, $y_{ij} > 0$. v_{ij} represents as an instrumental quantity to the input in i. u_{ij} stands for being a kind of instrumental for the output in i. $i = 1, 2 \ldots, m \; j = 1, 2, \ldots, n \; n, r = 1, 2, \ldots, s$.

x_{ij} and y_{ij} are known data, and v_i and u_r are independent variables corresponding to the weight coefficients $v = (v_1, v_2, \ldots, v_m)^T$ and $u = (u_1, u_2, \ldots u_m)^T\}$, with a corresponding efficiency evaluation factor for each DMU:

$$h_j = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_r x_{ij}} \quad j = 1, 2, \cdots, n \tag{6}$$

The coefficients v and u are appropriately chosen so that $h_i \leq 1, j = 1, 2, \ldots, n$ can be satisfied.

The efficiency aspect of the j_0 th DMU is now evaluated. With the weighting coefficients v and u as the independent variables, the efficiency index of the j_0 th DMU as the target, and the efficiency indexes of all DMUs $h_i \leq 1, j = 1, 2, \ldots, n$ as the elements, the CCR model is composed as follows:

$$(C^2R)\begin{cases} \max \dfrac{\sum_{r=1}^{s} u_r y_{r j_0}}{\sum_{i=1}^{m} v_i x_{ij_0}} = V_P \\ \dfrac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1, j = 1, 2, \cdots, n \\ v = (v_1, v_2, \cdots, v_m)^T \ge 0 \\ u = (u_r, u_1, \cdots, u)^T \ge 0 \end{cases} \tag{7}$$

It can be seen that evaluating the j_0 st DMU using the above model is invalid with respect to all other DMUs. Applying matrix notation to describe the above CCR model gives:

$$(P)\begin{cases} \max \dfrac{u^T y_{j_0}}{v^T x_{j_0}} = V_P \\ \dfrac{u^T y_j}{v^T x_j} \le 1, j = 1, 2, \cdots, n \\ v \ge 0, u \ge 0 \end{cases} \tag{8}$$

Using the Charnes-Cooper change, organize the above equation as:

$$(P)\begin{cases} \max \mu^T y_{j_0} = V_p \\ w^T x_j - \mu^T y_j \ge 0 \quad (j = 1, 2, \cdots, n) \\ w^T x_{j_0} = 1 \\ w \ge 0, \mu \ge 0 \end{cases} \tag{9}$$

A linear program for (P) yields a pairwise program as:

$$(D)\begin{cases} \min \theta = V_D \\ \sum_{j=1}^{n} x_j \lambda_j + s^- = \theta x_{j_0} \\ \sum_{j}^{n} y_j \lambda_j - s^+ = y_{j_0} \\ \lambda_j \ge 0 \quad (j = 1, 2, \cdots, n) \\ s^+ \ge 0 \quad s^- \ge 0 \end{cases} \tag{10}$$

The following definition is made: If the linear programming (P) has the optimal solutions $w^0 > 0, \mu^0 > 0$ and the optimal value is $V_p = 1$, then $DMUj_0$ is said to be the DEA model.

According to the dyadic theorem of linear programming, it can be obtained that when the optimal value of the dyadic linear programming (D) is equal to 1, the optimal value of the linear programming (P) is also equal to 1. It can be seen that the dyadic linear programming can be utilized to determine the degree of validity of the DEA of $DMUj_0$.

III. C. 4) With respect to BCC models

In order to study the scale changing state of DMUs, the BCC model is obtained by applying the four axioms of the production possible set and the Shepard's distance function as the basis for the study of the variable scale gain model [15]. The model of BCC in linear mode can be expressed as follows:

$$\begin{aligned} &\text{Maximize} && \sum_{r=1}^{s}\mu_r y_{ro} - u_o \\ &\text{subject to} && \sum_{i=1}^{m}\omega_i x_{ko} = 1 \\ & && \sum_{r=1}^{s}\mu_r y_{rj} - \sum_{i=1}^{m}\omega_i x_{ij} - u_o \le 0, j = 1,\ldots,n \\ & && \mu_r, \omega_i \ge 0, \quad r = 1,\ldots,s; i = 1,\ldots,m \end{aligned} \tag{11}$$

BCC dyadic modeling:

$$\begin{aligned} &\text{Maximize} && \theta_o - \varepsilon(\sum_{i=1}^{m}s_i^- + \sum_{r=1}^{s}s_r^+) \\ &\text{subject to} && \sum_{j=1}^{n}x_{ij}\lambda_j + s_i^- = \theta_o x_{io}, i = 1,\ldots,m \\ & && \sum_{j=1}^{n}y_{rj}\lambda_j - s_r^+ = y_{ro}, r = 1,\ldots,s \\ & && \sum_{j=1}^{n}\lambda_j = 1 \\ & && \lambda_j, s_i^-, s_r^+ \ge 0, \forall i, j, r \end{aligned} \tag{12}$$

where ε is a non-Archimedean infinitesimal. Following the value of u_0 in the BCC model, the returns to scale of model (11) are judged as follows:

Assuming DMU_0 for the output portfolio (x_0, y_0) containing inputs efficiently, the following condition allows for a judgment on the returns to scale for DMU_0: when the returns to scale for the input-output portfolio (x_0, y_0) are constant only in some optimal solution case there is $u_0^* = 0$, when the input-output combination (x_0, y_0) has increasing returns to scale only in all optimal solution cases there is $u_0^* < 0$, when the input-output combination (x_0, y_0) has decreasing returns to scale only in all optimal solution cases there is $u_0^* > 0$. The u_0^* represents the best solution in model (11).

IV. Empirical analysis

This chapter applies the proposed methodology to provide a comprehensive evaluation of undergraduate education performance, discusses ideas for performance improvement, and analyzes the factors influencing the efficiency of undergraduate education scale and its gaps.

IV. A. Empirical Analysis of Educational Performance Evaluation in Undergraduate Colleges and Universities

IV. A. 1) Research hypothesis and sample selection

(1) Research hypotheses

The hypotheses of educational performance evaluation of undergraduate colleges and universities in this paper:

1) The labor involved in the scientific research output of different disciplines is basically equal in quality.

2) The quality level of graduates of different undergraduate colleges and universities is basically equal.

3) The years of different outputs of undergraduate colleges and universities are the same.

(2) Sample Selection

From the perspective of classification of undergraduate colleges and universities, this paper selects comprehensive colleges and universities directly under the Ministry of Education as an example, and uses the constructed undergraduate education performance evaluation system to conduct performance evaluation and empirical research. Comprehensive colleges and universities directly under the Ministry of Education are selected as samples because of their typicality. Comprehensive colleges and universities have a rich variety of disciplines, involve many categories, run a large scale of schooling, and generally have multiple faculties and departments, so the results of the study have a strong applicability.

(3) Data sources

This paper selects the relevant data of 12 comprehensive higher education institutions directly under the Ministry of Education in 2024. The data mainly come from the following sources:

1) Public information such as annual statement of accounts, annual undergraduate quality report, annual graduate quality report, and school profile published on the official website of each university.

2) Data about the operation of higher education institutions published by the departments and agencies of the Ministry of Education.

3) ESI database, Thomson Reuters database, Social Science Citation Index.

4) Information disclosure requests. Some of the data were obtained by means of information disclosure requests on the information disclosure network of each university.

5) The 2024 China University Alumni Donation Ranking published by China Alumni Network.

The above are the sources of data for the evaluation of educational performance of undergraduate colleges and universities, with nearly more than 1,000 data collected.

IV. A. 2) PCA-DEA analysis of evaluation indicators

(1) Constructing a new indicator system using PCA

Using SPSS23.0 statistical software and Principal Component Analysis (PCA), the performance inputs X_{pm} and output indicators Y_{pn} of 12 comprehensive higher education institutions were subjected to Principal Component Analysis (PCA) respectively, and the eigenvalues, variance contribution rates, and cumulative variance contribution rates of the principal components were found as shown in Table 2.

From the table, it can be seen that the cumulative variance contribution rate of the first 4 principal components in the input indicators has reached 76.37%, and only 5 principal components are needed to replace more than 75% of the information in the original 14 indicators. The cumulative variance contribution rate of the first 3 principal components of the output indicator has reached 77.59%, indicating that more than 75% of the information in the original 17 indicators can be replaced by these 3 components. Therefore, the input and output indicators are streamlined to 4 and 3 respectively, constituting the new input-output indicator system X^1_{pm} and Y^1_{pn}.

Table 2: Principal component eigenvalues and variance contribution rates

Principal component (Z_q)	Eigenvalue (λ_{xq})	Variance contribution /% (e_{xq})	Cumulation /% (F_x)	Principal component (H_s)	Eigenvalue (λ_{ys})	Variance contribution /% (e_{ys})	Cumulation /% (F_y)
Z1	6.564	32.651	32.651	H1	10.652	46.541	46.541
Z2	3.929	19.542	52.193	H2	4.162	18.185	64.726
Z3	2.979	14.819	67.012	H3	2.944	12.864	77.590
Z4	1.881	9.358	76.370	H4	1.651	7.213	84.803

Then SPSS was used to derive the eigenvectors corresponding to each principal component of the input indicators, and based on the eigenvectors, the principal component scores of the undergraduate education input and output indicators of each university were obtained, and the principal component scores of the indicators were transformed into positive values by using the leveling function, and the undergraduate education input and output indicator system of the 12 comprehensive colleges and universities is shown in Table 3.

Table 3: The input and output index system of undergraduate education in 12 universities

University (DMU)	X^1_1	X^1_2	X^1_3	X^1_4	Y^1_1	Y^1_2	Y^1_3
1	2.0930	0.6630	0.1873	0.3877	2.5777	0.0948	0.4951
2	0.9509	1.1311	0.5475	0.2134	0.9685	0.4124	0.1959
3	0.8522	0.6896	0.4463	0.2855	1.2867	0.6022	0.2336
4	1.1286	0.6536	0.3054	0.1865	1.6972	0.4142	0.4889
5	0.6804	0.6883	0.2343	0.0944	0.6311	0.4465	0.2708
6	1.4474	1.4607	0.3999	0.2012	1.2611	0.3682	0.2177
7	0.4610	0.5571	0.3517	0.3631	0.4446	0.5257	0.2282
8	0.6053	0.5897	0.5381	0.1938	0.5792	0.4719	0.3857
9	1.1934	0.5952	0.2593	0.1074	1.4845	0.2516	0.3651
10	0.7774	0.6399	0.5533	0.0411	0.9669	0.3361	0.3494
11	1.4102	0.8193	0.4315	0.1137	1.9007	0.4913	0.3627
12	1.0063	0.8505	0.4704	0.2273	1.4382	0.4099	0.2485

(2) Analysis using DEA model

Taking the proportion of variance contribution rate of each principal component as the weight, the principal component scores are weighted and averaged to calculate the composite score of input index E_x, and similarly the composite score of output index E_y, and the undergraduate education inputs and outputs of each university are ranked according to the scores E_x and E_y. PCA ranking. Each university represents a decision-making unit (DMU). Substituting the data X_{pm}^1 and Y_{pn}^1 from the above table into the models CCR and BCC models of data envelopment analysis, and applying DEAP-Version 2.1, the corresponding θ, λ, S^-, S^+, as well as calculating the rank difference between their inputs and rankings, and finally ranking the DEA comprehensive efficiency value 0. The PCA and DEA rankings of undergraduate education inputs and outputs of the 12 comprehensive universities are shown in Table 4.

Table 4: PCA and DEA rankings of physical education input and output

University (DMU)	E_x	Input ranking	E_y	Output ranking	Input and output dislocation	Integrated efficiency θ	Scale benefit	DEA ranking
1	0.8441088	2	1.2160573	1	1	1	-	1
2	0.4952294	3	-0.476932	8	-5	0.718	irs	12
3	-0.17018	7	0.2723920	4	3	1	-	1
4	-0.151293	6	0.5549865	3	3	1	-	1
5	-0.671274	12	-0.679973	10	2	0.835	irs	9
6	1.1796342	1	-0.238136	7	-6	0.943	drs	8
7	-0.524357	11	-0.742824	12	-1	1	-	1
8	-0.402881	10	-0.715741	11	-1	0.784	irs	11
9	-0.374663	9	-0.133565	6	3	1	-	1
10	-0.316935	8	-0.503492	9	-1	1	-	1
11	0.3568143	4	0.6421455	2	2	0.982	drs	7
12	0.1537251	5	-0.051698	5	0	0.815	irs	10

IV. B. Evaluation Summary and Improvement Analysis of Educational Performance of Sample Colleges and Universities

IV. B. 1) Measurement efficiency analysis

(1) Comprehensive efficiency analysis

The comprehensive efficiency value indicates the use of undergraduate education input performance level of the university, through which the efficiency value can analyze the input redundancy and output insufficiency of each decision-making unit. If the measured value of the university is 1, it means that the allocation of each element of the university's inputs is reasonable, the resources are fully utilized and the output value is optimal, and the DEA of the university's undergraduate education inputs is effective. If the value is less than 1, the DEA is invalid.

In these 12 comprehensive colleges and universities, the comprehensive efficiency value of colleges and universities 1, 3, 4, 7, 9, 10 is 1, indicating that their undergraduate education inputs are in an effective state, and analyzing in a strict sense, the rest of the comprehensive efficiency value is between 0-1, and the performance is in an ineffective state, and the average value of the comprehensive efficiency of each college and university reaches 0.923, indicating that there is a waste of resources of 0.077 compared with the optimal efficiency level. If the value of scale efficiency in the study of this paper is above the average value but does not reach 1, it is said to be relatively effective in DEA.

(2) Scale efficiency analysis

Scale efficiency is used to measure how the output changes in the case of increasing inputs, indicating whether the undergraduate education inputs of colleges and universities have reached the optimal scale, and scale efficiency is mainly divided into three cases of diminishing returns to scale (drs), constant returns to scale (-), and increasing returns to scale (irs). As can be seen from Table 4, universities 6 and 11 are increasing returns to scale, universities 2, 4, 8 and 12 are decreasing returns to scale, and the rest of the universities are constant returns to scale.

(3) Overall analysis

Based on the results of performance evaluation, the following conclusions can be drawn:

1) Colleges and universities 1, 3, 4, 7, 9 and 10 are DEA absolutely effective. The rank difference of the input-output ranking of colleges and universities 1, 3, 4, 7, 9 and 10 are all 1 or -1 or 3, and they are all in the scale reward constant, so the overall resource use efficiency of these colleges and universities is better, and they can be

considered to keep the current investment in undergraduate education unchanged and do further optimization for the use of undergraduate education input resources.

2) Colleges 6 and 11 are relatively effective for DEA. The difference between the input and output rankings of HEI 6 is large, in a state of diminishing returns to scale, and the DEA efficiency value is ranked high, indicating that the university itself has relatively better undergraduate education inputs, but the efficiency of fund utilization is not optimized, so there are problems such as irrational resource allocation or imperfect internal system within HEI 6. The input of HEI 11 is ranked 4th and the output is ranked 2nd, which is in diminishing returns to scale, so it can consider reducing the input appropriately and further improving the structure of the utilization of funds.

3) For the analysis of universities 2, 5, 8 and 12 which are relatively backward in DEA ranking, the input of university 2 is ranked 3rd, the output is ranked 8th, and the DEA ranking is 12th, and it is in the state of increasing returns to scale, which indicates that there are many deficiencies in the efficiency of resource utilization in this university, and it is urgent to carry out an in-depth analysis of many aspects of its own schooling and make reasonable adjustments. The input of university 5 is ranked 12th and the output is ranked 10th, which is in the state of increasing returns to scale, and the DEA efficiency value is 9th, so the university can consider appropriately increasing the input and further improving the structure of resource utilization. The input and output rankings of Colleges 8 and 12 are less changed, and their DEA efficiency values are at the back of the list, and they are all in the increasing returns to scale, so they can consider further increasing their inputs and improving the efficiency of resource utilization.

IV. B. 2) Analysis of overall input-output adjustments

In the type of constant returns to scale, when the value of the input redundancy indicator is zero, it indicates that the input level of the decision unit has reached the optimal state, and its input level is more reasonable, and when the value of the indicator is less than zero, it reflects the existence of input redundancy in the decision unit. In the analysis of the constant scale compensation model, when the value of the output insufficiency indicator is zero, it means that the output has reached the optimal level, and when the value of the indicator is greater than zero, there is the phenomenon of output insufficiency. The analysis of input and output indicator slack variables is shown in Table 5.

Among the 12 decision-making units selected, the six decision-making units of 1, 3, 4, 7, 9, and 10 have zero slack in the input indicators, indicating that their undergraduate education resource inputs are reasonable. While in the other decision-making units, the value of their indicators is less than zero, which indicates the phenomenon of input redundancy. Meanwhile, among the 12 decision-making units, only decision-making unit 6 has an output indicator value greater than zero, indicating that there is a significant output deficit in this university, while the rest of the indicators have a value of zero, indicating that the output value of the university has reached the optimal level, and should be adjusted according to the situation in a specific way.

Table 5: Analysis of relaxation variables of Input and Output indicators

DMU	Redundant input indicators		Insufficient output indicators
	S_1^-	S_2^-	S^+
1	0.000	0.000	0.000
2	-1.754	-1.136	0.000
3	0.000	0.000	0.000
4	0.000	0.000	0.000
5	-1.185	-0.978	0.000
6	-0.212	-0.135	0.462
7	0.000	0.000	0.000
8	-0.543	-0.271	0.000
9	0.000	0.000	0.000
10	0.000	0.000	0.000
11	-0.901	-0.667	0.000
12	-0.829	-0.645	0.000

IV. C. Analysis of the factors influencing the efficiency of the scale of undergraduate education and its gaps

This section further analyzes the differences in the performance of undergraduate education in colleges and universities at different levels, and focuses on the gap in the efficiency of the scale of undergraduate education between first-class colleges and ordinary colleges and universities, and explores the main factors affecting the efficiency of the scale. truncated model [16] regression results are shown in Table 6.

Model 1, model 4 and model 7 indicate that the funding resource index has a weak positive promotion effect on the scale efficiency of undergraduate education in colleges and universities, and the same weak effect of widening the efficiency gap between first-class colleges and universities and ordinary colleges and universities. Model 2, Model 3, Model 5 and Model 6 indicate that physical resource inputs of universities significantly increase the scale efficiency of undergraduate education in universities, but narrow the efficiency gap between top universities and ordinary universities. The regression coefficients of teaching activity indicators in Models 1-6 are all negative because the high-quality educational resources of top universities trigger the “siphon effect”, which attracts students to enroll in top universities.

In addition, the regression results of teaching auxiliary service indicators in Model 1-Model 6 indicate that teaching auxiliary service has a significant negative inhibitory effect on the scale efficiency of undergraduate education. The crude educational resource input method driven by relying on auxiliary services can ignore long-term and structural problems. Whether the educational funds are utilized at the most critical point, focusing on efficiency and effectiveness, whether the faculty can be sustained and smoothly replenished, and whether the structural problems of the undergraduate education model can be solved are more important to focus on. From model 7 and model 9, although teaching support services have narrowed the gap between the scale efficiency of first-class colleges and ordinary colleges and universities, the scale efficiency of undergraduate education in colleges and universities is declining, reflecting that the structural problems of undergraduate education resources are still more prominent.

Table 6: Regression results of the truncated model

	Scale efficiency of first-class university			Scale efficiency of ordinary universities			Scale efficiency difference		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Financial resources	0.044 (0.91)		0.013 (0.16)				0.018 (0.24)		
Material resources		8.72E-06*** (3.52)	9.75E-06*** (4.13)		1.22E-05*** (2.95)	1.24E-05*** (3.16)		-5.91E-06*** (-1.54)	-4.83E-06*** (-1.27)
Human resources of top universities	0.131 (1.15)		0.006 (0.05)				0.759** (2.92)		0.841** (3.18)
Administrative management of top universities		1.79E-06 (1.09)						1.25E-05*** (3.04)	
Human resources in ordinary universities				0.082 (0.57)		0.041 (0.40)	0.503** (2.73)		0.535** (2.91)
Administrative management of ordinary universities					1.23E-06 (0.27)			-7.84E-06 (-1.28)	
Teaching activities	-2.56E-04 (-0.97)	-1.56E-05 (-0.08)	-2.09E-05 (-0.12)	-7.13E-04 (-1.75)	-5.08E-04 (-1.52)	-4.99E-04 (-1.50)	-5.37E-04 (1.38)	-4.68E-04 (1.39)	-5.25E-04 (1.54)
Teaching support services	-1.79E-06*** (-5.52)	-2.21E-06*** (-5.93)	-1.93E-06*** (-8.64)	-1.82E-06*** (-3.35)	-2.24E-06*** (-3.86)	-2.11E-06*** (-6.25)	-1.79E-07 (-0.36)	-1.08E-06 (-1.78)	-3.41E-08 (-0.12)
Constant term	1.084*** (25.38)	0.995*** (46.25)	1.005*** (23.14)	1.062*** (20.71)	0.995*** (35.49)	1.004*** (19.24)	0.091 (1.43)	-0.065 (-1.82)	0.119 (1.74)
σ	0.072*** (21.24)	0.069*** (21.24)	0.069*** (21.24)	0.116*** (21.24)	0.112*** (21.24)	0.112*** (21.24)	0.111*** (21.24)	0.110*** (21.24)	0.110*** (21.24)

Among the human resource indicators, model 1, model 3, model 4 and model 6 all indicate that human resource input has a positive effect on the scale efficiency level of undergraduate education, i.e., the higher the human resource input, the higher the scale efficiency. Since the comparison of the efficiency difference between first-class colleges and ordinary colleges and universities is based on first-class colleges minus ordinary colleges and universities, the higher human resource input in first-class colleges and universities will expand the scale efficiency difference between first-class colleges and ordinary colleges and universities, and the higher human resource input in ordinary colleges and universities will expand the difference between the two, and the conclusions of models 7 and 9 are in line with the expectations. Model 8 indicates that the increase of undergraduate education administrative input will expand the scale efficiency gap between first-class colleges and ordinary colleges and universities, the reason may be that first-class colleges and universities have rich experience in education management and are more willing to increase the administrative input than ordinary colleges and universities, which leads to a more significant role of first-class colleges and universities than ordinary colleges and universities.

V. Conclusion

By constructing a PCA-DEA comprehensive evaluation model, the undergraduate education performance of 12 comprehensive colleges and universities directly under the Ministry of Education was analyzed in depth, and structural problems in the allocation of undergraduate education resources in colleges and universities were found. The performance evaluation results show that 50% of the colleges and universities have reached the DEA absolute effective state, with reasonable input-output ratios and full utilization of resources; 2 colleges and universities are DEA relatively effective, with room for optimization of resource allocation; the remaining 4 colleges and universities are ranked relatively late in DEA efficiency value, and they need to focus on improvement. From the perspective of scale efficiency, 33.33% of colleges and universities are in the state of increasing returns to scale, indicating that appropriately increasing educational inputs can bring greater output benefits. The analysis of influencing factors reveals that the input of physical resources has a significant enhancement effect on the scale efficiency of undergraduate education, with a regression coefficient of 9.75E-06; while teaching and learning support services have a negative effect on the scale efficiency, with a coefficient of -1.93E-06. The innovation path of industry-teaching integration should focus on relying on big data for talent cultivation decision-making, establishing a perfect university-enterprise collaborative education system, integrating teaching resources with the help of modern technology, constructing a networked course teaching system and establishing an open talent cultivation evaluation system. Colleges and universities should formulate differentiated development strategies according to their own scale and efficiency status, optimize the structure of resource allocation, deepen the connotation of industry-teaching integration, and promote the high-quality development of undergraduate education.

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