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The Efficiency of University Resource Allocation Based on DEA Model

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Abstract. The development of universities cannot be separated from the allocation of resources. Conduct empirical research on the efficiency of resource allocation in private universities to help them identify the current situation and problems of internal resource allocation, and promote high-quality development. This paper selects the undergraduate teaching status data of eight private undergraduate universities in Guangxi from 2018 to 2022, and uses DEA model to calculate the resource allocation efficiency of eight private undergraduate universities. The results show that the overall level of resource allocation efficiency of eight private undergraduate universities in Guangxi has maintained an upward trend, and the scale efficiency is significantly higher than the pure technical efficiency, which is the main factor affecting the overall efficiency improvement. Therefore, Guangxi private undergraduate universities should optimize the technical efficiency and management efficiency of resource allocation, strengthen professional construction and improve the quality of talent training.

Key words. Private universities; Resource allocation; Efficiency.

1. Introduction

Private universities refer to independent legal person educational institutions founded by funds and forces from all walks of life, approved and registered by the competent education department. Que Mingkun pointed out that since China's reform and opening up, higher education has undergone a historic leap forward development [1]. In 2019, the gross enrollment rate of higher education in China reached 51.6%, marking the beginning of the popularization stage of higher education in China. Wang Jun pointed out that china's vast population is a fundamental characteristic of the nation, and the unequal distribution of people across regions results in varying educational opportunities for students in different areas to access higher education[2].

Practice has proven that the development dependence of universities from the allocation of resources. Li Zhi defined resource allocation as the allocation of various resources such as human, financial, and material resources in different directions of use [3]. Koksal and Nalcaci believe that resource allocation is a complex and multi-level process that follows the principles of demand and allocates limited resources [4].

Based on the above research, internal resource allocation in universities refers to the process of reasonably allocating tangible resources, including human, financial, and

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material resources, through certain measures, methods, and means, to enable educational resources to flow from low efficiency links and places to high efficiency links and places, in order to improve resource utilization. Empirical research on the efficiency of resource allocation in private universities not just helps to better understand the current situation and problems of private universities, and that helps to propose corresponding policy recommendations and promote the healthy development of universities.

Regarding the efficiency of internal resource allocation in universities, Wolszczak Derlacz and Parkeka conducted a bootstrapped truncated regression analysis on the educational efficiency of 259 universities in 7 European countries. The regression results showed that the number of female university employees and regional medical institutions can have a significant impact on university efficiency [5]. Wu Yingping used strategic positioning and university characteristics as independent variables, and university efficiency as dependent variable to explore the influencing factors of university efficiency using quantile regression [6].The algorithms and models developed by Azat Tashev, Zhanar Takenova, and Mukaddas Arshidinova can not only be used to solve the problem of load allocation between teachers, but also to solve resource allocation problems in other fields of institutions [7].

This paper is to explore the efficiency of resource in private universities, and evaluate the efficiency of private universities in Guangxi, China, through Data Envelopment Analysis (DEA).

2. Introduction of Data Envelopment Analysis

2.1 The Emergence and Development of Data Envelopment Analysis

In 1978, A.Charnes and W.W. Cooper of the United States proposed a quantitative analysis method called data envelopment analysis (DEA) [8].DEA method can be used to evaluate the relative effectiveness of the same type of units with multiple inputs and outputs, and is widely used in efficiency evaluation and effect analysis in various fields. DEA model has been widely used in the evaluation of resource allocation efficiency of private universities, and has achieved good results. Through DEA model, we can evaluate the resource utilization efficiency, management efficiency, technical efficiency and other aspects of private universities, and provide reference and guidance for private universities to improve the efficiency of resource allocation. Manjari Sahai, Prince Agarwal, Vaibhav Mishra, Monark Bag, Vrijendra Singh analyzed DEA by measuring the supplier performance of multinational telecommunications companies and manufacturing enterprises. The company uses this method to evaluate its suppliers based on their requirements and standards, and finds the best supplier among them [9].Its basic assumption is that all decision making units (DMUs) can reach the optimal efficiency level, but the input and output indicators of different DMUs may be different. The DEA model compares and measures the input and output indicators of different decision-making units to obtain the relative efficiency of each decision-making unit, and then provides reference and decision-making basis for decision makers.

CCR model and BCC model are the two most widely used models of DEA model.

CCR model (Charnes-Cooper-Rhodes model) is one of the earliest DEA models. It assumes that each decision making unit (DMU) has the same input and output weight [10].The basic idea of the model is to determine the relative efficiency of each DMU and calculate the relative efficiency score of all DMUs through linear programming. The CCR model can be used to evaluate the technical efficiency and scale efficiency of each DMU. The technical efficiency reflects whether a DMU has reached the maximum production capacity under the existing scale and resources, while the scale efficiency reflects the capacity of a DMU to expand its scale.

The BCC model (Banker-Charnes-Copper model) is an improved version based on the CCR model. The BCC model considers the differences between DMUs and allows each DMU to have different input and output weights. The basic idea of this model is to find a set of optimal input and output weights through linear programming, so that all DMUs can be evaluated to the maximum. The BCC model is more flexible when dealing with DMUs of different sizes, and can be used to evaluate the technical efficiency, scale efficiency and comprehensive efficiency of each DMU.

In general, CCR model and BCC model are two very useful DEA models. They can be used to evaluate the efficiency and difference of each DMU and provide valuable decision support information.

2.2 Application of Data Envelopment Analysis in The Research on The Efficiency of University Resource Allocation

In the research on the efficiency of university resource allocation, DEA method can help evaluate the relative efficiency of each university in resource utilization, find out the inefficient universities, and provide reference for the improvement of resource allocation.
(1) CCR model
CCR model is a model based on the assumption of fixed return to scale and multiple inputs and outputs, which can be used to evaluate the overall technical effectiveness of the entire decision-making unit.

Under the assumption of fixed return to scale, the university to be evaluated for efficiency is regarded as a decision-making unit (DMU). Suppose there are n DMUs, and each DMUj uses m input factors, the input vector is X=（X1， X2...XM）, and the output vector is Y=（Y1， Y2...YM）. Charnes, Cooper and Rhodes combined this multi-input and multi-output situation with the virtual circle Vi and Ui, and proposed the initial CCR model form, as follows:

$$\begin{cases} \max h_j = \frac{\sum U^T Y_0}{\sum V^T X_0} \\ \frac{\sum_{r=1}^{s} U_\gamma Y_\eta}{\sum_{i=1}^{m} V_i X_\eta} \leq 1 \\ U \geq 0, V \geq 0 \\ j = 1,2,\dots n; i = 1,2,..m; r = 1,2,\dots s \end{cases} \tag{1}$$

Where: X0 represents the input of the evaluated decision-making unit;
Y0 represents the output of the evaluated decision-making unit;
Xij represents the input of the jth DMUj to the ith input;
Yrj represents the output of the jth DMUj to the rth output;
Vi represents the weight of the ith input;
Ui represents the weight of the r-th input.
Charnes, Cooper and Rhodes defined V, U as the weight to evaluate the efficiency

value of the decision-making unit, and the selection method of this weight is more objective than the assignment method. However, because fractional programming is a nonlinear model, it will produce infinite solutions, so they converted the original CCR model into the form of linear programming of linear programming:

$$\begin{cases} \max U^T Y_0 = \theta \\ V^T X_\eta - U^T Y_\eta \geq 0 \\ V^T X_0 = 1 \\ U \geq 0, V \geq 0 \\ j = 1,2, \dots n; i = 1,2, \dots m; r = 1,2, \dots s \end{cases} \tag{2}$$

And write its dual planning form according to the dual theory:

$$\begin{cases} \min h_j = \theta \\ \sum_{j=i}^{n} X_\eta \lambda_j - s_j^{-} = \theta X_0 \\ \sum_{j=i}^{n} Y_\eta \lambda_j - s_r^{-} = Y_0 \\ \lambda j \geq 0 \\ j = 1,2 \dots n; i = 1,2, \dots m; r = 1,2, \dots s \end{cases} \tag{3}$$

Where: hj is the efficiency index of DMU, representing the technical efficiency value;

λj represents the weight multiplier of each decision-making unit;

S-, S+ are relaxation variables.

When θ0=1 and relative to S-0=0，S+0=0, Pareto optimization is achieved, then the DMU is said to be DEA total technology effective; When θ0<1 andS-0≠0，S+0≠0, it means that at least one input or output partial invalid rate is used, which is a non-DEA total count valid state.

According to Banker&Morey [11], In CCR model, ∑λ The value of can be used to judge the scale return status of the evaluated unit as follows: when ∑λ= 1 means that the assessed unit is in the optimal production scale and belongs to fixed scale remuneration; Σλ< 1 means that the appraisal unit is smaller than the optimal production scale, and belongs to the increase of scale returns; Σλ> 1 means that the appraised unit is larger than the optimal production scale, and belongs to diminishing returns to scale. Pass Σλ To understand the scale return status of the assessed unit (DMU), which can be used to determine whether the allocation and utilization of resources are appropriate in management decision-making.

(2) BCC model

Because the CCR model is applicable to the evaluation of technical efficiency in the case of fixed returns to scale, some DMUs may not produce at the most suitable scale, but may produce under the increasing or decreasing variable returns to scale. Therefore, in 1984, Banker, Charnes and Cooper proposed the BCC model of variable returns to scale [12]. The relative efficiency measured by BCC model is pure technical efficiency.

The model is as follows:

$$\begin{cases} \min\ h_j = \theta \\ \sum_{j=i}^{n} X_\eta \lambda_j + s_j^{\ -} = \theta X_0 \\ \sum_{j=i}^{n} Y_\eta \lambda_j - s_r^{\ -} = Y_0 \\ \sum_{j=i}^{n} \lambda_j = 1; \lambda j \geq 0 \\ j = 1,2 \ldots n; i = 1,2,..m; r = 1,2, \ldots s \end{cases} \quad (4)$$

Where: X0 represents the input of the evaluated decision-making unit;

Y0 represents the output of the evaluated decision-making unit;

Xij represents the input of the jth DMUj to the ith input;

Yrj represents the output of the jth DMUj to the rth output;

hj is the efficiency index of DMUj, representing the pure technical efficiency value (PTE);

λj represents the weight of the ith input;

S -, S+ are relaxation variables.

The BCC model has one more constraint than the CCR model, that is, the return to scale is variable， When θ0=1 and relative to S-0=0， S+0=0, the DMU is pure technical efficiency effective, otherwise it is pure technical efficiency ineffective.

3. Research Design

3.1 Selection of Input and Output Indicators

(1) Select and determine the decision unit (DMU)

When selecting DMUs, there must be homogeneity between DMUs. As for the selection of input and output items of each decision-making unit, Cooper and others have given the following requirements [13]:

1) For all DMUs, each input and output value can be achieved, and these values must be positive and positively correlated.

2) The selection of these project inputs, outputs and decision-making units should align with the concerns of analysts or managers regarding the assessment of decision-making units' relative effectiveness.

3) From the principle of efficiency ratio, the input value should be as small as possible, while the output value should be as large as possible.

4) Different input and output units are not required to be consistent. It can be the number of people, area, cost, etc.

Moreover, an abundance of input and output indicators can result in a higher effective number of decision-making units, thereby diminishing the efficiency of the DEA method in its evaluative function.[14]. Therefore, the evaluation indicators should be as simple as possible on the premise of meeting the purpose.

(2) Determination of input-output indicators

The objective of resource allocation optimization is to efficiently harness human, material, and financial resources to achieve the comprehensive goals of higher education, including nurturing talent, societal service, and scientific research, while minimizing resource consumption [15]. Based on the above considerations, the input indicators selected in this paper include: the number of full-time teachers in X1, the average school building area of students in X2, and the average teaching daily operating expenses of students in X3. The output indicators include: the number of full-time students in Y1, the sum of the number of papers published and the number of monographs published in Y2. The input indicators reflect the financial, material and human inputs of universities respectively, and the output indicators reflect the functions of universities in cultivating talents and scientific research. Considering that Guangxi is located in the western region of China, the overall education level ranks low, and the overall scientific research level of private universities is not high, there are basically not many measurable quantitative indicators in terms of social services, Therefore, social services are not included as output indicators for evaluation in this study [16].

3.2 Data Source Description

This paper takes the running data of eight private undergraduate universities in Guangxi from 2018 to 2022 as a sample, and carries out horizontal and vertical analysis to investigate the resource allocation efficiency of private universities. The indicator data used are from the annual undergraduate teaching status data of each university, various yearbooks and data collected from the business departments of private undergraduate universities.

4. Empirical Analysis and Results

Based on the input orientation, the CCR and BCC models are used to calculate and analyze the input and output data of the resource allocation of eight private undergraduate universities in Guangxi from 2018 to 2022. Since the global DEA analysis is used, the calculated efficiency values can be compared horizontally and vertically. At the same time, the comprehensive technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE) of university resource utilization can be obtained by using CRR model and BCC model. Table 1 shows the efficiency results.

Table 1. Resource allocation efficiency of eight private undergraduate universities in Guangxi (2018-2022)

Universities	Efficiency/Year	2018	2019	2020	2021	2022
BH	TE	0.689	0.709	0.782	0.644	0.622
	PTE	0.816	0.726	0.785	0.653	0.625
	SE	0.844	0.977	0.997	0.985	0.995
	Remuneration to scale	IRS	IRS	IRS	IRS	DRS
CM	TE	0.488	0.485	0.504	1.000	1.000
	PTE	0.562	0.559	0.686	1.000	1.000
	SE	0.869	0.868	0.735	1.000	1.000
	Remuneration to scale	IRS	IRS	IRS	-	-
GL	TE	0.973	0.850	0.914	0.852	0.892
	PTE	1.000	0.938	0.939	0.956	0.980
	SE	0.973	0.907	0.974	0.892	0.910

Table 1. Resource allocation efficiency of eight private undergraduate universities in Guangxi (2018-2022) (continued)

Universities	Efficiency/Year	2018	2019	2020	2021	2022
GL	Remuneration to scale	IRS	IRS	IRS	IRS	IRS
IT	TE	0.592	0.843	1.000	0.667	0.771
	PTE	0.757	0.878	1.000	0.670	0.773
	SE	0.782	0.960	1.000	0.995	0.998
	Remuneration to scale	IRS	IRS	-	DRS	IRS
LZ	TE	0.717	0.774	0.662	0.718	0.804
	PTE	0.793	0.815	0.674	0.739	0.820
	SE	0.904	0.950	0.982	0.972	0.981
	Remuneration to scale	IRS	IRS	IRS	IRS	IRS
NN	TE	1.000	1.000	0.961	1.000	1.000
	PTE	1.000	1.000	0.971	1.000	1.000
	SE	1.000	1.000	0.990	1.000	1.000
	Remuneration to scale	-	-	DRS	-	-
NT	TE	0.728	0.855	0.753	0.828	1.000
	PTE	0.793	0.861	0.762	0.833	1.000
	SE	0.917	0.993	0.987	0.993	1.000
	Remuneration to scale	IRS	IRS	IRS	DRS	-
XS	TE	1.000	0.998	1.000	0.762	1.000
	PTE	1.000	1.000	1.000	0.799	1.000
	SE	1.000	0.998	1.000	0.953	1.000
	Remuneration to scale	-	IRS	-	IRS	-

Note: "IRS, DRS, -" respectively mean increasing returns to scale, decreasing returns to scale and unchanged returns to scale.

4.1. Comprehensive Technical Efficiency Analysis

Figure. 1 shows the comprehensive technical efficiency of resource utilization in 8 universities from 2018 to 2022. It can be seen from the figure that the comprehensive technical efficiency of resource utilization of NN university and XS university is high. There are few universities that have achieved effective results in the early stage, but by 2022, the comprehensive efficiency of resource utilization of four of the eight universities has achieved effective results, indicating that the overall efficiency of resource utilization of these eight universities has improved. From the vertical perspective of universities, for example, the comprehensive efficiency of resource utilization of BH in universities has experienced "rise first and then fall", the comprehensive efficiency of resource utilization of LZ university has experienced fluctuations, while the comprehensive efficiency of resource utilization of CM in universities has increased year by year. From the perspective of horizontal analysis, by 2022, the comprehensive efficiency of resource utilization of BH and IT in universities will still be less than 0.8, which is not high. In view of this, we need to focus on the following analysis of pure technical efficiency and scale efficiency.

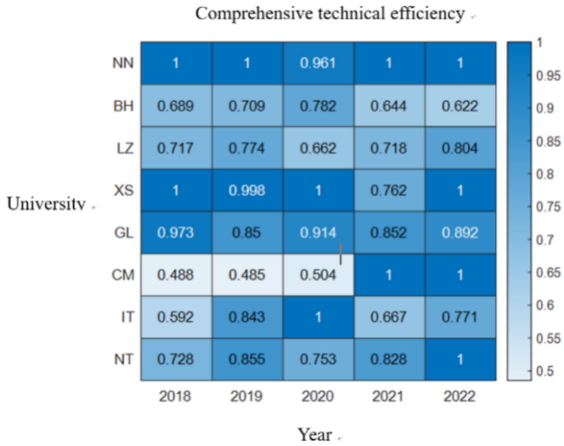

Figure 1. Comprehensive technical efficiency of resource allocation in 8 universities from 2018 to 2022

4.2. Pure Technical Efficiency Analysis

Figure. 2 shows the pure technical efficiency of resource allocation in 8 universities from 2018 to 2022. On the whole, the pure technical efficiency of NN university, XS university and GL university is relatively high. From the vertical perspective of universities, it is found that the pure technical efficiency of CM university has been greatly improved, while the pure technical efficiency of other universities fluctuates. From a horizontal perspective, it is found that by 2022, 4 of the 8 universities have achieved effective pure technical efficiency, which is more than that of other years. From the above analysis, it can be seen that in 2022, the comprehensive efficiency of resource utilization of BH university and IT university is less than 0.8, only 0.622 and 0.771 respectively. In 2022, the pure technical efficiency of BH university and IT university is only 0.625 and 0.773, respectively. It can be seen that the main reason for the low comprehensive efficiency of resource utilization in these two universities is the low level of pure technical efficiency. Therefore, in order to further improve the resource utilization efficiency of these two universities, it is necessary to focus on improving the management level of universities and allocating resources reasonably.

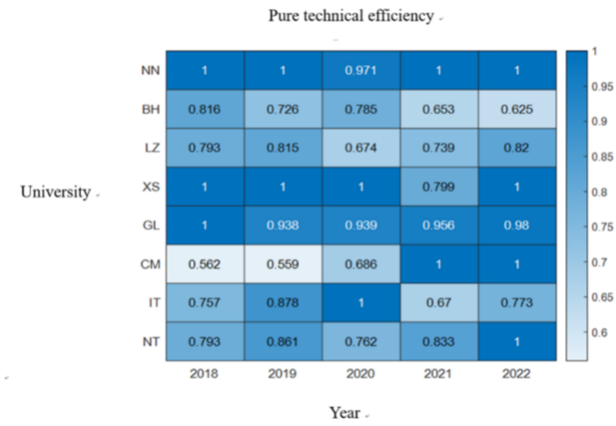

Figure 2. Pure technical efficiency of resource allocation in 8 universities from 2018 to 2022

4.3. Scale Efficiency Analysis

Figure. 3 shows the scale efficiency of resource allocation of eight universities in 2018-2022. On the whole, the scale efficiency of university resource allocation is relatively high, especially by 2022, the scale efficiency of four universities has reached effective, and the scale efficiency of the other four universities is also close to 1. From the perspective of time trend, in 2018, there were only 2 universities with effective scale efficiency, and the scale efficiency of other universities was also not high, which would be improved by 2022. This shows that, on the whole, the scale efficiency of university resources utilization is improved. By 2022, the space for improving the scale efficiency of university resource allocation has been limited. To further improve efficiency in the future, we need to start with improving pure technical efficiency.

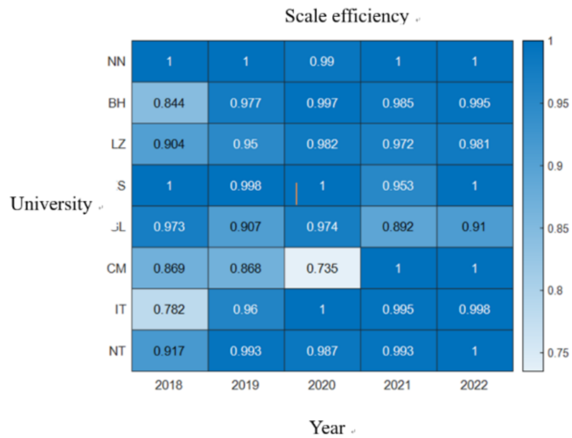

Figure 3. Resource allocation scale efficiency of 8 universities in 2018-2022

4.4. Overall Analysis

The comprehensive technical efficiency, pure technical efficiency and scale efficiency of resource allocation of 8 universities are averaged by year and visualized to obtain the overall resource allocation efficiency of these 8 universities from 2018 to 2022, as shown in Figure .4. It can be seen from the figure that, on the whole, the comprehensive technical efficiency has increased from 0.773 in 2018 to 0.886 in 2022, and there is still room for improvement. Through the decomposition analysis of the comprehensive technical efficiency, observations indicate that scale efficiency exhibits a notably higher level than pure technical efficiency, indicating that the pure technical efficiency is the main factor limiting the improvement of the efficiency of university resource allocation. Therefore, in order to further improve the efficiency of resource allocation in the future, it is necessary to improve the management level and reasonably allocate school resources.

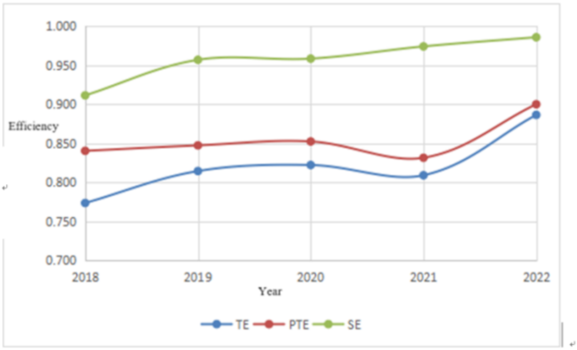

Figure 4. Overall situation of resource allocation efficiency of 8 universities in 2018-2022

In order to have an overall grasp of the resource allocation efficiency of each university, this paper calculates the annual average of the comprehensive technical efficiency of resource allocation of each university during the period 2018-2022, and visualizes it to obtain the average resource allocation efficiency of eight universities in 2018-2022, as shown in Figure. 5.

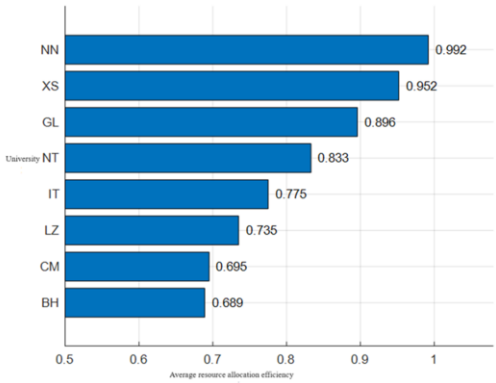

Figure 5. Average resource allocation efficiency of 8 universities in 2018-2022

According to Figure. 5, the top three universities in resource allocation efficiency are NN university, XS university and GL university. The comprehensive technical efficiency values of NN university and XS university both exceed 0.95, and the resource allocation efficiency is high. It can be seen that NN university and XS university are benchmarks that other universities need to learn in order to improve the efficiency of resource allocation. In addition, the comprehensive technical efficiency of CM university and BH university is relatively low, both less than 0.7, and there is much room for improvement.

5. Conclusions And Recommendations

5.1. Conclusion

Based on the data analysis of resource allocation efficiency of eight private undergraduate universities in Guangxi from 2018 to 2022, the following conclusions can be drawn:

(1) There are certain differences in the efficiency of resource allocation between 2018 and 2022 in Guangxi private undergraduate universities, but the overall trend is upward;

(2) From 2018 to 2022, the scale efficiency of resource allocation of Guangxi private undergraduate universities has been continuously improved, and pure technical efficiency is the main factor limiting the improvement of resource allocation efficiency of universities.

5.2. Suggestions

In view of the above conclusions, the following suggestions are put forward:

(1) Optimize technical efficiency. Technical efficiency is an important part of the efficiency of university resource allocation. If it is optimized, it will help to improve the overall efficiency. It is suggested that universities should strengthen the construction of teaching staff, improve teaching facilities and technical equipment, introduce advanced information technology and management technology, and improve technical efficiency.

(2) Optimize management efficiency. Management efficiency is also a key factor affecting the efficiency of resource allocation in universities. It is recommended that universities improve their management systems, strengthen the formulation and implementation of rules and regulations such as financial management, personnel management, and asset management, strengthen process management, increase supervision and evaluation of resource allocation, and ensure effective monitoring of resource allocation.

(3) The intensity of resource investment in universities should keep up with the speed of the development of school scale. The funding for resource construction in private universities mainly comes from tuition fees. While expanding the scale of education, universities should prepare resource construction plans in advance to ensure that resources are guaranteed in place.

(4) Optimize resource allocation structure. The resource allocation of private universities mainly revolves around the allocation of human, financial, and material resources. Private universities should fully consider the characteristics of their education, prioritize the allocation of financial resources, link budget management with work

execution, achieve work monetization, and thereby improve the efficiency of education management.

In short, the efficiency of resource allocation in universities needs to be comprehensively optimized from various aspects such as technical efficiency, management efficiency, scale development, resource allocation speed, and resource allocation structure. If universities can strengthen these aspects of work, it will help improve the efficiency of resource allocation.

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