Scientific Research Performance Evaluation of China's Higher Vocational Colleges from 2012 to 2021 based on DEA Method

Zhu Jun[1,2]

[1]Shanghai Publishing and Printing College, Shanghai, China
[2]Shanghai Research Institute of Publishing and Media, Shanghai, China

2399589311@qq.com

Abstract. In recent years, the input and output of scientific research in China's higher vocational colleges have shown a trend of rapid growth, but there is no corresponding performance evaluation research, which cannot accurately summarize the effect of scientific research work. Based on DEA method, this paper calculates the data released by relevant authorities from 2012 to 2021, analyzes and interprets the results, then puts forward optimization suggestions which provides useful reference for development and management of scientific research in higher vocational colleges.

Keywords: higher vocational colleges; scientific research performance; performance evaluation; DEA method.

1 Introduction

Through the integration of industry and education, higher vocational colleges not only provide technical skilled professional talents, but also serve the development of industrial technology. Although there is still a big gap between higher vocational colleges and undergraduate universities in terms of scientific research capabilities, But with China's strong support for vocational education in recent years, the status of scientific research work of higher vocational colleges is becoming increasingly prominent, and its development potential cannot be ignored. Therefore, it is important to accurately evaluate the scientific research performance of China's higher vocational colleges, which plays an important role in promoting management departments and colleges to make scientific research development plans, improve management abilities, rationally allocate scientific research resources, build high-level scientific research platforms and teams, so as to improve quality and efficiency of scientific technical achievements.

Until 2015, the amount of China's higher vocational colleges has just exceeded 400, and have been facing the problem of a shortage of teachers for a long time. There have been often only two or three teachers in a major who have to spend more time on teaching than on scientific research. At the same time, the teachers' academic backgrounds

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were mostly bachelor's or master's degrees, and didn't have high requirements for theoretical research abilities. They lacked good research environment, advanced facilities, and sufficient funds support. They also had few opportunities to participate high-standard academic activities and research teams. Therefore, higher vocational colleges generally do not attach much importance to scientific research work, which is often just to meet the needs of teachers' professional title promotion. Scientific research takes a relatively small proportion in the overall performance assessment of colleges, and its foundation is weak. As a result, the relative researches are scarce too. [1]

Further combing the existing researches, we can find that the discussions about scientific research of higher vocational colleges are mainly concentrated in the evaluation system and assessment system. Yang Xuming (2019) believed that the recognition of the scientific research achievements higher of high vocational colleges should not refer to the standards of undergraduate universities, but also need to include teaching seminars, corporate consultations, technical transformation, social training, and standard formulation as scientific research achievement;[2] Zhai Haiyin (2020) proposed that higher vocational colleges should establish diversified assessment mechanisms according to majors or research directions. For teachers engaged in basic discipline research, their theoretical influence should be evaluated, while for teachers engaged in applied discipline research, their actual contribution to economic and social benefits should be evaluated; [3] Liu Chunmei (2023) proposed to formulate a scientific research management system in line with the positioning of higher vocational colleges, explore diversified implementation paths, establish an evaluation system and incentive mechanism based on quality and contribution, and highlight the importance of scientific research in higher vocational colleges; [4] Xu Xiaoqin et al. (2023) suggested that higher vocational colleges should rationally allocate funds and resources according to the characteristics of different majors, so as to achieve optimal allocation of scientific research input and output. [5]

To sum up, the existing studies have discussed some problems in the evaluation of scientific research performance in higher vocational colleges and put forward corresponding optimization strategies, but there is still room for research expansion: On the one hand, the existing research lacks to show the development trend of the overall scientific research performance of China's higher vocational colleges in recent years; on the other hand, the existing research does not calculate the impact of each index of scientific research input and output, which cannot provide accurate basis for the government and higher vocational colleges to rationally allocate scientific research resources and improve scientific research management ability. Therefore, based on a quantitative efficiency analysis method, this paper forms a new research perspective about the scientific research performance of higher vocational colleges.

2 Research Design

2.1 Index and Data Sources

This paper selects indexes and data according to higher vocational colleges from the ***Science Technical Statistics of Higher Education Institutions from 2012 to 2021*** compiled by the Ministry of Science and Technology and Information Technology Department of China, then constructs the performance evaluation frame (Fig. 1).

	Primary Indexes	Secondary Indexes	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Input	Manpower	Number of schools	313	345	356	402	619	826	929	947	1000	1014
		Number of teaching and research staff	67731	74292	77872	87514	116444	142395	161538	166237	178837	187110
		Number of R&D personnel	9287	10572	10479	12451	17268	19346	23297	25337	27719	30080
		R&D results application and service personnel	1112	1609	1819	2443	2263	2754	3333	4055	4671	5603
	Funds	Scientific research funds (thousand yuan)	127724	124170	156073	178952	250927	272740	349951	453406	561838	698905
		Special fee for competent authorities (thousand yuan)	108200	168607	171937	215124	261295	291093	379548	479756	536867	743555
		Special fees for other government departments (thousand yuan)	135384	171945	181300	162522	292033	296863	355333	500917	450794	445711
Output	Awards	Number of scientific technical progress awards above provincial or ministerial level	77	59	59	79	84	89	82	47	67	80
	Papers and writings	Number of published scientific technical writings	2207	2709	2480	2987	3527	3843	3723	4104	3724	3623
		Number of published academic papers	31733	36293	36394	40248	48669	55834	60887	62934	64938	65911
	Projects	Number of basic research projects	1442	1792	1871	1900	2708	3062	3457	4131	4882	5914
		Number of basic applied projects	5742	7078	7320	8235	11924	14445	17953	21396	22468	24769
		Number of experimental development projects	539	712	649	826	1205	1559	1810	1973	2412	2569
		Number of R&D application projects	482	563	7320	8235	1225	1280	1276	1518	1755	2164
		Number of scientific technical service projects	621	695	649	826	1319	1784	2143	2617	3181	3337
		Entrusted funds of enterprises and institutions (thousand yuan)	194986	254012	260730	295191	350225	427862	624312	935323	1033685	1215752
	Intellectual property	Number of applications for invention patents	422	1167	1402	2258	3146	4512	6549	9093	9796	10964
		Number of applications for the utility model	858	2239	3354	6817	11656	14915	19403	22768	25271	33638
		Number of applications for designs	433	1102	1253	858	1391	2065	2035	3238	3886	4258
		Number of authorized invention patents	171	249	283	395	958	1666	1992	2345	2426	3567
		Number of authorized utility models	773	1587	2972	4761	9612	12623	15220	20118	21842	33321
		Number of authorized designs	277	492	1283	615	998	1733	1377	2380	3299	4074
		Patent sale amount (thousand yuan)	696	841	669	1571	3752	6567	15789	24168	33955	27827
	Technology transfer	Contract amount (thousand yuan)	3259	2423	16478	7560	10510	26936	52502	76653	52049	70496

Fig. 1. The indexes and data of Scientific Research Performance from 2012 to 2021

2.2 Analysis Method

Data Envelopment Analysis (DEA) method is a statistical method used to evaluate the relative efficiency of different decision-making units (DMUs) under multi-input and multi-output conditions. By constructing a unified input-output index system, DEA evaluates the efficiency of each DMU's input-output operation process, resulting in an overall evaluation of decision-making effectiveness. Compared to other statistical methods, DEA can objectively and quantitatively evaluate the performance level of each DMU in different operating conditions and provide direction for the improvement of influencing factors, providing a scientific basis for performance evaluation. This paper adopts the DEA-BCC model considering variable returns to scale, and the calculation formula is as follows:

$$\min_{\theta,\lambda}[\theta - \varepsilon(e^t s^- + e^t s^+)]$$

$$s.t.\begin{cases}\sum_{i=1}^{n}\lambda_i y_{ir} - s^+ = y_{0r}\\ \sum_{i=1}^{n}\lambda_i x_{ij} + s^- = \theta x_{0j}\\ \sum_{i=1}^{n}\lambda_i = 1\\ \lambda_i \geq 0; s^+ \geq 0; s^- \geq 0\end{cases}$$

In the formula, s^- is the relaxation variable corresponding to the input, $s^+$is the residual variable corresponding to the output. If θ = 1 and s^- =s^+= 0, it indicates that the DMU is DEA efficient, that is, in this system, the output obtained by the input of the unit has reached the optimal. If θ = 1 and $s^- \neq 0$ or $s^+ \neq 0$, then the DMU unit is DEA weakly efficient. That is, the output can be kept constant by reducing the input; If $\theta <$ 1, the DMU is said to be invalid DEA effectiveness. [6]

At the same time, the model can also decompose the comprehensive technical efficiency (TE) of each DMU into pure technical efficiency (PTE) and scale efficiency (SE), TE is a multi-faceted evaluation of DMU's resource utilization ability, PTE is the impact of management, technology and other factors on output efficiency under the premise of assuming optimal scale, SE is the impact of scale on output efficiency, so as to better compare the output efficiency of each DMU. [7]

DEA has been widely used in various fields. In this paper, we use DEA to evaluate the scientific research performance of higher vocational colleges. Each year from 2012 to 2021 is considered a DMU, and various evaluation indexes of input and output are regarded as performance influencing factors, which have good relevance.

3 Calculation Results and Descriptions

3.1 Step 1

For situations where a primary index includes multiple secondary indexes, we choose the entropy weighting method to determine the weights of each secondary index (Table 1), avoiding subjectiveness caused by manual scoring, and each specific data is multiplied by the weight to obtain the comprehensive data of performance indexes from 2012 to 2021 (Table 2):

Table 1. Secondary indexes weights of performance

	Primary Indexes	Secondary Indexes	Weights
Input	Manpower (X1)	Number of schools	0.274
		Number of teaching and research staff	0.253
		Number of R&D personnel	0.264
		R&D results application and service personnel	0.209
	Funds (X2)	Scientific research funds (thousand yuan)	0.409
		Special fee for competent authorities (thousand yuan)	0.294
		Special fees for other government departments (thousand yuan)	0.297
Output	Awards (X3)	Number of scientific technical progress awards above provincial or ministerial level	——
	Papers and writings (X4)	Number of published scientific technical writings	0.429
		Number of published academic papers	0.571
	Projects (X5)	Number of basic research projects	0.137
		Number of basic applied projects	0.136
		Number of experimental development projects	0.136
		Number of R&D application projects	0.238
		Number of scientific technical service projects	0.179
		Entrusted funds of enterprises and institutions (thousand yuan)	0.174
	Intellectual property (X6)	Number of applications for invention patents	0.126
		Number of applications for the utility model	0.122
		Number of applications for designs	0.107
		Number of authorized Invention patents	0.156
		Number of authorized utility models	0.138
		Number of authorized designs	0.128
		Patent sale amount (thousand yuan)	0.225
	Technology transfer (X7)	Contract amount (thousand yuan)	——

Table 2. The comprehensive data of performance indexes from 2012 to 2021

Year	X1	X2	X3	X4	X5	X6	X7
2012	19881.266	124254.306	77	19075.062	35214.541	528.591	3259
2013	21990.664	151416.154	59	21895.377	45773.515	1045.834	2423
2014	22917.411	168224.490	59	21854.905	48576.970	1485.410	16478
2015	26016.930	184716.110	79	24274.030	54976.514	2353.201	7560
2016	34619.382	266173.608	84	29316.407	63640.396	4405.306	10510
2017	41883.457	285295.997	89	33545.208	77688.669	6297.121	26936
2018	47912.002	360253.316	82	36380.518	112508.277	9533.008	52502
2019	49793.505	475253.896	47	37713.296	167362.601	13132.774	76653
2020	53748.813	521544.044	67	38695.263	184947.469	16163.763	52049
2021	56660.743	636909.556	80	39207.834	217236.110	17846.446	70496

In Table 2, It can be seen that the three most weighted secondary indicators are: Number of published academic papers, Number of published scientific technical writings, Scientific research funds, so we can learn that these three indexes have an extremely important impact on the evaluation of scientific research performance.

3.2 Step 2

Calculating the data in Table 2 by DEA method, the comprehensive technical efficiency (TE), pure technical efficiency (PTE), scale efficiency (SE), scale benefit evaluation, and DEA effectiveness of each DMU can be obtained. The results are shown in Table 3.

Table 3. The output efficiency of scientific research from 2012 to 2021

DMU	TE	PTE	SE	Scale benefit	DEA effectiveness
2012	1.096	1.225	0.895	Increase	Weakly efficient
2013	1.016	1.017	0.999	Increase	Weakly efficient
2014	1.020	1.072	0.951	Increase	Weakly efficient
2015	1.004	1.014	0.991	Decrease	Weakly efficient
2016	0.694	1.000	0.694	Decrease	Invalid
2017	1.013	1.033	0.980	Decrease	Weakly efficient
2018	1.053	1.068	0.986	Decrease	Weakly efficient
2019	1.074	1.078	0.997	Decrease	Weakly efficient
2020	1.030	1.033	0.997	Decrease	Weakly efficient
2021	1.066	1.157	0.921	Decrease	Weakly efficient

From the perspective of TE, except for 2016, all data are between 1.0-1.1 from 2012 to 2021, indicating that on the whole, the scientific research work of China's higher vocational colleges has achieved good performance, but each corresponding DEA effectiveness is weak, indicating that the optimal scientific research output efficiency has never been reached in these years. The reasons may be that the total inputs in scientific research were too large, but the outputs could not keep up with it completely, or the input structure of manpower and funds was not reasonable enough, leading to a lack of maximization of benefits. It should be noted that the TE data of 2015 is basically close to 1, indicating that the scientific research output efficiency of that year is relatively high, while the TE data of 2016 dropped to 0.694, indicating that the output efficiency of 2016 is relatively poor.

From the perspective of PTE, the data of most years are around 1, indicating that higher vocational colleges have generally matured in scientific research work and management, and made full use of invested scientific research resources. The PTE data of 2016 was 1.000, indicating that there is no room for improvement in this year, but due to the corresponding low TE data, it means that the inputs in this year was too much to fully convert into scientific research outputs. Of course, unlike the machinery or equipment investment, scientific research investment includes manpower and funds, which has a certain lag effect. Especially for 2016, the number of colleges increased by

53.98%, and scientific technical manpower increased by 32.78%, scientific research funds increased by 44.49%, while the outputs could not keep up with those increase in the same period, resulting in an invalid DEA effectiveness. However, these inputs were fully realized in the following year, therefore, it can be considered that the development and management of scientific research in higher vocational colleges in these years are efficient.

From the perspective of SE, except for 2016, the data of other years was above 0.9, indicating that the scale of scientific research inputs in these years were generally reasonable and effective. Meanwhile, the SE data of 2016 dropped to 0.694, consistent with the analysis results of PTE. The scale benefit evaluation data also shows that the scale benefit evaluation of 2012, 2013, 2014, and 2019 is "increasing", indicating that increasing inputs in scientific research can increase the outputs in these years. Other years' scale benefit evaluations data are "decreasing", indicating that these years' inputs have already been too high, and the outputs cannot keep up with the inputs increase.

3.3 Step 3

Projection analysis can be used to compare the output indexes of scientific research in each year with the ideal value under the strong DEA effectiveness state, and the projected data and relative proportion of each output index in each year are obtained (Table 4), so as to show the output status of various scientific technical achievements in each year and analyze the trend of output efficiency. If the projected data is 0, it means that the index is highly efficient and does not need to be adjusted; if the projected data is positive, it means that the index still needs to be improved; if the projected data is negative, it means that there is already superfluous space, and even if it is reduced, it will not affect the efficiency.

Table 4. The Projected data and corresponding proportion of scientific research output indexes

Year	X3		X4		X5		X6		X7	
	Data	Proportion (%)	Data	Proportion (%)	Data	Proportion (%)	Data	Proportion (%)	Data	Proportion (%)
2012	-26.645	-34.60	-1779.865	-9.33	2109.517	5.99	626.968	118.61	0.000	0.00
2013	13.742	23.29	-1653.726	-7.55	-77.208	-0.17	545.040	52.12	7017.660	289.63
2014	1.662	2.82	-2095.201	-9.59	3874.978	7.98	1383.867	93.16	0.000	0.00
2015	0.000	0.00	-509.573	-2.10	1656.555	3.01	0.000	0.00	1050.971	13.90
2016	0.000	0.00	158.073	0.54	21515.516	33.81	555.212	12.60	18215.830	173.3
2017	0.000	0.00	-1510.576	-4.50	9636.854	12.40	-110.510	-1.75	7307.887	27.13
2018	0.000	0.00	1263.008	3.47	1627.849	1.45	-427.450	-4.48	-6654.814	-12.68
2019	29.399	62.55	-1728.739	-4.58	-9637.136	-5.76	0.000	0.00	-18590.185	-24.25
2020	0.000	0.00	0.000	0.00	-6723.340	-3.64	-1742.746	-10.78	18974.546	36.46
2021	0.000	0.00	7957.105	20.29	-3211.866	-1.48	0.000	0.00	0.000	0.00

Taking DMU 2016 as an example, in terms of scientific technical manpower and funds, it achieves a reasonable input-output relationship, the output of papers and works still needs to increase by 158.073, accounting for 0.54% of the total, while scientific technical projects need to increase by 33.81%, especially in the transfer of technology, which needs to increase by 173.32%, further specifying the root cause of the low comprehensive efficiency and scale efficiency in 2016.

Looking at the last five years from 2017 to 2021, the output of papers and works has changed from surplus to shortage, and the shortage in 2021 is not small, indicating that higher vocational colleges should further strengthen theoretical research; while the output of scientific technical projects has changed from shortage to surplus, indicating that higher vocational colleges have given sufficient attention to vertical and horizontal projects in these years and achieved better development trends; intellectual property has always been in a just or slightly surplus state, indicating that the output of intellectual property in these years is sufficient; In terms of winning awards for scientific technical achievements, it is similar to intellectual property, except for one year occasionally, all years meet the output requirements. In terms of technology transfer, it is slightly more than one year slightly less than one year, and the overall performance is relatively poor, and it needs to be improved in the future.

In addition, by analyzing the data of 2021 alone, we can find that the projection data of three of the five output indicators in this year is 0, and the projection data of projects is also very small, only 1.48% of the surplus space, indicating that other output indexes except papers and writings have been in high efficiency and the overall state is very good.

3.4 Step 4

After removing a certain input or output index one by one, continue to calculate comprehensive technical efficiency (TE) by DEA method, we can get the average TE data under different index combinations, and then compare it with the original TE data to get absolute variables, thus getting the sensitivity ranking of these seven indexes affecting the results of scientific research performance (Table 5), and correspondingly the degree of influence on the performance evaluation results of each index. [8]

Table 5. Sensitivity ranking of performance indexes

Index removed	TE	Absolute variables	Ranking
Manpower (X1)	0.963	0.043	3
Funds (X2)	0.956	0.051	2
Awards (X3)	0.989	0.018	5
Papers and writings (X4)	0.893	0.114	1
Projects (X5)	1.008	0.002	7
Intellectual property (X6)	0.973	0.033	4
Technology transfer (X7)	1.004	0.003	6

It can be seen that in the evaluation of the scientific research performance of higher vocational colleges from 2012 to 2021, the index with the greatest influence is the output of papers and writings, while the output indexes of scientific technical projects and technology transfer have little impact on the TE data, indicating that theoretical research is still the absolute focus of scientific research in higher vocational colleges, but the effect of transforming scientific technical achievements is poor and has low influence on industry.

The impact of scientific technical manpower and funds ranks second and third, and their impact is almost the same, indicating that neither human resources nor funds can be ignored in scientific research investment, and both will have a high impact on scientific research performance.

It should be noted that in the statistical data of scientific research output indexes, the output of papers and works is entirely reflected by the number of publications, which does not distinguish between publication levels and cannot reflect the quality of theoretical research; The intellectual property indexes are also simply calculated by the number of applications and authorizations for different categories, but do not distinguish the subtypes within each category, such as combining technical inventions and apparatus inventions into invention patents, and cannot reflect the quality of intellectual property. The same is true for the indexes of scientific technical projects. Therefore, while affirming the rapid growth of scientific research achievements in recent years, we should also remain calm. On the one hand, quantity is the basis of quality, without sufficient quantity, it is difficult to achieve high-quality results, and on the other hand, quality is the soul of quantity, so high-quality results can better promote the continuous development of scientific research work. Only by paying attention to the growth of quantity and attaching importance to the improvement of quality, can we better promote the comprehensive, coordinated, and sustainable development of scientific research work in higher vocational colleges.

4 Conclusions

This study uses DEA method to calculate the input and output data of scientific research of China's higher vocational colleges from 2012 to 2021, clearly displayig the overall performance status and judgments of relative indexes in these years in a quantitative form, which has high application value and practical significance.

4.1 Rising Scientific Research Inputs Can Effectively Improve the Corresponding Output, and Higher Vocational Colleges Must Deepen the Integration of Industry and Education to Obtain More Industrial Funds

This study shows that rising scientific research inputs can effectively improve scientific research outputs, and the scientific research performance from 2012 to 2021 is basically maintained in an effective state. Therefore, in order to further improve scientific research ability of higher vocational colleges, more scientific research inputs are still needed in the future. However, the continuous increase in scientific research inputs can not only rely on government finance, but also need to obtain more industrial resources through deepening the integration of industry and education. Industries are the main service objects of higher vocational colleges. Through positive participation in solving practical problems, more industrial research funds and projects can be obtained, and more application-oriented scientific research results can be produced. Therefore, colleges should actively establish long-term and stable cooperative relations with industries, build united scientific research teams and carry out research work jointly, forming a good relationship of mutual promotion.

4.2 Theoretical Research is the Primary Focus of Scientific Research, and Higher Vocational Colleges Need to Combine Industrial Demands and Resources to Enhance the Ability of Theoretical Research

This study also shows that the index of the greatest impact on the scientific research performance for higher vocational colleges is papers and writings, indicating theoretical research is the top priority of scientific research of higher vocational colleges. From the data of the recent five years from 2017 to 2021, we can see that the output of papers and writings has shifted from surplus to shortage, indicating that we must pay more attention to and strengthen the theoretical research work. In order to effectively improve the ability of theoretical research, higher vocational colleges should focus on industrial positioning, reflect the judgment of the development trend of the industries, the mining of technological innovation ability and the satisfaction of application needs, so that the theoretical research directions and contents are more in line with the characteristics of vocational colleges.

4.3 Current Scientific Research Outputs Focus on Quantity Rather than Quality, and Higher Vocational Colleges Need to Implement the New Development Concept to Improve the Quality of Research Achievements

Although the results of the output indexes seem to be reasonable, the index of technology transfer has little influence on the comprehensive technical efficiency of performance, reflecting the phenomenon that current scientific research outputs focus on quantity rather than quality. The solution of this problem requires higher vocational colleges to carry out scientific research work in accordance with the new development concept. On the one hand, we should insist on quality sense, pay more attention to the contribution of scientific research achievements to regional and industrial development progress, not simply use the number of papers and patents as the evaluation criteria for scientific research evaluation. On the other hand, we also should focus on sustainable development, establish and improve the mechanism for the transformation and application of scientific technical achievements, promote technology transfer, and make greater contributions to national economic and social development.

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