

# Research on the Transformation Efficiency of Scientific and Technological Achievements of Ministry-affiliated Universities Based on Network DEA

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## ABSTRACT

Previous studies on the transformation of scientific and technological achievements in universities were based on the black box model, and the results obtained were not comprehensive enough. This paper divides the transformation of scientific and technological achievements of universities into the knowledge research and development stage and the value transformation stage. The two-stage network DEA model is used to study the transformation efficiency of scientific and technological achievements of 55 subordinate universities based on the data from 2009 to 2017. The research in this paper finds that the overall efficiency of the transformation of scientific and technological achievements in Chinese universities is relatively stable, and the efficiency of the knowledge research and development stage is relatively high, but the efficiency of the value realization stage is seriously low, resulting in a low level of overall efficiency. "985" engineering colleges and "double first-class" colleges have higher input and output efficiency, and cluster analysis is used to classify and summarize the technological transformation of each college. Finally, corresponding development suggestions are put forward.

## KEYWORDS

Network DEA; ministry-affiliated universities; transformation of scientific and technological achievements; efficiency

## 1. INTRODUCTION

As the source of scientific and technological research and development and innovation, universities are an important part of the system to promote high-quality development of science and technology. Since the 18th Party Congress, the state has increased its support for scientific and technological innovation in universities, and according to statistics, the total investment in research and experimental development (R&D) in China in 2019 was 2,214.36 billion yuan, an increase of 12.5% over the previous year, achieving double-digit growth for four consecutive years, however, the shortcomings in the transformation of scientific and technological achievements in China's universities are still prominent, and the mechanism for the transformation of achievements is not yet sound, and there is a lack of technology transfer support mechanism and service capacity that are in line with international standards. By using the network DEA (Data Envelopment Analysis), the author researches the efficiency of science and technology achievement transformation in universities under the ministry to find out the problems in the process of transformation of science and technology

achievements in universities, so as to better serve the transformation of science and technology achievements in universities.

## 2. LITERATURE REVIEW

The methods for measuring the efficiency of scientific and technological transformation of universities are mainly divided into parametric and non-parametric methods. Stochastic Frontier Approach (SFA) is the most used algorithm among parametric methods, for example, F. T. Aleskerov et al. used data envelopment analysis and stochastic frontier analysis model to evaluate the study of cost efficiency of higher education institutions[1]; Brzezicki Łukasz used DEA, SFA and StoNED evaluated the efficiency of teaching and scientific activities in 58 public academic institutions in 2014[2].

The early research of scholars regarded the scientific and technological activities of universities as a "black box" model. Since the transformation of scientific and technological achievements in universities is a complex process involving multiple indicators and stages, the stochastic frontier method is difficult to solve these difficult problems, so the non-parametric method represented by DEA has been widely used in the study of the efficiency of scientific and technological innovation in universities. For example, Xue Wuzhao et al. used three-stage DEA and Malmquist index methods to evaluate static and dynamic efficiency of research input-output data of universities directly under the Ministry of Education from 2010-2017[3]; Zhang Chonghui et al. proposed a three-stage multi-criteria decision making (MCDM) non-radial super-efficient data envelopment analysis with Bootstrapping [4]. Aleksandra Parteka et al. studied the productivity change patterns of 266 public higher education institutions in European countries based on the Bootstrapped Malmquist index and concluded that there was a large national significance in productivity change [5]. Brendan Cantwell used DEA-Tobit regression analysis to study the extent to which markers of inter-institutional stratification and organizational segmentation predict global status in U.S. research universities [6]; Marcella Bernardo used the classical CCR model and the ZSG CCR DEA (Zero Sum Gain Data Envelopment Analysis CCR ) model to measure the performance assessment of university library management in Brazil, and It is argued that by redistributing resources, it helps to improve the efficiency of library management [7]. Mehdi Soltanifar used a combination of data envelopment analysis and Malmquist productivity index to analyze the performance between different private universities in Iran and concluded that there is a large gap between the units in terms of the number of research products and the number of graduated students [8].

With the continuous research on the efficiency of scientific and technological achievements in colleges and universities, more and more scholars recognize that the transformation of scientific and technological achievements in colleges and universities is a multi-stage transformation process, and the conclusions obtained by using only black box model research are not comprehensive enough. At present, more scholars take the network DEA model into consideration the inner connection and structure of the transformation of scientific and technological achievements, and conduct a more comprehensive and systematic study on the efficiency of the transformation of scientific and technological achievements in colleges and universities. The concept of network DEA was first proposed by Fare and Grosskopf and constructed the basic framework of network production system DEA model. Kao constructs a two-stage network DEA model based on the assumption of constant payoffs of scale, and sets the same weights for the same elements in two stages to reflect the parallelism between sub-processes.

There are many results of using network DEA models to study the transformation of scientific and technological achievements in universities. For example, Nazarko et al used DEA method to analyze the relative efficiency of higher education activities of 19 polytechnics in Poland [9]; Marti Sagarra et al used traditional ratio and network DEA methods to assess the teaching and research efficiency of 55 universities in Mexico from 2007 to 2012 [10]; Mehdi et al based on the efficiency model to

classify the target universities into research, teaching and teaching-research, and analyzed the teaching and research performance of private universities in Korea from 2010 to 2016 using a two-stage network DEA approach [11]; Du Yamin and Wonchul Seo used the DEA-Malmquist model to investigate the static and dynamic scientific and technological efficiency of inputs and outputs of R&D activities in universities in various regions of China and their development and management are investigated and suggestions for improvement are made [12]; Delimiro et al. used the data envelopment analysis (DEA) approach and output-oriented CCR, BCC and SBM models to study the efficiency of Colombian public universities and ranked them using a Pareto effective cross-efficiency mode [13]; Zhao Huanhuan et al. used a two-stage network of input sharing DEA model to measure the science and technology activities of provincial universities in China and to extract indicators of factors affecting the efficiency of university science and technology activities [14]; Yang and Hirofumi used the directed distance network DEA model to evaluate the efficiency of 64 research 211 universities for the period of 2010-2013 and combined with the Luenberger productivity index for time period efficiency development was studied [15]. There are also Yang and Shao [16], Pan Wen Tsao et al [17], and Sreekanth [18] to study the efficiency of transformation of science and technology achievements in different industries and different regions.

Through the collation of existing literature, it is found that most scholars' research on the transformation efficiency of university science and technology achievements is mainly based on black box model research, and this method is not comprehensive enough to study the transformation of university science and technology achievements, while in fact, the transformation efficiency of university science and technology achievements is a complex process of multi-chain, multi-stage and multi-output, so a new method is needed for in-depth research. The innovations of this paper are (1) dividing the transformation of university science and technology achievements into knowledge development stage and value transformation stage, and using network DEA model to study the efficiency of transformation of science and technology achievements of 55 ministry universities from 2009 to 2017. (2) The transformation efficiency of scientific and technological achievements in colleges and universities is analyzed from various dimensions, such as the change of years, "985", "211" project colleges and universities, "double first-class" colleges and universities, and individual colleges and universities.

### **3. EVALUATION INDEX SYSTEM AND EVALUATION ANALYSIS MODEL**

#### **3.1. Evaluation Index System**

The data in this paper originated from the Compilation of Science and Technology Statistics of Higher Education Institutions, and in order to ensure the accuracy of research data and the validity of research results, the data of 55 universities from 2009-2017 were finally selected as the samples for the study of the efficiency of transformation of scientific and technological achievements in universities, in combination with the categorization statistics of the Ministry of Education on the nature of relevant universities and the elimination of some universities with serious data deficiencies. Secondly, with different selected indicators, the results when using DEA model to evaluate the transformation efficiency of scientific and technological achievements in colleges and universities will be different. In the two-stage transformation process of scientific and technological achievements in universities, the knowledge R&D stage is mainly based on the input of participating personnel and funds, and the number of people invested in R&D projects in the current year and the expenditures in the current year are chosen as the first stage input indicators, and the manpower and funds can effectively reflect the stability of scientific and technological personnel indicators and the actual situation of funds expenditures in the process of transformation efficiency of scientific and technological achievements; the basic research results in the knowledge R&D stage are measured by papers, Monographs and national projects are used to measure the basic achievements, which are important supports for the development of disciplines and cannot produce direct economic benefits, and the application

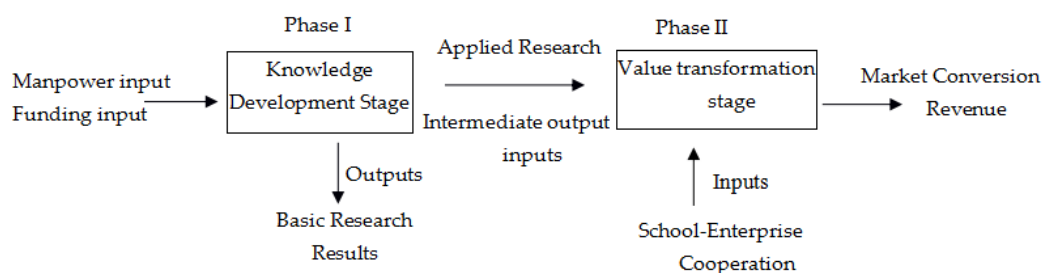
achievements outputted at this stage are measured by patents, and the application achievements will be regarded as intermediate products that can be involved in the next production stage. In the value transformation stage of scientific and technological achievements, the number of patents of intermediate products and the number of contracts signed will be used as the input of this stage, and the patent income and contract income earned constitute the output indexes of the value transformation stage. The specific indicators are shown in Table 1.

**Table 1.** Input-output variables for measuring the efficiency of science and technology conversion in higher education institutions

Category name	Indicator Description	Name of Indicator	Description
First stage input		R&D staff (person-years)	No. of people invested in R&D projects in the year
First stage input		R&D expenses (thousand dollars)	R&D project expenditure funds for the year
Phase I Output		Monographs (Parts)	No. of monographs published
Phase I Output		No. of papers (articles)	No. of papers published
Phase I Output		National-level projects (items)	No. of national-level projects accepted
Intermediate Products		No. of patents (pieces)	No. of patents sold per year
Phase II Input		No. of contracts (copies)	No. of contracts signed per year
Phase II Output		Patent income (thousand dollars)	Actual patent revenue per year
Phase II Output		Contract revenue (thousand dollars)	Actual annual contract revenue

### 3.2. The stage of transformation of scientific and technological achievements

At present, some scholars have used production function [19,20] and some scholars have used DEA model to measure the efficiency of the transformation of scientific and technological achievements in universities, but they only consider the input at the beginning end of knowledge research and development and the output at the end of value transformation, which is only a single black box model, and the results obtained are not comprehensive enough to make a systematic and comprehensive analysis of the whole process and sub-processes of the transformation of scientific and technological achievements in universities [21, 22,23]. On the basis of the network DEA model proposed by Fare et al, the network DEA model for transformation of university science and technology achievements is established, and the process of transformation of university science and technology achievements is divided into two stages: knowledge research and development and value transformation [24], and the overall efficiency and the efficiency of each stage are measured by using the network DEA model, according to Figure 1, in the stage of knowledge research and development, manpower and funds need to be invested to produce basic research results and applied research results, where the applied research results are further transformed into market revenue in the process of value transformation stage.



**Figure 1.** Flowchart of transformation of scientific and technological achievements.

### 3.3. Data Source

The data in this paper are derived from the Compendium of Science and Technology Statistics of Higher Education Institutions. To ensure the accuracy of the research data and the validity of the research results, the data of 55 universities from 2009-2017 were finally selected as the samples for the research on the efficiency of transformation of scientific and technological achievements in universities by combining the categorization statistics of the Ministry of Education on the nature of relevant universities and excluding Renmin University of China, Tianjin University, China University of Political Science and Law, Communication University of China, Beijing Normal University, Beijing University of Traditional Chinese Medicine, China University of Mining and Technology (Beijing), Northeast Forestry University and Southwest Jiaotong University, which have serious data deficiencies.

### 3.4. Evaluation Analysis Model

Considering the stage and complexity of the transformation process of scientific and technological achievements in universities, according to the difference between additive and multiplicative indices in the network DEA structure model, the multiplicative model is a nonlinear fractional model, which is difficult to solve directly; while the additive model can adjust the stage weights according to the actual situation and can be applied to the situation of variable returns to scale (VRS), so we choose the additive index model for the solution.

Suppose there are colleges and universities, each of which is denoted as, and in the first stage there are inputs, final outputs, intermediate outputs, and as intermediate inputs, which participate in the second stage transformation together with the additional input in the second stage, and is the final output in the second stage. Where, are the weight vectors of the transformation process in each stage of the model, for any given decision unit, where, denote the efficiency of the first stage, the second stage, and the overall stage, respectively, and and denote the weights of the transformation process and satisfy then under the assumption of constant returns to scale, the following addition in the form of ratios is given by integrating the efficiency values of the two stages Model.

$$\begin{aligned}
\theta^0 &= \max \omega_1 \theta_1^0 + \omega_2 \theta_2^0 \\
&= \max \omega_1 * \frac{\sum_{t=1}^T u_t z_{to} + \sum_{f=1}^F w_f z_{fo}}{\sum_{i=1}^I v_i x_{io}} + \omega_2 * \frac{\sum_{b=1}^B p_b y_{bo}}{\sum_{t=1}^T u_t z_{to} + \sum_{e=1}^E h_e x_{eo}} \\
s.t. &\frac{\sum_{t=1}^T u_t z_{tj} + \sum_{f=1}^F y_f z_{fj}}{\sum_{i=1}^I v_i x_{ij}} \leq 1 \forall j \\
&\frac{\sum_{b=1}^B p_b y_{bj}}{\sum_{t=1}^T u_t z_{tj} + \sum_{e=1}^E h_e d_{ej}} \leq 1 \forall j \\
&v_i, u_t, w_f, h_e, p_b \geq 0, \forall i, t, f, e, b
\end{aligned} \tag{1}$$

Combined with the way scholars' previous research results assign weights according to the proportional relationship of each stage input to the whole process input, we stipulate that

$$\omega_1 = \frac{\sum_{i=1}^I v_i x_{io}}{\sum_{i=1}^I v_i x_{io} + \sum_{t=1}^T w_t z_{to} + \sum_{e=1}^E h_e x_{eo}} \tag{2}$$

$$\omega_2 = \frac{\sum_{t=1}^T u_t z_{to} + \sum_{e=1}^E h_e x_{eo}}{\sum_{i=1}^I v_i x_{io} + \sum_{t=1}^T u_t z_{to} + \sum_{e=1}^E h_e x_{eo}} \quad (3)$$

According to this measurement, the total efficiency of the decision unit is found by the following equation

$$\begin{aligned} \theta^o = \max & \frac{\sum_{t=1}^T u_t z_{to} + \sum_{f=1}^F w_f z_{fo} + \sum_{b=1}^S p_b y_{bo}}{\sum_{i=1}^I v_i x_{io} + \sum_{t=1}^T u_t z_{to} + \sum_{e=1}^E h_e x_{eo}} \\ \text{s.t.} & \frac{\sum_{t=1}^T u_t z_{to} + \sum_{f=1}^F w_f z_{fo}}{\sum_{i=1}^I v_i x_{ij}} \leq 1 \forall j \\ & \frac{\sum_{b=1}^S p_b y_{bj}}{\sum_{t=1}^T u_t z_{tj} + \sum_{e=1}^E h_e x_{ej}} \leq 1 \forall j \\ & v_i, u_t, w_f, h_e, p_b \geq 0, \forall i, t, f, e, b \end{aligned} \quad (4)$$

It can be transformed into a linear model by C-C transformation as follows

$$\begin{aligned} \theta^o = \max & \sum_{t=1}^T u'_t z_{to} + \sum_{f=1}^F w'_f z_{fo} + \sum_{b=1}^S p'_b y_{bo} \\ \text{s.t.} & \sum_{i=1}^I v'_i x_{ij} - \sum_{t=1}^T u'_t z_{tj} - \sum_{f=1}^F w'_f z_{fj} \geq 0 \quad \forall j \\ & \sum_{t=1}^T u'_t z_{tj} + \sum_{e=1}^E h'_e x_{ej} - \sum_{b=1}^S p'_b y_{bj} \geq 0 \quad \forall j \\ & \sum_{i=1}^I v'_i x_{io} + \sum_{t=1}^T u'_t z_{to} + \sum_{e=1}^E h'_e x_{eo} = 1 \\ & v'_i, u'_t, w'_f, h'_e, p'_b \geq 0, \forall i, t, f, e, b \end{aligned} \quad (5)$$

## 4. RESULTS

### 4.1. Analysis of the transformation of scientific and technological achievements of universities by year

The overall transformation efficiency of scientific and technological achievements of universities under the ministry is recorded as S, the efficiency of knowledge R&D stage is recorded as S1, and the efficiency of value transformation stage is recorded as S2, and the transformation efficiency of achievements in previous years is shown in Table 2. the average value of overall transformation efficiency is 0.402, the average value of knowledge R&D stage efficiency is 0.829, and the average value of value transformation stage efficiency is 0.343, which indicates that universities in China focus on basic research results R&D, and pay less attention to This indicates that our universities pay attention to the research and development of basic research results and not enough attention to the transformation of applied results. According to the annual report on the transformation of scientific and technological achievements, only 30.1% of national universities have set up technology transfer institutions, and the established university scientific research transformation institutions also have different degrees of scattered function positioning, low service level, weak role and little talent reserve, which are difficult to effectively undertake the responsibility and mission of transferring and transforming scientific and technological achievements of universities. Therefore, from these data, we can see that the scientific and technological achievements of colleges and universities focus on knowledge research and development and despise the process of value transformation.

In the knowledge research and development stage, the changes of efficiency in each year are less different, and fluctuate and fluctuate during the sample period, but the efficiency in each year is significantly higher than the efficiency in each year of the overall transformation stage. In the value transformation stage, the ups and downs of efficiency changes are consistent with the ups and downs of overall transformation efficiency, and the efficiency of each year is lower than that of overall transformation; from the perspective of the development of efficiency in the knowledge R&D stage and value transformation stage, there is an obvious incongruity between the input in the first stage and market transformation in the second stage of scientific and technological achievements in China's universities, which is due to the fact that the scientific and technological evaluation in China's universities has traditionally focused on the number of papers and impact factor, forming The reason is that the scientific and technological evaluation of our universities has traditionally focused on the number of papers and impact factor, forming the undesirable culture of "papers only" and "SCI first", and the phenomenon of emphasizing basic achievements rather than transformation process.

**Table 2.** Efficiency of transformation of scientific and technological achievements in universities over the years.

<b>Year</b>	<b>S</b>	<b>S1</b>	<b>S2</b>
2009	0.372	0.839	0.313
2010	0.416	0.857	0.363
2011	0.469	0.828	0.398
2012	0.489	0.851	0.415
2013	0.359	0.795	0.319
2014	0.306	0.774	0.256
2015	0.444	0.861	0.361
2016	0.496	0.861	0.424
2017	0.269	0.792	0.237
Mean	0.402	0.829	0.343

#### **4.2. Analysis of transformation efficiency of scientific and technological achievements in ministries and colleges by category**

The results in Table 3 show that the average levels of overall conversion efficiency, knowledge R&D efficiency, and value conversion efficiency of 985-engineering institutions are higher than those of 211 engineering institutions, and the efficiency levels of 985-engineering institutions are higher than those of 211-engineering institutions in all years. The main reason is that the 985 engineering institutions are better than the 211 en-gineering institutions in terms of financial investment, faculty, service capability, man-agement level, and ability to transform results.

**Table 3.** Efficiency of transformation of scientific and technological achievements of 985 project institutions and 211 project over the years.

Year	Transformation of scientific and technological achievements of "985" universities			Transformation of scientific and technological achievements in "211" universities		
	S	S1	S2	S	S1	S2
2009	0.426	0.832	0.373	0.316	0.847	0.251
2010	0.464	0.872	0.391	0.366	0.842	0.334
2011	0.484	0.849	0.404	0.454	0.806	0.393
2012	0.552	0.884	0.465	0.423	0.816	0.362
2013	0.411	0.832	0.357	0.306	0.757	0.280
2014	0.331	0.792	0.279	0.280	0.755	0.231
2015	0.440	0.866	0.347	0.448	0.857	0.376
2016	0.515	0.889	0.431	0.477	0.832	0.418
2017	0.307	0.795	0.271	0.230	0.788	0.202
Mean	0.438	0.846	0.369	0.367	0.811	0.316

From Table 4, the overall transformation efficiency, knowledge R&D efficiency and value realization efficiency of "first-class universities" are higher than those of "first-class disciplines" universities. In the stage of knowledge R&D, the efficiency of knowledge R&D of "double first-class" universities is relatively stable with an average value of 0.8 or more, while in the stage of value transformation, the efficiency of science and technology achievement transformation of "double first-class" universities is only 0.3 or more, and "The efficiency of "first-class universities" was above 0.2 in 2014 and 2017, while the performance of "first-class disciplines" universities was not satisfactory. This indicates that the transformation process of scientific and technological achievements of "double first-class" universities in China also has the phenomena of poor input-output operation system and low transformation efficiency.

**Table 4.** Efficiency of transformation of scientific and technological achievements of universities of "first-class universities" and "first-class disciplines" in the past years.

Year	First-rate universities			First-rate subjects		
	S	S1	S2	S	S1	S2
2009	0.426	0.822	0.365	0.365	0.862	0.302
2010	0.464	0.864	0.405	0.363	0.84	0.291
2011	0.484	0.85	0.403	0.464	0.832	0.378
2012	0.552	0.887	0.454	0.381	0.831	0.319
2013	0.411	0.829	0.348	0.347	0.79	0.320
2014	0.331	0.79	0.281	0.271	0.766	0.215
2015	0.44	0.861	0.346	0.438	0.847	0.372
2016	0.515	0.882	0.425	0.487	0.829	0.442
2017	0.307	0.787	0.268	0.145	0.787	0.107
Mean	0.437	0.841	0.366	0.362	0.821	0.305

#### 4.3. Analysis of transformation efficiency of scientific and technological achievements of ministry universities by individuals

From Table 5, it can be seen that the efficiency of science and technology achievement conversion of Tsinghua University is at the front line in both the stage of knowledge re-search and development and the stage of value transformation, while China University of Petroleum (East China) is at the bottom of the sample universities with only 0.114; the efficiency values of achievement conversion

of other universities are more different from each other. "Tsinghua University and Zhejiang University have higher overall efficiency during the Eleventh Five-Year Plan and the Thirteenth Five-Year Plan, while Xi'an University of Electronic Science and Technology and China University of Petroleum (East China) have lower overall transformation efficiency of scientific and technological achievements, which is only about 0.1. Tsinghua University, Zhejiang University and East China University of Science and Technology ranked in the top three in terms of overall conversion efficiency, while China University of Central and Eastern Petroleum (East China), Xi'an University of Electronic Science and Technology and East China Normal University ranked in the last three in terms of overall conversion efficiency.

**Table 5.** Average value of transformation efficiency of scientific and technological achievements in ministry universities.

NO.	Name	S1 Mean	S2 Mean	S Total Mean	Rank
1	PKU	0.962	0.469	0.575	10
2	THU	1.000	1.000	1.000	1
3	BJTU	0.773	0.174	0.203	47
4	USTB	0.768	0.174	0.239	43
5	BUCT	0.701	0.366	0.424	20
6	BUPT	0.953	0.434	0.505	16
7	CAU	0.827	0.286	0.367	29
8	BJFU	0.855	0.122	0.196	50
9	NCEPU	1.000	0.319	0.370	28
10	CUP	0.817	0.114	0.166	52
11	CUGB	0.842	0.677	0.676	6
12	NKU	0.636	0.339	0.386	25
13	DUT	0.824	0.196	0.289	38
14	NEU	0.959	0.502	0.540	13
15	JLU	0.820	0.180	0.250	42
16	NENU	0.695	0.656	0.599	8
17	FDU	0.963	0.538	0.583	9
18	Tongji	0.923	0.367	0.449	19
19	SJTU	1.000	0.646	0.716	4
20	ECUST	0.864	0.821	0.824	3
21	DHU	0.717	0.248	0.330	34
22	ECNU	0.582	0.096	0.154	53
23	NJU	0.881	0.129	0.214	46
24	SEU	0.875	0.399	0.513	15
25	CUMTB	0.893	0.197	0.270	39
26	HHU	0.850	0.162	0.235	45
27	JNU	0.994	0.454	0.529	14
28	NAU	0.628	0.254	0.347	31
29	CPU	0.914	0.368	0.461	18
30	ZJU	1.000	0.839	0.879	2
31	HFUT	0.688	0.280	0.330	33
32	XMU	0.662	0.133	0.201	48
33	SDU	0.780	0.250	0.362	30
34	OUC	0.899	0.234	0.300	36
35	UPC	0.593	0.067	0.114	55
36	WHU	0.972	0.308	0.405	23
37	HUST	0.986	0.435	0.542	12
38	CUG	0.583	0.262	0.264	40

39	WUT	0.875	0.328	0.423	21
40	HZAU	0.754	0.261	0.297	37
41	CCNU	0.836	0.450	0.411	22
42	HNU	0.572	0.167	0.235	44
43	CSU	0.997	0.567	0.661	7
44	SYSU	0.814	0.134	0.188	51
45	SCUT	0.721	0.298	0.385	26
46	CQU	0.782	0.201	0.259	41
47	SWU	0.811	0.352	0.398	24
48	SCU	0.977	0.597	0.686	5
49	UESTC	0.777	0.263	0.340	32
50	SWJTU	0.782	0.438	0.552	11
51	XDU	0.865	0.073	0.126	54
52	CHD	0.908	0.360	0.476	17
53	NWAFU	0.758	0.124	0.197	49
54	SNNU	1.000	0.267	0.301	35
55	LZU	0.665	0.488	0.381	27
	Mean	0.829	0.343	0.402	

\*Note: Peking University(PKU), Tsinghua University(THU), Beijing Jiaotong University(BJTU), University of Science & Technology Beijing(USTB), Beijing University of Chemical Technology(BUCT), Beijing University of Posts and Telecommunications(BUPT), China Agricultural University(CAU), Beijing Forestry University( BJFU), North China Electric Power University(NCEPU), China University of Petroleum, Beijing(CUP), China University of Geosciences, Beijing(CUGB), Nankai University(NKU), Dalian University of Technology(DUT), Northeastern University(NEU), Jilin University( JLU), Northeast Normal University(NENU), Fudan University(FDU), Tongji University(Tongji), Shanghai Jiao Tong University(SJTU), East China University of Science and Technology(ECUST), Donghua University(DHU), East China Normal University(ECNU), Nanjing University(NJU), Southeast University(SEU), China University of Mining and Technology(CUMTB), Hohai University(HHU), Jiangnan University(JNU), Nanjing Agricultural University(NAU), China Pharmaceutical University(CPU), Zhejiang University(ZJU), Hefei University of Technology(HFUT), Xiamen University(XMU), Shandong University(SDU), Ocean University of China(OUC), China University of Petroleum(UPC), Wuhan University(WHU), Huazhong University of Science and Technology(HUST), China University of Geosciences, Wuhan(CUG), Wuhan University of Technology(WUT), Huazhong Agricultural University(HZAU), Central China Normal University(CCNU), Hunan University(HNU), Central South University(CSU), Sun Yat-sen University(SYSU), South China University of Technology(SCUT), Chongqing University(CQU), Southwest University(SWU), Sichuan University(SCU), University of Electronic Science and Technology of China(UESTC), Xi'an Jiaotong University(SWJTU), Xidian University(XDU), Chang'an University(CHD), Northwest A&F University(NWAFU), Shaanxi Normal University(SNNU), Lanzhou University(LZU)

In the knowledge R&D stage, five universities, namely Tsinghua University, Shanghai Jiao Tong University, Zhejiang University, North China University of Electric Power and Shaanxi Normal University, ranked at the forefront of the sample universities in terms of efficiency in the knowledge R&D stage, while 13 universities, including Peking University, Tongji University and Fudan University, had the average value of efficiency in the knowledge R&D stage above 0.9, while East China Normal University, China University of Petroleum (East China), China University of Geosciences (Wuhan) and The average value of the efficiency of knowledge R&D stage of Hunan University is only about 0.5. From the perspective of the overall efficiency of the transformation of scientific and technological achievements in the sample universities, the overall efficiency of the transformation of scientific and technological achievements in universities under the ministry of China is not high, and the national average value is only 0.402.

The efficiency of both the knowledge R&D stage and value transformation stage of Tsinghua University is on the frontier side, the total average efficiency of the science and technology achievement transformation stage of Zhejiang University and East China University of Science and Technology reaches above 0.8, and the total average efficiency of science and technology achievement transformation of several institutions, such as Si-chuan University, Shanghai Jiaotong University, Central South University, Fudan University, Northeastern University, Northeast Normal University and China University of Geo-sciences (Beijing), is above 0.6, while The average efficiency of scientific research results transformation in East China Normal University, China University of Petroleum (East China) and Xi'an University of Electronic Science and Technology is less than 0.1, which are 0.09, 0.06 and 0.07 respectively. It shows that there is obvious variability and low efficiency in the efficiency of scientific and technological results transformation in Chinese universities.

Through the analysis of network DEA model, it can be seen that the overall efficiency of transformation of scientific and technological achievements in China's colleges and universities is between the efficiency levels of knowledge research and development and value transformation, mainly due to the effective investment of China's colleges and universities in human and material resources in the early stage to form a certain scientific foundation; while there is obvious variability between the efficiency of each stage in colleges and universities, and the efficiency of knowledge research and development stage is higher than the efficiency of value transformation stage, reflecting that there is a poor operation mechanism between R&D stage and value transformation stage, and the effectiveness, success rate and utilization rate of scientific and technological achievements transformation in colleges and universities are not high, which hinders the orderly implementation of scientific and technological achievements transformation system. Therefore, Chinese universities should improve the effectiveness of value transformation of scientific and technological achievements in the future, improve the operation mechanism of transformation system, and take into account the effective integration of knowledge research and development and value transformation.

#### 4.4. Clustering analysis

The transformation of scientific and technological achievements in colleges and universities is a multi-chain and multi-level complex process. Combining with the previous division of the stages of transformation of scientific and technological achievements, the 55 colleges and universities in this paper are divided into four categories with the mean value as the boundary, as shown in Table 6.

**Table 6.** Cluster analysis of the efficiency of transformation of scientific and technological achievements in ministry universities.

Category	High value conversion efficiency (Efficiency value $\geq 0.343$ )	Low value conversion efficiency (Efficiency value $< 0.343$ )
High efficiency of knowledge development (Efficiency value $\geq 0.829$ ),	PKU, THU, BUPT, CUGB, NEU, FDU, Tongji, SJTU, ECUST, SEU, JU, CPU, ZJU, HUST, CCNU, CSU, SCU, CHD	BJFU, NCEPU, NJU, CUMTB, HHU, OUC, WHU, WUT, XDU, SNNU
Inefficient knowledge development (Efficiency value $< 0.829$ )	BUCT, NENU, SWU, SWJTU, LZU	BJTU, USTB, CAU, CUP, NKU, DUT, JLU, DHU, ECNU, NAU, HFUT, XMU, SDU, UPC, CUG, HZAU, HNU, SYSU, SCUT, CQU, UESTC, NWFU

The first category belongs to universities with "double high" efficiency of knowledge R&D and value transformation, which form an effective coupling effect between the two stages of science and

technology achievement transformation, the results of knowledge R&D stage can be used in the value transformation stage, and the value transformation feeds back to the knowledge R&D stage, mainly including 18 universities such as Peking University, Tsinghua University and Fudan University. Among them, the knowledge R&D efficiency of Tsinghua University, Zhejiang University and Shanghai Jiao Tong University reaches 1.0; the efficiency of Shanghai Jiao Tong University in the process of value transformation is only 0.646. It can be seen that for universities with strong R&D capability and high commercialization efficiency, they should not only increase the investment in knowledge R&D, but also pay more attention to the work of value transformation, otherwise it is difficult to improve the efficiency of transformation of scientific and technological achievements in universities. Such universities should improve the awareness of commercialization of scientific and technological achievements in the stage of knowledge R&D, do a good research on market demand in the stage of value transformation, seek cooperation with enterprises and intermediaries for transformation of achievements, and improve the effectiveness and commercialization of transformation of achievements.

The second category belongs to colleges and universities with high efficiency of knowledge research and development and low efficiency of value transformation, which do not form organic coupling between the two stages of transformation of scientific and technological achievements and have very high potential of value transformation. The assessment and reward are strong, but the transformation is not complete or the transformation process is not smooth in the process of value transformation, which leads to the overall transformation efficiency of scientific and technological achievements in colleges and universities is not high. Therefore, we should increase the funds and scientific researchers' investment in commercialization of scientific and technological achievements, and both of them can promote the smooth realization of the value of scientific and technological achievements.

The third category of universities include five universities, namely, Beijing University of Chemical Technology, Northeast Normal University, Southwest University, Xi'an Jiaotong University and Lanzhou University, which have low efficiency of knowledge research and development and high efficiency of value transformation, for example, Lanzhou University has 0.665 efficiency of knowledge research and development and 0.488 efficiency of value transformation, and its universities have formulated and implemented promulgated management measures for transformation of scientific and technological achievements and established an expert advisory committee for transformation of scientific and technological achievements. Composed of professionals proficient in industry results transaction and operation process, legal, venture capital, property rights evaluation and financing, especially focusing on the participation of talents with familiarity with international industry operation process, the advisory committee mainly provides consulting assistance to the transformation of scientific and technological achievements, so that the transformation of scientific and technological achievements input and output has better synergistic performance.

The fourth category of universities consists of 22 universities including Beijing Jiaotong University, Beijing University of Science and Technology, China Agricultural University and Nankai University, which are "double low" universities in terms of knowledge research and development efficiency and value transformation efficiency. There are certain challenges to improve the overall efficiency of science and technology achievement transformation in these universities, which may be due to insufficient investment in knowledge research and development ability, resulting in low value transformation efficiency, or the lack of a complete value transformation operation system in the process of value transformation, so these universities should always pay attention to their knowledge creation ability and potential commercial value of science and technology achievements.

## 5. CONCLUSION AND COUNTERMEASURES

### 5.1. Research Conclusion

Taking the transformation of scientific and technological achievements in universities as the entry point, the network DEA model was used to measure and empirically analyze the efficiency of transformation of scientific and technological achievements in 55 universities of the Ministry of Education from 2009 to 2017, and the efficiency of each stage was categorized and studied, and the conclusions of the study are as follows.

(1) In terms of efficiency in each year, the overall level of efficiency of science and technology achievement transformation in our universities is not satisfactory, only 0.402, showing a wave-like development. From the perspective of each stage of science and technology achievement transformation, the annual average value of efficiency of knowledge research and development stage of our universities is high, maintaining around 0.8, while the efficiency of value transformation stage has a serious low phenomenon, only around 0.4. The main reason is that the operation of science and technology achievement transformation system of our universities is unstable, and there is uncoordinated between knowledge research and development stage and value transformation stage, showing a situation of emphasizing research rather than transformation, which leads to The effectiveness and utilization rate of the transformation of scientific and technological achievements are not high.

(2) From the perspective of university categories, the average level of transformation efficiency, knowledge R&D efficiency and value transformation efficiency of 985 project institutions is higher than that of 211 project institutions; in the transformation of scientific and technological achievements of "double first-class" universities, the overall transformation efficiency of "first-class universities" is higher than that of "first-class disciplines" universities. The average level of knowledge R&D efficiency and value transformation efficiency is higher than that of "first-class disciplines" universities, while in the value transformation stage, the transformation efficiency of scientific and technological achievements of "double first-class" universities is only about 0.3, and "first-class universities The efficiency of "first-class universities" in 2014 and 2017 is only about 0.2, which indicates that the transformation process of scientific and technological achievements of "double first-class" institutions in China also has the phenomenon of poor input-output operation system and low transformation efficiency.

(3) From the individual level, the efficiency of both the knowledge research and development stage and value transformation stage of Tsinghua University is on the frontier side, the overall average efficiency of the science and technology achievement transformation stage of Zhejiang University and East China University of Science and Technology reaches above 0.8, the overall average efficiency of science and technology achievement transformation of seven universities, including Sichuan University, Shanghai Jiaotong University and Central South University, is above 0.6, while the average efficiency of East China Normal University, China University of Petroleum (East China) and Xi'an University of Electronic Science and Technology, the average efficiency of scientific research results transformation in three institutions is less than 0.1, 0.09, 0.06 and 0.07 respectively, which shows that there is obvious variability in the efficiency of scientific and technological results transformation among universities in China.

(4) According to the division of the stages of transformation of scientific and technological achievements in universities, the 55 universities under the ministry are divided into four categories by taking the average value of efficiency as the boundary, and corresponding development suggestions are made for the advantages and shortcomings of each category of universities, and information feedback mechanism and risk early warning mechanism are established for the two stages of transformation of scientific and technological achievements in universities.

## 5.2. Recommendation

Combined with the empirical research of this paper, there are several suggestions for the transformation of scientific and technological achievements in colleges and universities as follows.

(1) In view of the fact that the overall efficiency level of science and technology achievement transformation in China's ministerial colleges and universities is not ideal and the efficiency of value transformation stage is seriously low, colleges and universities should optimize the management level and scale level of science and technology achievement transformation, specifically optimize the internal resource allocation ability of colleges and universities, integrate the effective connection between knowledge research and development and value transformation stages, set up service companies specializing in achievement transformation, and form a reasonable, systematic and effective management system and scale level. At the same time, we pay attention to the performance assessment mechanism that teachers' scientific and technological innovation and transformation process are equally important, and improve the innovation spirit, innovation consciousness and scientific research transformation ability of scientific researchers.

(2) In view of the fact that the overall transformation efficiency, knowledge research and development efficiency and value transformation efficiency of 985 project institutions and "first-class universities" are higher than those of 211 project institutions and "first-class disciplines" colleges and universities respectively, the future should adhere to the development direction of optimizing structure, risk control and benefit priority. Specifically, in the process of setting up the "double first-class" universities, we should pay attention to the rationalization of the control scale, which is an important choice to prevent the waste of scientific research resources and improve the quality; to form a structure oriented to the market demand, to optimize the professional structure, discipline structure and strategic layout structure of universities, to strengthen the construction of regional university achievement transformation demonstration zones, and to drive the scientific and technological transformation of universities. It should also strengthen the construction of regional university achievement transformation demonstration zones to drive the transformation of scientific and technological achievements of universities to deepen cooperation and exchange; establish the evaluation system of scientific and technological achievements, prevent the early warning of achievement transformation risks, and improve the economic and social benefits of scientific and technological transformation of universities.

(3) There are obvious differences in the efficiency of the two stages of transformation of scientific and technological achievements in China's deployed universities, such as Nankai University, Dalian University of Technology, Jilin University and other universities still have the problem of "double low" efficiency of knowledge development and value transformation, which requires these universities to pay attention to both "incremental" and "quality" work. "In other words, on the basis of expanding the scale of existing science and technology resources, further improving and upgrading the management of science and technology services and related system, and avoiding the long-term expansion of "increment" and neglecting the implementation of results transformation. In addition, we should also pay attention to avoid the phenomenon of "incremental" expansion for a long time and ignore the transformation of achievements, such as Nanjing University and other universities with higher than average efficiency of knowledge R&D and lower than average value of value transformation. At the same time, universities should give full play to the role of existing scientific research talents, base on university scientific research infrastructure, take social and economic benefits as the guide and external market resources as the basis, establish a good docking mechanism between scientific and technological achievements and market demand, guide the third-party evaluation of scientific and technological achievements, and serve the value transformation to the national "neck" technology. In order to promote theoretical development and innovation capacity together.

(4) Cluster analysis of the efficiency of scientific and technological achievements transformation in colleges and universities shows that there is obvious heterogeneity between the efficiency of each stage of scientific and technological achievements transformation in colleges and universities, and for the first category of "double high" colleges and universities with strong R&D capability and high commercial transformation efficiency, they should continue to increase the preliminary investment in knowledge R&D, improve the commercialization of scientific and technological achievements at the stage of knowledge R&D, and stimulate the motivation of scientific and technological achievements transformation. For the second category of universities with high R&D efficiency but low value transformation efficiency, firstly, they should increase the management and classification of basic research and application research results, improve the awareness of commercial value service and transformation of application results, and secondly, change the scale expansion from "pre-input-driven" to "technology transformation-driven". For the third category of universities with low efficiency of R&D and high efficiency of value transformation, they should improve the investment in scientific and technological personnel and funds, and increase the production of basic and application results. For the fourth category of universities with "double low", it is necessary to evaluate and assess the system of transformation of scientific and technological achievements and learn from the experience of other universities in all aspects from knowledge creation to value transformation. At the same time, universities should strengthen the construction of linkage mechanism with the market and establish feedback mechanism for risk control in the process of transformation of scientific and technological achievements.

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