Research on the Evaluation of the Transformation Capability of Scientific and Technological Achievements of Chinese Universities Based on Entropy Weight Method and Cluster Analysis

Jing YIN[1], Guanghui ZHU[2], Mingle ZHOU[2, *]

*zhouml@qlu.edu.cn

Department of Economics and Management, Qilu University of Technology (Shandong Academy of Sciences), Jinan 250353, China[1]
Shandong Computer Science Center (National Supercomputer Center in Jinan), Qilu University of Technology (Shandong Academy of Sciences), Jinan 250014, China[2]

Abstract: The transformation of scientific and technological achievements is crucial for the combination of science and technology and economy. Universities are important subjects in the transformation of scientific and technological achievements, which are crucial to promoting economic development and social progress. From the perspective of transformation process of scientific and technological achievements, this study constructs an evaluation index system to assess the level of science and technology achievement conversion in Chinese universities. The research data was collected from the "Compilation of Science and Technology Statistics for Higher Education Institutions in 2021" published by the Department of Science and Technology, Ministry of Education, China. The entropy weight method and cluster analysis were used to evaluate the transformation capability of scientific and technological achievements of universities in 31 provinces and cities (except for Hong Kong, Macao and Taiwan) in China. Research indicates that there are large differences in the transformation capability of scientific and technological achievements among Chinese universities in different provinces and cities. In addition, universities in some provinces and cities have uneven development levels in various stages of achievement transformation process. The theoretical and practical implications of this study are presented at the end.

Keywords: Universities, Transformation Of Scientific And Technological Achievements, Transformation Capacity Of Achievements, Entropy Weight Method, Cluster Analysis.

1 INTRODUCTION

The transformation of scientific and technological achievements is a key link of scientific and technological innovation. As an important subject to promote and implement the activities of transformation of scientific and technological achievements, universities' ability to enhance the transformation of scientific and technological achievements plays an important role in promoting the sustainable growth of national economy. Thus, it is essential to systematically evaluate the capability of universities to transform scientific and technological achievements.

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In addition, the evaluation can identify the problems in the process of transformation in higher education institutions. This is significant for exploring effective ways for universities to improve the transformation capability of scientific and technological achievements.

The transformation of scientific and technological achievements refers to the process of transforming scientific and technological achievements from laboratories and research centers into useful products and services to meet market demand and achieve economic and social benefits. The term "transformation of scientific and technological achievements" is a unique term in China's science and technology management. Internationally, scholars mostly use the concepts of "technology transfer", "technological innovation" and so on [15]. The scope of existing research on technology transfer is very extensive. However, as a whole, the existing literature mainly focuses on the patterns of technology transfer [2, 9], the factors that constrain technology transfer [4-5], and the evaluation of technology transfer efficiency [1, 6]. Few studies have been conducted in the literature from the perspective of technology transfer capability. In order to fill the gaps of existing studies, this research constructs an assessment indicator system, aiming to evaluate the technology achievement transformation capability of Chinese universities. This study attempts to find out the questions existing in the conversion of scientific and technological achievements of universities in various regions, and accordingly gives directions and suggestions for improvement to help universities improve their conversion capability.

2 LITERATURE REVIEW

The existing literature has studied the transformation of scientific and technological achievements mainly around three aspects. First, the existing literature has studied the modes and ways of transformation of scientific and technological achievements. Moortel and Crispeels [9] compare the patterns and cooperation paths of technology transfer conducted by Chinese and Western economies on the basis of constructing a theoretical framework for international intertechnical transfer. They found that technology transfer between international is mainly carried out in two ways: formal and informal ways. Baglieri et al. [2] conducted a study by collecting data from 60 universities in the United States and found that the main modes of technology transfer conducted by universities were university-enterprise partnerships, entrepreneurial teaching, patent transfer and business incubation.

Second, the existing literature has empirically studied the efficiency of technology transfer in research subjects. Rory et al. [14] empirically analyzed the relationship between knowledge spillover performance and university-enterprise alliances and technology transfer in U.S. universities around talent, resources, institutions, and finance. Danquah [7] used stochastic frontier analysis to study the efficiency of technology transfer in sub-Saharan African countries from 1970 to 2010. They found that human capital, research and development, and trade openness positively affect the efficiency of achievements transfer.

Third, the existing literature has explored the significant factors that influence the transformation of scientific and technological achievements. Das [8] studied the efficiency of technology transfer in 15 regions by constructing a computable general equilibrium model. Human capital, level of economic development and regional management capacity were found to be the main factors affecting technology transfer. Madanmohan et al. [12] found that R&D

investment and availability of skilled personnel, transfer pathways, government involvement and learning culture of firms influenced technology transfer capability.

By combing existing literature, it is found that the existing studies mainly focused on the transfer efficiency in the evaluation of the achievements transfer. Relatively little literature has studied the transformation capacity of scientific and technological achievements. Therefore, to make up for the deficiencies of existing literature, this research conducted a comprehensive evaluation of the transformation capability of scientific and technological achievements of universities in each region of China.

3 CONSTRUCTION OF INDEX SYSTEM

In the university, the activity of science and technology transformation is a complex process of many elements input, output, transfer and application. It can be mainly divided into three stages: project development, result output, and transfer application [13]. The evaluation of scientific and technological achievement transformation activities should cover the whole process of achievement transformation. In the evaluation, the index system should be constructed according to the characteristics and rules of universities. The constructed index system should reflect both the existing strength and development potential of scientific and technological innovation of universities, as well as the ability to transform scientific and technological achievements. Therefore, this study constructs the evaluation index system based on whole process of transformation of scientific and technological achievements. The level of scientific and technological research and development, the level of scientific and technological output and the level of transformation of scientific and technological achievements are primary indicators of the index system. They can reflect the strength of science and technology achievement transformation of universities comprehensively.

A school's research projects, research personnel, and financial investment are important indicators of its research strength and social status. This study selected science and technology manpower, science and technology funding, science and technology projects, and international science and technology exchanges as secondary indicators from the statistical compilation. Specifically, it includes 11 tertiary indicators such as the number of teaching and research personnel, the number of research and development personnel, internal and external expenditure funds, international academic conferences and so on. These indicators reflect the level of scientific and technological innovation in the process of transformation of scientific and technological achievements of universities, and reflect the competitiveness and R&D level of universities.

Scientific and technological achievements are the fruits of creative labor formed by researchers after scientific and technological research and development. The number of scientific and technological achievements determines the level of scientific research output of universities. Therefore, this study selected the scientific and technological achievements in the statistical data compilation as the secondary indicators of the second stage evaluation. The main forms of scientific and technological achievements are scientific papers, scientific works, invention patents and so on. Nine indicators, such as published scientific and technical works, academic papers and the number of patents granted, were selected as the tertiary indicators of the evaluation system, so as to reflect the level of scientific and technical output of universities.

The transfer capability reflects the activity process of science and technology output and input among countries, regions, industries and within the system of science and technology itself. Based on the statistical data in compilation and the principle of accessibility of indicators, present study mainly measures the level of transformation of scientific and technological achievements through the revenue obtained from transfer of results. Specifically, it includes 3 tertiary indicators: the actual income in the year of patent sale, the amount of technology transfer contract and the actual income in the year of technology transfer. The evaluation index system constructed in this research is presented in Table 1.

4 METHODOLOGY

4.1 Data Collection and Instrument

The data used in this research was collected from the "Compilation of Science and Technology Statistics of Higher Education Institutions in 2021" published by the Department of Science and Technology, Ministry of Education, China. This compilation details the overall status of science and technology activities of 2078 higher education institutions and their affiliated hospitals in China in 2020.The content covers the situation of science and technology manpower, science and technology funding, science and technology projects, science and technology output and so on. In addition, this compilation does not include data on the science and technology activities of higher education institutions in Taiwan, Hong Kong and Macao of China. Therefore, statistics from 31 provinces and cities, excluding Hong Kong, Macao and Taiwan, were

Table 1: Assessment indicator system for the ability to transform scientific and technological achievements.

Primary indicators	Secondary indicators	Tertiary indicators	Variable name	Relevance
Level of scientific and technological research and development	Science and technology manpower	Number of teaching and research staff (Person)	X1	Positive
		Number of R&D staff (Person)	X2	Positive
		Number of R&D results application and science and technology service personnel (Person)	X3	Positive
	Science and technology funding	Internal and external expenditure funding (1000 yuan)	X4	Positive
		Research and development project current year expenditure funds (1000 yuan)	X5	Positive
		R&D results application current year expenditure funds (1000 yuan)	X6	Positive

		Technology project services current year expenditure funds (1000 yuan)	X7	Positive
	Science and technology projects	Number of R&D projects (Item)	X8	Positive
		Number of R&D results application projects (Item)	X9	Positive
		Number of science and technology service projects (Item)	X10	Positive
	International science and technology exchanges	International academic conferences (Time)	X11	Positive
Level of scientific and technological output	Scientific and Technological achievements	Publication of scientific and technical works (Item)	X12	Positive
		Published academic papers (Item)	X13	Positive
		National level project acceptance (Item)	X14	Positive
		Number of patent applications (Item)	X15	Positive
		Number of patents granted (Item)	X16	Positive
		Number of patent sale contracts (Item)	X17	Positive
		Number of technology transfer contracts (Item)	X18	Positive
	Scientific and technical achievement awards	Number of national-level awards (Item)	X19	Positive
		Number of provincial and ministerial awards (Item)	X20	Positive
Level of transformation of scientific and technological achievements	Transformation revenue	Actual revenue in the year of patent sale (1000 yuan)	X21	Positive
		Technology transfer contract amount (1000 yuan)	X22	Positive
		Actual income in the year of technology transfer (1000 yuan)	X23	Positive

selected for analysis in this study. Excel software and IBM SPSS Statistics 27 are the data analysis tools used in this study.

4.2 Entropy Weight Method

In information theory, information entropy is a measure of the degree of uncertainty and disorder [10]. The principle of entropy method of assigning weights is to determine the indicator weights based on the amount of information contained in the observations of each indicator. The more information, the less uncertainty. The smaller the entropy value of the index, the greater its influence on the comprehensive evaluation [16]. In this research, the entropy weight method is used to assign the indicator weights to reduce the influence of subjective judgments, which makes the research findings out more objective and precise.

4.3 Cluster Analysis Method

Clustering is a classification method that groups data into clusters with similar characteristics. Data in clusters have a higher similarity, while data between clusters have a lower similarity

[3]. Systematic clustering is one of the most commonly used clustering methods. Systematic clustering method is to split or aggregate data according to certain data connection rules, certain hierarchical structure, and finally form a hierarchical sequence of clustering solutions. The basic idea of this method is to cluster variables that are close to each other into classes first according to their distance, and variables that are farther away into classes later. This is done sequentially until each variable is grouped into the appropriate class [11]. In multivariate statistical analysis, the purpose of dimensionality reduction can also be achieved by clustering analysis.

5 ANALYSIS

5.1 Entropy Weight Method Analysis

The method used in this study is the entropy weight method, and the specific calculation procedure is shown below [16].

First, the indicators are selected. Suppose there are m evaluation objects and n indicators, then x_{ij} represents the evaluation value of the jth indicator of the ith evaluation object (i=1,2,…,m; j=1,2,…,n).

Second, the data standardization process. In this research, the extreme value method was applied to dimensionless each tertiary index to eliminate the difference in magnitude between different units. Each evaluation indicator can usually be divided into positive and negative indicators due to their different characteristics. The higher the value of the positive indicator, the better the evaluation. On the contrary, the smaller the value of the negative indicator, the better the evaluation. Therefore, different metrics require different normalization algorithms to process data. For positive indicators, it is necessary to use equation (1). For the negative indicator, it needs to be processed by equation (2). Table 1 shows that X1 to X23 are all positive indicators. Thus, the data were normalized in this study using equation (1).

$$X_{ij}=\frac{x_{ij}-\min\{x_j\}}{\max\{x_j\}-\min\{x_j\}} \tag{1}$$

$$X_{ij}=\frac{\max\{x_j\}-x_{ij}}{\max\{x_j\}-\min\{x_j\}} \tag{2}$$

Third, the weight of the ith evaluation object in the jth indicator is determined using equation (3).

$$Y_{ij}=\frac{X_{ij}}{\sum_{i=1}^{m}X_{ij}} \tag{3}$$

Fourth, the information entropy of the jth indicator is calculated using Equation (4).

$$e_j=-\frac{1}{\ln m}\sum_{i=1}^{m}\left(Y_{ij}*\ln Y_{ij}\right) \tag{4}$$

Fifth, the information utility value of the jth indicator is calculated using equation (5).

$$d_j = 1 - e_j \tag{5}$$

Sixth, the weight of the jth indicator is calculated using equation (6).

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{6}$$

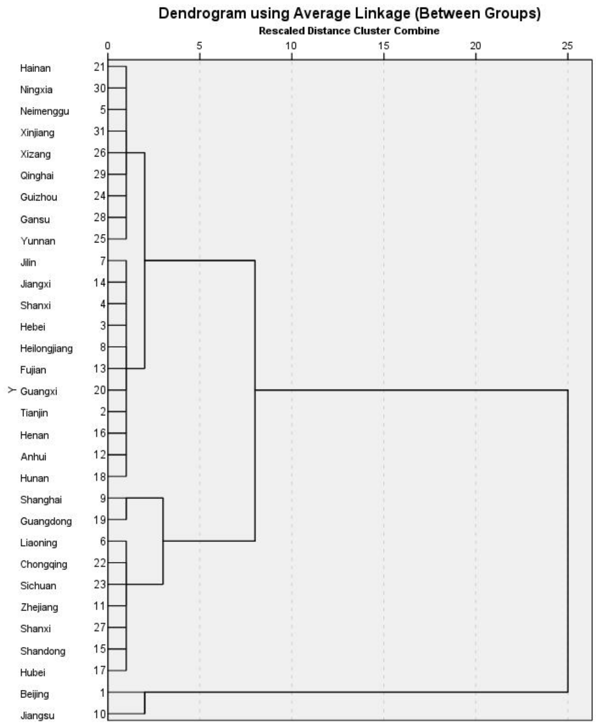

Figure 1: Dendrogram.

Table 2: Entropy value and entropy weight of each index.

Variable name	Indicator name	Entropy value	Entropy weight
X1	Number of teaching and research staff	0.9342	0.0179
X2	Number of R&D staff	0.9167	0.0226
X3	Number of R&D results application and science and technology service personnel	0.8697	0.0354
X4	Internal and external expenditure funding	0.8612	0.0377
X5	R&D project current year expenditure funds	0.8334	0.0452
X6	R&D results application current year expenditure funds	0.7600	0.0652

X7	Technology project services current year expenditure funds	0.8362	0.0445
X8	Number of R&D projects	0.9087	0.0248
X9	Number of R&D results application projects	0.8268	0.0470
X10	Number of science and technology service projects	0.8854	0.0311
X11	International academic conferences	0.8157	0.0500
X12	Publication of scientific and technical works	0.9319	0.0185
X13	Published academic papers	0.9009	0.0269
X14	National level project acceptance	0.7765	0.0607
X15	Number of patent applications	0.8930	0.0290
X16	Number of patents granted	0.8960	0.0282
X17	Number of patent sale contracts	0.7883	0.0575
X18	Number of technology transfer contracts	0.8020	0.0538
X19	Number of national-level awards	0.5950	0.1099
X20	Number of provincial and ministerial awards	0.9135	0.0235
X21	Actual revenue in the year of patent sale	0.8026	0.0536
X22	Technology transfer contract amount	0.7433	0.0697
X23	Actual income in the year of technology transfer	0.8249	0.0475

Seventh, the composite score of the ith evaluation object is calculated using equation (7).

$$S_i=\sum_{j=1}^{n}\left(W_j * X_{ij}\right) \tag{7}$$

According to the above steps, the weights of the tertiary indicators calculated by using Excel software are shown in Table 2. Then, the overall scores of science and technology achievement transformation capability and the scores of indicators at each level of universities in each province and city were calculated. The 31 provinces and cities were ranked according to the size of the scores. The results are displayed in Table 3.

5.2 Systematic Clustering Analysis

In order to better assess the capability of universities in each region to transform scientific and technological achievements, this study further analyzed 31 provinces and cities using cluster analysis. SPSS software is used for analysis. S1, S2, S3 and S were selected as clustering variables. The clustering analysis was performed using the systematic clustering method, and a clustering dendrogram was derived. As shown in Figure 1.

6 RESULTS AND DISCUSSION

As can be seen from Table 3, Jiangsu Province ranks first in terms of overall score. This reflects the leading position of universities in Jiangsu Province in the transformation of scientific and technological outcomes. Beijing, Shanghai, Guangdong and Zhejiang follow Jiangsu Province in the ranking. The universities in these regions have relatively strong ability to transform scientific and technological achievements. Universities in the cities of Chongqing, Liaoning, Hunan, Anhui and Tianjin have a medium level of achievement transformation capability. However, Ningxia, Hainan, Qinghai and Tibet, provinces with weaker economic bases, ranked low in the comprehensive score. This indicates that universities are less capable of transforming their achievements. Therefore, it can be seen that there are large gaps in the capability to transform scientific and technological achievements among universities in different regions.

Table 3: Indicator score and ranking.

Number	Province	S1	Ranking	S2	Ranking	S3	Ranking	S	Ranking
1	Beijing	0.3248	2	0.1648	4	0.1490	1	0.6385	2
2	Tianjin	0.0804	13	0.0865	14	0.0347	12	0.2015	14
3	Heibei	0.0706	17	0.0456	19	0.0087	18	0.1250	20
4	Shanxi	0.0481	22	0.0321	21	0.0054	20	0.0856	22
5	Neimeng	0.0124	26	0.0143	26	0.0012	27	0.0279	26
6	Liaoning	0.1118	10	0.1346	7	0.0331	13	0.2795	11
7	Jilin	0.0539	20	0.0420	20	0.0291	14	0.1250	19
8	Heilongjiang	0.0801	14	0.0579	18	0.0051	21	0.1431	17
9	Shanghai	0.2527	3	0.1068	9	0.1295	2	0.4891	3
10	Jiangsu	0.3774	1	0.2674	1	0.1060	4	0.7508	1
11	Zhejiang	0.1585	7	0.1710	3	0.0604	8	0.3899	5
12	Anhui	0.0749	16	0.1259	8	0.0143	17	0.2151	13
13	Fujian	0.0635	18	0.0905	12	0.0084	19	0.1624	16
14	Jiangxi	0.0505	21	0.0297	22	0.0245	15	0.1047	21
15	Shandong	0.1551	8	0.0896	13	0.0988	5	0.3435	8
16	Henan	0.0873	12	0.0741	16	0.0149	16	0.1763	15
17	Hubei	0.1929	5	0.1053	10	0.0506	10	0.3488	7
18	Hunan	0.1229	9	0.0729	17	0.0602	9	0.2559	12
19	Guangdong	0.2199	4	0.1015	11	0.1264	3	0.4478	4
20	Guangxi	0.0541	19	0.0831	15	0.0040	22	0.1413	18
21	Hainan	0.0083	28	0.0054	29	0.0009	29	0.0145	29
22	Chongqing	0.0791	15	0.1721	2	0.0383	11	0.2895	10
23	Sichuan	0.1051	11	0.1512	5	0.0724	6	0.3286	9
24	Guizhou	0.0204	24	0.0154	25	0.0027	23	0.0385	25
25	Yunnan	0.0280	23	0.0254	23	0.0009	28	0.0543	23
26	Xizang	0.0000	31	0.0002	31	0.0001	30	0.0003	31
27	Shanxi	0.1781	6	0.1397	6	0.0692	7	0.3869	6
28	Gansu	0.0187	25	0.0237	24	0.0015	26	0.0439	24
29	Qinghai	0.0048	30	0.0026	30	0.0000	31	0.0074	30
30	Ningxia	0.0066	29	0.0072	28	0.0019	25	0.0156	28
31	Xinjiang	0.0121	27	0.0095	27	0.0025	24	0.0241	27

Note: Score for the level of science and technology research and development, S1; Score for the level of scientific and technological output, S2; Score for the level of transformation of scientific and technological achievements, S3; Overall Score, S

Table 4: Clustering results.

Category	Province	S1 Average score	S2 Average score	S3 Average score	S Average score
I	Beijing, Jiangsu	0.35	0.22	0.13	0.69
II	Shanghai, Guangdong, Liaoning, Chongqing, Sichuan, Zhejiang, Shanxi, Shandong, Hubei	0.16	0.13	0.08	0.37
III	Tianjin, Hebei, Shanxi, Neimenggu, Jilin, Heilongjiang, Anhui, Fujian, Jiangxi, Henan, Hunan, Guangxi, Hainan, Guizhou, Yunnan, Xizang, Gansu, Qinghai, Ningxia, Xinjiang	0.04	0.04	0.01	0.10

Further analysis illustrates that there are some provinces and cities with large differences in the ranking of each level of indicators. The universities in two provinces, Heilongjiang and Hubei, have higher levels of scientific and technological research and development process than their achievements output and transformation process. In Liaoning, Anhui, Fujian, Guangxi and Chongqing, the level of scientific and technological output of universities is stronger than their own level of research and development and transformation of results. The universities in Jilin, Jiangxi and Shandong are stronger in the third stage than in the first two stages. Therefore, universities in some regions have uneven development of their levels in each stage of the whole process of science and technology achievement transformation.

As can be seen from Figure 1, the 31 provinces and cities in China can be divided into 3 categories, defined as I, II and III. The specific classification is shown in Table 4. Table 4 shows that Beijing and Jiangsu belong to category I. The universities in this category have the highest average S scores, which indicates that the universities in Beijing and Jiangsu have the strongest capacity to transform scientific and technological achievements among the universities in China. The high level of economic development and the strong government investment in scientific research in Beijing and Jiangsu provide good environment and conditions for the transformation of scientific and technological achievements. In addition, these provinces have many research institutes, colleges and universities as well as scientific research talents, which strongly support the transformation of science and technology productions of universities.

Shanghai, Guangdong, Liaoning, Chongqing, Sichuan, Zhejiang, Shanxi, Shandong and Hubei belong to category II. Universities in category II have relatively strong ability to transform scientific and technological achievements. It can be seen that most regions in this category have average economic strength. Universities have uncoordinated development of strength in each stage of science and technology achievement transformation activities. Thus, universities should focus on strengthening the management of science and technology achievement transformation and planning the whole process of achievement transformation in an integrated manner.

Other 20 provinces and cities such as Tianjin, Hebei, Shanxi belong to category III. In these provinces and cities, universities have the capacity to transform scientific and technological achievements at the medium level and below. Compared with other categories, universities have more balanced development strength in all stages. Most of the provinces and cities in this category belong to the central and western regions of China with weak economic power. Coupled with the low government investment in scientific research, the number of scientific and technological achievements produced is relatively small. In addition, the market development in these provinces and cities is not perfect and the competition environment in the market is not mature enough. These lead to the scientific and technological achievements cannot be popularized and applied, which in turn restricts the transformation of scientific and technological achievements of universities. Therefore, higher education institutions in these regions should introduce social funds, technical support and scientific and technological talents from multiple channels. The government should increase support for scientific research, improve relevant policies and make efforts to develop the market.

7 CONCLUSIONS

Based on the whole process of transformation of scientific and technological achievements, this study established an assessment index system for the transfer capability of scientific and technological achievements in universities from three dimensions of research and development, output and transfer of scientific and technological achievements. A comprehensive evaluation of 31 provinces, cities and autonomous regions across China was conducted using entropy weighting and clustering methods. The research results indicate that the transformation capability of scientific and technological achievements of universities in different regions of China varies widely. In addition, universities in some regions have uneven development in the level of each stage of the conversion process. In this study, 31 provinces and cities were divided into three categories based on the scientific and technological achievement transformation capability of universities in each province and city. The provinces in category I have high economic level. Local governments provide sufficient financial support for the transformation of scientific and technological achievements. Talents gather here, and universities have a strong ability to transform their achievements. The provinces in category II have an average economic base. The universities in these regions have uneven development of strength in each stage of conversion of science and technology achievements. Category III has a weak economic foundation and little support from local government for scientific research. These regions are relatively short of scientific and technological talents. There is a lot of room to promote the capability of higher education institutions to transform their achievements.

7.1 Theoretical and Practical Implications

This research complemented and improved the evaluation research on the transformation of scientific and technological achievements and enriches the theoretical understanding of the science and technology achievement transformation. Thus, this research has certain theoretical value significance. This research carefully analyzed the empirical results, and provided an empirical basis for scientifically and accurately judging the scientific and technological achievement conversion ability of universities in each province and city. In addition, present study analyzed problems of universities in the process of transformation of scientific and technological achievements through the empirical results, and pointed out the path direction for universities to improve the transformation ability of scientific and technological achievements. Therefore, present study also has certain practical significance.

7.2 Limitations and Future Research

Firstly, this research evaluated the transformation capability of scientific and technological achievements of universities in each province and city in China from a horizontal perspective. Future researches can carry out relevant studies from the longitudinal timeline in order to understand the dynamic trend of the development of science and technology achievements conversion capacity of universities in various regions of China over the years. Secondly, considering the feasibility and data collectability, only some more representative and operational tertiary indicators were selected in this study. More indicators can be included in future studies for a more comprehensive and specific analysis.

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