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Research on Performance Evaluation of University Science and Technology Achievement Transformation based on DEA Method

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Abstract

As the core subject of scientific and technological innovation, the efficiency of university scientific and technological achievement transformation is an important indicator for measuring the allocation of innovation resources and the level of social development. Based on the scientific research input and output data of universities in 25 provinces in China from 2019 to 2023, this study adopts the Super-efficiency CCR-DEA model and the Super-efficiency CCR-Malmquist index model to conduct a dual measurement and evaluation study on the short-term static and long-term dynamic efficiency of university scientific and technological achievement transformation in various provinces. The study finds that: (1) There is a certain correlation between the level of regional economic development and the efficiency of university achievement transformation, but the two are not a simple linear relationship. The actual performance of transformation efficiency depends more on the rationality of scientific research resource allocation and the practical effect of innovation output. (2) The total factor productivity of university achievement transformation in the 25 provinces continues to rise. The efficiency presents a pattern of "superior in the East, inferior in the West; strong in the South, weak in the North". It is suggested that universities should improve policies, attach importance to technology, introduce talents, promote transformation, and promote the optimized development of scientific research management.

Keywords

Higher Education Institutions; Super-efficiency CCR-DEA Model; Transformation of Scientific Research Achievements.

1. Introduction

In contemporary society, scientific and technological progress has become the core driving force for national development. The competition in comprehensive national strength among countries worldwide is increasingly manifested as a contest of scientific and technological capabilities. As a major developing country striving to build an innovative nation, China has continuously expanded the depth and breadth of its scientific and technological innovation. Modern science and technology have been fully integrated into various fields such as national economic construction, social development, and people's livelihood improvement, emerging as a key factor in promoting productivity enhancement and modernization drive. Notably, despite significant progress made in the transformation of scientific and technological achievements and the sustained growth in the quantity of scientific research outputs in China, relevant data indicates that the actual conversion rate of invention patents in China currently remains below 40%, a figure that shows a distinct gap compared with major developed countries[1]. This situation suggests that China still faces numerous challenges in improving the efficiency of transforming scientific and technological achievements, and urgent measures need to be taken to address them.

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The transformation of scientific and technological achievements is a core link in promoting the conversion of scientific and technological innovation into real productive forces. As important subjects of knowledge innovation, institutions of higher education play a pivotal role in this process. With their high-quality reserve of scientific research talents, improved experimental facilities, and efficient information exchange platforms, universities occupy an irreplaceable position in the national innovation system. The revised Science and Technology Progress Law of 2007 authorized project undertakers to legally obtain intellectual property rights formed through projects funded by fiscal funds, but it did not fully resolve the difficulties faced by universities in the approval procedures and other aspects of the transformation of intellectual property achievements. To remove the aforementioned institutional barriers, the amended Law on Promoting the Transformation of Scientific and Technological Achievements in 2015 granted universities the right to dispose of and benefit from scientific and technological achievements, allowing universities to "independently decide on transfer, licensing, or investment by valuation" and stipulating that "all income obtained from the transformation of scientific and technological achievements shall be retained by the university itself." The introduction of these higher-level laws has triggered an upsurge in local reforms on the right to benefit from scientific and technological achievements. By the end of 2020, 28 provinces, autonomous regions, and municipalities directly under the Central Government across the country had revised their relevant laws and regulations to promote the transformation of scientific and technological achievements. In August 2016, the Several Opinions on Strengthening the Transfer and Transformation of Scientific and Technological Achievements in Institutions of Higher Education, jointly issued by the Ministry of Education and the Ministry of Science and Technology, further emphasized that the transformation of scientific and technological achievements is an important part of the scientific and technological work of universities. It requires universities to closely link scientific research activities with the needs of economic and social development and provide sustained technological support for industrial transformation and upgrading. This indicates that universities bear important social responsibilities in promoting the transformation of achievements. However, according to the 2022 China Patent Survey Report released by the China National Intellectual Property Administration, the implementation rate of invention patents in universities was 16.9% and the industrialization rate of invention patents was 3.9% in 2022, far lower than the 59.4% implementation rate and 48.1% industrialization rate of enterprise patents. This current situation makes the transformation of scientific and technological achievements a prominent problem restricting the improvement of the efficiency of scientific and technological innovation in universities and even the whole country. If the scientific research achievements of universities cannot effectively align with market demands, they will inevitably face the dilemma of being idle. Therefore, against the backdrop of the generally low efficiency of achievement transformation in universities at present, in-depth research on the efficiency of transforming scientific and technological achievements holds important theoretical value and practical significance.

The measurement of the efficiency of transforming scientific and technological achievements in universities is mainly conducted through the ratio of outputs to inputs. As important subjects of scientific and technological innovation, universities' rational allocation of innovative educational resources and the level of social development can both be reflected through the efficiency of transforming scientific and technological achievements in local universities. Therefore, measuring the efficiency of transforming scientific and technological achievements in universities is of great significance.

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2. Organization of the Text

Definition of the Concept of Transformation of Scientific and Technological Achievements

At present, the academic community has divided the definition of the transformation of scientific and technological achievements into two aspects: narrow sense and broad sense. The narrow-sense perspective mainly holds that the transformation of scientific and technological achievements is a single process. Yin Ximing[2]et al. concluded through analysis that the transformation of scientific and technological achievements refers to the process of directly converting scientific and technological achievements into factors of production. In contrast, the broad-sense perspective regards it as a multi-stage process. Wang Chujun[3] argued that the transformation of scientific and technological achievements includes two stages: R&D creation and value creation; Tian Qingfeng[4]et al. studied the efficiency of transformation from two dimensions: the output of scientific and technological achievements and their transformation. According to the definition of scientific and technological achievements in the revised Law on Promoting the Transformation of Scientific and Technological Achievements (2015), the transformation of scientific and technological achievements refers to the process of conducting a series of subsequent activities on scientific and technological achievements, which aligns with the narrow-sense concept.

With the increasing vitality of the transformation of scientific and technological achievements, how to accurately measure and evaluate its efficiency has attracted widespread attention. Currently, academic research on the evaluation of the transformation efficiency of scientific and technological achievements in universities focuses on different aspects in terms of research methods and indicator selection.

Research Methods for the Efficiency of Transformation of Scientific and Technological Achievements

Regarding research methods for university scientific research performance, early studies mainly relied on traditional linear comprehensive evaluation methods, measuring university scientific research outputs by constructing evaluation indicator systems. Xiong Guojing[5]et al. conducted a comprehensive comparative analysis of the scientific and technological innovation capabilities of universities in different provinces in the Pearl River Delta region. Cai Wenbo[6]et al. used inter-provincial panel analysis to examine the scientific and technological innovation capabilities of Chinese universities and their main influencing factors based on the AHP-TOPSIS model and quantile regression model. Zhou Caiyun[7]et al. and Xu Xiaodong[8]et al. employed principal component analysis and factor analysis, respectively, and found that there are significant differences in the scientific and technological innovation capabilities of universities across different provinces in China.

With the deepening of research, scholars have found that linear comprehensive evaluation methods are difficult to objectively and accurately measure the efficiency of scientific research innovation. The key challenge in measuring university scientific research innovation efficiency lies in the fact that scientific research innovation is a comprehensive system with multiple inputs and outputs. Linear comprehensive evaluation methods only consider output indicators while ignoring input indicators. To address this problem, many scholars have begun to adopt non-linear methods to measure university scientific research innovation efficiency, among which Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) are widely favored.

Stochastic Frontier Analysis is a parametric approach that defines the frontier of optimal efficiency using a production function. Additionally, it employs the expected condition of technical inefficiency as a measure of technical efficiency. This approach ensures that the final results are not easily affected by outliers, leading many scholars to use it to evaluate university scientific research innovation efficiency. For example, Cai Rong[9]et al. used this method to

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conduct a comparative analysis of the scientific research efficiency of 48 public undergraduate universities in Jiangsu Province. However, Gao Qing[10]et al. pointed out that although the SFA method effectively accounts for contextual interference factors and management inefficiency, it faces difficulties in indicator selection and struggles to accurately measure multi-output problems.

In contrast to SFA, Data Envelopment Analysis measures efficiency through linear programming. It does not require knowledge of the specific form of the production frontier and can evaluate the multi-output performance of decision-making units (DMUs) using only input and output data. The key to measuring scientific research innovation efficiency with the DEA model lies in the reasonable setting of input and output variables. Some domestic scholars have analyzed the scientific and technological innovation efficiency of universities in different regions and categories based on various improved DEA models. For instance, Rong Yaohua[11]et al. took 72 universities directly under the Ministry of Education as the research object and found that there are significant differences in the scientific and technological innovation efficiency of universities in different regions, with an overall upward trend and substantial room for development.

Selection of Evaluation Indicators for the Efficiency of Transformation of Scientific and Technological Achievements

The indicator system mainly consists of two types of indicators: input indicators and output indicators. Input indicators are primarily divided into human input and financial input, while output indicators are usually benefit-related indicators. Qiu Feng selected teaching and research personnel, R&D service personnel, R&D funds, and the number of authorized patents as input indicators, and patent sales income and technology transfer income as output indicators to measure the transformation efficiency of scientific and technological achievements in universities across different regions. Yang Jun argued that in addition to technology transfer income and patent sales income, awards are also one of the main manifestations of the transformation of scientific and technological achievements in universities.

Through a review of existing literature, it is found that the overall indicator systems for evaluating the transformation of scientific and technological achievements in universities are consistent. However, there are certain differences in the selection of specific indicators, data availability, and the specific research questions addressed.

Summary

Existing studies mostly use only one method to measure the efficiency of the transformation of scientific and technological achievements, leading to one-sidedness in efficiency evaluation. Therefore, building on the aforementioned perspectives and considering the actual research context, this study focuses on the narrow-sense transformation of scientific and technological achievements. It employs two methods—the DEA Super-Efficiency CCR model and the Super-Efficiency CCR-Malmquist Index model—using panel data from 2019 to 2023 as the sample to conduct a dual short-term static and long-term dynamic measurement and evaluation of the transformation efficiency of scientific and technological achievements in universities across various provinces in China.

3. Indicator Selection and Data Sources

3.1. Selection of the Evaluation Indicator System

Currently, there is no unified standard for evaluating the efficiency of transforming scientific and technological achievements. Existing evaluation standards are generally based on various elements that promote achievement transformation, boasting a certain degree of scientificity

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and aligning with the national overall layout for scientific and technological development. Therefore, to minimize misjudgments, indicators with universal applicability should be selected as much as possible to ensure the scientificity and reliability of efficiency measurement results. Relevant indicators must be quantifiable and accessible, as well as representative and objective. Additionally, publicly available statistical data from official channels should be adopted.

Combining existing literature and the research objectives of this paper, we adhere to the principle of prioritizing quantifiable indicators, consider requirements such as the consistency and accessibility of data collection across universities, and ultimately select indicators that can comprehensively and objectively reflect the expected goals of efficiency measurement. The final input and output indicators for evaluating the transformation efficiency of scientific and technological achievements in this paper are as follows:

Input Indicators, including teaching and research personnel, R&D achievement application and scientific and technological service personnel, as well as funding expenditures. On one hand, scientific research personnel are the main participants in university scientific and technological innovation activities, undertaking the important tasks of generating, creating, transferring, transforming, and applying scientific and technological achievements in production. The scale of their input can directly reflect the vitality of scientific and technological innovation activities. In universities, personnel involved in the transformation of scientific and technological achievements are basically teaching and research personnel, or those engaged in R&D achievement application and scientific and technological services. On the other hand, funding support is a crucial foundation for scientific research and production activities. All activities related to scientific and technological innovation are inseparable from financial input, whose scale directly affects the output scale and efficiency of scientific and technological innovation activities. Therefore, funding expenditures for research and development projects, as well as for R&D achievement application and scientific and technological service projects, are also selected as input indicators.

Table 1. Evaluation Indicator System for the Efficiency of Transformation of Scientific and Technological Achievements

Indicator Types	Indicator Name	Scheme 2
Input	Teaching and research personnel	Person
	R&D achievement application & tech service personnel	Person
	Research and development project expenditure	1000 Yuan
	R&D achievement application & tech service project expenditure	1000 Yuan
Output	Patent grants	Item
	Achievement awards	Item
	Technology transfer contract amount	1000 Yuan

(2) Output Indicators, including the number of authorized invention patents, the number of awarded achievements, and the volume of technology transfer contracts. Patent rights refer to the exclusive rights enjoyed by inventors for their inventions and creations, serving as a core manifestation of the output of scientific and technological innovation activities. Among various types of patents, invention patents-compared with utility model patents and design patents-are an internationally recognized core indicator reflecting technologies with independent intellectual property rights. Thus, the number of authorized invention patents is selected as an output indicator for scientific and technological innovation activities. In addition, awards for scientific and technological achievements reflect the government’s final recognition of

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theoretical and applied innovations, as well as the academic value of university scientific and technological achievements. Finally, as the main force in basic theoretical research, universities have accumulated a large number of scientific and technological innovation achievements. However, only by integrating these achievements with the needs of social development and effectively transforming them into real productive forces can social progress be promoted. University technology transfer is precisely the direct manifestation of this transformation. Therefore, technology transfer income is selected as an output indicator,see Table 1.

3.2. Data Sources

The indicator data in this paper are derived from the Compilation of Statistics on Science and Technology of Higher Education Institutions published by the Ministry of Education from 2019 to 2023, as well as the China Statistical Yearbook from the same period. Due to missing data in the Compilation of Statistics on Science and Technology of Higher Education Institutions for Hong Kong, Macao, Taiwan, as well as Ningxia, Qinghai, Tibet, Hainan, Xinjiang, and Guangxi, 25 provinces in China were selected as the research subjects to measure the efficiency of scientific and technological achievement transformation in higher education institutions.

The Data Envelopment Analysis (DEA) model requires that the number of Decision Making Units (DMUs) be more than twice the total number of input and output indicators. In this study, there are 25 DMUs and a total of 7 input and output indicators; therefore, the prerequisites for using the DEA model are satisfied.

4. Research Methods

4.1. Super-Efficiency CCR Model

The DEA evaluation model is a common resource allocation efficiency evaluation model based on input-output theory. It does not have special requirements for the dimensions of evaluation indicators, and the weights of the indicators can be quantitatively determined according to internal calculation procedures, thereby achieving a simple and quick multi-input and multi-output evaluation decision through non-parametric settings. This model is widely used because it is suitable for multi-indicator evaluation, is not affected by the dimensions of indicators, does not require presetting indicator weights, does not need a clear input-output production function model, and can propose improvement directions for inefficient states. The CCR model was first established by Rhodes and others as a non-parametric analysis method to evaluate the relative efficiency of multiple input-output decision-making units. This method projects decision-making units onto the frontier through linear programming at the mathematical level and then evaluates their relative efficiency based on the distance of the unit from the frontier. In this study, the CCR method will be used to calculate the efficiency of the transformation of scientific and technological achievements in higher education institutions across provinces in China. However, considering that the early classical CCR model may produce units with an efficiency value of 1 in the efficiency evaluation, which cannot reflect the principle of evaluating 'better among the best,' the super-efficiency CCR can accurately measure the input efficiency of decision-making units and rank the efficient ones. Therefore, this study chooses to use the super-efficiency CCR model for analysis. The super-efficiency DEA model based on the CCR model is:

$$minimize\theta$$

$$subject\ to \sum_{j=1}^{n} x_{ij}\lambda_j \leq \theta \mathrm{x_{io}}, \mathrm{i} = 1,2,\ldots,\mathrm{m},$$

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$$\sum_{j=1}^{n} y_{rj}\,\lambda_j \geq y_{ro}, r = 1,2,\ldots,s,$$

$$\lambda_j \geq 0, j \neq o \quad (1)$$

4.2. Malmquist Model

Since the traditional DEA model can only analyze the technical efficiency of DMUs independently for each year and cannot identify the intertemporal dynamic efficiency changes of DMUs, this paper uses the super-efficiency CCR-DEA model to measure the efficiency of scientific research outcomes transformation in universities across provinces, and introduces the Malmquist index method to calculate the total factor productivity index in order to understand the dynamic trends of scientific research outcomes transformation in universities in each province. The specific formulas are as follows:

$$\mathrm{TFP} = \frac{D_c^{t+1}(x^{t+1},y^{t+1})}{D_c^{t}(x^{t},y^{t})} \times \sqrt{\frac{D_c^{t}(x^{t+1},y^{t+1}) \times D_c^{t}(x^{t},y^{t})}{D_c^{t+1}(x^{t+1},y^{t+1}) \times D_c^{t+1}(x^{t},y^{t})}} \quad (2)$$

In the above formula, Dct(xt, yt) is the distance function of (xt, yt) in period t; Dct+1(xt+1, yt+1) is the distance function of (xt+1, yt+1) in period t+1; Dct(xt+1, yt+1) is the distance function of (xt+1, yt+1) in period t; Dct+1(xt, yt) is the distance function of (xt, yt) in period t+1. When TFP > 1, it indicates that total factor productivity increased from period t to t+1; when TFP = 1, it indicates that total factor productivity remained unchanged from period t to t+1; when TFP < 1, it indicates that total factor productivity decreased from period t to t+1.

5. Empirical Results and Analysis

5.1. Static Analysis of the Efficiency of Technology Achievement Transformation

5.1.1. Overall Analysis

This study uses Dearun software to construct a CCR model, input the selected data on scientific research inputs and outputs from universities in various provinces from 2019 to 2023, and conduct an analysis to obtain DEA efficiency results. Table 2 presents a static analysis of the scientific and technological achievement transformation efficiency of universities in various provinces from 2019 to 2023. Technical efficiency is a technical evaluation of the allocation pattern and utilization efficiency of university research inputs. Returns to scale are mainly judged by comparing changes in inputs/outputs with scale. Among them, decreasing returns to scale mean that increasing inputs results in a lower proportionate increase in output, suggesting the scale should be reduced. Increasing returns to scale mean that increasing inputs results in a higher proportionate increase in output, suggesting the scale should be expanded. Constant returns to scale mean that inputs and outputs change in the same proportion, indicating an optimal scale,see Table 2.

As shown in Table 2, the average technical efficiency of universities in various provinces showed an overall upward trend from 2019 to 2023, with a slight decline in 2023, but remained around 0.9 overall. The number of provinces with a technical efficiency greater than or equal to 1 accounts for less than 50% of the total sample of provinces nationwide, indicating that a considerable number of provinces have relatively low efficiency in transforming scientific and technological achievements. From the perspective of returns to scale, the average number of provinces experiencing increasing returns to scale in transforming university scientific and

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technological achievements is 3, the average number of provinces experiencing decreasing returns to scale is 22, and the only province with constant returns to scale is Chongqing in 2022.

Table 2. A Static Analysis of the Efficiency of Technology Transfer from Universities Across Provinces from 2019 to 2023

DEA efficiency DEA efficiency		2019	2020	2021	2022	2023
Technical efficiency	Mean	0.84	0.83	0.95	0.98	0.82
	Number of provinces with technical efficiency ≥1	4	2	9	11	2
Analysis of Returns to Scale	Increasing number of provinces	1	3	6	4	3
	Number of declining provinces	24	22	19	20	22
	Number of unchanged provinces	0	0	0	1	0

Based on the above studies, it can be seen that there is certain potential for improvement in the efficiency of transforming scientific and technological achievements in universities across provinces, and there is still significant room for growth in both the investment of research resources and the efficiency of achievement transformation in these universities.

5.1.2. Panel Analysis

In order to deeply analyze the differences in the efficiency of scientific and technological achievements transformation among universities in various provinces, a comparative segmentation is carried out based on the classification of universities in each province and the results of detailed provincial data processing. The panel comparison results of the efficiency of scientific and technological achievements transformation in universities across provinces from 2019 to 2023 are shown in Tables 3, 4, and 5 below.

As shown in Table 3, based on annual cross-sectional data, the technology efficiency of transforming scientific and technological achievements in universities in some provinces exhibits significant fluctuations: Shanxi Province jumped from 0.587 in 2019 to 1.058 in 2022; Shanghai increased from 0.657 in 2020 to 1.824 in 2022. In contrast, Jiangsu Province's efficiency values have remained relatively stable over the years, ranging from 1.028, 1.017, 1.025, 1.155, to 0.987, with smaller fluctuations. Measured by the five-year average, Guizhou, Jiangsu, and Jilin rank the top three, with average efficiencies of 1.108, 1.042, and 1.040 respectively, although Guizhou experienced a significant decline in 2023; Jiangxi, Tianjin, and Hebei rank at the bottom, with averages of 0.755, 0.740, and 0.692. These results indicate that while regional economic development level is positively correlated with universities' efficiency in transforming scientific and technological achievements, it is not strictly corresponding; whether efficiency reaches the effective frontier mainly depends on the match between the scale of research investment and the output of achievement transformation. In addition, the transformation process has a significant lag effect, leading to continuous fluctuations in efficiency values in consecutive years.

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Table 3. Technological Efficiency (TE) of Scientific and Technological Achievements Transformation in Universities Across Provinces

Province	2019	2020	2021	2022	2023	Mean	Ranking
Beijing	0.772	0.694	0.918	1.027	0.866	0.855	16
Tianjin	0.651	0.744	0.593	0.944	0.768	0.740	24
Hebei	0.883	0.670	0.740	0.607	0.560	0.692	25
Shanxi	0.587	0.863	0.600	1.058	0.696	0.761	21
Inner Mongolia	0.651	0.905	0.954	0.649	0.622	0.756	22
Liaoning	0.783	0.906	0.943	0.704	0.725	0.812	17
Jilin	1.115	1.152	0.990	0.979	0.967	1.040	3
Heilongjiang	0.894	0.880	0.994	0.995	0.747	0.902	12
Shanghai	0.715	0.657	0.703	1.824	0.818	0.943	9
Jiangsu	1.028	1.017	1.025	1.155	0.987	1.042	2
Zhejiang	0.923	0.802	1.061	1.105	0.924	0.963	7
Anhui	0.772	0.808	1.146	1.059	0.804	0.918	10
Fujian	0.666	0.760	0.835	0.799	0.858	0.784	18
Jangxi	0.672	0.655	0.994	0.811	0.641	0.755	23
Shandong	0.744	0.684	0.801	0.817	0.763	0.762	20
Henan	0.847	0.902	1.038	0.923	0.790	0.900	13
Hubei	0.845	0.849	0.818	0.917	0.878	0.862	15
Hunan	0.891	0.786	0.911	1.021	1.137	0.949	8
Guangdong	0.647	0.612	0.921	0.780	0.850	0.762	19
Chongqing	0.954	0.934	1.151	1.053	0.796	0.978	6
Sichuan	0.723	0.901	1.188	1.113	0.966	0.978	5
Guizhou	1.307	0.994	1.307	1.265	0.668	1.108	1
Yunnan	0.907	0.672	1.107	1.108	0.754	0.910	11
Shaanxi	0.894	0.855	0.914	0.938	0.892	0.899	14
Gansu	1.098	0.964	1.033	0.766	1.035	0.979	4

The annual cross-sectional data in Table 4 indicate that the pure technical efficiency of transforming scientific and technological achievements in universities varied significantly in most provinces between 2019 and 2023: Shanxi Province was 0.603 in 2021, rapidly rising to 1.143 the following year. In contrast, the efficiency values for Jilin Province were 1.183, 1.164, 1.034, 1.002, and 1.042 for each year respectively; for Hubei Province, the values were 1.062, 1.015, 0.945, 1.032, and 0.992; and for Shaanxi Province, they were 0.951, 0.893, 0.920, 0.940, and 0.907, showing relatively limited fluctuation. When ranked by the five-year average, Guizhou, Jiangsu, and Jilin were in the top three, with average pure technical efficiencies of 1.118, 1.116, and 1.085, respectively; Hebei, Jiangxi, and Tianjin were at the bottom, with averages of 0.772, 0.769, and 0.748, respectively. Based on the five-year average of pure technical efficiency, only a few provinces had relatively low university efficiency, while most provinces had high overall average pure technical efficiency, all above the average technical efficiency, reflecting significant differences between provinces in the technical and management levels of transforming scientific and technological achievements in universities.

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Table 4. Pure Technical Efficiency (PTE) of the Transformation of Scientific and Technological Achievements in Universities by Province

Province	2019	2020	2021	2022	2023	Mean	Ranking
Beijing	1.032	0.902	1.004	1.183	0.977	1.020	8
Tianjin	0.657	0.764	0.594	0.955	0.771	0.748	25
Hebei	0.990	0.762	0.807	0.671	0.630	0.772	23
Shanxi	0.604	0.885	0.603	1.143	0.698	0.787	22
Inner Mongolia	0.838	0.960	0.959	0.651	0.634	0.808	21
Liaoning	0.892	1.007	1.005	0.706	0.748	0.872	19
Jilin	1.183	1.164	1.034	1.002	1.042	1.085	3
Heilongjiang	0.925	0.946	1.119	1.041	0.752	0.956	15
Shanghai	0.904	0.773	0.715	1.859	0.856	1.021	7
Jiangsu	1.089	1.099	1.070	1.185	1.136	1.116	2
Zhejiang	0.980	0.827	1.089	1.110	0.960	0.993	12
Anhui	0.798	1.009	1.205	1.276	0.924	1.042	4
Fujian	0.669	0.788	0.860	0.840	0.904	0.812	20
Jangxi	0.674	0.659	1.005	0.841	0.665	0.769	24
Shandong	0.844	0.859	0.994	1.018	0.961	0.935	17
Henan	0.900	1.107	1.238	1.031	0.839	1.023	5
Hubei	1.062	1.015	0.945	1.032	0.992	1.009	9
Hunan	0.921	0.951	0.985	1.110	1.142	1.022	6
Guangdong	0.793	0.727	1.046	1.070	1.177	0.962	14
Chongqing	0.957	0.934	1.154	1.053	0.828	0.985	13
Sichuan	0.780	0.931	1.208	1.113	0.984	1.003	10
Guizhou	1.308	0.999	1.317	1.299	0.668	1.118	1
Yunnan	0.955	0.703	1.207	1.109	0.755	0.946	16
Shaanxi	0.951	0.893	0.920	0.940	0.907	0.922	18
Gansu	1.137	0.981	1.043	0.777	1.048	0.997	11

As shown in Table 5, from the perspective of each year, from 2019 to 2023, the efficiency of the scale of universities' technology transfer has improved significantly in most provinces. Looking at the five-year average efficiency, Guizhou Province, Chongqing City, and Tianjin City rank the top three, with average efficiencies of 0.992, 0.991, and 0.989, respectively; Beijing, Shandong Province, and Guangdong Province rank the bottom three, with average efficiencies of 0.837, 0.816, and 0.798, respectively. From the perspective of the five-year average efficiency, there is a considerable contrast between the level of local economic development and the scale efficiency of university technology transfer. Except for a few provinces where university efficiency is relatively low, such as Guangdong and Shandong, the overall scale efficiency averages of universities in the vast majority of provinces are relatively high and exceed the average comprehensive efficiency. This reflects that the differences in the scale level of university technology transfer among provinces are relatively small, with more disparities reflected in technological and management levels.

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Table 5. Scale Efficiency (SE) of Scientific and Technological Achievements Transformation in Universities Across Provinces

Province	2019	2020	2021	2022	2023	Mean	Ranking
Beijing	0.748	0.769	0.915	0.868	0.886	0.837	23
Tianjin	0.990	0.974	0.998	0.989	0.996	0.989	3
Hebei	0.893	0.878	0.917	0.905	0.888	0.896	19
Shanxi	0.971	0.975	0.995	0.925	0.998	0.973	7
Inner Mongolia	0.777	0.942	0.995	0.997	0.981	0.938	14
Liaoning	0.878	0.900	0.938	0.997	0.970	0.936	15
Jilin	0.942	0.990	0.957	0.977	0.928	0.959	12
Heilongjiang	0.967	0.930	0.888	0.956	0.993	0.947	13
Shanghai	0.791	0.849	0.984	0.981	0.956	0.912	18
Jiangsu	0.944	0.925	0.957	0.974	0.869	0.934	16
Zhejiang	0.942	0.969	0.975	0.995	0.962	0.969	9
Anhui	0.967	0.801	0.951	0.830	0.870	0.884	21
Fujian	0.995	0.964	0.971	0.952	0.950	0.966	10
Jangxi	0.997	0.994	0.989	0.964	0.963	0.982	5
Shandong	0.882	0.796	0.806	0.802	0.794	0.816	24
Henan	0.942	0.815	0.838	0.895	0.942	0.886	20
Hubei	0.796	0.836	0.866	0.889	0.885	0.854	22
Hunan	0.967	0.827	0.925	0.920	0.996	0.927	17
Guangdong	0.816	0.842	0.881	0.729	0.723	0.798	25
Chongqing	0.997	1.000	0.997	1.000	0.961	0.991	2
Sichuan	0.928	0.968	0.984	1.000	0.982	0.972	8
Guizhou	0.999	0.995	0.992	0.973	0.999	0.992	1
Yunnan	0.949	0.956	0.917	0.999	0.999	0.964	11
Shaanxi	0.940	0.957	0.993	0.998	0.984	0.974	6
Gansu	0.966	0.982	0.990	0.986	0.988	0.982	4

5.2. Dynamic Analysis of the Efficiency of Scientific and Technological Achievements Transformation

To further illustrate the dynamic changes in the efficiency of technology transfer at universities in various provinces, this study uses Dearun to construct a super-efficiency Malmquist index model to analyze the selected objects, obtaining an overall dynamic analysis of the efficiency of technology transfer at universities in each province from 2019 to 2023.

As shown in Table 6, from 2019 to 2023, the average M index of China's scientific and technological achievements transformation efficiency was 1.006, indicating a slight overall increase in transformation efficiency. During this period, 13 provinces had an M index of scientific and technological achievements transformation efficiency below 1, among which Hebei, Jilin, Heilongjiang, Chongqing, Guizhou, and Yunnan had M indices below 0.9, indicating a significant downward trend in their transformation efficiency. Conversely, 12 provinces had an M index above 1, showing that about half of the provinces had a relatively favorable development trend in transformation efficiency. This demonstrates that there are significant differences in the development levels of scientific and technological achievements transformation across different provinces in China.

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Table 6. Analysis of the Malmquist Index of Scientific and Technological Achievement Transformation in Universities Across Provinces

Province	effch	techch	pech	sech	tfpch
Beijing	1.023	1.097	0.978	1.046	1.123
Tianjin	1.224	0.964	1.203	1.017	1.180
Hebei	0.472	1.342	0.612	0.772	0.634
Shanxi	0.844	1.406	0.871	0.969	1.187
Inner Mongolia	0.972	0.983	0.859	1.131	0.956
Liaoning	0.961	0.963	0.785	1.224	0.926
Jilin	0.443	1.958	0.647	0.684	0.867
Heilongjiang	0.995	0.839	0.938	1.061	0.835
Shanghai	1.585	0.723	1.470	1.078	1.145
Jiangsu	0.993	0.967	0.980	1.014	0.960
Zhejiang	0.995	1.005	0.935	1.064	1.001
Anhui	1.403	0.742	0.792	1.772	1.042
Fujian	1.302	0.990	1.252	1.040	1.290
Jangxi	0.664	1.436	0.704	0.943	0.954
Shandong	0.907	1.132	0.972	0.933	1.026
Henan	0.712	1.311	0.916	0.777	0.933
Hubei	1.170	0.888	1.007	1.162	1.039
Hunan	1.096	1.164	0.964	1.137	1.276
Guangdong	1.438	0.915	1.290	1.115	1.315
Chongqing	0.810	1.029	0.796	1.018	0.834
Sichuan	1.153	1.158	1.017	1.133	1.335
Guizhou	0.637	0.802	0.664	0.960	0.511
Yunnan	0.902	0.922	0.933	0.967	0.831
Shaanxi	1.016	0.983	1.004	1.012	0.999
Gansu	0.728	1.294	0.730	0.997	0.943
Mean	0.978	1.081	0.933	1.041	1.006

Provinces with significant improvement in M index efficiency include Guangdong (1.315), Sichuan (1.335), Hunan (1.276), and Fujian (1.290), with TFPCH values above 1.1, suggesting that technological progress (TECHCH) or technical efficiency (EFFCH) has driven the improvement in transformation efficiency. Provinces with a significant decline in efficiency include Guizhou (0.511), Heilongjiang (0.835), and Hebei (0.634), with TFPCH values below 0.9, reflecting issues such as technological regression or insufficient resource allocation.

6. Conclusion and Recommendations

6.1. Conclusion

Using 25 provinces in China as the research subjects, this study employs the super-efficiency DEA model and the super-efficiency DEA-Malmquist index model to conduct a dual measurement analysis of the efficiency of the transformation of scientific and technological achievements in provincial universities, considering both short-term static and long-term dynamic perspectives. Compared with previous studies, this research innovatively combines the two efficiency measurement models and explores the differences in short-term efficiency through a comparative decomposition of indicators. The main research findings are as follows:

(1) Short-term static analysis The study shows that there is a certain correlation between regional economic development levels and the efficiency of universities in transforming scientific and technological achievements. A strong economic foundation can provide favorable

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conditions for the transformation of achievements, such as financial support, policy guarantees, talent reserves, and market environment, but the relationship between the two is not simply linear. The practical performance of transformation efficiency depends more on the rational allocation of research resources and the actual effectiveness of innovative outputs. From a temporal perspective, the efficiency of university technology transfer exhibits phase-based fluctuations, with notable differences in transformation effectiveness across different years. Further analysis reveals that provinces that perform well in terms of pure technical efficiency generally also have high overall technical efficiency. Moreover, interprovincial comparisons show significant differences among regions in universities' technical capabilities and management systems for technology transfer, while differences in the scale of transformation are relatively smaller.

(2) Long-term dynamic analysis

Empirical findings indicate that the total factor productivity of universities' technology transfer in China's 25 provincial-level regions has maintained a continuous upward trend. This growth trend is primarily influenced by both the technology progress index and the technical efficiency index, manifested in the improvement of regional technological innovation capabilities, the introduction and assimilation of high-tech, and the optimization of management systems, all of which jointly promote enhanced transformation efficiency. In terms of spatial distribution, the efficiency of technology transfer shows clear regional heterogeneity, with the eastern regions outperforming the western regions and the southern regions stronger than the northern regions. The study finds that the coordinated improvement of technological progress and technical efficiency is the core driver of transformation. In response to this phenomenon, it is recommended that regions with relatively lagging transformation efficiency strengthen policy guidance and institutional innovation, while high-efficiency regions need to further reinforce their driving and radiation effects.

6.2. Recommendations

Based on the aforementioned research conclusions and the current situation in our country, the following recommendations are proposed:

First, improving the efficiency of transforming scientific and technological achievements in universities requires a systematic improvement strategy. The primary step is to establish a dynamic optimization mechanism driven by market demand, accurately grasping industry technology needs and consumer market feedback through in-depth market research, and building a precise transformation system that coordinates 'universities-government-enterprises.' In terms of implementation, it is recommended to establish a management network covering the entire life cycle of scientific and technological achievements: in the short term, focus on optimizing the structure of research and development investment and resource allocation efficiency; in the medium and long term, focus on improving the management system and gradually enhancing technological maturity. At the same time, it is necessary to continuously increase investment in scientific and technological innovation, optimize the structure of research funding usage, and focus on supporting research and development projects with market potential.

Second, cultivating innovative talents should be regarded as a core task. By optimizing the research evaluation system and improving incentive mechanisms in combination, the vitality of scientific and technological innovation in universities can be fully unleashed. Specifically: first, a talent cultivation system based on research practice should be established, focusing on developing the academic literacy and innovative thinking of young researchers, stimulating their interest in research and innovation potential; second, a long-term mechanism for research integrity should be established and improved, strengthening academic ethics and creating a fair, just, and upright academic environment for researchers.

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