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Technological achievements in regional economic development: An econometrics analysis based on DEA

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ABSTRACT

“Double circulation” is an important strategic choice under the development of the new situation. The transformation of university scientific and technological achievements and the coordinated development of regional economy are of great significance to the construction and development of the new paradigm. In this paper, DEA method is used to measure the transformation efficiency of scientific and technological achievements of universities in 31 provinces and autonomous regions (excluding Hong Kong, Macao and Taiwan), and the entropy weight-Topsis model is used to evaluate the quality of regional economic development. The comprehensive scores of the two systems are coupled and coordinated finally. It is found that the transformation efficiency of scientific and technological achievements of universities in 31 provinces and autonomous regions (excluding Hong Kong, Macao and Taiwan) is mostly DEA effective, and the transformation ability of scientific and technological achievements of universities is strong in the regions where university resources are concentrated and the economically developed regions, meanwhile there is a big gap between regions. The transformation ability of scientific and technological achievements in the central and western regions has a big room for improvement. The transformation level of scientific and technological achievements of universities in most provinces is still at a middle level of coordination with the level of regional economic development. In view of the above research conclusions, some countermeasures and suggestions are put forward in order to promote the transformation of scientific and technological achievements and regional economic development can be more coordinated.

1. Introduction

Today’s world is undergoing a major change unprecedented in a century, and with the outburst of COVID-19, continuous expansion of China’s economic volume and economic structure optimization are greatly challenged. The new development paradigm is a major strategic choice made by the Party and the State based on the actual situation of economic development at home and abroad, and is also a necessary path for the high-quality development of China’s economy. Under the objective law of economic development, China is gradually losing the comparative advantage of some traditional industries, while many industries are facing “neck” problems in key technology areas. Therefore, we need the support of the innovation ecosystem, the fundamental thing is to have a domestic science and technology innovation cycle that can really circulate (Xuemei Xie et al., 2023) [1]. Data show that the annual publication of papers

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indexed by Science Citation Index (SCI) in universities accounts for about 80% of the country, and the authorization of invention patents accounts for about 20% of the country, so it can be said that universities are the sources, leading areas and important growth poles of science and technology innovation (Maria Garcia-Vega. et al., 2020) [2]. The transformation of scientific and technological achievements of universities serves the real economy and can empower the high-quality development of regional economy, while the regional economic development can fully support the scientific research innovation of universities. Therefore, studying the coupled and coordinated relationship between the transformation of scientific and technological achievements of universities and regional economic development can help promote the balanced development of both and promote the construction of a new development paradigm.

The transformation of scientific and technological achievements is a key link to realize the deep integration of scientific and technological innovation and economic development, which is of great significance to promote regional economic development and social progress (Daniele Battaglia et al., 2017) [3]. As a research hotspot, many scholars have carried out research on the university scientific and technological transformation achievements, which, from the existing literature, mainly includes the following three aspects. The first one is the research on the transformation of scientific and technological achievements of universities and regional innovation development, such as Yidan Qin et al. (2023) [4] studied the influence of efficient scientific and technological innovation by using three-stage DEA model based on the samples of universities in 31 provinces; Tomal, Mateusz (2021) [5] measured the co-ordination level of socio-economic-infrastructural development and examines its obstacles. Secondly, it is the research on the issue of system construction of university scientific and technological transformation achievements, Mita Marra et al. (2022) [6] studied the University-industry Collaborations issue, finding how learning processes get unevenly located in space, local presence of research-oriented university plays a crucial role, explore which firm-level factors drive the innovation and interactions between companies and universities; Fengshu Li et al. (2021) [7] analyzed the relationship between government subsidies and the commercial value, based on the data from high-tech industry of 27 provinces and autonomous regions in china from 2009 to 2019, finidng the government subsidies have a significant double threhold effecton the economic value from scientific and technological achievements. Thirdly, the research on the transformation efficiency of achievements, for example, Ding Ma et al. (2022) [8] used the dynamic network slacks-based measurement model to measure the stage efficiencies, inter-stage linkage efficiencies and inter-period carry-over efficiencies, a Malmquist decomposition is calculated to infer the paths and restrictions of effiiency enhancement; Chengdong Wang et al. (2023) [9] studied the effectiveness of resource allocation for innovation and entrepreneurship education in Chinese universities based, finding that the impute of university resources, students' resources and platform resources positively affect the efficiency while the government resources and intermediary resources have a negative influence. However, few scholars have studied the coupling relationship between the university scientific and technological transformation achievements in universities and regional economic development. DEA is an important method to measure the efficiency of innovational and development. Therefore, this paper uses DEA model to measure the efficiency of university science and technology transformation level in 31 provinces, cities and autonomous regions (excluding Hong Kong, Macao and Taiwan), evaluates the quality of their regional economic development by using entropy weight-Topsis model, and the coupling coordination degree between the university scientific and technological transformation achievements and regional economic development is measured and analyzed.

2. Analysis of the coupling mechanism between the transformation of scientific and technological achievements of universities and regional economic development

During China's rapid economic growth in the past, it was often criticized for the mismatch between the speed and quality of economic development (Paravee Manee et al., 2020) [10]. Therefore, in the new development pattern, we pay more attention to the high-quality economic development, and technological innovation can play an important role in promoting the high-quality development of national economic growth. A number of scholars have now confirmed the significant contribution of universities to the regional economy, such as Jan Youtie et al. (2008) [11], who studied the functional transformation of Georgia Tech (from its traditional role of education and research to that of a knowledge center promoting innovation) to promote technological innovation and economic development in its region, and the study concluded that universities play a greater role in technology-based economic development. Alice Bertoletti et al. (2022) [12], Ioannis Dokas et al. (2022) [13] and others combined traditional econometric methods with random forests to analyze data and investigated the influence degree of the characteristics of higher education system on regional economic development, noting in particular that the most important factors for regional economic development are scale of higher education, internationalization of students and research productivity. Some detailed case study of the University of Waterloo in Canada to demonstrate the university's contribution to the growth and innovation of the local and regional economy (Allison Bramwell.et al., 2008; Juying Zeng et al., 2023) [14,15]. Tao Z et al. (2022) [16] also conducted an empirical study on the regional characteristics of university, industry, and government collaborative innovation in the Yangtze River Delta region based on the triple helix algorithm in terms of two dimensions: collaborative relationship among innovation agents and spatial association among regions. It was found that universities and industries in the Yangtze River Delta region have strong interaction, interdependence, and coupling in innovation. Xuemei Xie et al. (2023) [17] conducted a meta-analysis of 50 independent empirical samples, comprising 29,456 observations, in order to test the collaborative innovation-innovation performance relationship, both subgroup analyses and meta-regressions to explore how formal and informal institutions might moderate the collaborative-innovation-innovation-performance link, the study shows collaborative innovation strongly and positively correlates with firms' innovation performance. The findings suggest that the productive interactions established between universities and regions contribute to the development of human capital, the diffusion of digital knowledge and job creation in STEM-intensive industries; Schaeffer P R et al. (2021) [18] explains the contribution of universities to the regional ecosystem of innovation and entrepreneurship based on the view of the technology transfer process from academia to the market. In a mutually beneficial symbiotic perspective, the flow of university information and knowledge nourishes local innovation and entrepreneurship, especially in emerging countries where innovation capacity is still low. The internal institutional structure of universities also influences to some extent the regional contribution of universities. From the perspective of the promotion path, the most crucial part is the transformation of university scientific and technological achievements into enterprises to promote regional economic development. As the main body of the market, enterprises play a leading role in regional economic development, while the development of enterprises needs to rely on their technological innovation. The supply side of enterprises' technological innovation mainly originates from the breakthroughs in their own technological fields and the spillover effect of knowledge (Sánchez-Barrioluengo M et al., 2018) [19], and it is often difficult for enterprises to achieve innovation breakthroughs in their own technological fields, which requires high requirements for their innovation capabilities and requires them to invest heavily in R&D personnel and R&D capital, while there are externalities in enterprise innovation, resulting in insufficient motivation for enterprises to initiate innovation. Previous scholars have found that the closer the geographical distance between enterprises and universities, the lower the cost of knowledge transfer, and the more opportunities for enterprises to acquire industry frontier tacit knowledge that is difficult to disseminate or directly exploited (Singh, J et al., 2013) [20]. Despite the input of external resources such as government subsidies, there are problems such as acceptance distortion and rent-seeking distortion (Yang Song et al. , 2022) [21], and it is difficult for enterprises to make significant breakthroughs in the short term in technological innovation realized by themselves. In contrast, the knowledge spillover effect is that enterprises obtain innovation resources by sharing the research results and experiences of other organizations, and the scientific and technological achievements of universities are one of the most important channel resources for enterprises' technological innovation. Researchers in universities undertake a large number of national major topics, and under the guarantee of environmental system, universities are able to pick up many creative achievements in key technology areas, so they can be the curatorial and leading area of national technological innovation. Juying Zeng et al. (2023) [22] analyzed the annual report on the transformation of scientific and technological achievements and found that Guangdong Province has achieved greater results in the joint construction of innovation platforms by universities and enterprises and the transformation chain of scientific and technological achievements. Therefore, the scientific and technological achievements of universities, especially those with professional tacit characteristics, local enterprises have the innate advantage of preferential access. The transformation of university's scientific and technological achievements, whether transferred, licensed or valued for investment, can eventually serve the real economy, which can promote regional economic development through multiple paths such as driving employment, injecting innovation power and increasing GDP increment.

On the other hand, regional economy also has a pivotal role in scientific and technological innovation and transformation of university scientific and technological achievements. From the perspective of input and output of scientific and technological achievements, the regional economy has an important influence on the financial input, human input, output reward, achievement transformation system and supporting facilities of universities. In terms of capital investment, generally the more developed the regional economy is, the more financial resources the government can allocate to universities. From the actual situation, the public budget expenditure, general budget expenditure, "three public funds" budget expenditure and government procurement expenditure

Table 1
Evaluation index system of university scientific and technological transformation achievements and regional economic development.

System	Primary Indicator	Secondary Indicator	Tertiary Indicator	Logo
Transformation of scientific and technological achievements in higher education subsystem	R&D investment in science and technology in universities	Technology manpower input	Research and Development Full-Time Staff	A11
			R&D results application and science and technology services full time staff	A12
			Senior title teaching and research staff	A13
		Investment in science and technology	Science and technology funding expenditure costs	A21
			Expenditure on R&D results application and science and technology service projects	A22
	R&D output in science and technology in universities	Results output	Publication of scientific and technical works	A31
			Published academic papers	A32
			Number of patents granted	A33
		Results transformation	Number of contracts	A41
			Contract amount	A42
			Actual annual revenue	A43
Regional economic development subsystem	Regional economic development level	Total economic volume	Gross GDP	B11
			Per capita GDP	B12
		Economic structure	Tertiary industry growth rate	B21
			Ratio of primary industry to secondary industry	B22
		Economic development potential	Number of urban population employed	B31
			Growth rate of local fiscal general budget revenue	B32
		Consumption level	Disposable income per inhabitant	B41
			Per capita consumption expenditure	B42

for universities in economically developed provinces such as Guangdong and Jiangsu are much higher than those in other economically less developed regions. In terms of manpower investment, economically developed regions have strong population gathering power, which can integrate various resources such as high quality living conditions, education and medical care, employment opportunities and income level. At the same time, population mobility and high-quality human resources can effectively promote regional economic growth (Mabel Sanchez-Barrioluengo et al. , 2018) [23], and governments and universities in economically developed regions tend to adopt more vigorous talent introduction policies to attract more high-end talents and have great advantages in the talent "snatching war". Economically developed regions also lead the country in terms of system construction and platform construction in terms of results transformation system and supporting settings. For example, Limei Chen et al. (2020) [24] and Weihong Li et al. (2022) [25] found from the perspective of patent operation that Jiangsu Province has greatly promoted the transformation effect of scientific and technological achievements by formulating policy measures with a high degree of fit. Agasisti T et al. (2022) [26] examined how the efficiency of universities is influenced by the characteristics of the regions in which they are located and found that the management efficiency of universities is closely related to the environment in which they are located; specifically, universities in socioeconomically developed regions tend to be more efficient. Therefore, from the perspective of system theory, the universities need to innovate ideas in the links of scientific and technological innovations, make rational use of resources inside and outside the university, optimize the construction of university service system, realize the scientific collaborative governance effect with society and enterprises (Seung-Pyo Jun et al., 2020) [27].

3. Research design

3.1. Indicator system

The indicator system is directly linked to the reliability of the research results, so the selection of indicators should conform to multiple principles such as objectivity, scientificity and accessibility, etc. Based on the studies of Lorella Cannavacciuolo et al. (2023) [28], this paper constructs the following evaluation indicator system for the two systems of university scientific and technological transformation achievements and regional economic development (Table 1 below). In the subsystem of university scientific and technological transformation achievements, R&D input and output are taken as the first-level indicators, and R&D input can be subdivided into human input and financial input, while R&D output is divided into 2 s-level indicators of outcome output and outcome transformation. In the subsystem of regional economic development, four secondary indicators, namely, total economic volume, economic structure, economic development potential and consumption level, are used to measure the level of regional economic development.

3.2. Research methodology

3.2.1. DEA evaluation model

Data Envelopment Analysis (DEA), based on relative efficiency and linear programming methods, can assess the relative validity between the evaluation objectives of multiple inputs and outputs. Using DEA method to measure and calculate the innovation performance of univeristy scientific and technological transformation achievements is consistent with the characteristics of innovation with multiple inputs and outputs, which can better avoid the influence of subjective factors and better and more objectively evaluate the innovation efficiency of university scientific and technological transformation achievements scientifically.

DEA models can be divided into two types, CCR models and BCC models, according to the degree of variability of the payoffs of scale. Among them, Charnes et al. proposed the CCR model in 1978, which refers to the assessment of the relative effectiveness of decision making units (DMUs) when the payoff of scale is constant, while the BCC model was proposed by Banker et al., in 1984 with a modification of the CCR model for the assessment under variable scale payoffs. The technical efficiency (TE) and pure technical efficiency (PTE) of each DMU can be obtained using the CCR and BCC models, and the scale efficiency (SE) of each decision unit can be obtained by dividing the two, that is, SE = TE/PTE.

3.2.2. Entropy-weighted TOPSIS model

Entropy weight method is a method to assign objective weights to indicators separately, and calculate indicator weights according to the numerical dispersion degree among indicators, which excludes subjective influence and makes the results more objective and fair. TOPSIS model is one of the comprehensive evaluation methods for multi-objective decision making of limited solutions, and is an analysis method applicable to multiple indicators and multiple solutions for selection. The entropy-weighted TOPSIS model is a method that combines the entropy-weighted method and TOPSIS. Based on the TOPSIS model, the entropy-weighted method is used to determine the indicator weights, which not only reflects the importance of the indicator weights scientifically, but also reflects the changes of the indicator weights over time dynamically. Subsequently, the corresponding optimal distance, inferior distance and proximity between the evaluated unit and the ideal target are then derived. The entropy weight TOPSIS model is used to evaluate the quality of regional economic development, which can reflect the overall situation of regional economic development in a scientific and reasonable manner. The steps are.

(1) Data standardization. Standardization of regional economic development evaluation indicators, mainly using extreme value standardization methods.

$$\begin{aligned} &\text{Positive indicators}: X'_{ij} = \frac{X_{ij} - \min X_j}{\max X_{ij} - \min X_{ij}} \\ &\text{Negative indicators}: X'_{ij} = \frac{\max X_{ij} - X_{ij}}{\max X_{ij} - \min X_{ij}} \end{aligned} \tag{1}$$

Where: X'_{ij} is the standardized outcome of the jth indicator data set in year I, denote the original and normalized values of the jth (j = 1,2, …,m) indicator in year i (i = 1,2, …,n), respectively; $\max X_{ij}$ and $\min X_{ij}$ denote the maximum and minimum values in the jth column of indicators, respectively.

(2) Calculation of index weights.

The entropy value method is used to calculate the weight of regional economic development evaluation indicators, and the steps are shown below.

① Obtain the weight of indicators. The weight P_{ij} of the jth item (or column) indicator in the ith year (or row) is:

$$P_{ij} = X'_{ij} \Big/ \sum_{i=1}^{n} X'_{ij} \tag{2}$$

② Find the entropy value of the indicator. The entropy value E_j of the jth indicator is:

$$E_j = -k \sum_{i=1}^{n} P_{ij} \ln P_{ij} \tag{3}$$

where: k = 1/lnn, n is the number of years (or rows); $0 \leq E_j \leq 1$; when $P_{ij} = 0$, let $P_{ij} \ln P_{ij} = 0$.

③ Derive the indicator entropy redundancy D_j:

$$D_j = 1 - E_j \tag{4}$$

④ Calculate the weighting result W_j:

$$W_j = D_j \Big/ \sum_{j=1}^{m} D_j \tag{5}$$

(3) Determination of positive and negative ideal solutions

Determine the optimal solution Z^+ and the inferior solution Z^- of the evaluation object, where the optimal solution consists of the maximum value of each column in the matrix Z; the inferior solution consists of the minimum value of each column in the matrix Z.

(4) The distances Di+ and Di-of the 31 provinces (municipalities directly under the Central Government and autonomous regions) to the optimal and inferior solutions are calculated as follows:

$$\text{Distance to the positive ideal solution}: D_j^+ = \sqrt{\sum_{i=1}^{n} \left(z_i^+ - z_{ij}\right)^2} \tag{6}$$

$$\text{Distance to the negative ideal solution}: D_j^- = \sqrt{\sum_{i=1}^{n} \left(z_i^- - z_{ij}\right)^2} \tag{7}$$

(5) Calculation of the comprehensive evaluation index. T_j is the evaluation index in the jth year, and the value range is (0, 1]. The closer the index value is to 1, the higher the evaluation score is, while the closer it is to 0, the lower the evaluation score is. The evaluation index is calculated by the following formula:

$$T_j = \frac{D_j^-}{D_j^+ + D_j^-} \tag{8}$$

3.2.3. Coupled coordination model

The coupling degree is used to describe the degree of interaction and mutual influence between multiple systems or elements within a system, and the coordination degree is a measure of how good or bad this interaction is. The steps are.

(1) Normalize the original data x_{ij} with the following equation (9).

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \tag{9}$$

(2) Calculate the comprehensive level index of transformation of scientific and technological achievements of universities and regional economic development.
(3) Calculate the coupling degree of transformation of scientific and technological achievements of universities and regional economic development with the following formula (10).

$$C = 2\{(S * F)/[(S + F) * (S + F)]\}^{1/2} \tag{10}$$

(4) Calculate the coupling coordination degree with the following equations (11) and (12).

$$T = \partial S + \beta F \tag{11}$$

$$D = \sqrt{C * T} \tag{12}$$

Among them, S denotes the comprehensive level index of regional economic development; F denotes the comprehensive level index of transformation of scientific and technological achievements of universities; D denotes the coupling coordination degree; T denotes the overall benefit index; ∂ an β denote the coefficients to be determined, and this paper considers that the two systems of transformation of scientific and technological achievements of universities and regional economic development are equally important, that is, $\partial = \beta = 0.5$.

3.3. Research sample and data

This paper takes 31 provinces (municipalities directly under the central government and autonomous regions) in China (excluding Hong Kong, Macao and Taiwan regions in China) as the research object, and selects relevant data from "2020 Compendium of Science and Technology Statistics of Higher Education Institutions" and "China Science and Technology Statistical Yearbook" for analysis, in which a small number of indicators with missing data are processed by interpolation method.

Table 2
Decomposition of input-output efficiency of scientific and technological achievements transformation efficiency in universities.

Cities	Technical efficiency	Pure technical efficiency	Scale efficiency	
Jiangsu	1.000	1.000	1.000	–
Beijing	1.000	1.000	1.000	–
Shanghai	1.000	1.000	1.000	–
Tianjin	1.000	1.000	1.000	–
Hubei	1.000	1.000	1.000	–
Shaanxi	1.000	1.000	1.000	–
Zhejiang	1.000	1.000	1.000	–
Heilongjiang	0.799	0.848	0.943	drs
Guangdong	0.944	1.000	0.944	drs
Shandong	0.838	1.000	0.838	drs
Hunan	1.000	1.000	1.000	–
Henan	1.000	1.000	1.000	–
Hebei	0.771	0.900	0.856	drs
Chongqing	1.000	1.000	1.000	–
Liaoning	0.826	0.831	0.995	drs
Fujian	0.856	0.868	0.986	irs
Jiangxi	0.775	0.792	0.979	irs
Sichuan	1.000	1.000	1.000	–
Guangxi	0.796	0.801	0.993	irs
Shanxi	0.917	0.922	0.994	irs
Jilin	1.000	1.000	1.000	–
Anhui	1.000	1.000	1.000	–
Qinghai	1.000	1.000	1.000	–
Yunnan	0.999	1.000	0.999	drs
Gansu	1.000	1.000	1.000	–
Guizhou	1.000	1.000	1.000	–
Inner Mongolia	1.000	1.000	1.000	–
Xinjiang	1.000	1.000	1.000	–
Tibet	0.756	1.000	0.756	irs
Ningxia	1.000	1.000	1.000	–
Hainan	1.000	1.000	1.000	–
Mean	0.944	0.967	0.977	

4. Empirical analysis

4.1. Static efficiency analysis based on DEA-BCC model

The transformation of scientific and technological achievements of universities serves the real economy and can empower the high-quality development of regional economy, while the regional economic development can fully support the scientific research innovation of universities. In order to continuously improve the transformation efficiency of scientific and technological achievements, the measurement of its technological innovation efficiency and data collection and analysis are important prerequisites for realizing scientific and reasonable assessment of the transformation efficiency of scientific and technological achievements of universities. In order to truly and objectively reflect the current situation of the innovation efficiency of university scientific and technological transformation achievements, the data must be accurate and effective.

Based on the BCC model, the technological innovation efficiency of the selected 31 provinces (municipalities directly under the Central Government and autonomous regions) for the innovation efficiency of university scientific and technological transformation achievements were analyzed, and the comprehensive technical efficiency, pure technical efficiency and scale efficiency were obtained (see Table 2). “Drs” represents the decreasing scale payoff of the decision unit, "-" represents the optimal scale state, and “Irs” represents the increasing scale payoff of the enterprise.

4.1.1. Technical efficiency analysis

From Table 2 the mean value of transformation efficiency of scientific and technological achievements of universities in 31 provinces (municipalities directly under the central government and autonomous regions) is 0.944, as well as the mean value of its decomposition index pure technical efficiency is 0.967 and the mean value of scale efficiency is 0.977. The mean value of comprehensive efficiency value of transformation efficiency of scientific and technological achievements of universities is lower than 1, indicating that overall, the mean value of comprehensive technical efficiency does not meet the conditions of validity. There are 20 provinces and cities in which the transformation efficiency of university science and technology achievements is in DEA effective state, accounting for 65%, and the transformation efficiency of university science and technology achievements in the remaining 11 provinces and cities does not reach the frontier side of efficiency, but in these provinces and cities that do not meet DEA effective, all of them realize weakly effective, i.e. the comprehensive technical efficiency exceeds 0.5, which shows that overall, the comprehensive technical efficiency is at a high level and the transformation efficiency of university science and technology achievements is more significant.

Further, it is found that the transformation efficiency of university science and technology achievements in Jiangsu, Beijing, Shanghai, Hubei, Shaanxi, Zhejiang, Tianjin and other 20 provinces and cities is in the state of high scale efficiency and high pure technical efficiency, and the high efficiency of transformation of university science and technology achievements in Jiangsu province is mainly attributed to the number of transformation contracts and the number of patents granted, and Jiangsu is far ahead in the part of science and technology achievements output nationwide. Unlike Jiangsu, the transformation ability of Beijing and Shanghai is based on high investment, and the number of full-time personnel and the total amount of science and technology expenditure in these two places have absolute advantages in quantity, and the number of “double first-class” universities in these provinces and cities is also the largest in China, which can also reflect the side of China’s “double first-class” university construction. This can also reflect that the construction of “double first-class” universities has strongly promoted the transformation of scientific and technological achievements of universities. Among the remaining provinces and cities that achieve DEA, besides relying on high input and high output, there are individual provinces and cities such as Inner Mongolia and Xinjiang that rely on low input and low output to achieve DEA, mostly in the less developed regions in central and western China, where the number of universities is small and the number of “double first-class” construction universities and other high-level institutions is only a few. As a result, the number of researchers is low, the output of scientific and technological achievements is low, and the financial allocation for university research funds is low, and a large number of enterprises absorb the scientific and technological achievements of universities are also lacking, and the construction of the corresponding transformation system of scientific and technological achievements is not sufficient compared with the developed eastern regions.

The innovation efficiency of university scientific and technological transformation achievements in 11 provinces and cities is not in DEA effective state, and the level of pure technical efficiency and scale efficiency is basically the same, but the scale efficiency is closer to the frontier of efficiency, which shows that the internal management problem of universities in provinces and cities is the main factor that restricts the improvement of transformation efficiency of university scientific and technological achievements. In the provinces and cities where technological innovation efficiency is in DEA effective state, both pure technical efficiency and scale efficiency are located on the frontier side of efficiency, while scale payoff is unchanged, which indicates that universities in these provinces and cities can effectively use the existing input resources and allocate resources reasonably and appropriately to achieve the goal of maximizing output.

4.1.2. Pure technical efficiency analysis

The analysis of the pure technical efficiency derived from the study was able to reveal how much of the lack of pure technical efficiency is responsible for the fact that the comprehensive technical efficiency of the conversion of the university scientific and technological transformation achievements has not reached an effective state based on the input-oriented model. Pure technical efficiency is more reflective of the approach and level of daily operation and management.

As can be seen from Table 2, the mean value of pure technical efficiency of selected universities’ scientific and technological achievements conversion is 0.967, which indicates that the internal management level of universities' scientific and technological achievements conversion is high and the difference between different provinces and cities is not significant, and the pure technical efficiency of universities' scientific and technological achievements conversion in Jiangsu, Beijing and Shanghai reaches 1. The lowest pure technical efficiency is Jiangxi, but it also reaches 0.792, which achieves weak effectiveness, except for Heilongjiang, Hebei, Liaoning, Fujian, Guangxi and Shanxi, all of these provinces and cities, the pure technical efficiency did not reach DEA effective, which indicates that the low pure technical efficiency is an important reason for the low comprehensive technical efficiency of the conversion of scientific and technological achievements of universities in these provinces and cities, the daily operation and management level is relatively low and needs to be improved urgently. The management and technology of universities and other factors have affected the technological innovation of enterprises efficiency.

4.1.3. *Scale efficiency analysis*

Scale efficiency can measure whether the conversion of the scientific and technological transformation achievements is at the optimal scale under the input orientation. If the conversion of the innovation efficiency of university scientific and technological transformation achievements is in the state of diminishing returns to scale, it is necessary to further reduce the scale of production and lower the input of production factors; on the contrary, it is necessary to increase the scale of production and raise the input of factors in order to obtain the maximum profit. Table 2 shows that the average scale efficiency of science and technology conversion in 31 provinces and cities is 0.977, which means that the scale efficiency of science and technology conversion in universities is relatively stable and the difference between different provinces and cities is not significant. It is observed that Guangdong, Shandong, Hebei, Yunnan and Tibet are provinces and cities with low overall technical efficiency mainly caused by low payoffs for scale relative to pure technical efficiency, which indicates that most of the conversion of scientific and technological achievements of universities is relatively smooth and effective in management and technological innovation, mostly or due to the scale.

Observing Table 2, we get that there are 6 provinces and cities in the state of diminishing returns to scale for university science and technology conversion, the number of provinces and cities with increasing returns to scale is 5, and there are 20 provinces and cities with constant returns to scale for university science and technology conversion. Continuing the study, it is concluded that the scale efficiency of non-DEA effective conversion of university science and technology achievements are lower than the comprehensive technical efficiency, which indicates that to improve the innovation efficiency of conversion of university science and technology achievements, scale control has more room for improvement than pure technical control. In the case of increasing returns to scale, we need to pay attention to the decrease of scale efficiency when the scale of inputs increases further.

From the above analysis, we can see that the comprehensive technical efficiency is not effective mainly because the scale of scientific and technological achievement conversion in universities has not reached the efficiency frontier surface. On the whole, the overall level of innovation efficiency of scientific and technological achievements conversion in universities in all provinces and cities is high, but the resource utilization rate and development space need to be further explored deeply, and the resource allocation needs to be optimized continuously.

4.2. *Comprehensive score of regional economic development system—based on entropy TOPSIS model*

4.2.1. *Data normalization and calculation of indicator weights*

As shown in Table 3 below, the 8 indicators selected by 31 provinces (municipalities directly under the Central government and autonomous regions) were first standardized to eliminate the influence of different dimensions. After the data was standardized, the weight of the indicators was calculated to obtain the corresponding weight of each indicator of the regional economic development system.

4.2.2. *Calculation of the distance to the optimal and inferior solutions*

The distances Di+ and Di-of the eight economic indicators of 31 provinces (municipalities directly under the Central Government and autonomous regions) to the optimal and inferior solutions are calculated, as shown in Table 4.

4.2.3. *Comprehensive evaluation index of regional economic development*

Based on the entropy-weighted TOPSIS model, the quality of regional economic development of 31 provinces (municipalities directly under the central government and autonomous regions) is evaluated, and the specific results are shown in Table 5. From the comprehensive evaluation index of regional economic development system, Beijing, Shanghai, Guangdong, Jiangsu and Zhejiang provinces and cities have the highest scores and their economic development levels are the most excellent, which is consistent with the development reality and supports the rationality of the system index construction in this paper. The scores of Guizhou, Ningxia,

Table 3
Regional economic development indicator weights.

Indicators	Gross GDP (billion)	Per capita GDP	Tertiary industry growth rate	Ratio of primary industry to secondary industry	Number of urban population employed	Growth rate of local fiscal general budget revenue	Disposable income per inhabitant	Per capita consumption expenditure
W_j	0.1714	0.1730	0.0430	0.0319	0.1522	0.0437	0.2231	0.1616

Table 4
Distance of 8 indicators to positive and negative ideal values.

Cities	Optimal distance	Worst distance
Beijing	0.154034	0.3285
Tianjin	0.265544	0.169916
Hebei	0.328178	0.091245
Shanxi	0.352699	0.067045
Inner Mongolia	0.319625	0.095074
Liaoning	0.30723	0.100802
Jilin	0.358365	0.053142
Heilongjiang	0.36009	0.050064
Shanghai	0.155877	0.331776
Jiangsu	0.176531	0.254209
Zhejiang	0.172802	0.234071
Anhui	0.315365	0.100528
Fujian	0.24843	0.165187
Jiangxi	0.332827	0.082824
Shandong	0.263052	0.164835
henna	0.312149	0.124947
Hubei	0.290946	0.122444
Hunan	0.307383	0.106709
Guangdong	0.184661	0.274454
Guangxi	0.35212	0.072067
Hainan	0.351105	0.073216
Chongqing	0.312025	0.099964
Sichuan	0.31087	0.113294
Guizhou	0.366547	0.061259
Yunnan	0.353933	0.06602
Tibet	0.39024	0.042291
Shaanxi	0.328114	0.088052
Gansu	0.383473	0.042645
Qinghai	0.371452	0.053161
Ningxia	0.362314	0.06203
Xinjian	0.353207	0.059023

Table 5
Regional economic development evaluation index.

Cities	Relative closeness	Relative closeness ranking
Beijing	0.680780527	1
Tianjin	0.390198404	7
Hebei	0.217549185	17
Shanxi	0.159728967	22
Inner Mongolia	0.229261282	16
Liaoning	0.247044968	13
Jilin	0.129139571	27
Heilongjiang	0.122061767	29
Shanghai	0.680353273	2
Jiangsu	0.590167508	4
Zhejiang	0.575293419	5
Anhui	0.241716551	15
Fujian	0.399371767	6
Jiangxi	0.19926263	19
Shandong	0.385230578	8
henna	0.285857501	10
Hubei	0.296194728	9
Hunan	0.257692959	12
Guangdong	0.597789034	3
Guangxi	0.169893648	21
Hainan	0.172549274	20
Chongqing	0.242638137	14
Sichuan	0.267099317	11
Guizhou	0.143193629	25
Yunnan	0.157207562	23
Tibet	0.097774901	31
Shaanxi	0.211579147	18
Gansu	0.100077522	30
Qinghai	0.125199477	28
Ningxia	0.14617855	24
Xinjian	0.143179648	26

Heilongjiang, Gansu, Jilin and Tibet are relatively low, indicating that their economic development levels still have much room for improvement.

4.3. Coupling coordination degree analysis

In this paper, the comprehensive level index of university science and technology achievement transformation system is expressed by the comprehensive technical efficiency F calculated by DEA model, and the comprehensive level index of regional economic development is expressed by the system similarity closeness S. The coupling degree and coordination degree of each province and city are calculated according to the coupling and coordination model, and the calculation results are shown in Table 6 below.

From the results of coupling degree, the coupling degree of Beijing, Shanghai, Guangdong, Jiangsu and Zhejiang is the highest, which is close to 1, indicating that the development of university achievement transformation system and regional economic development system in these five regions is more orderly and stable, and the capability of university science and technology achievement transformation and regional economic development level in these five regions are among the leading levels in China. In addition, the high coupling degree of Fujian and Shandong, for example, is also due to the high degree of interaction and mutual influence between the transformation ability of university scientific and technological achievements and their regional economic development, but it does not mean that the transformation ability or economic level of these regions is stronger or the development of both is coordinated, which is the limitation of the coupling degree and cannot be used to evaluate the good or bad degree of development. The coupling degree of Jiangsu and Zhejiang, two strong economic and educational provinces, ranks in the top five and is greater than 0.9, which reflects that the coupling relationship between the system of transformation of scientific and technological achievements of universities and the system of economic development level is more coordinated and perfect, that is, the degree of interaction between the ability of transformation of scientific and technological achievements of universities and the regional economic development level is relatively strong. The coupling degree of Gansu, Qinghai, Jilin and Tibet has a large gulf compared with other regions, indicating that the degree of interaction between their two systems is relatively low.

The coupling degree is used to measure the degree of mutual influence between systems, while the coordination degree can be used to evaluate the degree of influence for good or bad. The higher the coordination degree is, the more coherent the development of regional economic development level and regional university science and technology achievement transformation level is. From the calculation results of coordination degree, Beijing and Shanghai have the highest coordination degree, which is 0.9083 and 0.9082 respectively, followed by Jiangsu and Zhejiang, but there is still much room for improvement compared with Beijing and Shanghai. From the comprehensive view of the two systems in the region, the efficiency level of the transformation of scientific and technological achievements of universities in Shanghai, Beijing, Jiangsu and Zhejiang is relatively better than the economic development level, and the mismatch of the development level of the two systems leads to the decrease of the coordination degree. On the whole, the level of university scientific and technological transformation achievements is relatively better than the level of economic development. There are provinces and cities with higher level of transformation of scientific and technological achievements of universities but lower coordination, such as Guizhou, Gansu and Qinghai, etc. There are more factors influencing the relatively higher level of transformation of scientific and technological achievements of universities in these regions. On the one hand, most of these regions have “ministerial” universities and “double first-class” universities, and the scientific research power of universities does not only come from the provincial level. On the other hand, the scientific and technological achievements of universities do not only serve the local enterprises, but also produce cross-regional transformation contracts and economic results.

With reference to the studies of Wu Yuming (2011) [31] and Jiang Tianying (2014) [32] and based on the actual results of this paper, the coordination degree was classified into four levels as shown in Table 7 below, and the coordination degrees of 31 provinces and cities were mapped according to the assigned levels using ArcGIS software to visualize the data, as shown in Fig. 1 below.

Table 6
Coupling degree and coordination degree.

Regions	Coupling degree	Coordination degree	Coordination ranking	Regions	Coupling degree	Coordination degree	Coordination ranking
Beijing	0.9818	0.9083	1	Hubei	0.8397	0.7377	9
Tianjin	0.8987	0.7904	6	Hunan	0.8072	0.7125	12
Hebei	0.8286	0.6400	19	Guangdong	0.9745	0.8667	5
Shanxi	0.7109	0.6186	22	Guangxi	0.7615	0.6064	26
Inner Mongolia	0.7790	0.6920	15	Hainan	0.7085	0.6445	18
Liaoning	0.8420	0.6721	17	Chongqing	0.7928	0.7018	13
Jilin	0.6365	0.5995	27	Sichuan	0.8157	0.7189	11
Heilongjiang	0.6781	0.5588	30	Guizhou	0.6620	0.6152	24
Shanghai	0.9817	0.9082	2	Yunnan	0.6855	0.6295	20
Jiangsu	0.9662	0.8765	3	Tibet	0.6369	0.5214	31
Zhejiang	0.9630	0.8709	4	Shaanxi	0.7593	0.6782	16
Anhui	0.7919	0.7012	14	Gansu	0.5751	0.5625	29
Fujian	0.9315	0.7647	7	Qinghai	0.6289	0.5948	28
Jiangxi	0.8067	0.6269	21	Ningxia	0.6671	0.6183	23
Shandong	0.9290	0.7538	8	Xinjian	0.6620	0.6151	25
Henan	0.8316	0.7312	10				

From the figure, it is easy to see that the level of transformation of scientific and technological achievements of universities in most of the provinces and cities in China and the level of regional economic development are at a moderate coordination level, and the overall has more room for upward movement, and there are large differences between regions. There are only 5 regions in 31 provinces (municipalities directly under the Central Government and autonomous regions) in China where the transformation of scientific and technological achievements of universities and regional economic development are highly coordinated. The highest coordination level is Beijing, including Beijing, Shanghai, Jiangsu, Zhejiang and Guangdong, which are the five provinces and cities with the highest coordination level and are in high coordination, and are the leaders nationwide, but there are certain gaps among these five provinces and cities, among which Guangdong has just entered the stage of high coordination. After that, all provinces and cities such as Tianjin, Fujian, Shandong, Hubei and Henan are in moderate coordination level one after another, and the transformation of scientific and technological achievements of universities in these five regions is more coordinated with the development of regional economy compared with most provinces. However, at the same time, the comprehensive technical efficiency scores of university science and technology achievement transformation system and the relative closeness scores of regional economic development subsystem in Shandong and Fujian are not high, and both systems need to be paid attention to. There are 26 provinces and cities in the moderate coordination stage, occupying 83% of the overall. From specific analysis, almost all provinces and cities are in the state of reconciliation, the level of conversion of scientific and technological achievements of universities is constrained by regional economic development, and the government will spend more funds on promoting regional economic development, and the level of conversion of scientific and technological achievements of universities begins to be benignly coupled with regional economic development. Taking Fujian, Shandong and Liaoning as examples, the restriction of their coordination degree improvement is more caused by the relatively better regional economic development level. For example, Shandong is a large population, agricultural, food production, rural labor export, and food conversion and processing province, and its GDP and per capita disposable income are among the highest in the country, making it an important economic hub. However, there are only two "double first-class" universities in Shandong, which are not rich in scientific research achievements, so the level of transformation of scientific and technological achievements of universities is far less than the level of regional economic development.

5. Conclusion and suggestion

Based on the measurement of the transformation level of university scientific and technological achievements and regional economic development level in 31 provinces and cities, besides its coupling and coordination research, the main conclusions are as follows.

(1) The transformation ability of university scientific and technological achievements is stronger in regions with concentrated university resources and economically developed regions, and there is a big division between regions. As for the regions, there is more space for upward transformation ability of scientific and technological achievements in central and western regions. The transformation ability of eastern regions such as Zhejiang and Jiangsu have good performance, while the transformation ability of university scientific and technological achievements in Tibet, Guangxi and Jiangxi are relatively low, mainly because of the small number of universities and the underdeveloped level of economic development, which are at a disadvantage in the investment of scientific research talents in universities, poor allocation of university funds and the number of enterprises.

(2) Coupling degree measurement demonstrates that Beijing, Shanghai and other five regions have the highest coupling degree. The reason for their high coupling degree is that their universities' scientific and technological achievements transformation ability and their regional economic development level interact with each other to a higher extent, but this does not mean that the two systems in these five regions develop in a coordinated way. Compared with other regions, the coupling degree of Gansu and Qinghai has more space to rise, and the low coupling degree indicates that the degree of interaction between their two systems is relatively low.

(3) Coordination degree measurement results demonstrates that the level of university scientific and technological transformation achievements in most provinces and cities and the level of regional economic development are at a moderate level of coordination, with a large space to improve in general, the differences between regions are large and the development levels of the two systems do not match each other, leading to a low level of coordination. On the whole, there are more provinces (municipalities directly under the central government and autonomous regions) where the level of transformation of university scientific and technological transformation achievements is relatively higher than the level of economic development. There are more factors influencing the relatively level of university scientific and technological transformation achievements. On the one hand, the scientific research motivation of "ministry" universities and "double first-class" construction universities in these regions not only comes from the provincial level, on the other hand, the university scientific and technological achievements

Table 7
Coordination grading.

Coordination value range	Coordination level
$0.0 < D \leq 0.3$	Low coordination
$0.3 < D \leq 0.5$	Antagonistic coordination
$0.5 < D \leq 0.8$	Moderate coordination
$0.8 < D \leq 1.0$	High coordination

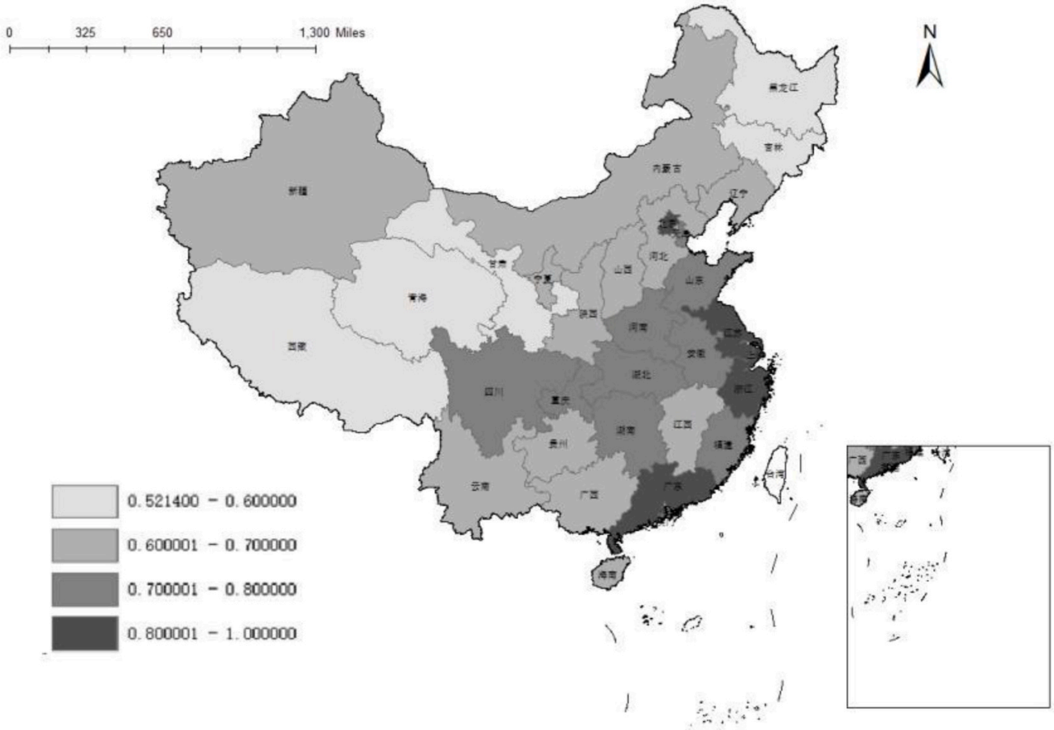

Fig. 1. Coordination degree distribution chart.

will produce cross-regional transformation contracts and economic effectiveness. The lack of coordination in Zhejiang and Shandong is caused by the superior level of regional economic development, which is not rich in university resources but has a high level of economic development.

According to the above conclusions, the following countermeasure suggestions are put forward in order to promote more coordinated transformation of scientific and technological achievements of universities and regional economic development.

(1) The central and western regions should speed up the transformation ability of university scientific and technological achievements and start from two aspects: university resources and enterprise resources. Referring to the experience of Harbin Institute of Technology Weihai Campus and other off-site campuses, the construction of off-site campuses and branch offices of scientific research institutions of “double first-class” universities should be actively introduced. On the other hand, great opportunity of the construction of the western part of the country should be effectively grasped, effective policies to attract high-quality business and high-quality capital should be actively adopted, so as to attract more enterprises to move in. At the same time, a good job of scientific research input and output should be done, increase the investment and support of university scientific research funds, establish a sound mechanism to reward scientific research output of universities, and make good use of national strategic advantages and institutional advantages to introduce scientific research talents and retain scientific research talents. The government should encourage university-enterprise cooperation, unblock the “first kilometer” and “last kilometer” of scientific and technological transformation achievements, and promote the docking of all factors such as technology, capital and market. Using the “combination punch” of the system, the government should promote the development of scientific and technological transformation ability in western universities.

(2) There is space for improvement in the coordination between the scientific and technological transformation achievements and regional economic development in China. It is necessary to pay attention to the problem of uncoordinated development of the two systems and promote the balanced and coordinated development. For most regions where the coordination is not high due to the mismatch of regional economic development, it is necessary to focus on the painful point of “the last kilometer” for the scientific and technological transformation achievements, so that the university scientific and technological achievements can be transformed and serve the regional economic development. The government needs to strengthen the top-level design and policy guidance for scientific and technological achievements, so as to improve the practicality and landing rate of scientific research achievements. Encourage local university-enterprise cooperation and encourage the use of scientific and technological achievements for investment and entrepreneurship. For Henan and other provinces where the university scientific and technological transformation achievements is not matched, efforts should be made to create a “highway” for the scientific and technological transformation achievements and implement supporting policies for technical barriers and financing constraints.

At the same time, from the supply side to encourage university scientific research output. In addition to the introduction of talents, increase the investment in scientific research funds and other conventional policies, we can take "after the results" subsidies and other new policies, that is, there are subsidies only after the output and other methods.

Author contribution statement

Lingrong Wu: Conceived and designed the research; Performed the research; Wrote the paper.
Weizhong Chen: Performed the research; Analyzed and interpreted the data; Wrote the paper.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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