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Research on Spatial Differentiation of Technological Innovation Efficiency of Enterprise

Based on the Super-efficiency DEA-Malmquist Model

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***Abstract*—Through the application of the super-efficiency DEA-Malmquist method, the article measures the efficiency of enterprise technological innovation, analyzes the characteristics of time and space evolution and efficiency change of technological innovation during 2006-2016, and quantitatively adjusts the input and output factors of improving enterprise technological innovation. The research shows that: first, the technical efficiency of technological innovation of enterprises: in terms of time series changes, the potential of input of existing production factors cannot be tapped, and the input of technical elements should be increased. Moreover, in the provinces with inefficient technical efficiency, there are widespread factors such as redundant input of factors and insufficient output of benefits. Each province and region can make quantitative adjustments to the input and output factors in the development of high-tech industries according to their own conditions. Second, enterprise technology innovation Malmquist efficiency index: average technical efficiency change, average technical level change and average total factor productivity change were 1.024, 0.976 and 0.996, respectively, both close to 1. There is a significant difference in technical efficiency between regions, and it is gradually developing towards economically developed areas along the southeast coast, and there is a significant spillover effect.**

Keywords—technological innovation; efficiency; space-time measurement; super-efficiency DEA-Malmquist

I. INTRODUCTION

In the report of the 19th National Congress of the Communist Party of China, General Secretary Xi Jinping pointed out: We need to deepen the reform of the science and technology system, establish a technological innovation system with enterprises as the mainstay, market-oriented, and deep integration of production, education and research, strengthen support for SMEs' innovation, and promote technological innovation.

The goal of combining technology with enterprises is to achieve the transformation of technological achievements into productivity. Under the premise that the level of technology marketization is difficult to change in the short term, the breakthrough to improve the rate of achievement conversion is to adjust the research and development content based on the productivity situation and improve the degree of engineering feasibility. So, what is the current efficiency of technological innovation? What factors constrain efficiency improvement? Is there a spatial relationship? This paper uses the ultra-efficient DEA method to measure the comprehensive technical efficiency of enterprise science and technology innovation. At the same time, the Malmquist productivity index model is used to analyze the dynamic changes of the efficiency and the characteristics of the provincial differences. Through the above methods, the author tries to answer the above three questions, and hopes to learn from the government's policy measures to promote scientific and technological innovation.

II. REVIEW OF RELATED RESEARCH

The domestic literature has a good research basis for the efficiency of the input of science and technology and the efficiency of the transformation of scientific and technological achievements. In terms of the output efficiency of science and technology input, the DEA method is mainly used for efficiency evaluation, such as Fan Hong [1], Xie Youcai [2], Wu Xue [3], and Wang Gang [4]. In the transformation of scientific and technological achievements, the qualitative analysis method is mainly used to analyze the transformation efficiency and existing problems of scientific and technological achievements, such as Cai Yuezhou [5], Yang Shanlin [6], Dong Jie [7], Zhao Zhiyun [8], Mao

Xuefeng [9]. The research on scientific and technological innovation in foreign literature is divided into two parts. The first part is related policies and regulations issued by government departments. Foreign governments believe that the relevant policies and regulations issued by government departments are crucial for creating a favorable external environment and promoting the commercial transformation of scientific and technological achievements [10] [11]. The second part is the measurement and evaluation method of scientific and technological innovation ability. Todorovic et al. used the “comprehensive indicator method”; Aldridge and Audretsch, Krabel and Mueller, and Samila and Soren-son all belong to the modeling metrology; Anderson et al. belong to the DEA efficiency evaluation method [12] [13] [14] [15] [16].

III. Research Methods and Data Description

A. Research Methods

1) Super-efficiency DEA method: In the analysis results of the general DEA model, it is often the case that a plurality of DMUs are evaluated as valid. Especially when the number of input and output indicators is large, the number of effective DMUs will be larger. The efficiency value obtained by the DEA model is at most 1, and the effective DMU efficiency values are the same, so the efficiency of these effective DMUs cannot be further distinguished. To solve this problem, Andersen and Petersen proposed a way to further distinguish the effective DMU from its effectiveness, which was later called the super-efficiency DEA model. The core of the super-efficiency DEA model is to remove the evaluated DMU from the reference set. That is, the efficiency of the evaluated DMU is derived from the leading edge of other DMUs. The effective DMU's super efficiency value is generally greater than 1. This makes it possible to distinguish between effective DMUs [17]. Super-efficiency DEA model:

$$\min\left[\theta-\varepsilon\left(\hat{e}^T S^- + e^T S^+\right)\right]$$

$$s.t.\begin{cases}\sum_{j=1,j\neq 0}^{n} X_j\lambda_j + S^- = \theta X_0 \\ \sum_{j=1,j\neq 0}^{n} X_j\lambda_j - S^+ = Y_0 \\ \lambda_j \geq 0,\ j=1,2,\ldots,k-1,k,Kn \\ S^- \geq 0, S^+ \geq 0, \sum_{j=1}^{n}\lambda_j = 1\end{cases} \quad (1)$$

2) Malmquist productivity index method: The Malmquist Productivity Index method is mainly applied to the study of trends in dynamic efficiency changes. Färe et al. define the Malmquist Productivity Index (tfpch) for two adjacent periods. The expression is as follows:

$$M_0\left(x_t, y_t, x_{t+1}, y_{t+1}\right) = \left[\frac{D_0^{t+1}\left(x_{t+1}, y_{t+1}\right)}{D_0^{t+1}\left(x_t, y_t\right)} \times \frac{D_0^{t}\left(x_{t+1}, y_{t+1}\right)}{D_0^{t}\left(x_t, y_t\right)}\right]^{1/2} \quad (2)$$

Where: $D_0^t(x_t, y_t), D_0^{t+1}(x_{t+1}, y_{t+1})$ is the input distance function compared to the frontier technique according to the production point at the same time period (i.e. t and t+1). $D_0^t(x_t, y_t), D_0^{t+1}(x_{t+1}, y_{t+1})$ is the input distance function obtained by comparing the production point with the frontier surface technology in the mixed period, the Malmquist productivity index can be decomposed into two parts: technical efficiency change (effch) and technical change (techch). Equation (2) can be rewritten as:

$$M_0\left(x_t, y_t, x_{t+1}, y_{t+1}\right) = \underbrace{\frac{S_0^t\left(x_t, y_t\right)}{S_0^t\left(x_{t+1}, y_{t+1}\right)} \times \frac{D_0^t\left(x_{t+1}, y_{t+1}\right)}{D_0^t\left(x_t, y_t\right)}}_{effch} \times \underbrace{\left[\frac{D_0^t\left(x_{t+1}, y_{t+1}\right)}{D_0^{t+1}\left(x_{t+1}, y_{t+1}\right)} \times \frac{D_0^t\left(x_t, y_t\right)}{D_0^{t+1}\left(x_t, y_t\right)}\right]^{1/2}}_{techch} \quad (3)$$

Where: effch represents technical efficiency change, techch represents technical change, and Malmquist productivity index (tfpch) can be expressed by the product of the two.

B. Research Indicators and Data Selection

According to the requirements of the DEA method, the number of input and output indicators selected should be no more than half of the number of decision units. In order to fully reflect the level of technological innovation efficiency of enterprises in various provinces, referring to the research of relevant scholars mentioned above, this paper takes the investment of science and technology and the input of personnel and the number of patents as input indicators in various regions, and the new product income and industrial output value of each region are output indicators. The data comes from the China Statistical Yearbook and the China Statistical Yearbook on Science and Technology.

IV. Empirical Results Analysis

A. Analysis of the Efficiency of Enterprise Technology Innovation Based on Super-efficiency DEA Model

According to formula (1), by running the software Maxdea7, this paper calculates the various efficiency indicators of enterprise technology innovation from 2006 to 2016. From a national perspective, the average overall efficiency between 2006 and 2016 was 1.014, and the highest was 1.241, which was at a high level. The lowest overall efficiency value is 0.827 in 2006, which means that if the current production factors are fully utilized, the output can be nearly doubled at the current level. From the overall trend of enterprise technology innovation efficiency (see “Table I”), the comprehensive technology efficiency curve can be roughly divided into three stages:

- 2006-2008 is the first phase. In this phase, the comprehensive efficiency is rising from 0.827 in 2006 to 1.241 in 2008. The comprehensive efficiency in 2008 increased rapidly, mainly due to the economic rise faster in China at this stage, the total output value and profit of the producers performed better. It is also mainly due to the company's response to the use of advanced technology, intensive production, and the fierce market competition brought about by the new technological revolution represented by the United States.
- 2008-2010 is the second stage. Year 2008 is obviously an inflection point. This is related to the economic crisis in 2008. The enterprise market is sluggish, resulting in insufficient investment in R&D, which leads to slow growth of technological progress.
- The period from 2010 to 2016 is the third stage, in which the efficiency of technological innovation of enterprises continues to increase. During this period, enterprises have gradually matured. In order to survive in a highly competitive market and maintain certain economic benefits, enterprises are forced to adopt advanced technologies and improve technical efficiency to maintain their market competitiveness from the perspective of improving production efficiency. At the same time, the government's role in the industrial development zone of the enterprise is increasingly obvious. The division of labor between enterprises in the industrial zone is continuously refined, and the organization of product production and R&D activities is more flexible and efficient. The government has established various forms of industry incubators, encourages talents to start businesses, and supports the development of small and micro-tech enterprises in terms of taxation. Due to the in-depth development of global integration, Chinese enterprises have been included in the global production network. This promotes domestic enterprises to optimize the industrial structure, enhance the industrial level, and promote the continuous improvement of technical efficiency by anti-driving mechanism.

TABLE I. RESULTS OF EFFICIENCY EVALUATION OF SCIENTIFIC AND TECHNOLOGICAL CONVERSION RESULTS OF ENTERPRISES IN VARIOUS PROVINCES FROM 2006 TO 2016

Regions	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average
Beijing	0.729	0.948	0.957	0.900	0.966	0.948	0.957	0.977	0.984	0.961	0.969	0.936
Tianjin	0.764	0.957	0.979	0.946	1.000	0.963	0.980	1.001	0.986	0.975	0.969	0.956
Hebei	0.853	0.972	0.986	0.978	0.977	0.973	0.989	0.996	0.977	0.959	0.944	0.964
Shanxi	0.891	0.973	0.927	0.916	0.915	0.937	0.951	0.950	0.926	0.922	0.918	0.930
Inner Mongolia	0.755	1.003	0.976	1.043	1.056	1.056	1.037	1.053	1.024	0.981	1.006	0.999
Liaoning	0.781	0.935	0.939	0.959	0.971	0.981	0.999	1.006	1.000	0.991	0.958	0.956
Jilin	0.868	1.076	1.119	1.176	1.090	1.111	1.123	1.001	1.102	1.118	1.111	1.081
Heilongjiang	0.816	0.928	0.902	0.917	0.905	0.906	0.912	0.919	0.907	0.896	0.896	0.900
Shanghai	0.756	0.945	1.025	0.931	1.014	0.999	1.021	1.010	1.016	0.991	1.000	0.973
Jiangsu	0.715	0.897	0.951	0.931	0.963	0.961	0.985	0.985	0.990	0.990	0.993	0.942
Zhejiang	0.748	0.849	0.948	0.919	0.966	0.948	0.970	0.986	0.981	0.990	0.993	0.936
Anhui	0.724	0.792	0.896	0.921	0.962	0.932	0.957	0.966	0.971	0.967	0.978	0.915
Fujian	0.750	0.930	0.917	0.927	0.948	0.914	0.932	0.935	0.934	0.932	0.926	0.913
Jiangxi	0.824	0.940	0.968	0.938	0.961	0.958	0.985	0.997	0.987	0.974	0.983	0.956
Shandong	0.722	0.894	0.955	0.972	1.008	0.934	1.001	1.015	0.901	0.991	0.991	0.944
Henan	0.768	0.875	0.941	0.949	0.952	0.942	0.951	0.999	0.963	0.962	0.947	0.932
Hubei	0.768	0.893	0.910	0.921	0.952	0.928	0.959	0.978	0.977	0.980	0.975	0.931
Hunan	0.749	0.888	0.928	0.945	0.977	0.946	0.986	1.007	1.011	1.014	1.004	0.951
Guangdong	0.772	0.801	0.939	0.935	0.959	0.944	0.960	0.973	0.980	0.988	1.000	0.932
Guangxi	0.810	0.941	0.969	0.983	1.017	0.971	0.989	1.030	0.986	1.021	1.000	0.974
Hainan	2.293	3.134	9.674	1.612	3.228	1.402	1.217	1.151	1.202	0.855	1.070	2.440
Chongqing	0.626	0.835	0.949	0.939	1.013	0.986	0.981	0.995	1.009	1.014	1.002	0.941
Sichuan	0.739	0.869	0.914	0.945	0.966	0.987	0.980	0.973	0.973	0.965	0.945	0.932
Guizhou	0.748	0.841	0.892	0.921	0.908	0.935	0.938	0.940	0.937	0.932	0.904	0.900
Yunnan	0.890	0.937	0.947	1.007	0.982	0.964	0.966	0.977	0.966	0.943	0.897	0.952
Shaanxi	0.791	0.872	0.888	0.920	0.930	0.943	0.943	0.939	0.929	0.927	4.879	1.269
Gansu	0.757	0.929	0.863	0.900	0.919	0.966	0.957	0.976	0.973	0.937	0.907	0.917
Qinghai	0.815	0.938	1.159	1.201	1.113	1.172	1.220	1.199	1.204	1.435	1.004	1.133
Ningxia	0.760	1.016	0.845	0.906	0.933	0.943	0.970	0.996	0.878	1.106	0.883	0.931
Xinjiang	0.844	0.972	0.974	0.989	0.985	1.018	1.044	1.045	1.056	0.944	0.934	0.982
Average	0.827	0.993	1.241	0.982	1.051	0.986	0.995	0.999	0.991	0.989	1.100	1.014

B. Ways and Potentials for Improving the Efficiency of Technological Innovation of Enterprises

In view of the current status of technological innovation efficiency of enterprises in various provinces and cities, this paper uses the model method to find the reasons for inefficient development from the original input-output data, proposes ways to improve, and calculates the improvement potential of future variables. Below, the article analyzes the development of technological innovation efficiency of enterprises in various provinces and cities in 2016 from the historical data, and calculates the improvement potential of input and output factors of DEA provinces and cities ("Table II"). "Table II" shows the reasons for the inefficiency and improvement potential of the DEA effective areas. The improvement of the input and output indicators in different provinces and regions is obviously different, such as the 5% redundancy of Beijing's funding, while the Heilongjiang is as high as 13.7%; Beijing personnel's input redundancy ratio is 9.9%, while Ningxia is as high as 37.6%; Beijing patents have an input redundancy ratio of 9%, while Jilin has a high of 25.8%. According to the model result data, each province and city can make adjustments according to the actual situation of input and output in the process of technological innovation development.

Through the analysis of the input and output adjustment and improvement potential of the scientific and technological innovations of enterprises in various provinces and cities in "Table II" in 2016, and the analysis of the relaxation variables of the provinces and universities in the past ten years, it shows that the input of the basic factors in the process of enterprise achievement transformation is more redundant, which makes the effective output seriously insufficient. Therefore, improving the use efficiency of each input factor, increasing output, and optimizing production factor allocation capacity are the key factors to improve the efficiency of scientific and technological innovation of enterprises in various provinces and cities.

TABLE II. REASONS FOR THE EFFICIENCY OF DEA PROVINCES IN 2016 AND THE IMPROVEMENT POTENTIAL

DMU	Technical Value	Invalid Value of Input	Radial Efficiency of Input	Resilience	Outlay			Personnel			Patent			New Product Income			Industrial Output Value		
					Percentage	*Resilience*	*Outlay value*	*Percentage*	*Resilience*	*Personnel value*	*Percentage*	*Resilience*	*Patent value*	*Percentage*	*Resilience*	*new product income value*	*Percentage*	*Resilience*	*Industrial output value*
Beijing	0.969	0.031	0.031	0.970	-0.050	0.000	1.579	-0.099	0.000	3.089	-0.090	-0.028	2.795	0.000	0.000	2.445	0.000	0.054	2.495
Tianjin	0.969	0.031	0.031	0.973	-0.054	0.000	1.669	-0.103	0.000	3.210	-0.089	0.000	2.777	0.000	0.000	2.540	0.000	0.043	2.638
Hebei	0.944	0.056	0.056	1.248	-0.094	-0.059	1.533	-0.186	0.000	3.144	-0.156	-0.050	2.583	0.000	0.000	2.433	0.000	0.000	2.794
Shanxi	0.918	0.082	0.082	0.951	-0.110	-0.013	1.223	-0.248	0.000	2.778	-0.199	0.000	2.224	0.000	0.000	2.055	0.000	0.000	2.449
Inner Mongolia	1.006	-0.006	-0.006	1.020	0.008	-0.082	1.352	0.018	-0.032	3.018	0.014	0.000	2.365	0.000	0.404	2.362	0.000	0.000	2.613
Liaoning	0.958	0.042	0.042	0.994	-0.068	-0.114	1.433	-0.133	0.000	3.044	-0.113	-0.131	2.455	0.000	0.000	2.390	0.000	0.000	2.595
Jilin	1.111	-0.111	-0.111	1.007	0.147	0.000	1.472	0.327	-0.315	2.971	0.256	0.000	2.575	0.000	0.000	2.315	0.000	0.000	2.561
Heilongjiang	0.896	0.104	0.104	0.928	-0.137	0.000	1.181	-0.318	-0.039	2.695	-0.255	0.000	2.193	0.000	0.000	1.829	0.000	0.000	2.411
Shanghai	1.000	0.000	0.000	0.978	0.001	-0.001	1.821	0.001	0.000	3.382	0.001	0.000	2.969	0.000	0.000	2.678	0.000	0.135	2.760
Jiangsu	0.993	0.007	0.007	1.035	-0.015	-0.027	2.138	-0.026	0.000	3.802	-0.024	0.000	3.441	0.000	0.000	3.012	0.000	0.000	3.035
Zhejiang	0.993	0.007	0.007	1.089	-0.015	0.000	1.997	-0.027	0.000	3.701	-0.024	-0.038	3.253	0.000	0.000	2.932	0.000	0.000	2.891
Anhui	0.978	0.022	0.022	1.019	-0.039	0.000	1.700	-0.076	0.000	3.307	-0.071	-0.208	2.900	0.000	0.000	2.616	0.000	0.000	2.710
Fujian	0.926	0.074	0.074	1.155	-0.130	-0.153	1.470	-0.252	0.000	3.139	-0.224	-0.268	2.520	0.000	0.000	2.442	0.000	0.000	2.754
Jiangxi	0.983	0.017	0.017	1.017	-0.026	-0.136	1.364	-0.052	0.000	3.024	-0.047	-0.350	2.379	0.000	0.000	2.367	0.000	0.000	2.612
Shandong	0.991	0.009	0.009	1.115	-0.019	-0.285	1.830	-0.032	0.000	3.613	-0.028	-0.081	3.048	0.000	0.000	2.852	0.000	0.000	3.006
Henan	0.947	0.053	0.053	1.163	-0.093	-0.168	1.507	-0.182	0.000	3.286	-0.151	-0.113	2.608	0.000	0.000	2.563	0.000	0.000	2.865
Hubei	0.975	0.025	0.025	1.047	-0.044	-0.144	1.605	-0.083	0.000	3.291	-0.071	-0.121	2.713	0.000	0.000	2.591	0.000	0.000	2.774
Hunan	1.004	-0.004	-0.004	1.064	0.006	-0.092	1.670	0.012	0.000	3.354	0.010	0.000	2.895	0.000	0.000	2.646	0.000	0.000	2.745
Guangdong	1.000	0.000	0.000	1.135	0.001	-0.159	2.024	0.001	0.000	3.811	0.001	-0.183	3.314	0.000	0.000	3.018	0.000	0.000	3.056
Guangxi	1.000	0.000	0.000	1.066	-0.001	0.000	1.298	-0.001	0.000	2.901	-0.001	-0.154	2.380	0.000	0.000	2.232	0.000	0.000	2.595
Hainan	1.070	-0.070	-0.070	0.808	0.043	0.000	0.653	0.163	-0.457	2.027	0.128	0.000	1.960	0.000	0.000	1.423	0.000	0.271	2.088
Chongqing	1.002	-0.002	-0.002	0.977	0.004	0.000	1.612	0.007	0.000	3.172	0.006	-0.198	2.681	0.000	0.000	2.505	0.000	0.071	2.637
Sichuan	0.945	0.055	0.055	1.267	-0.090	-0.017	1.526	-0.178	0.000	3.058	-0.161	-0.228	2.546	0.000	0.000	2.358	0.000	0.000	2.738
Guizhou	0.904	0.096	0.096	0.937	-0.113	-0.058	1.011	-0.272	0.000	2.570	-0.236	0.000	2.227	0.000	0.000	1.868	0.000	0.000	2.417
Yunnan	0.897	0.103	0.103	0.944	-0.131	-0.138	0.998	-0.296	0.000	2.571	-0.258	0.000	2.243	0.000	0.000	1.894	0.000	0.000	2.430
Shaanxi	4.879	-3.879	-3.879	1.284	1.044	0.000	0.775	6.088	4.394	3.263	10.270	-10.098	2.820	0.000	0.766	1.372	0.000	0.000	2.627
Gansu	0.907	0.093	0.093	0.904	-0.143	-0.192	1.199	-0.294	-0.183	2.676	-0.216	0.000	2.096	0.000	0.000	2.093	0.000	0.119	2.316
Qinghai	1.004	-0.004	-0.004	0.775	0.005	-0.220	0.940	0.009	0.000	2.204	0.008	0.000	1.894	0.000	0.000	1.680	0.000	0.000	2.001
Ningxia	0.883	0.117	0.117	0.782	-0.071	0.000	0.533	-0.298	-0.376	1.868	-0.258	0.000	1.939	0.000	0.000	1.069	0.000	0.000	2.047
Xinjiang	0.934	0.066	0.066	0.893	-0.061	0.000	0.873	-0.172	-0.078	2.366	-0.152	0.000	2.154	0.000	0.000	1.562	0.000	0.000	2.321

V. Analysis of the Efficiency Technology Innovation of Enterprises Based on Malmquist Productivity Index

A. *General Characteristics of Malmquist Productivity Index and Decomposition*

"Table III" shows the Malmquist index and its decomposition results of the technological innovation efficiency of enterprises in various provinces from 2006 to 2016. "Table IV" shows the Malmquist index and its decomposition results of the average enterprise technology innovation efficiency in each year from 2006 to 2016.

As can be seen from "Table III", among the total factor productivity of provinces and cities across the country, Beijing, Inner Mongolia, Jiangsu, Anhui, Shandong, Hubei, Hunan, Chongqing, Sichuan, Shaanxi, and Ningxia are all greater than 1. Shaanxi is the region with the highest total factor productivity in China, and Hainan is the region with the lowest total factor productivity in China. This shows that the current national science and technology innovation efficiency in China is generally showing a trend of good development. However, Tianjin, Hebei, Shanxi, Liaoning, Jilin, Heilongjiang, Shanghai, Zhejiang, Fujian, Jiangxi, Henan, Guangdong, Guangxi, Hainan, Guizhou, Yunnan, Gansu, Qinghai, and Xinjiang with a total factor productivity of less than 1 should focus on improving the growth rate of technological innovation.

TABLE III. MALMQUIST EXPONENTIAL DECOMPOSITION OF TECHNOLOGICAL INNOVATION EFFICIENCY OF ENTERPRISES IN VARIOUS PROVINCES FROM 2006 TO 2016

Regions	Technical Efficiency Change (Effch)	Technical Level Change (Techch)	Total-Factor Productivity Change (Tfpch)	Regions	Technical Efficiency Change (Effch)	Technical Level Change (Techch)	Total-Factor Productivity Change (Tfpch)
Beijing	1.033	0.974	1.001	Henan	1.022	0.980	0.999
Tianjin	1.027	0.974	0.995	Hubei	1.025	0.980	1.003
Hebei	1.011	0.986	0.996	Hunan	1.031	0.979	1.007
Shanxi	1.004	0.983	0.985	Guangdong	1.027	0.967	0.991
Inner Mongolia	1.033	0.977	1.005	Guangxi	1.022	0.978	0.997
Liaoning	1.022	0.980	0.999	Hainan	1.002	0.860	0.864
Jilin	1.015	0.975	0.987	Chongqing	1.053	0.969	1.013
Heilongjiang	1.010	0.981	0.989	Sichuan	1.026	0.983	1.006
Shanghai	1.031	0.970	0.995	Guizhou	1.020	0.975	0.992
Jiangsu	1.036	0.972	1.002	Yunnan	1.001	0.981	0.981
Zhejiang	1.030	0.969	0.994	Shaanxi	1.024	1.101	1.133
Anhui	1.032	0.972	1.000	Gansu	1.021	0.974	0.992
Fujian	1.024	0.978	0.997	Qinghai	1.022	0.977	0.997
Jiangxi	1.019	0.982	0.999	Ningxia	1.023	0.988	1.006
Shandong	1.036	0.970	1.000	Xinjiang	1.011	0.985	0.995
				Average value	1.024	0.976	0.996

TABLE IV. MALMQUIST INDEX DECOMPOSITION OF TECHNOLOGY INNOVATION EFFICIENCY OF ENTERPRISES IN 2006-2016

Year	Technical Efficiency Change (Effch)	Technical Level Change (Techch)	Total-Factor Productivity Change (Tfpch)	Year	Technical Efficiency Change (Effch)	Technical Level Change (Techch)	Total-Factor Productivity Change (Tfpch)
2006-2007	1.176	0.838	0.986	2011-2012	1.014	0.977	0.991
2007-2008	1.029	0.941	0.967	2012-2013	1.009	0.985	0.994
2008-2009	1.006	0.960	0.965	2013-2014	0.988	1.003	0.991
2009-2010	1.021	1.020	1.040	2014-2015	0.996	1.011	1.007
2010-2011	0.994	0.983	0.977	2015-2016	0.999	1.054	1.056
				Average value	1.023	0.977	0.997

From the perspective of decomposition indicators, technological advances have a large impact on total factor productivity. Shaanxi Province, which has high total factor productivity, has higher technical efficiency changes (1.024) and technical level changes (1.101). Hainan Province (0.864), which has the lowest total factor productivity, has a higher technical efficiency (1.002) and the lowest level of technical change (0.860). Therefore, Hainan Province should vigorously improve its technical level.

According to “Table IV”, the article further analyzes the dynamic changes of various indicators in various regions of China from 2006 to 2017.

In terms of the average value, the national total factor productivity is 0.997, and the overall performance is high. The technical efficiency changes and technical level changes are 1.023 and 0.977 respectively. It can be seen that the total factor productivity gradually transitions to relying on technical efficiency to drive, and the technical level efficiency has no obvious effect on the national factor production efficiency improvement. From the perspective of the dynamic evolution of the total factor productivity in the country, the total factor productivity shows a dynamic wave with a normal wave that increases first, then decreases and then increases. In 2006-2016, it rose from the original minimum 0.965 volatility to a peak of 1.056, and its average value was 0.997<1, indicating that the national technological innovation efficiency of the country has undergone a process of first improving and then weakening and then improving. From the indicators of its decomposition, technical efficiency changes are relatively consistent with the trend of total factor productivity. Technical efficiency changes are always the main drivers of total factor productivity.

Judging from the trend of its evolution (“Table IV”), it shows a trend of rising first, then lowering and then rising, indicating that although the current technological innovation efficiency is in a relatively delicate development stage, the influence of policy support and external power intervention is more obvious.

B. *Time-space Differences of Interprovincial Malmquist Productivity Index*

Based on the results of the super-efficiency DEA-Malmquist model, the productivity index of the production efficiency index was spatially analyzed using Arc GIS 10.2 software using the Malmquist productivity index values of the provinces in 2006-2007, 2009-2010, 2012-2013 and 2015-2016. According to the value of Malmquist productivity index, each province and city is divided into 10 categories and plotted as a spatial distribution map, which more intuitively reflects the spatial evolution pattern of inter-provincial Malmquist productivity during the study period (“Fig. 1” “Fig. 2” “Fig. 3” and “Fig. 4”). Specific to the cross-section year, the provinces with large Malmquist productivity index values in 2006-2007 are Ningxia, Inner Mongolia, Gansu, Beijing, Chongqing, Qinghai, Xinjiang, Fujian, Hunan and other provinces and cities. The total factor productivity of enterprise science and technology innovation has progressed rapidly, while the lower-ranking provinces and regions mainly include Shaanxi, Jilin, Shanxi, Anhui, Yunnan, Zhejiang, Guangdong, and Hainan. On the whole, the index value has not been related to the level of economic development. However, the distribution of high-level areas and high-level areas is concentrated in the northwestern inland provinces, indicating that the northwestern provinces and regions with relatively poor economic development in 2006-2007 value the development of technological innovation. And on this basis, it supports and drives the rapid start and development of the region's economy. In 2009-2010, the distribution of all levels of the Malmquist Productivity Index was more dispersed, with various types of provinces and cities cross-distributed. The areas with higher level are mainly distributed in the central provinces. With the continuous implementation and deepening of the “centralization strategy of the central region”, the achievements in technological innovation of enterprises are remarkable. By 2012-2013, the spatial pattern of TPF has changed significantly. In the region where the total factor productivity of China's central and eastern regions has progressed rapidly, it is worth mentioning that Guangdong has transitioned from a low-level zone in 2009 to a high-level zone. The efficiency is improved faster. By 2015-2016, total factor productivity continued to shift to the southeastern coastal areas, mainly because of the economic development of the southeastern coastal areas and the increasing investment, which has a clear driving effect on the development of technological innovation.

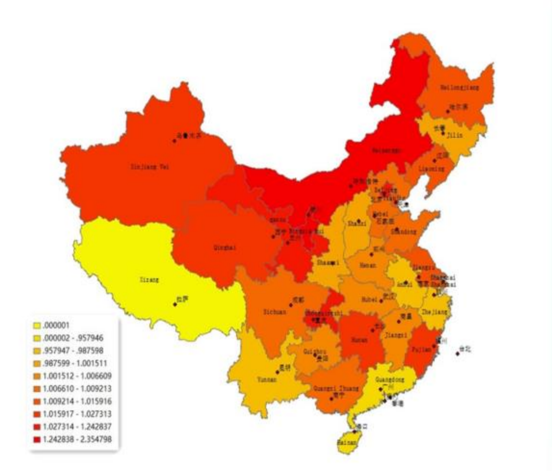

Fig. 1. Evolution of the spatiotemporal pattern of the interprovincial Malmquist productivity index 2006-2007.

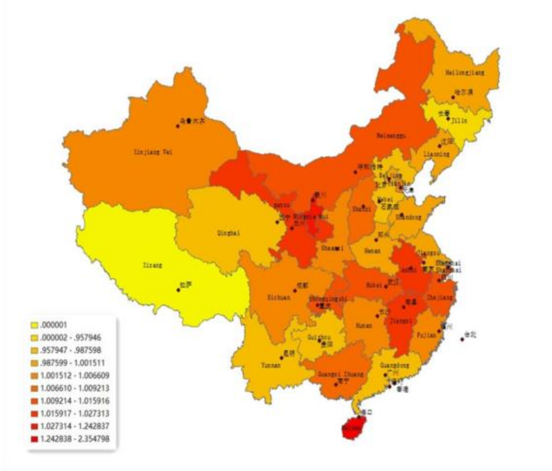

Fig. 2. Evolution of the spatiotemporal pattern of the interprovincial Malmquist productivity index 2009-2010.

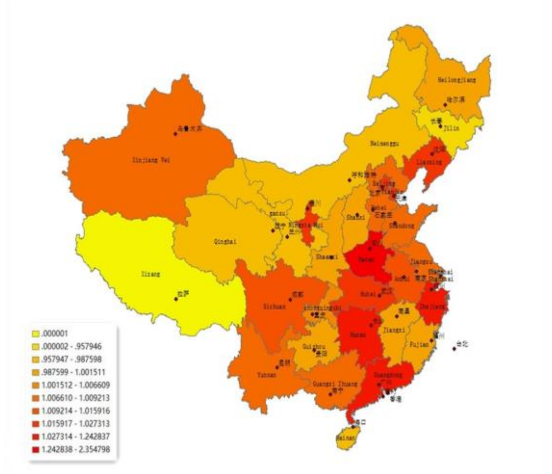

Fig. 3. Evolution of the spatiotemporal pattern of the interprovincial Malmquist productivity index 2012-2013.

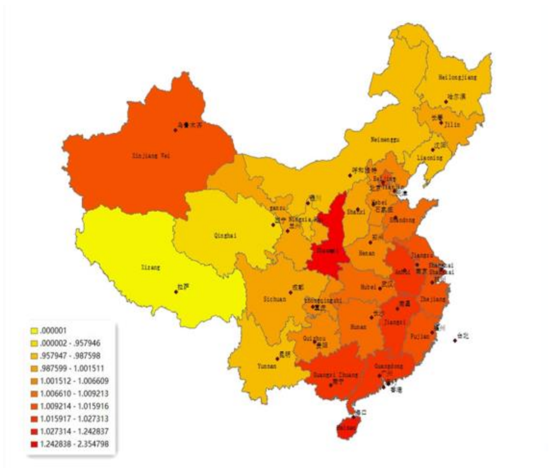

Fig. 4. Evolution of the spatiotemporal pattern of the interprovincial Malmquist productivity index 2015-2016.

VI. CONCLUSION

Using the DEA-Malmquist method, under the framework of total factor productivity analysis, this paper comprehensively analyzes the spatiotemporal and interprovincial differences of Chinese enterprises technological innovation efficiency from 2006 to 2016, and obtains the following conclusions:

The first is the evaluation of the efficiency of enterprise science and technology innovation: First, from the timing of development, from 2006 to 2016, the efficiency of technological innovation of Chinese enterprises is generally fluctuating, and the potential of existing production factors cannot be fully explored. Therefore, we should increase investment in technological elements in development. The key to improving the efficiency of enterprise science and technology innovation is to improve the efficiency of technology and speed up the renewal of technological innovation of enterprises. ② Through the analysis of the provinces of scientific and technological innovation efficiency of enterprises, it can be found that there are widespread factors such as redundant input of resources and insufficient output of benefits. The development of technological innovation of enterprises in various provinces and cities in 2016 was selected and analyzed, and the improvement potential of input and output was calculated through the model. Each province and city may make a quantitative adjustment of the input and output factors in industrial development according to actual conditions.

The second is the evaluation of the Malmquist efficiency index of enterprise technology innovation: there is a significant difference in the technical efficiency level between the economically developed areas in the southeast coast and the central and western regions. From 2006 to 2016, with the development of the economy, the technical efficiency level in the southeast coastal areas improved significantly, and there was a significant spillover effect between provinces and cities. It shows that the development of science and technology innovation in various provinces and cities is more dependent on local input, thus making technological improvement and progress.

In view of the characteristics of technological innovation in enterprises in various regions, it is necessary to adapt measures to local policies and measures to promote technological innovation in enterprises. For the southeast coastal areas, the economic development foundation is good, and the background advantage is obvious. On this basis, cross-regional cooperation with enterprise science and technology should be used as a carrier to promote technological innovation and foster new technological forms. The central and western regions should selectively develop technological innovations of their dominant enterprises according to their different development characteristics, and give full play to the role of science and technology in promoting local economic development. For the northeast region, as a traditional heavy industry base in China, the development inertia is large, and it is difficult to accelerate the speed of technological innovation in enterprises in the short term. Therefore, on the basis of the existing, we should accelerate the development of technological innovation in enterprises, build enterprise technology alliances based on cooperation among enterprises, and at the same time use the powerful spillover effects of enterprise technology to drive the development of related traditional industries. On the whole, the state and all levels of government should promote the development of scientific and technological innovation from the overall situation, promote the free flow of scientific and technological elements such as talents, technology and information, improve the efficiency of resource allocation, and jointly promote the efficiency of technological innovation.

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