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Study on Urban Efficiency Measurement and Spatiotemporal Evolution of Cities in Northwest China Based on the DEA–Malmquist Model

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Abstract: Urban efficiency can effectively measure the management and allocation level of urban factor inputs. Based on the data of 30 prefecture-level cities in Northwest China from 2006 to 2015, urban efficiency is measured by data envelopment analysis (DEA). Then the spatiotemporal evolution rule is identified by Malmquist model. The results illustrate that the overall average urban efficiency of cities in Northwest China each year from 2006 to 2015 was at the low level. Only Jiayuguan, Yulin, Yan'an, and Karamay reached the high average urban efficiency, while Dingxi, Pingliang, Guyuan, Shangluo, Tianshui, Longnan, and Baiyin were at the inefficient level. Most cities in Northwest China were still in the "growing" stage of increasing returns to scale. The scale of urban investment was relatively insufficient, and economies of scale had not yet formed. Cities with decreasing returns to scale were mainly distributed in the capital cities and the central and sub-central cities of Guanzhong-Tianshui Economic Zone with relatively abundant urban resources and capital. Cities with constant returns to scale were mainly distributed in four cities including Yan'an, Yulin, Jiayuguan, and Karamay with high efficiency. The overall comprehensive efficiency, technical efficiency, and scale efficiency of cities in Northwest China were not only low, but also showing a downward trend. The overall progress of urban technology had failed to make up for the shortfall caused by low efficiency, resulting in total factor productivity (TFP) decreasing by 0.5%. Therefore, the cities in Northwest China should continuously improve their technical efficiency and scale efficiency, and ultimately enhance the comprehensive efficiency.

Keywords: urban efficiency; DEA; Malmquist index; Northwest China

1. Introduction

Urban efficiency refers to the efficiency in urban operations during a certain time period and under certain technical conditions [1]. Urban efficiency is essentially relative efficiency, which is usually calculated by evaluating the cities with the same input–output index. The higher the urban efficiency of the city, the better the economic, social, and ecological operation effects of the city [2]. This definition is adopted as the basis in this study. Urban efficiency can effectively measure the management and allocation level of urban factor inputs. Urban efficiency can also be called urban factor resource efficiency [3]. At present, China's urbanization process is accelerating, and the urban structural system is also improving [4]. The phenomenon of "high input, high consumption, and low output" in urban development is prominent. Urban efficiency is generally not high, especially in less developed areas. This directly leads to a large amount of resource consumption, which reduces the quality of urban development [5]. Cities are the primary sources of input–output activities, and urban efficiency has become a hot issue in academic studies [6]. The studies on urban efficiency mainly focus on three aspects. The first is the "efficiency–productivity" theory. Solow [7] put forward "Solow Surplus" and considered that urban technical progress is the main source of efficiency growth. The second is the "efficiency–size" theory. Alonso [8] pointed out there is an optimal city size that maximizes the difference between urban income and cost, meaning the highest urban efficiency. The third is the "efficiency–logistics" theory. Prudhomme et al. [9] pointed out that the relative location of address and workplace in a city, and the speed of movement of people and goods have a direct impact on urban efficiency. Most of the studies in China were based on the existing theories abroad applied to empirical studies on Chinese cities. Pan et al. [10] used data envelopment analysis (DEA) and exploratory spatial data analysis (ESDA) methods to measure the urban efficiency of 35 provincial cities of China in 2010. Di et al. [11] measured the urban efficiency of 53 coastal cities in eastern China from 2005 to 2014 by the slacks-based measure (SBM) model from the perspective of unexpected output. Luo et al. [12] used the super-efficient SBM model and Malmquist index to measure the green development efficiency of resource-based cities in central China from 2011 to 2015. It was found that the existing studies on urban efficiency mainly concentrated on provincial capital cities, municipalities, and cities in the eastern and central developed areas of China but lacked attention on the cities in the underdeveloped northwest region. In addition, most of the existing studies analyzed the trend of efficiency in discontinuous years within a certain time period, but few traced the dynamic evolution process of efficiency in successive years, which made it impossible to effectively explain the dynamic evolution of urban total factor productivity (TFP) and technical change and its causes.

At present, the cities in Northwest China are developing rapidly. However, due to the restriction of geographical location, institutional environment, and economic foundation, the quality of urban development in Northwest China is still far behind that in Eastern and Central China. Li et al. [13] pointed out that regardless of technical efficiency or scale efficiency, cities in underdeveloped regions in China are far backwards than those in developed regions. Wang et al. [14] pointed out that the lack of early capital accumulation results in low efficiency in underdeveloped regions in China. Ren et al. [15] pointed out that the cities in underdeveloped regions in China urgently need to promote effective urban development by improving urban efficiency. Therefore, the systematic and quantitative measurement of urban efficiency in Northwest China and the analysis of its spatiotemporal evolution rule are in need of enlightenment to improve the quality of urban development. At present, the system of the city governing county is the administrative division system in most areas in China. The city governing county, also known as the "city leading county", refers to the system of taking the central city with a relatively developed economy as the first-level regime to govern a part of the surrounding counties and county-level cities. In the system of the city governing county, cities at the prefecture level are the political, economic, and cultural centers of their regions, as shown in Figure 1. The cities in this study are prefecture-level cities in Northwest China. In this study, the DEA–Malmquist model is used to analyze the urban development quality and compare the development potential of different cities by measuring the urban efficiency and identifying the spatiotemporal evolution rule of the cities in Northwest China from 2006 to 2015, which can provide decision support for the cities in Northwest China to formulate a reasonable urban development system and improve their urban competitiveness.

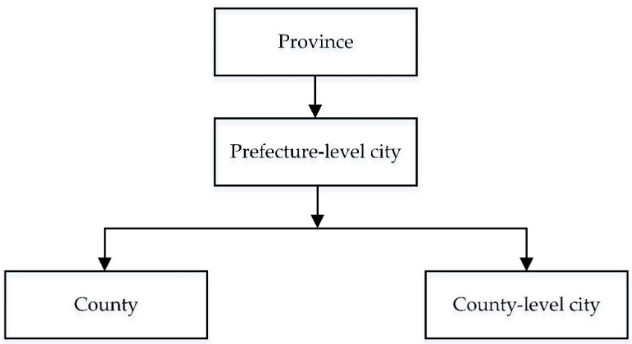

Figure 1. System of the city governing county.

2. Materials and Methods

2.1. Methods

2.1.1. DEA Model

Charnes et al. [16] first proposed the DEA model in 1978. The DEA is a method for measuring the efficiency of decision-making unit (DMU) [17]. The DEA judges the effectiveness of DMU by a mathematical programming model. Macmillan [18] pointed out earlier that the DEA model can be used to evaluate regional input–output behavior. Charnes [19] clearly pointed out that since a city is a complex input–output system, urban efficiency is the most suitable use of the DEA model to evaluate. Therefore, we selected the DEA model to measure the urban efficiency of cities in Northwest China. The DMUs of this study are the prefecture-level cities in Northwest China. The DEA is divided into the Charnes, Cooper, and Rhodes (CCR) model with the assumption of constant returns to scale and the Banker, Charnes, and Cooper (BCC) model with the assumption of variable returns to scale [20]. The analysis procedure is that there are n DMUs whose input and output vectors are as follows:

$$X_j = \left(x_{1j}, x_{2j}, \ldots, x_{mj}\right)^{\mathrm{T}} > 0,\ j = 1, 2, \ldots, n, \tag{1}$$

$$Y_j = \left(y_{1j}, y_{2j}, \ldots, y_{sj}\right)^{\mathrm{T}} > 0, j = 1, 2, \ldots, n, \tag{2}$$

where m represents the number of input indicators, and s represents the number of output indicators. Based on Formulas (1) and (2), the constraint equations of the CCR model are established as follows:

$$\text{s.t.}\begin{cases} \min\theta = \theta_0 \\ \sum_{j=1}^{n} X_j\lambda_j + s^- = \theta X_0 \\ \sum_{j=1}^{n} Y_j\lambda_j - s^+ = Y_0 \\ \lambda \geq 0;\ j = 1, 2, \ldots, n; s^+ \geq 0; s^- \geq 0 \end{cases}, \tag{3}$$

Based on this, constrained equations of the BCC model can be obtained by adding the constraint condition $\sum_{j=1}^{n} \lambda_j = 1$. According to different orientations, the DEA model is divided into input-oriented (pursuing input minimization under given output) and output-oriented (pursuing output maximization under given input) [21]. The results of the DEA include comprehensive efficiency, technical efficiency, scale efficiency, and returns to scale. Comprehensive efficiency reflects the allocation, utilization, and scale agglomeration efficiency of factor resources. Technical efficiency reflects the allocation and utilization efficiency of factor resources. Scale efficiency reflects the scale agglomeration efficiency of factor resources [22]. The range of comprehensive efficiency, technical efficiency, and scale efficiency are all between (0,1). The higher the value is, the higher the efficiency. The product of technical efficiency and scale efficiency is comprehensive efficiency. Returns to scale are divided into three cases: increasing returns to scale (IRS), constant returns to scale (CRS), and decreasing returns to scale (DRS).

2.1.2. Malmquist Model

The Malmquist model is based on DEA and calculates the input–output efficiency by the ratio of distance function [23]. Malmquist index divides TFP change into comprehensive efficiency change (subdivided into technical efficiency change and scale efficiency change) and technical change [24]. The formula is as follows:

$$M_{\mathrm{v,c}}^{t,t+1} = \frac{D_{\mathrm{v}}^{t+1}(x_i^{t+1}, y_i^{t+1})}{D_{\mathrm{v}}^{t}(x_i^{t}, y_i^{t})} \times \left[\frac{D_{\mathrm{v}}^{t}(x_i^{t}, y_i^{t})}{D_{\mathrm{c}}^{t}(x_i^{t}, y_i^{t})} \Big/ \frac{D_{\mathrm{v}}^{t+1}(x_i^{t+1}, y_i^{t+1})}{D_{\mathrm{c}}^{t+1}(x_i^{t+1}, y_i^{t+1})}\right] \times \left[\frac{D_{\mathrm{c}}^{t}(x_i^{t}, y_i^{t})}{D_{\mathrm{c}}^{t+1}(x_i^{t}, y_i^{t})} \Big/ \frac{D_{\mathrm{c}}^{t}(x_i^{t+1}, y_i^{t+1})}{D_{\mathrm{c}}^{t+1}(x_i^{t+1}, y_i^{t+1})}\right] \tag{4}$$

where (x_i^t, y_i^t) and $\left(x_i^{t+1}, y_i^{t+1}\right)$ are the input–output vectors of the No. i DMU in the period t and $t + 1$ respectively. $D^t(x_i^t, y_i^t)$ and $D^{t+1}\left(x_i^{t+1}, y_i^{t+1}\right)$ are the distance functions of production points in the period t and $t + 1$, respectively. Subscript with v is a case of variable returns to scale, while subscript with c is a case of constant returns to scale. The three items on the right side of the formula are the technical efficiency change, scale efficiency change, and technical change under the condition of variable returns to scale. All the figures are taken as reference by 1, representing an increase of more than 1, and a decrease of less than 1.

2.2. Data Collection and Processing

The connotation of urban efficiency is rich, focusing on the interaction, differences, and coordination among urban operation elements [25]. The DEA model assumes that input and output occur at the same time, and the data of DMU can be measured quantitatively. Therefore, according to the principles of systematization, comparability, feasibility, representativeness, and accessibility, the urban efficiency evaluation system of cities in Northwest China is established, while avoiding the strong linear relationship between indicators. The input indicators of urban efficiency should fully reflect the resource allocation of urban production factors. According to the classification of factors of production in economics and considering the importance of science and education and information in modern cities, five factors of production reflecting the characteristics of urban land, capital, labor, science, and education and information are selected as the input indicators of urban efficiency. Urban built-up area is selected as the indicator of land. The scope of built-up area generally refers to the area covered by the outline of built-up area, which is the scope of actual construction land in a city. Urban built-up area can reflect the urban construction and development in the geographical distribution. In particular, land is the carrier of urban operation. In the case of scarcity of land resources, as an input factor, land can fully reflect the unique constraint in urban operation [26]. Fixed assets investment is selected as the indicator of capital. Fixed assets investment is the workload of building and purchasing fixed assets in monetary terms. Fixed assets investment can reflect the scale of capital investment in production activities. Total number of employees is selected as the indicator of labor. Total number of employees is the total number of industrial personnel in the first, second, and third industrial units divided by industry. Total number of employees can reflect the amount of labor. Investment in R&D and education is selected as the indicator of science and education. Investment in R&D and education refers to the actual expenditure of the whole society for basic research, applied research, experimental development, and education during the statistical year. Investment in R&D and education can well reflect the investment of science and education of a city. Postal service volume is selected as the indicator of information. Postal service volume refers to the total amount of postal services used by postal departments in monetary terms, which can effectively reflect the information transmission in urban production activities. The output indicators of urban efficiency should fully reflect the results of the input of resources of urban production factors. Therefore, regional GDP, which includes both material production and non-material production, is selected as the output indicator. Theoretically, the real output of a city should be reflected by green GDP, which deducts the cost of economic loss from GDP. In addition, environmental factors should also be considered in the urban efficiency evaluation system. However, the DEA model is a method of calculating relative efficiency. If only the indicators of DMU are relatively consistent, there will be no big deviation in the results. Therefore, most of the existing studies still use the above indicators to establish the urban efficiency evaluation system of cities [1,27,28]. The urban efficiency evaluation system of cities in Northwest China is shown in Table 1.

Table 1. Urban efficiency evaluation system of cities in Northwest China.

Indicator Attribute	Variable	Indicator Meaning	Evaluation Purpose
Input	X_1	Urban built-up area	Land
	X_2	Fixed assets investment	Capital
	X_3	Total number of employees	Labor
	X_4	Investment in R&D and education	Science and education
	X_5	Postal service volume	Information
Output	Y_1	Regional GDP	Economic aggregate

Because of the lack of data in Haidong City, Turpan City, and Hami City, this study does not include them in the scope of evaluation. Therefore, the DMUs in this study are 30 prefecture-level cities in Northwest China except Haidong, Turpan, and Hami, which also meets the DEA model requirement that the number of DMU must be more than two times the number of input and output indicators [29]. According to Table 1, the data are selected from the China Urban Statistical Yearbook (2007–2016).

3. Results

3.1. Urban Efficiency Values of Cities in Northwest China

Using the input-oriented BCC model, the urban efficiency values of 30 prefecture-level cities in Northwest China from 2006 to 2015 are calculated by DEAP 2.1 software, as shown in Table 2.

Table 2. Urban efficiency values of cities in Northwest China from 2006 to 2015.

Decision-Making Unit (DMU)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average Value
Xi'an	0.804	0.905	0.879	1.000	0.953	0.909	0.833	0.901	1.000	0.493	0.8677
Tongchuan	0.666	0.564	0.726	0.633	0.904	0.798	0.775	0.861	0.798	1.000	0.7725
Baoji	0.848	0.860	0.626	0.791	0.716	0.694	0.728	0.803	0.898	0.694	0.7658
Xianyang	0.755	0.789	0.802	0.831	0.740	0.750	0.756	0.921	1.000	0.716	0.8060
Weinan	1.000	0.890	0.693	0.804	0.653	0.640	0.582	0.661	0.688	0.503	0.7114
Yan'an	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.813	0.9813
Hanzhong	0.985	1.000	0.890	0.950	0.775	0.772	0.783	0.823	0.668	0.619	0.8265
Yulin	0.681	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.9681
Ankang	0.783	0.550	0.510	0.582	0.476	0.541	0.664	0.750	0.577	0.680	0.6113
Shangluo	0.584	0.430	0.459	0.586	0.523	0.639	0.618	0.649	0.567	0.585	0.5640
Lanzhou	0.729	0.563	0.692	0.669	0.578	0.666	0.725	0.836	0.872	0.503	0.6833
Jiayuguan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.570	0.9570
Jinchang	1.000	1.000	1.000	0.916	0.919	0.799	0.762	0.884	0.916	0.391	0.8587
Baiyin	0.778	0.574	0.775	0.654	0.536	0.488	0.568	0.650	0.531	0.396	0.5950
Tianshui	0.708	0.525	0.564	0.591	0.487	0.435	1.000	0.558	0.418	0.397	0.5683
Wuwei	0.804	0.748	0.687	0.669	0.569	0.422	0.503	0.535	0.569	0.514	0.6020
Zhangye	0.711	0.644	0.768	0.788	0.572	0.477	0.554	0.717	0.531	0.516	0.6278
Pingliang	0.646	0.427	0.479	0.439	0.535	0.420	0.336	0.410	0.371	0.304	0.4367
Jiuquan	0.750	0.774	0.624	0.917	0.867	0.908	0.997	0.902	1.000	1.000	0.8739
Qingyang	0.774	0.747	0.672	0.847	0.562	0.565	0.858	0.770	0.764	0.740	0.7299
Dingxi	0.651	0.535	0.468	0.507	0.366	0.293	0.295	0.297	0.304	0.312	0.4028
Longnan	1.000	0.986	0.568	0.635	0.421	0.346	0.443	0.464	0.449	0.550	0.5862
Xining	0.715	0.620	0.680	0.881	0.591	0.644	0.585	0.756	0.784	0.527	0.6783
Yinchuan	0.582	0.552	0.699	0.766	0.941	0.833	0.960	0.968	1.000	0.424	0.7725
Shizuishan	0.602	0.697	0.727	0.822	0.674	0.743	0.740	0.891	1.000	0.840	0.7736
Wuzhong	0.787	0.633	0.509	0.736	0.702	0.495	0.525	0.556	0.591	0.667	0.6201
Guyuan	0.433	0.372	0.501	0.447	0.576	0.497	0.617	0.654	0.675	0.770	0.5542
Zhongwei	0.497	0.586	0.598	0.689	0.604	0.576	0.559	0.658	0.674	0.769	0.6210
Urumqi	1.000	0.735	1.000	0.757	0.688	1.000	0.740	0.835	0.777	0.666	0.8198
Karamay	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.996	0.9996
Average value	0.776	0.723	0.720	0.764	0.698	0.678	0.717	0.757	0.747	0.632	0.7212

3.2. Urban Efficiency Evaluation of Cities in Northwest China

It has been reported that the efficiency value is [0,0.6) inefficient, [0.6,0.8) low, [0.8,0.9) medium, [0.9,1) high, with 1 being efficient [30]. Referring to the efficiency standard, it can be seen from Table 2 that the overall urban efficiency of cities in Northwest China each year from 2006 to 2015 was in the range of [0.6,0.8), which was at the low level. The highest value was only 0.776 in 2006, as shown in Figure 2.

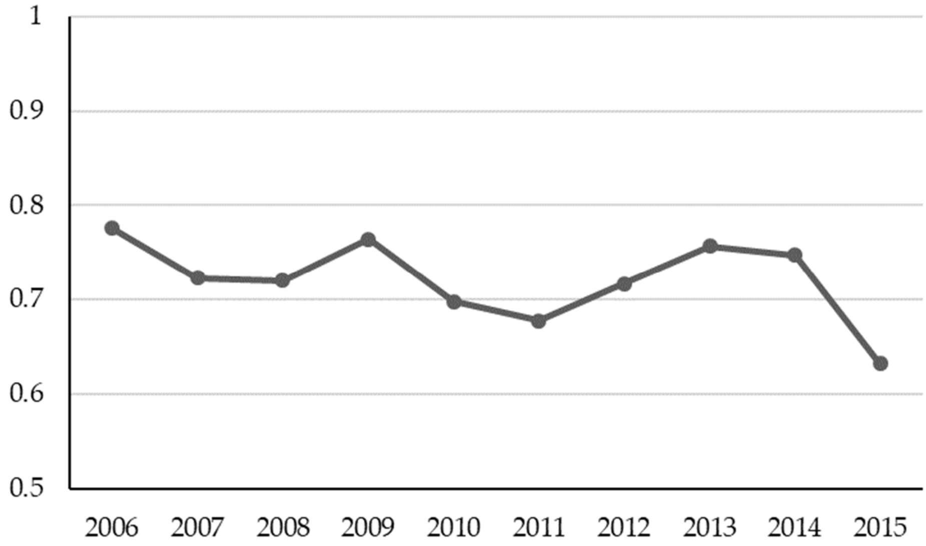

Figure 2. Overall urban efficiency of cities in Northwest China from 2006 to 2015.

From 2006 to 2015, the distribution of average urban efficiency in Northwest China was scattered. Based on the above efficiency classification method, average urban efficiency value of cities in Northwest China is clustered, as shown in Table 3.

Table 3. Classification of average urban efficiency value of cities in Northwest China.

Urban Efficiency	Meaning	DMU	Number
[0,0.6)	inefficient	Dingxi, Pingliang, Guyuan, Shangluo, Tianshui, Longnan, Baiyin	7
[0.6,0.8)	low	Wuwei, Ankang, Wuzhong, Zhongwei, Zhangye, Xining, Lanzhou, Weinan, Qingyang, Baoji, Yinchuan, Tongchuan, Shizuishan	13
[0.8,0.9)	medium	Xianyang, Urumqi, Hanzhong, Jinchang, Xi'an, Jiuquan	6
[0.9,1)	high	Jiayuguan, Yulin, Yan'an, Karamay	4
1	efficient		0

As can be seen from Table 3, the average urban efficiency of none of the 30 cities in Northwest China reached the efficient level from 2006 to 2015, and only four cities reached the high level, accounting for only 13.3% of the total DMU. However, there were 26 cities with medium, low or inefficient urban efficiency, accounting for 86.7% of the total DMU. Combined with Table 2, it was found that four cities including Jiayuguan, Yulin, Yan'an, and Karamay with high average urban efficiency are typical "resource-based" cities. Among them, Karamay is an important petroleum and petrochemical base in China. Yan'an is rich in tourism resources and has the reputation of "the museum of Chinese revolution". Yulin has abundant reserves of coal, natural gas, and oil. Jiayuguan is a typical "iron and steel city", rich in iron ore resources, which is a new industrial modernization regional central city. The average urban efficiency of these four cities from 2006 to 2015 were all above 0.95. In addition, there were as many as nine years of efficient urban efficiency. In the process of development, these cities could adapt to local conditions, fully relying on their own unique resource advantages, reasonable investment scale, and appropriate allocation of resources to achieve the city's "efficient" development. However, seven cities including Dingxi, Pingliang, Guyuan, Shangluo, Tianshui, Longnan, and Baiyin, with inefficient average urban efficiency, fell into the "universal poverty trap". These cities were densely populated by poor counties at the national level, short of capital for urban development, relatively inadequate scale of urban investment, and are in urgent need of measures such as policy tilt and financial support to get rid of poverty.

3.3. Returns to Scale of Cities in Northwest China

By using the input-oriented BCC model and DEAP 2.1 software, we calculated the returns to scale of cities in Northwest China from 2006 to 2015, as shown in Table 4.

Table 4. Returns to scale of cities in Northwest China from 2006 to 2015.

DMU	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Xi'an	drs	drs	drs	crs	drs	drs	drs	drs	crs	drs
Tongchuan	irs	irs	irs	irs	irs	irs	irs	irs	irs	crs
Baoji	drs	drs	drs	drs	drs	drs	drs	drs	irs	irs
Xianyang	drs	drs	drs	irs	drs	drs	drs	drs	crs	drs
Weinan	crs	drs	irs	irs	irs	irs	irs	irs	irs	irs
Yan'an	crs	crs	crs	crs	crs	crs	crs	crs	crs	irs
Hanzhong	drs	crs	irs	irs	irs	irs	irs	irs	irs	irs
Yulin	irs	crs	crs	crs	crs	crs	crs	crs	crs	crs
Ankang	irs	irs	irs	irs	irs	irs	irs	irs	irs	irs
Shangluo	irs	irs	irs	irs	irs	irs	irs	irs	irs	irs
Lanzhou	drs	drs	drs	drs	drs	drs	drs	drs	drs	irs
Jiayuguan	crs	crs	crs	crs	crs	crs	crs	crs	crs	irs
Jinchang	crs	crs	crs	irs	irs	irs	irs	irs	irs	irs
Baiyin	crs	irs	irs	irs	irs	irs	irs	irs	irs	irs
Tianshui	drs	irs	irs	irs	irs	irs	crs	crs	irs	irs
Wuwei	irs	irs	irs	irs	irs	irs	irs	irs	irs	irs
Zhangye	irs	irs	irs	irs	irs	irs	irs	irs	irs	irs
Pingliang	irs	irs	irs	irs	irs	irs	irs	irs	irs	irs
Jiuquan	irs	irs	irs	irs	irs	irs	irs	irs	crs	crs
Qingyang	irs	irs	irs	irs	irs	irs	irs	irs	irs	irs
Dingxi	irs	irs	irs	irs	irs	irs	irs	irs	irs	irs
Longnan	crs	irs	irs	irs	irs	irs	irs	irs	irs	irs
Xining	drs	drs	irs	irs	irs	irs	irs	crs	irs	irs
Yinchuan	drs	drs	drs	drs	drs	drs	drs	drs	crs	irs
Shizuishan	irs	irs	irs	irs	irs	irs	irs	irs	crs	irs
Wuzhong	irs	irs	irs	irs	irs	irs	irs	irs	irs	irs
Guyuan	irs	irs	irs	irs	irs	irs	irs	irs	irs	irs
Zhongwei	irs	irs	irs	irs	irs	irs	irs	irs	irs	irs
Urumqi	crs	drs	crs	drs	drs	crs	drs	drs	drs	drs
Karamay	crs	crs	crs	crs	crs	crs	crs	crs	crs	irs

According to Table 4, we identified the evolution trend of the returns to scale of cities in Northwest China, as shown in Figure 3.

We can see from Table 4 and Figure 3 that 190 of the 300 observation values from 2006 to 2015 were increasing returns to scale, accounting for 63.3% of the total, indicating that the development system of most cities in Northwest China were in the stage of increasing returns to scale, which is also consistent with the overall economic development pattern of the cities in Northwest China. The economic level of cities in Northwest China is still generally backward compared with those in the eastern and central regions. Most cities are still in the "growth" stage of increasing returns to scale. The scale of urban investment is relatively insufficient. The economies of scale have not yet formed. There is still a gap in the ability of cities to digest and absorb resources. Cities in Northwest China can further increase the scale of production to increase the urban efficiency. It is worth noting that the returns to scale of 11 cities including Tongchuan, Ankang, Shangluo, Wuwei, Zhangye, Pingliang, Qingyang, Dingxi, Wuzhong, Guyuan, and Zhongwei increased each year from 2006 to 2015, indicating that these cities lacked capital and facilities support for development. The scale of investment was insufficient, and it had long felled into the "universal poverty trap", thus restricting the improvement of urban efficiency, which can be confirmed by the inefficient or low level of the average urban efficiency of these cities from 2006 to 2015 in Table 3. Therefore, these cities should continue to strengthen the construction of urban scale, increase the investment of capital and the introduction of talent, realize the rational flow of capital, labor and other factors of production, promote the formation of urban economies of scale to achieve efficient urban development. Fifty-three observation values were decreasing returns to scale, accounting for 17.7% of the total. They were distributed in seven cities including Xi'an, Baoji, Xianyang, Lanzhou, Xining, Yinchuan, and Urumqi. It is not difficult to find that Xi'an, Lanzhou, Xining, Yinchuan, and Urumqi are the capital of the five northwest provinces in China. In addition, Xianyang belongs to the central city of Guanzhong-Tianshui Economic Zone, and Baoji is the sub-central city of Guanzhong-Tianshui Economic Zone. These cities were rich in resources and funds. However, the unreasonable allocation of resources or inappropriate investment of funds resulted in serious waste. These cities fell into the trap of "high input, high consumption, and low output" extensive economic development model, which also restricted the improvement of urban efficiency. The average urban efficiency of these cities from 2006 to 2015 was at the low or medium level, and they had not yet entered the "high efficiency" club. Fifty-seven observation values were constant returns to scale, mainly distributed in four cities including Yan'an, Yulin, Jiayuguan, and Karamay, accounting for 19% of the total. From 2006 to 2015, the four cities were in the stage of constant returns to scale for nine years. Their urban resources allocation was reasonable, and the capital investment was appropriate, thus achieving the "efficient" development of the city. The average of urban efficiency from 2006 to 2015 also entered the "high efficiency" club.

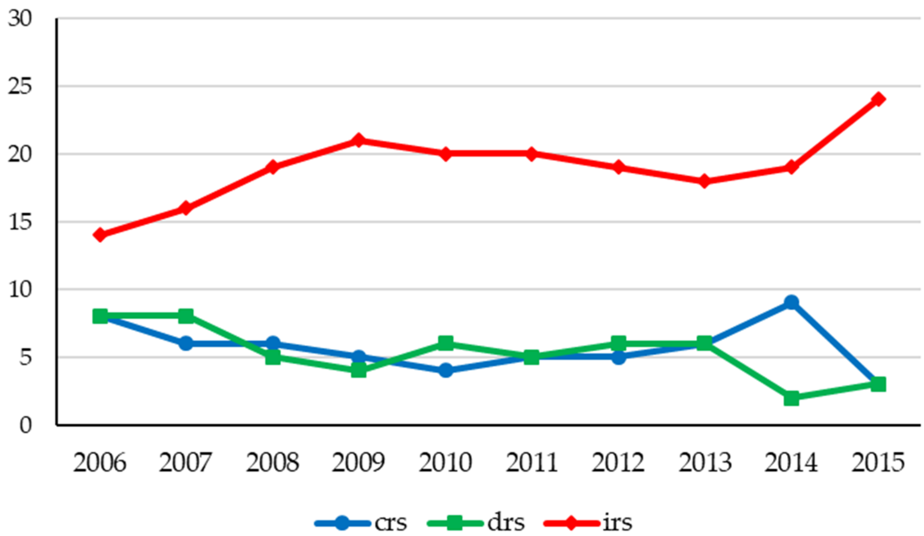

Figure 3. Evolution trend of the returns to scale of cities in Northwest China.

3.4. Spatiotemporal Evolution of Cities in Northwest China

The BCC model only measures the static value of urban efficiency, which cannot reflect the change of urban efficiency in a certain time period and its reasons. Malmquist index can track the change of urban efficiency in a certain time period, and its decomposition can clearly reflect the reasons for the change of urban efficiency. By using the DEAP 2.1 software and Malmquist model, the TFP and its decomposition of cities in Northwest China from 2006 to 2015 are calculated, as shown in Table 5.

Table 5. Overall **total factor productivity** (TFP) and its decomposition of cities in Northwest China from 2006 to 2015.

Period	Comprehensive Efficiency Change	Technical Change	Technical Efficiency Change	Scale Efficiency Change	TFP Change
2006–2007	0.917	1.048	0.975	0.941	0.961
2007–2008	1.003	1.015	1.006	0.998	1.018
2008–2009	1.066	0.933	1.065	1.001	0.995
2009–2010	0.903	1.097	0.987	0.915	0.990
2010–2011	0.958	1.145	0.987	0.971	1.097
2011–2012	1.066	0.943	1.009	1.056	1.005
2012–2013	1.065	0.877	1.023	1.041	0.934
2013–2014	0.974	1.080	1.002	0.972	1.052
2014–2015	0.843	1.083	0.885	0.953	0.914
Average value	0.974	1.021	0.992	0.982	0.995

According to Table 5, we identified the evolution trend of overall TFP and its decomposition of cities in Northwest China from 2006 to 2015, as shown in Figure 4.

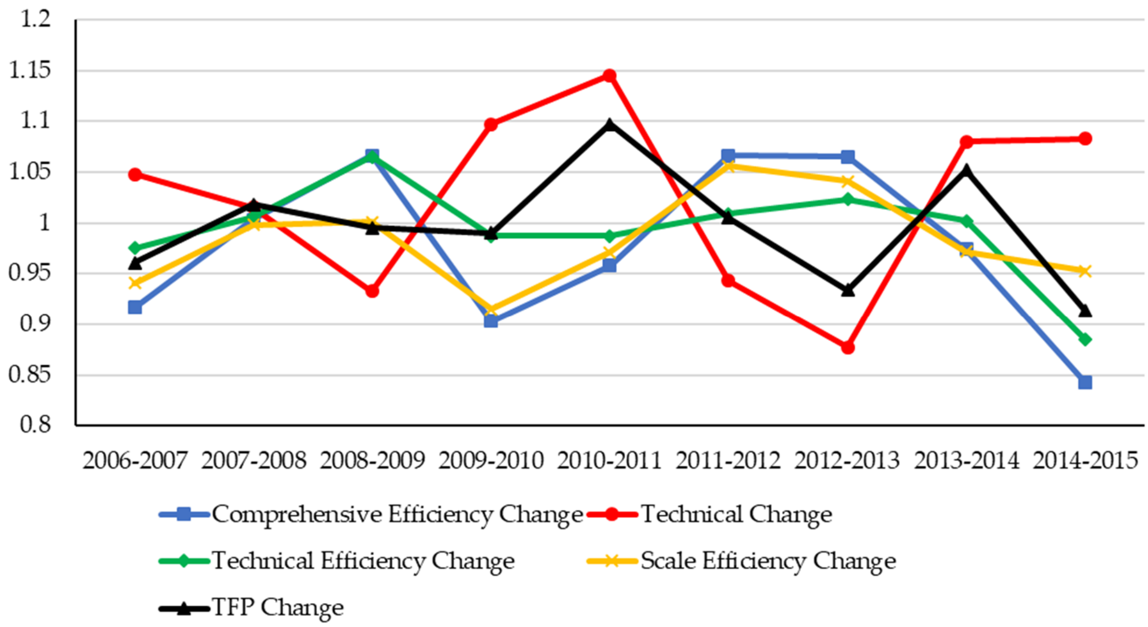

Figure 4. Evolution trend of overall TFP and its decomposition of cities in Northwest China.

We can see from Table 5 and Figure 4 that the average change of comprehensive efficiency of cities in Northwest China from 2006 to 2015 was 0.974, decreasing by 2.6%. The average change of technical efficiency was 0.992, decreasing by 0.8%. The average change of scale efficiency was 0.982, decreasing by 1.8%. The average change of technology was 1.021, increasing by 2.1%. The average change of TFP was 0.995, decreasing by 0.5%. Urban comprehensive efficiency showed a downward trend. Technical efficiency and scale efficiency also showed a downward trend, indicating that the whole northwest city was still in the extensive stage of technology use, and the resources and energy that could be reached by the existing technical level had not been fully tapped. Urban technology showed an overall upward trend, which also confirms the effect of technical innovation and introduction of cities in Northwest China since the implementation of the western development strategy. Based on the above analysis, the decline of TFP of cities in Northwest China was mainly caused by the decline of comprehensive efficiency caused by the decline of urban technical efficiency and scale efficiency, and the overall progress of urban technology could not make up for the shortfall caused by low efficiency. Therefore, the urban development of cities in Northwest China cannot be promoted only by technical progress, but also by tapping the energy level of existing technologies, in order to promote the efficiency progress with technical progress, and then promote the progress of TFP, in order to promote the city's health and sustainable development.

For each DMU, the urban TFP and its decomposition of 30 prefecture-level cities in Northwest China from 2006 to 2015 are shown in Table 6.

Table 6. TFP and its decomposition of cities in Northwest China from 2006 to 2015.

DMU	Comprehensive Efficiency Change	Technical Change	Technical Efficiency Change	Scale Efficiency Change	TFP Change
Xi'an	0.947	1.041	1.000	0.947	0.986
Tongchuan	1.046	0.952	1.000	1.046	0.997
Baoji	0.978	1.036	0.977	1.001	1.013
Xianyang	0.994	1.039	0.989	1.005	1.033
Weinan	0.927	1.035	0.941	0.984	0.959
Yan'an	0.977	0.974	0.991	0.986	0.952
Hanzhong	0.950	1.034	0.978	0.971	0.982
Yulin	1.044	1.131	1.043	1.001	1.180
Ankang	0.985	1.038	1.008	0.976	1.022
Shangluo	1.000	1.040	1.008	0.992	1.040
Lanzhou	0.960	1.001	0.937	1.024	0.960
Jiayuguan	0.939	0.925	1.000	0.939	0.869
Jinchang	0.901	1.035	1.000	0.901	0.932
Baiyin	0.928	1.037	0.986	0.941	0.962
Tianshui	0.938	1.006	0.988	0.949	0.944
Wuwei	0.951	1.038	0.999	0.952	0.988
Zhangye	0.965	1.030	0.997	0.968	0.994
Pingliang	0.920	1.040	0.998	0.921	0.957
Jiuquan	1.033	0.994	1.011	1.021	1.026
Qingyang	0.995	1.015	1.000	0.995	1.010
Dingxi	0.922	1.042	1.006	0.916	0.960
Longnan	0.936	1.026	1.000	0.936	0.960
Xining	0.967	1.050	0.968	0.999	1.015
Yinchuan	0.966	1.039	0.964	1.002	1.004
Shizuishan	1.038	1.053	1.043	0.995	1.093
Wuzhong	0.982	1.026	0.982	1.000	1.007
Guyuan	1.066	0.980	1.000	1.066	1.045
Zhongwei	1.050	1.033	1.000	1.050	1.085
Urumqi	0.956	0.995	0.957	0.999	0.951
Karamay	1.000	0.965	1.000	1.000	0.964
Average value	0.974	1.021	0.992	0.982	0.995

According to Table 6, we identified the evolution trend of TFP and its decomposition of cities in Northwest China from 2006 to 2015, as shown in Figure 5.

We can see from Table 6 and Figure 5 that the technical efficiency of six cities including Yulin, Ankang, Shangluo, Jiuquan, Dingxi, and Shizuishan increased from 2006 to 2015. Nine cities including Xi'an, Tongchuan, Jiayuguan, Jinchang, Qingyang, Longnan, Guyuan, Zhongwei, and Karamay remained unchanged, while the other 15 cities declined in technical efficiency. Nine cities including Tongchuan, Baoji, Xianyang, Yulin, Lanzhou, Jiuquan, Yinchuan, Guyuan, and Zhongwei improved urban scale efficiency, while two cities including Wuzhong and Karamay remained unchanged. The other 19 cities declined in urban scale efficiency. Only six cities including Tongchuan, Yulin, Jiuquan, Shizuishan, Guyuan, and Zhongwei improved their comprehensive efficiency. The other 24 cities decreased their comprehensive efficiency. Only 20% of the total cities improved their comprehensive efficiency. Too few cities with improved urban comprehensive efficiency also directly led to a decrease by 2.6% in the average change of overall urban comprehensive efficiency in Northwest China from 2006 to 2015. Combined with Table 3, it was found that the urban efficiency of cities in Northwest China was not only at the low level generally, but also showing a downward trend. Seven cities including Tongchuan, Yan'an, Jiayuguan, Jiuquan, Guyuan, Urumqi, and Karamay were decreased technically, and the remaining 23 cities were all improved technically, indicating that these 23 cities had made certain breakthroughs in technical introduction and reform. Thirteen cities including Baoji, Xianyang, Yulin, Ankang, Shangluo, Jiuquan, Qingyang, Xining, Yinchuan, Shizuishan, Wuzhong, Guyuan, and Zhongwei were TFP improved, while that of the other 17 cities decreased. Obviously, the overall improvement of urban technology promoted the improvement of TFP to a certain extent, but the overall excessive decline of urban comprehensive efficiency dragged on the improvement of TFP, resulting in the overall TFP of cities in Northwest China still decreasing by 0.5%. This shows that generally the urban development of cities in Northwest China was still in a dynamic but immature stage, and there were still some problems in the urban development mode. It is urgent to change the mode of economic growth, promote efficiency progress with technical progress, and then promote the progress of TFP. It is worth noting that Yulin was the only city which the technical efficiency, scale efficiency, comprehensive efficiency, technology and TFP had improved in all cities in Northwest China. Yulin's TFP had increased by 18%, and it was also the city with the largest increase in TFP in all cities in Northwest China. Yulin could give full play to its rich reserves of coal, natural gas, and oil resources, while paying attention to the effective excavation of technology, to achieve a comprehensive upgrading of technology and efficiency, thus promoting the city's rapid development. This development mode is worth learning from other cities.

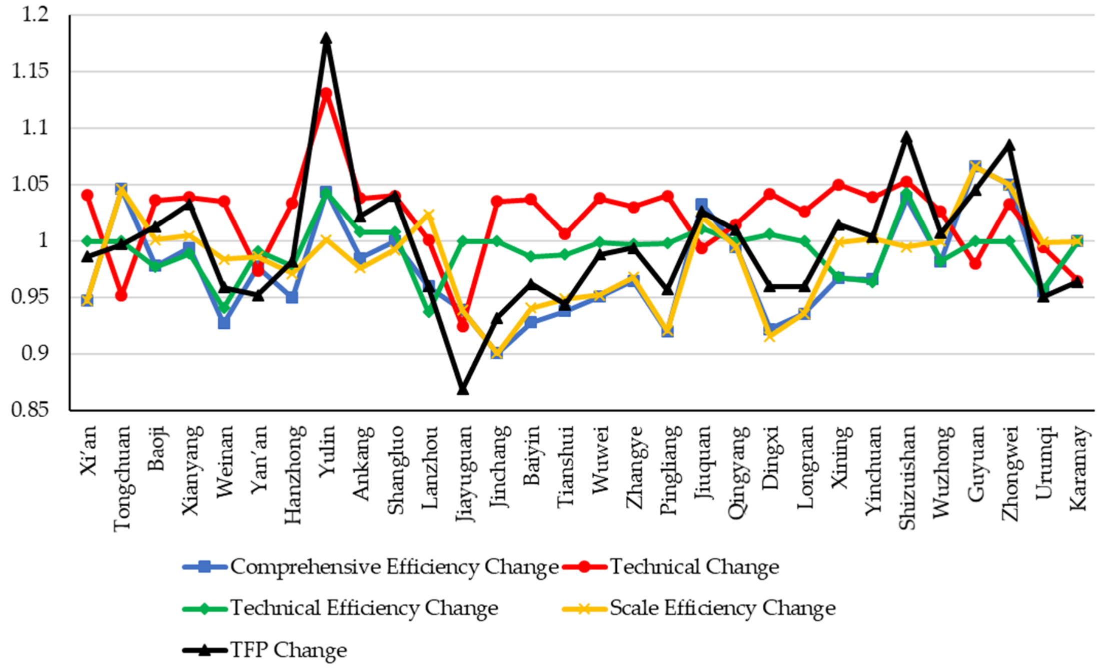

Figure 5. Evolution trend of overall TFP and its decomposition of cities in Northwest China.

4. Conclusions and Discussion

Based on the data of 30 prefecture-level cities in Northwest China from 2006 to 2015, urban efficiency is measured by DEA. Then the spatiotemporal evolution rule is identified by Malmquist model. The results illustrate that the overall average urban efficiency of cities in Northwest China each year from 2006 to 2015 was at the low level. Only Jiayuguan, Yulin, Yan'an, and Karamay reached the high average urban efficiency, while Dingxi, Pingliang, Guyuan, Shangluo, Tianshui, Longnan, and Baiyin were at the inefficient level. Most cities in Northwest China were still in the "growing" stage of increasing returns to scale. The scale of urban investment was relatively insufficient, and economies of scale had not yet formed. Cities with decreasing returns to scale were mainly distributed in the capital cities and the central and sub-central cities of Guanzhong-Tianshui Economic Zone with relatively abundant urban resources and capital. Cities with constant returns to scale were mainly distributed in four cities including Yan'an, Yulin, Jiayuguan, and Karamay with high efficiency. The overall comprehensive efficiency, technical efficiency, and scale efficiency of cities in Northwest China were not only low, but also showing a downward trend. The overall progress of urban technology had failed to make up for the shortfall caused by low efficiency, resulting in TFP decreasing by 0.5%.

The above conclusions imply a strong policy implication that the four resource-based cities with high urban efficiency including Jiayuguan, Yulin, Yan'an, and Karamay should continue to rely on their own resource advantages, constantly attract funds and technology, promote the diversification of industrial structure, and achieve a steady increase in urban efficiency through rational development and utilization of resources. The seven cities with inefficient efficiency including Dingxi, Pingliang, Guyuan, Shangluo, Tianshui, Longnan, and Baiyin should take the key poverty alleviation projects as the platform, bundle and centralize the financial funds, get rid of poverty through precise and effective poverty alleviation, and constantly improve the urban efficiency. The provincial capitals of the five northwest provinces and the central and sub-central cities of Guanzhong-Tianshui Economic Zone should be brought into full play to cultivate the central nodes of the underdeveloped areas in the northwest, and the radiation of the central cities to the surrounding cities should be strengthened in order to break the "universal poverty trap". The cities in Northwest China should strive to improve the allocation and utilization of factor resources in the process of development, in order to enhance the urban technical efficiency. At the same time, the cities in Northwest China should optimize the urban structure, improve the scale of factor resources concentration level, in order to enhance the urban scale efficiency, and ultimately achieve the promotion of urban comprehensive efficiency. In addition, the cities in Northwest China should grasp the policy opportunity of the western development, carry on the technical innovation and introduction unceasingly, promote the continuous upgrading of the urban production technology, drive the efficiency progress by the technical progress, and finally realize the progress of the urban TFP.

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