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Research on the Influence of Different Types of Industrial Agglomeration on Ecological Efficiency in Western China

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Abstract: In this study, we used the super-efficient global slacks-based measure of directional distance functions (SBM-DDF) model to evaluate the ecological efficiency and changes in 12 provinces in western China between 2006 and 2020. We then used two linear and nonlinear regression models to analyze in detail the influence mechanisms of different industrial agglomeration forms on the local ecological efficiency. The results show the following: the overall ecological efficiency in the western China region shows a dynamic upward trend. The ecological efficiency of western China is quite different, with the overall characteristics of "high in south and low in north", "slow in south and fast in north", and "three-way polarization." Different types of industrial agglomeration in western China have obvious differences in terms of ecological efficiency. Both specialized agglomeration and unrelated diversification agglomeration in western China have a significant negative impact on ecological efficiency. The relationship between agglomeration-related diversity and ecological efficiency in the western region is of the "U" type. This study's results can also provide a reference for the formulation of industrial transformation and ecological protection policies in the implementation process of the second round of the western development strategy. This study thus has fundamental significance in the promotion of the second round of western development work.

Keywords: industrial agglomeration; ecological efficiency; SBM-DDF; western China

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1. Introduction

Most provinces and cities in western China have experienced two large-scale industrial migrations in China's economic history: the construction of the third front in 1964 and western development in 2000. During these two periods, the country has built resource-based industrial projects, including the military, petroleum, steel, metallurgy, chemical, and machinery industries, in many provinces and cities in the western region, which have formed the foundation of industrial development in western China today [1,2]. As the above industries have a great dependence on natural resources, they show obvious industrial agglomeration phenomena. After decades of development, the contradiction between environmental pollution caused by traditional resource-based industries in western China and local ecological security has become more and more intense [3,4]. Faced with increasingly severe ecological environment problems, it is necessary to carry out a mechanism analysis of the influence of different industrial agglomeration forms on ecological efficiency while scientifically measuring the ecological efficiency in western China. This study is of fundamental significance for the promotion of the second round of western development work, which sets ecological protection as a priority.

As a form of spatial organization, industrial agglomeration accelerates the flow and sharing of elements between the enterprises within the cluster, and also promotes knowledge creation and dissemination among the enterprises in the cluster, thus producing a

significant external economy for the enterprises in the cluster [5,6]. Marshall first proposed that the agglomeration externality comes from the labor pool, the input share, and the knowledge spillover [7]. However, because excessive agglomeration will also cause negative externalities such as congestion effect, the current mainstream view on industrial agglomeration and emission reduction is that the relationship between the two is nonlinear. According to the theory of "cluster life cycle", different agglomeration stages show different externality characteristics, and different externalities have different effects on emission reduction [8–12]. Specifically, industrial agglomeration will not only bring positive externalities, such as resource sharing and technology spillover [13–17], but also may affect the production behavior of local enterprises due to the "competition effect" and the "crowding effect", thus producing negative externalities such as pollution agglomeration and resource competition [18–20]. According to the differences of forms, industrial agglomeration can be subdivided into specialization, related diversification, and irrelevant diversification [21]. Specialization refers to the high convergence of enterprises in the same industry within a specific region [7]. Related diversification refers to the phenomenon where enterprises in different industries with strong levels of technology correlation gather in a specific region, whereas irrelevant diversification refers to the phenomenon where enterprises in different industries with weak levels of technology correlation gather in a specific region [22].

Ecological efficiency was first introduced into the economic field by the German scholar Schaltegger. The basic connotation of ecological efficiency is to reduce the negative impact of economic growth on the ecological environment through the efficient utilization of regional resource elements [23–26]. It is generally defined as the following: ecological efficiency is equal to the ratio of economic output to the total resource consumption and total environmental impact. Ecological efficiency shows the comprehensive efficiency of the ecological resources in the economy, resources, and environment required to meet the needs of human development. This index effectively makes up for the traditional defect of relying solely on the increase in factors, quantity expansion, and scale improvement to achieve economic growth [27].

At present, ecological efficiency evaluation has become an important means to analyze the relationship between the regional economy and ecological environment. The evaluation methods of ecological efficiency mainly include the data envelopment analysis (DEA) model, ecological footprint, the technique for order preference by similarity to an ideal solution (TOPSIS), and the hierarchical analysis method [28–32]. The DEA model has become a more commonly used model with its advantages of less evaluation indicators, accurate evaluation results, and less loss of index original information. Fukuyama combines the slacks-based measure (SBM) and the directional distance function (DDF) to form the slacks-based measure of directional distance functions (SBM-DDF) model [33]. It not only solves the problem of the DDF model in measuring the input or output relaxation, but also eliminates the irrationality of the traditional DEA model to take pollutant discharge as an input variable, which is a measurement method consistent with the reality [34].

Although previous studies have focused on the role of industrial agglomeration in the resource-based industry transformation, as well as the relationship between industrial agglomeration and ecological environment, other studies in energy conservation and emissions reduction, technological progress, environmental carrying capacity, and so on, have failed to further explore the influence of different types of industrial agglomeration on the ecological efficiency mechanism. To this end, in this study, we used the super-efficiency global SBM-DDF model to evaluate the ecological efficiency and change situation of 12 provinces in western China from 2006 to 2020 and analyzed the influence mechanism of different industrial agglomeration forms on the local ecological efficiency by using linear and nonlinear regression models.

We specifically discuss the following questions in depth. What is the status quo of industrial agglomeration in western China? What is the ecological efficiency in western China? What is the relationship between industrial agglomeration and ecological efficiency in western China? A systematic study of the above problems will help us to gain a better

understanding of the characteristics of industrial agglomeration and the development trends of ecological efficiency in western China. It will also help to clarify the internal relationship between industrial agglomeration and ecological efficiency in western China. There are three main innovations in this paper. (1) In this paper, we considered the heterogeneity of geographical factors in western China; therefore, we analyzed the southern and northern parts of the region separately. (2) This study discusses the impact of the three industrial agglomeration modes on ecological efficiency, respectively, which is more comprehensive than research focusing only on the single industrial agglomeration form. (3) We chose the SBM-DDF model to partly solve the calculation error problem by using the DEA model and the DDF model only.

The conclusion of this article will provide a supplementary contribution to the relevant research on industrial agglomeration and ecological protection in western China, and it will also provide corresponding guidance and reference for the formulation of industrial and ecological policies in other resource-based regions.

2. Materials and Methods

2.1. Study Area

Western China includes 12 provincial administrative regions, namely the 5 southwest provinces (Chongqing, Sichuan, Yunnan, Guizhou, and Tibet), the 5 northwest provinces (Shaanxi, Gansu, Qinghai, Xinjiang, and Ningxia), and Inner Mongolia and Guangxi (Figure 1). Western China varies greatly from eastern China and central China in terms of natural conditions, economic conditions, and social conditions, which are mainly reflected in the following aspects. (1) Western China has a vast land area, with a land area of 6,7816,600 square kilometers, far exceeding eastern China (1294 million square kilometers) and central China (11,028 million square kilometers). (2) The population in western China is relatively small. In 2021, the population of western China was 382.81 million, much lower than eastern China (563.72 million) and slightly higher than central China (364.69 million). (3) The GDP of western China is relatively low. In 2021, the GDP of western China was 23.97 trillion yuan, much lower than that of eastern China (59.22 trillion yuan) and central China (25.01 trillion yuan), and Chongqing is the only provincial government region with per capita GDP exceeding the national level. (4) The proportion of secondary industry in western China is still relatively high. In 2021, the proportion of secondary industry in western China was 40.27%, higher than in eastern China (36.99%) and slightly lower than in central China (41.97%). However, the proportion of heavy industry in western China is far greater than that of central China. In addition to the above characteristics, coal, oil, and natural gas in western China account for 46.30%, 41.8%, and 83.22% of national proportions, respectively. In addition, the reserves of a variety of colored metals also rank among the top in China [3,4,35]. Moreover, the ecosystem diversity of western China is clear, including 5 typical ecological zones: semi-arid farming and pastoral zone, oasis edge zone, hot and dry river valley, limestone mountain area, and the Qinghai–Tibet Plateau [36].

2.2. Model

2.2.1. Method for Measuring the Degree of Industrial Agglomeration

In this study, the Krugman specialization index was calculated using the industrial sales output index to measure the degree of industrial specialization [37]. The formula is as follows:

$$spe = \sum_{k=1}^{n} \left| E_{ik}/E_i - E_k/E \right| \quad (1)$$

spe indicates the degree of specialization; E_{ik}/E_i *i* indicates the share of the *k* industry sales output value in the regional industrial sector; and E_k/E indicates that the sales value of k industries in the national industrial sector accounts for the share of the total industrial sales. The *spe* threshold is (0,2); the greater the value, the higher the degree of specialization, and the lower the value, the lower the degree of specialization.

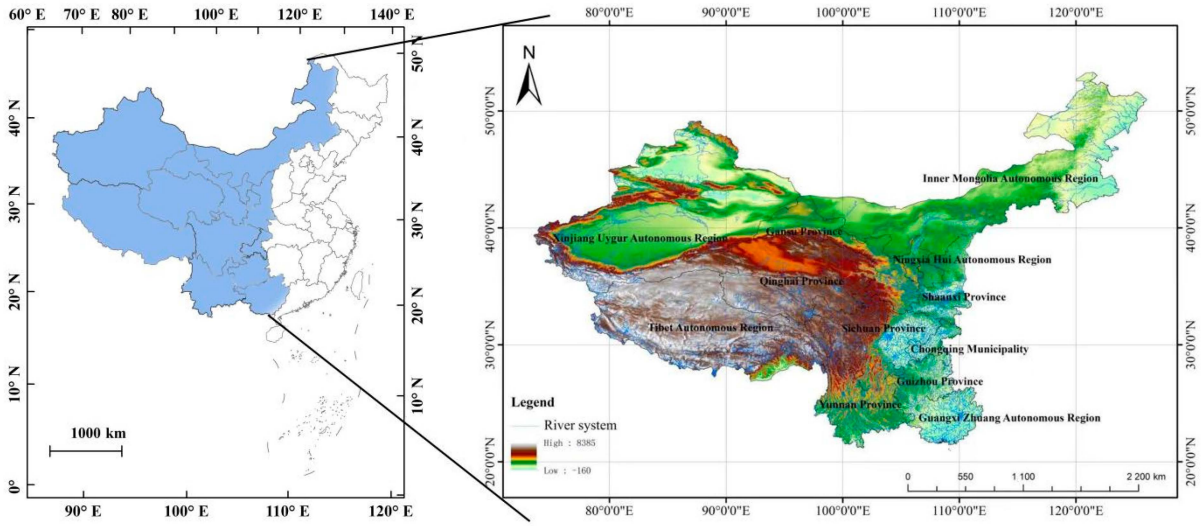


Figure 1. Western China (source: author's collation based on this article).

Based on the input/output relationship and the technical distance between different industries, the entropy index method was used to measure the correlation diversification and independent diversification [22]. Next, referring to the method of Pan et al., 35 double-digit industries in the industrial sector were divided into 4 categories, and the entropy index of employees in large industries was used to express independent diversification [38]. The weighted sum of the entropy index of the employees in the subdivision industries indicated related diversification. The formula for this is as follows:

$$ud = \sum_{k=1}^{N} V_k \ln(\frac{1}{V_k}) \tag{2}$$

$$V_k = \sum_{l=1}^{M_k} V_l \tag{3}$$

$$rd = \sum_{k=1}^{N} V_k H_k \tag{4}$$

$$H_k = \sum_{l=1}^{M_k} \frac{V_l}{V_k} \ln(\frac{1}{V_l/V_k}) \tag{5}$$

rd and *ud* indicate the degree of related diversification and unrelated diversification, respectively; *k* indicates large industries according to the input/output relationship and technical distance; *l* indicates subdivision industries in large industries; *N* indicates the number of subdivision industries in large industries; M_k indicates the *k* number of subdivisions in large industries; and *V* indicates the proportion of employees to the total number of industrial employees. The greater the value of the rd threshold (0,1.37), the stronger the degree of correlation diversification. The greater the value of the urd threshold (0,2.69), the higher the degree of independent diversification.

2.2.2. Measurement Method of Ecological Efficiency

In this study, SBM and DDF were combined to form an SBM-DDF model for the industrial ecological efficiency measurement [33,34,39]. Suppose the DMU_j represents a decision unit with *J* decision units, each DMU uses *M* inputs $x = (x_i, x_2, \cdots, x_m) \in R_M^+$ to produce *N* expected output $c = (c_1, c_2, \cdots, c_n) \in R_N^+$ and Q non-expected output $d = (d_1, d_2, \cdots, d_q) \in R_Q^+$, then the product may be set as follows:

$$P^t(x^t) = \left\{ (c^t, d^t) : \sum_{j=1, j\neq k}^{J} \lambda^t c_{jn}^t \geq c_{kn}^t, \forall_n; \sum_{j=1, j\neq k}^{J} \lambda_j^t d_{jq}^t \leq d_{kq}^t, \forall_q; \sum_{j=1, j\neq k}^{J} \lambda_j^t x_{jm}^t \leq x_{jm}^t, \forall_m; \sum_{j=1, j\neq k}^{J} \lambda_j^t = 1, \lambda_j^t \geq 0, \forall_j \right\} \quad (6)$$

λ_j^t represents the weight of the observed value of the decision unit—the ownership weight is nonnegative, and the sum is 1, indicating that the scale reward is variable. To improve the cross-period comparability of industrial ecological efficiency during the study period, the global production possible set $P^G = \left\{ P^1 \cup \cdots \cup P^T \right\}$ was obtained using the full-period production possible set construction [40]. The global SBM-DDF model considering super efficiency is as follows:

$$\begin{aligned} &\overline{S_V^t}(x^{i,j}, c^{i,j}, d^{i,j}, e^x, e^c, e^d) = \tfrac{1}{2}\max\left[\tfrac{1}{N} \sum_{m=1}^{M} \tfrac{s_m^x}{e_m^x} + \tfrac{1}{N+K} \left(\sum_{n=1}^{N} \tfrac{s_n^c}{e_n^c} + \sum_{k=1}^{K} \tfrac{s_q^d}{e_q^d} \right) \right] \\ &s.t. \sum_{j=1, j\neq k}^{J} \lambda_j^t x_{jm}^t + s_m^x \leq x_{km}^t, \forall_m \\ &\quad \sum_{j=1, j\neq k}^{J} \lambda_j^t c_{jn}^t - s_n^c \geq c_{kn}^t, \forall_n \\ &\quad \sum_{j=1, j\neq k}^{J} \lambda_j^t d_{jq}^t + s_q^d \leq d_{kq}^t, \forall_q \\ &\quad \sum_{j=1, j\neq k}^{J} \lambda_j^t = 1 \\ &\quad s_m^x \geq 0, \forall_m; s_n^c \geq 0, \forall_n; s_q^d \geq 0, \forall_q; \lambda_j^t \geq 0, \forall_j \end{aligned} \quad (7)$$

x, c, and d represent the input, expected output, and non-expected output, respectively; λ represents the parameters to be evaluated; $(x^{i,j}, c^{i,j}, d^{i,j})$ represent the input and output vectors for the j DMU of the period; (e^x, e^c, e^d) mean that the input and output expansion values are positive direction vectors; and (s_n^x, s_m^c, s_q^d) represent the input and output relaxation vectors.

From the perspective of input–output, this study selected natural resource consumption, such as water, land, and energy necessary for industrial production, and social-economic factors, such as labor and capital, as input indicators. The selected economic value created by industrial activities is the expected output, and the selected pollutant emissions brought by industrial activities are the non-expected output (Table 1).

Table 1. Quantitative measurement index of ecological efficiency.

Index Type	Index Name	Index Explanation	Author (s)
Input indicator	Water consumption	Total industrial water	Bakirtas and Cetin (2017) [41] Kocak and Sarkgunesi (2018) [42] Zhou et al. (2019) [43]
	Land consumption	Area of industrial construction land	
	Energy consumption	Total industrial energy consumption	
	Labor input	Number of industrial employees	
	Capital input	Industrial fixed assets	
Output indicator	Economic value creation	Industrial value added	Tian et al. (2021) [26] Evgenii (2017) [44] Tang and Meng (2021) [45] Yang et al. (2022) [46] Zhang et al. (2022) [47]
	Wastewater discharge	COD emissions industrial wastewater	
		Ammonium nitrogen emissions from industrial wastewater	
	Waste gas discharge	SO_2 emissions from industrial emissions	
		Smoke (dust) emissions from industrial waste gas	
	Solid waste discharge	Emissions from industrial solid waste	

2.2.3. Panel Tobit Regression Model

Industrial ecological efficiency calculated based on the global SBM-DDF model was greater than 0, and therefore Stata 15.0 software was used to analyze the impact of industrial agglomeration on the ecological efficiency Tobit regression model [21]. The results of a

likelihood ratio (LR) showed a significant P-value, and thus the random effect panel Tobit model was used to conduct regression analysis of industrial agglomeration and ecological efficiency in resource-based regions in western China. The linear and nonlinear propositions between them were examined separately. The regression model is as follows:

$$Y_{it} = \alpha + \mu_{it} + \vartheta X_{it} + \varepsilon_{it} \quad (8)$$

Y_{it} is the explained variable, which indicates the industrial ecological efficiency of the t period in i provinces;μ_{it} is the function form of the explanatory variable; α and ε_{it} are the intercept terms and random disturbance terms, respectively; and X_{it} is a control variable. In this study, μ_{it} can be(λspe), $(\lambda spe + \phi spe^2)$, (λrd), $(\lambda rd + \phi rd^2)$, (λud), or $(\lambda ud + \phi ud^2)$, resulting in 6 regression models (indicated as models 1–6).

In addition to industrial agglomeration, other factors affecting ecological efficiency are regional development level, energy structure, openness, technological progress, environmental regulation intensity, and marketization degree [48,49]. The ratio of per capita GDP (pgdp) coal consumption to total energy consumption (estur), Chinese and foreign investment in industrial enterprises (open), R&D funds, and industrial added value of industrial enterprises above the previous period (tech); the ratio of completed investment in industrial pollution control to industrial added value (envir); and the ratio of main business income of non-state-owned enterprises to the main business income of enterprises above scale (mark) were all measured and included in the regression model in the form of control variables.

2.3. Sources of Data

Due to the limited availability of data and the consistency of the statistical caliber, the period chosen for this study was 2006–2020. The data were obtained from the China Statistical Yearbook [50], China Industrial Statistics Yearbook, China Environmental Statistics Yearbook [51], and 12 provinces (districts) in western China [52–62]. The stock of industrial fixed assets was estimated using the perpetual inventory method, and the depreciation rate [63], based on Shan's study, was set at 11.0. The industrial added value was converted into a comparable price based on the year 2000, eliminating the influence of price change factors [64].

3. Results

3.1. Industrial Agglomeration Status in Western China from 2006 to 2020

Based on formulas (1)–(5), the three industrial agglomeration conditions in western China were measured. Specific results are shown in Table 2.

By observing Table 2, we can see that, from 2006 to 2020, industrial specialization in western China generally declined dynamically, with the average value decreasing from 0.82 to 0.74. Moreover, the average value of industrial specialization in the northwest is higher than the average value in the southwest. The change trend of average industrial specialization in the northwest and southwest regions is basically the same; however, the change range in the southwest regions is even smaller. From a provincial perspective, Xinjiang, Shaanxi, and Gansu showed the most significant declines, with 0.22, 0.21, and 0.17 declines, respectively. The degree of industrial-related diversification in western China roughly shows a "U"-type change trend, where it declines first and then rises. The average fluctuation of industrial-related diversification first decreased from 1.43 in 2006 to 1.38 in 2011, and finally it gradually recovered to 1.45 in 2020. The average of industry-related diversification in the northwest is higher than the average in the southwest. From the perspective of the provinces, Guangxi saw the biggest increase in industry-related diversification, and its measurement result increased by 0.15. The average value of unrelated industrial diversification in western China fluctuated around 1.15, but the average value in northwest China fluctuated more. From the perspective of the provinces, the most obvious growth rate of industry-irrelevant diversification was in Xinjiang, where the degree of industry-irrelevant diversification increased by 0.10. In contrast, the most

obvious decline in industry-unrelated diversification was in Gansu province, where the degree of industry-independent diversification was reduced by 0.11. By observing the empirical results, we found the measure of industrial specialization concentration in Tibet fluctuated slightly around 0.04. However, the degree of industrial-related diversification and non-related diversification in Tibet was less than 0.005.

Table 2. Industrial agglomeration in western China from 2006 to 2020.

Type	Region	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Specialization	Chongqing	0.83	0.82	0.82	0.81	0.80	0.82	0.81	0.77	0.79	0.80	0.80	0.81	0.81	0.82	0.83
	Sichuan	0.82	0.83	0.83	0.85	0.86	0.82	0.80	0.79	0.78	0.78	0.79	0.79	0.78	0.78	0.80
	Shanxi	0.71	0.73	0.75	0.73	0.70	0.69	0.66	0.64	0.61	0.53	0.53	0.51	0.50	0.50	0.52
	Yunnan	0.97	0.98	0.92	0.91	0.89	0.88	0.86	0.85	0.84	0.84	0.85	0.86	0.86	0.87	0.86
	Guizhou	0.89	0.89	0.86	0.87	0.88	0.90	0.89	0.86	0.83	0.72	0.75	0.77	0.80	0.82	0.82
	Guangxi	0.83	0.84	0.82	0.84	0.85	0.83	0.81	0.80	0.79	0.78	0.78	0.77	0.78	0.79	0.79
	Gansu	0.88	0.89	0.86	0.87	0.88	0.90	0.89	0.86	0.83	0.72	0.72	0.71	0.71	0.72	0.71
	Qinghai	1.15	1.13	1.09	1.08	1.06	1.05	1.03	1.00	1.00	0.99	0.97	0.97	0.96	0.96	0.97
	Ningxia	0.85	0.86	0.84	0.83	0.83	0.86	0.89	0.93	0.92	0.93	0.93	0.92	0.91	0.91	0.93
	Tibet	0.04	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04
	Xinjiang	1.10	1.03	1.01	1.00	0.92	0.94	0.91	0.83	0.82	0.83	0.81	0.80	0.79	0.79	0.81
	Inner Mongolia	0.82	0.82	0.82	0.81	0.80	0.82	0.81	0.77	0.79	0.80	0.80	0.79	0.80	0.80	0.82
	Mean	0.82	0.82	0.80	0.80	0.79	0.80	0.78	0.76	0.75	0.73	0.73	0.73	0.73	0.73	0.74
Related diversification	Chongqing	1.58	1.58	1.60	1.61	1.61	1.58	1.58	1.57	1.59	1.61	1.63	1.63	1.64	1.65	1.66
	Sichuan	1.55	1.56	1.59	1.61	1.62	1.62	1.62	1.63	1.63	1.64	1.64	1.65	1.66	1.65	1.66
	Shanxi	1.77	1.78	1.79	1.79	1.81	1.73	1.74	1.83	1.83	1.83	1.82	1.82	1.81	1.81	1.83
	Yunnan	1.63	1.63	1.61	1.61	1.60	1.61	1.61	1.65	1.69	1.71	1.70	1.71	1.71	1.71	1.72
	Guizhou	1.55	1.46	1.40	1.37	1.31	1.34	1.34	1.36	1.41	1.55	1.54	1.55	1.57	1.57	1.59
	Guangxi	1.53	1.54	1.57	1.60	1.61	1.61	1.62	1.64	1.64	1.63	1.64	1.64	1.65	1.65	1.68
	Gansu	1.55	1.46	1.43	1.41	1.40	1.35	1.31	1.34	1.34	1.35	1.36	1.36	1.39	1.40	1.40
	Qinghai	1.51	1.47	1.39	1.45	1.43	1.3	1.30	1.3	1.31	1.31	1.30	1.29	1.29	1.29	1.31
	Ningxia	1.34	1.32	1.31	1.32	1.37	1.35	1.33	1.32	1.33	1.37	1.36	1.36	1.35	1.36	1.36
	Tibet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Xinjiang	1.60	1.55	1.58	1.57	1.63	1.58	1.58	1.58	1.59	1.60	1.58	1.58	1.56	1.56	1.58
	Inner Mongolia	1.58	1.6	1.6	1.61	1.61	1.58	1.57	1.57	1.58	1.61	1.6	1.6	1.61	1.61	1.62
	Mean	1.43	1.41	1.41	1.41	1.42	1.39	1.38	1.40	1.41	1.43	1.43	1.43	1.44	1.44	1.45
Unrelated diversification	Chongqing	1.25	1.26	1.25	1.25	1.25	1.24	1.24	1.25	1.26	1.26	1.26	1.24	1.21	1.21	1.20
	Sichuan	1.29	1.27	1.24	1.22	1.20	1.20	1.19	1.17	1.18	1.20	1.21	1.21	1.22	1.23	1.23
	Shanxi	1.24	1.25	1.24	1.23	1.23	1.22	1.22	1.24	1.24	1.24	1.23	1.22	1.21	1.21	1.22
	Yunnan	1.32	1.29	1.30	1.30	1.29	1.30	1.30	1.30	1.31	1.30	1.29	1.29	1.28	1.28	1.29
	Guizhou	1.21	1.23	1.24	1.24	1.25	1.25	1.26	1.26	1.27	1.28	1.28	1.29	1.31	1.32	1.31
	Guangxi	1.27	1.25	1.22	1.21	1.21	1.2	1.19	1.18	1.18	1.19	1.20	1.21	1.21	1.23	1.23
	Gansu	1.31	1.29	1.28	1.28	1.27	1.25	1.24	1.23	1.22	1.22	1.20	1.20	1.18	1.19	1.20
	Qinghai	1.24	1.25	1.25	1.26	1.26	1.31	1.32	1.32	1.33	1.34	1.32	1.32	1.30	1.31	1.32
	Ningxia	1.30	1.31	1.31	1.31	1.31	1.33	1.32	1.32	1.33	1.34	1.33	1.32	1.32	1.33	1.33
	Tibet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Xinjiang	1.18	1.17	1.18	1.19	1.21	1.21	1.25	1.29	1.25	1.30	1.29	1.29	1.28	1.29	1.28
	Inner Mongolia	1.25	1.25	1.24	1.25	1.26	1.24	1.25	1.25	1.25	1.26	1.26	1.27	1.26	1.26	1.27
	Mean	1.16	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.16	1.16	1.16	1.15	1.16	1.16

3.2. Ecological Efficiency Level in Western China from 2006 to 2020

Based on Formulas (6) and (7), the ecological efficiency of western China was measured, and the results are shown in Figure 2.

According to Figure 2, from 2006 to 2020, overall ecological efficiency in western China generally showed a fluctuating and rising trend, and the average ecological efficiency in southwest China was higher than that in northwest China. However, the increase in ecological efficiency in southwest China was less than that in northwest China. The trend of the mean value of ecological efficiency in the northwest and southwest was basically consistent, except in 2008. From the perspective of the provinces, the ecological efficiency of Guizhou, Gansu, and Ningxia decreased significantly, with 0.22, 0.11, and 0.11, respectively. In contrast, in Xinjiang, Inner Mongolia, and Chongqing, the ecological efficiency increased relatively significantly, to 0.25, 0.2, and 0.18, respectively. Additionally, Tibet's ecological efficiency also rose slightly, from 0.32 in 2006 to 0.44 in 2020. Therefore, the ecological effect in western China is generally characterized by "high in the south and low in the north", "slow in the south and fast in the north", and "three-way polarization."

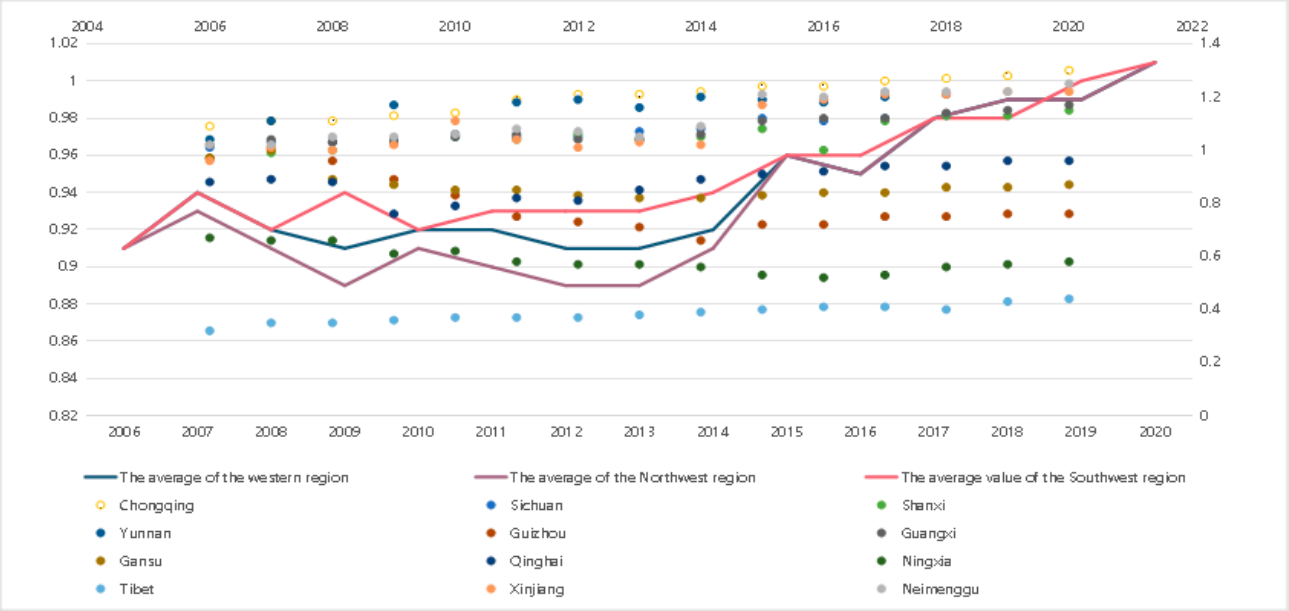


Figure 2. Ecological efficiency in western China 2006−2020.

3.3. The Impact of Industrial Agglomeration on the Ecological Efficiency of Western China

Based on Formula (8), the relationship between industrial specialization agglomeration, industrial-related diversification agglomeration, industrial-unrelated diversification agglomeration, and ecological efficiency in western China was measured empirically. The results are shown in Table 3.

Table 3. Regression results of the impact of industrial agglomeration on ecological efficiency in western China.

Explanatory Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
spe	−0.444 ***	−1.873 **				
	(−2.75)	(−2.15)				
spe^2		0.824				
		(1.546)				
rd			−0.158	−4.387 ***		
			(−1.03)	(−2.86)		
rd^2				1.462 ***		
				(2.55)		
ud					−0.447 **	−0.298
					(−1.985)	(−0.08)
ud^2						−0.072
						(−0.07)
pgdp	−0.273 ***	−0.261 ***	−0.216 ***	−0.245 ***	−0.187 *	−0.186 **
	(−3.55)	(−3.29)	(−2.54)	(−3.25)	(−1.78)	(−1.59)
$pgdp^2$	0.025 ***	0.023 ***	0.018 ***	0.022 ***	0.013 ***	0.014 ***
	(5.54)	(5.48)	(4.93)	(5.56)	(4.36)	(4.31)
estur	−0.843 ***	−0.898 ***	−0.862 ***	−0.835 ***	−0.833 ***	−0.834 ***
	(−4.49)	(−4.74)	(−4.55)	(−4.87)	(−4.63)	(−4.49)
open	−0.171	−0.205	0.056	0.035	0.288	0.288
	(−0.34)	(−0.37)	(0.18)	(0.16)	(0.49)	(0.49)
tech	5.778 **	6.607 **	5.973 **	4.071 **	5.779 *	5.802 **
	(2.14)	(2.41)	(2.11)	(1.72)	(2.07)	(2.02)
envir	2.735	3.16	4.090	2.572	6.877 **	6.864 ***
	(0.98)	(1.16)	(1.36)	(0.91)	(1.99)	(1.88)
mark	0.021*	0.012	0.031 **	0.027 **	0.023	0.023
	(1.77)	(0.67)	(1.94)	(1.77)	(1.09)	(1.11)
Constant	2.662 ***	3.313 ***	2.354 **	5.446 ***	2.676 ***	2.577
	(8.38)	(5.49)	(6.37)	(4.11)	(5.78)	(0.43)
Observations	120	120	120	120	120	120
Number of ID	12	12	12	12	12	12

Note: * P < 0.1; ** P < 0.05; *** P < 0.01. The values in brackets were t values, and other values were regression coefficients. *spe*: specialization; *rd*: related diversification; *ud*: unrelated diversification; *pgdp*: regional development level; *estur*: energy structure; *open*: opening degree to the outside world; *tech*: technical progress; *envir*: environmental regulation intensity; *mark*: degree of marketization; constant: constant term; observations: number of observations.

As can be seen in Table 3, specialized agglomeration in western China has a significant negative impact on ecological efficiency. During the study period, the decrease in professional concentration in western China contributed to the improvement of local ecological efficiency. The effect of related diversification agglomeration in western China on ecological efficiency is characterized by the "U" curve with a cut-off value of 1.46. During the study period, the degree of industrial-related diversification agglomeration in western China, except Tibet, all exceeded the critical value, among which the effect of industrial-related diversification agglomeration in Chongqing, Sichuan, and Yunnan was significantly better than that in other provinces. Nonrelevant diversification agglomeration in western China has a significant negative impact on ecological efficiency. Through the empirical results, we find the decline of industrial-related diversification and agglomeration degree in Chongqing, Sichuan, and Yunnan has the most obvious effect on improving their respective ecological efficiency.

In most models, the "U"-shaped curve relationship exists between the economic development level (*pgdp*) and ecological efficiency in western China. This result demonstrates the existence of an environmental EKC curve between industrial agglomeration and resource usage in this region [7]. There is a negative correlation between the energy structure (*estur*) and the ecological efficiency because the development and consumption of resource-based industries in western China often brings SO_2, dust and other pollution [3]. The degree of openness (*open*) has a limited effect on improving ecological efficiency. This result is related to the insufficient local application of advanced production technology and management experience of foreign enterprises. Technological progress (*tech*) has effectively improved ecological efficiency, whereas pollution control (*envir*) has no significant effect on improving ecological efficiency. The improvement of marketization degree (*mark*) is conducive to the improvement of industrial ecological efficiency, perhaps because the market economy is beneficial to the free flow of production factors and the optimal allocation of resources.

4. Discussion

The empirical results of this study show that ecological efficiency in western China has generally increased dynamically, but ecological efficiency in western China varies greatly. The influence of different industrial agglomeration types on ecological efficiency in western China is obviously different.

On the one hand, the ecological efficiency of western China varies greatly, showing the characteristics of "high in south and low in north", "slow in south and fast in north", and "three-way polarization." There will be great differences in the evaluation results of ecological efficiency caused by the selection of different spatial scales [63]. Northwest China is an important energy and chemical industry base, and the industrial structure in this region has obvious characteristics of heavy industrialization, and there is an overlap between this resource-rich area and the ecologically fragile area [64]. The above reasons lead to the ecological problems in the area being more prominent. Compared with northwest China, southwest China has undertaken more non-ferrous metal-related industries in the process of several industrial transfers [65]. It is also because of the technological driving role of the Sichuan–Chongqing city agglomeration in southwest China, that ecological efficiency in southwest China is slightly better than that of northwest China. The special geological and climatic conditions of the Qinghai–Tibet Plateau are in the pending development stage.

On the other hand, both specialized agglomeration and irrelevant diversified agglomeration have a significant negative impact on ecological efficiency in western China. The relationship between diversification and agglomeration and ecological efficiency in western China is a "U" -shaped curve. Industrial professional agglomeration in western China is usually manifested as the resource-based industry agglomeration of fossil energy mining and processing and non-ferrous metal mining or smelting [66,67]. The energy consumption of these industries is large, and the production technology is backward. Irrelevant diversification often means that emerging industries outside of resource-based industries are concentrated in the region. In this case, it is difficult to overflow knowledge and improve

the efficiency of resource utilization. The sticky effect of resource-based industries on production factors and the crowding-out effect of other industries lead to the difficulty of multi-stage recycling of resources [68]. The relevant diversified agglomeration in western China is mainly developed around resource-based industries, and it is difficult to show the scale effect of joint pollution control in its early stages. More importantly, related diversified agglomeration is conducive to the formation of industrial symbionts, which are conducive to resource recycling and waste recycling and can improve the efficiency of resource utilization and reduce pollutants and waste emissions [20].

5. Conclusions

In this study, we used the super-efficient global SBM-DDF model to evaluate the ecological efficiency and changes in 12 provinces in western China between 2006 and 2020. We then used two linear and nonlinear regression models to analyze in detail the influence mechanisms of different industrial agglomeration forms on local ecological efficiency. The results show that overall ecological efficiency in the western China region shows a dynamic upward trend. The ecological efficiency of western China is quite different, with the overall characteristics of "high in the south and low in the north", "slow in the south and fast in the north", and "three-way polarization." Different types of industrial agglomeration in western China have obvious differences regarding ecological efficiency. Both specialized agglomeration and unrelated diversification agglomeration in western China have a significant negative impact on ecological efficiency. The relationship between the related diversification of agglomeration and ecological efficiency in western China conforms to the EKC curve, which is presented in the "U"-type shape. The research conclusion can provide a reference for the formulation of industrial transformation and ecological protection policies in the implementation process of the second round of the western development strategy. Our conclusion can also provide a reference for the formulation of industrial transfer and upgrading policies in other resource-based regions.

Based on the above conclusions, we believe the possible industrial optimization and upgrading paths in western China are as follows. (1) We will transform the economic growth pattern and improve the energy utilization structure. For a long time, economic growth in western China mainly relied on resource factor input and "two high and low" industries. The economic growth mode not only accelerates energy consumption and ecological destruction but is also not conducive to coordinated and sustainable regional development. In the future, we need to abandon the traditional extensive economic growth mode, promote the transformation and upgrading of enterprises, encourage the development and application of modern energy and green technologies, and expand the utilization scope and intensity of new energy sources, such as photovoltaic, wind power, and hydropower. (2) We will reasonably control the degree of industrial agglomeration and explore the development of producer services related to traditional industries in western China. Although industrial agglomeration can produce technology and knowledge spillover effects, improve production efficiency, and promote economic growth, too high of an agglomeration scale will also cause ecological damage [17]. Therefore, the region should adjust the industrial scale, optimize the industrial layout, and accelerate the industrial transformation and upgrading, and other measures, to achieve the win–win situation of economic benefits and ecological benefits. (3) We will strengthen regional cooperation between cities and improve the regional joint prevention and control system for the ecological environment. Local governments should build a platform for extensive consultation and co-governance, realize resource reallocation and restructuring of factors, strengthen the connection between industrial planning and the environmental regulation system, and improve ecological quality. The optimization of industrial structures in western China should not only play the role of environmental regulation in promoting industrial structures. In addition, while changing the growth model, various means should be adopted to improve the level of environmental protection technology to increase the local sustainable development capacity.

However, this study had several limitations. For example, ecological efficiency is the result of the interaction between human activities and other natural factors. The change of ecological efficiency is not only related to industrial agglomeration, but it is also difficult to remove the influence of meteorological conditions, topography, and living forms on expression efficiency. Our future research will combine ground meteorological observations, high altitude detection data, and environmental pollutants to further explore the impact of natural and climatic factors on ecological efficiency to build a more reasonable evaluation index system.

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