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An Empirical Analysis of Regional Logistics Efficiency and Its Determinants in Sichuan Province: Evidence from DEA and Tobit Models

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Abstract: This study investigates the regional logistics efficiency of Sichuan Province, China, from 2011 to 2019, using a combination of the Data Envelopment Analysis-Banker, Charnes, and Cooper (DEA-BCC) model and the Tobit model. The primary objective is to assess the efficiency of the logistics industry and identify the key determinants influencing this efficiency within the context of high-quality development. A comprehensive input-output index system and a set of influencing factor variables were constructed to evaluate logistics performance across various regions of the province. The findings indicate that factors such as the level of economic development, urbanization, and geographical location significantly enhance regional logistics efficiency. In contrast, the level of informatization and the industrial structure exhibit clear inhibitory effects. Specifically, a higher degree of informatization does not necessarily correspond with improved logistics efficiency, potentially due to inefficiencies in technology adoption or uneven infrastructure development. Furthermore, the current industrial structure, with its reliance on traditional industries, may hinder the optimization of logistics systems. Based on these results, several policy recommendations are put forward, including the optimization of the industrial structure, better integration of information technologies in logistics processes, and the strategic utilization of Sichuan's geographical advantages. This research provides valuable insights for policymakers aiming to enhance logistics efficiency as part of the region's broader economic development strategy.

Keywords: Sichuan Province; Regional logistics efficiency; DEA-BCC model; Tobit model; High-quality development; Industrial structure; Urbanization; Informatization

1 Introduction

China's economy has transitioned from a phase of high-speed growth to a phase of high-quality development. The logistics industry is a fundamental, strategic, and pioneering sector that supports the national economy. Under the context of high-quality development, the logistics industry faces new challenges and opportunities. High-quality development of logistics is an important part of economic high-quality development and an indispensable force to drive economic high-quality development. According to relevant data, the ratio of total social logistics cost to GDP has decreased to 14.4% in 2023, a reduction of 3.6% compared to 18% ten years ago. However, compared to the average level of developed countries (8%-9%), it remains relatively high. Therefore, improving logistics efficiency is of significant practical importance for national economic development. Sichuan Province is located at the junction of the Yangtze River Economic Belt and the "Belt and Road" Economic Belt. It serves as a strategic link connecting the south and north, facilitating east-west transportation and promoting the coordinated development of both economic belts. It is an important hub for China's westward opening and plays a crucial role in transportation and logistics industry integration. Therefore, analyzing logistics efficiency and its influencing factors in Sichuan Province is of great significance for accelerating the construction of a modern logistics system, building a national demonstration zone for high-quality logistics development, and providing solid logistics service support for actively integrating into the new development pattern, with domestic circulation as the mainstay and the domestic and international circulations reinforcing each other. This study focuses on various regions of Sichuan Province, selects relevant logistics data from 2011 to 2019, first calculates logistics efficiency across the regions using the DEA model, and then analyzes the influencing factors of logistics efficiency using the Tobit model, followed by providing related recommendations.

2 Literature Review

The DEA method originated from research on productivity and is a relative efficiency evaluation method for multi-input and multi-output data [1]. In the literature applying DEA to evaluate logistics efficiency, Cavaignac et al. [2] used the DEA method to analyze the logistics efficiency of 132 third-party logistics companies (3PLs) in France in 2016; Bayraktar et al. [3] utilized the Logistics Performance Index (LPI) in DEA to measure national-level efficiency and analyze influencing factors; Zheng and Xu [4], taking Lianyungang in Jiangsu Province as an example, applied the DEA model to evaluate the logistics efficiency of Lianyungang Port's logistics data from 2008 to 2017, and found issues such as irrational resource allocation, redundant inputs, and logistics management inefficiencies during this period. Huo [5] constructed a DEA model to analyze the comprehensive efficiency, pure technical efficiency, and scale efficiency of logistics in 17 prefecture-level cities in Shandong Province from 2011 to 2017, and proposed recommendations based on the analysis results. Xia et al. [6], based on the three-stage DEA and Malmquist index, selected relevant input-output and environmental indicators for 12 provinces, municipalities, and autonomous regions in the western region from 2017 to 2021 to evaluate logistics efficiency, and the study showed that logistics development in the western region is uneven, with related recommendations proposed. Xue et al. [7] took the data from 16 cities in Shandong Province from 2017 to 2021 as samples and comprehensively measured the efficiency of the logistics industry in these 16 cities using the DEA and Malmquist index models.

In terms of research on the influencing factors of logistics efficiency, Pei [8] measured the logistics efficiency of the Guangdong-Hong Kong-Macao Greater Bay Area urban agglomeration from 2013 to 2022 and argued that factors such as the degree of regional openness, economic development level, energy utilization efficiency, informatization level, and government support are the main influencing factors of logistics efficiency. Shang and Chu [9], taking the logistics industry of Liaoning Province as the research object, used the Tobit model to study the influencing factors of green development in Liaoning's logistics industry based on logistics data from 2005 to 2019, and found that informatization level, government support, number of patents, and openness were positively correlated with the green development of Liaoning's logistics industry. Gong [10], based on existing research, selected comprehensive logistics efficiency, pure technical logistics efficiency, and scale efficiency as explained variables to establish regression models, and the analysis found that informatization level had no significant impact on logistics efficiency, while comprehensive efficiency and pure technical efficiency were significantly affected by industry factors, economic development level, and location factors.

To further study the efficiency of the logistics industry and its influencing factors, some scholars have combined DEA and Tobit models for empirical analysis. Gong et al. [11], at the provincial level, used the DEA model to measure regional logistics efficiency in China and found significant differences in logistics efficiency across regions. They further studied the factors influencing regional logistics development using the Tobit model, selecting variables that affect logistics efficiency in different regions and conducting an empirical study on China's overall logistics level. Qin [12], based on the DEA model, calculated the logistics efficiency of Qinghai from 2004 to 2013 and used the Tobit two-stage model to analyze the factors influencing logistics efficiency in Qinghai. The study showed that Qinghai's logistics comprehensive efficiency was relatively high, with fluctuating returns to scale; logistics resource utilization, specialization degree, and human resources had a significant positive impact on Qinghai's logistics efficiency. Liu [13], based on the policy perspective of accelerating the industrial upgrading and economic transformation of the Yangtze River Economic Belt and the Silk Road city circle, used DEA to measure the logistics efficiency of the Central Yangtze River Economic Belt from 2006 to 2012. The study showed that the overall level of logistics in the Central Yangtze River Economic Belt was relatively low, and the Tobit model was used to analyze the influencing factors of the region in more depth, followed by several recommendations.

By reviewing the relevant literature, with the continuous growth of research on logistics efficiency, the research approach has gradually shifted from a single model to a combination of multiple models. By constructing DEA and Tobit models, not only can the logistics industry's efficiency be measured, but its influencing factors can also be empirically studied. Therefore, based on existing literature, this study uses DEA and Tobit models to conduct an empirical analysis of logistics efficiency and its influencing factors in Sichuan Province, using logistics data from 2011 to 2019.

3 Logistics Efficiency Evaluation of Sichuan Province Based on the DEA Model

3.1 Research Methodology

DEA is a non-parametric method used to measure the relative efficiency of decision-making units (DMUs), evaluating the relative effectiveness of similar decision-making units. The principle of DEA is to keep the input of each DMU constant and use linear programming to determine the production frontier. Each DMU is then projected onto the frontier, and the relative effectiveness is assessed by comparing the distance between the DMU and the frontier. Since DEA does not require the assumption of artificial weights, it is an objective method. The DEA model is typically divided into the Charnes, Cooper, and Rhodes (CCR) model and the BCC model. The CCR model assumes constant returns to scale, and it cannot calculate the scale efficiency. The DEA-BCC model, assuming variable returns to scale, breaks down comprehensive efficiency into scale efficiency and pure technical efficiency, which better aligns with real-world situations. Therefore, the BCC model is used in this study to calculate the logistics efficiency of Sichuan Province [14]. The DEA-BCC model is as follows:

Assume there are N DMUs DMU_{j} $\{DMU_j j = 1, 2 \ldots n\}$, each DMU has $m(\mathrm{i} = 1, 2 \ldots, m)$ input indicators and s $(r = 1, 2, \ldots, s)$ output indicators. The goal is to minimize input while maintaining output constant, namely:

$$\begin{cases} \min \theta \\ \sum_{j=1}^{n} \lambda_i X_{ij} + S^- = \theta_{X_0} \\ \sum_{j=1}^{n} \lambda_i Y_{ij} + S^+ \leq Y_0 \\ \sum_{j=1}^{n} \lambda_i = 1 \\ \lambda_i \geq 0, S^- \geq 0, S^+ \geq 0 \end{cases}$$

where, λ_j are the key factors forming the effective frontier; $S^+$and $S^-$are both greater than or equal to 0 , and they extend horizontally and vertically based on λ_{j} to form a complete envelope surface. θ represents the "distance" between the DMU and the complete envelope surface, i.e., the input-output efficiency value.

3.2 Indicator Selection and Data Sources

Based on the value-added statistics of China's logistics industry, transportation, warehousing, and postal industries account for more than 85% of the total production value of the logistics industry. Therefore, data from these three sectors in Sichuan Province are selected to replace the relevant logistics data in order to establish the corresponding indicators [15].

The selection of logistics industry indicators must consider both scientific rigor and practicality. Referring to existing literature, this paper organizes and summarizes the selection of indicators in relevant literature in recent years, as shown in Table 1. The total fixed asset investment in the logistics industry, the number of logistics industry employees, and the logistics network mileage are chosen as input indicators. Among these, the total fixed asset investment in logistics is the sum of transportation, warehousing, and logistics industries; the number of logistics industry employees is based on the year-end data for transportation, warehousing, and postal industries; and Sichuan's transportation mode is primarily road transport. This study refers to the research [16] and uses road mileage as the indicator for network mileage. The study selects freight turnover, freight volume, and the total output value of the logistics industry as output variables, using data from transportation, warehousing, and postal industries as substitutes. Due to the unavailability of relevant indicator data for Deyang City, Meishan City, Guang'an City, Ya'an City, Aba Tibetan and Qiang Autonomous Prefecture, and Liangshan Yi Autonomous Prefecture, these regions are not analyzed in this study. The above data are sourced from the *Sichuan Statistical Yearbook (2011-2019)*, and the statistical yearbooks and bulletins of various cities and states.

Table 1. Input-output indicator system for the influencing factors of logistics efficiency in Sichuan Province

Indicator	Indicator Content	Indicator	Reference Literature
Input Indicators	Logistics workforce (per 10,000 people)	X_1	Zhou and Huang [17]
	Total fixed asset investment in logistics (in 100 million RMB)	X_2	
	Network mileage (in 10,000 km)	X_3	Zhang [16]
Output Indicators	Freight volume (in 10,000 tons)	Y_1	Gong et al. [18]
	Freight turnover (in 100 million ton-kilometers)	Y_2	
	Logistics industry value (in 100 million RMB)	Y_3	

4 Empirical Results Analysis

Based on the analysis in Section 2.2, data from Sichuan Province's cities and states from 2011 to 2019 were collected and processed. Using the Deap 2.1 software, an empirical study of the logistics efficiency in Sichuan's cities and states from 2011 to 2019 was conducted. The overall efficiency (θ^*), pure technical efficiency (σ^*), scale efficiency (S^*), and returns to scale for each city/state were calculated, with results presented in Tables 2–5. Pure technical efficiency reflects the impact of logistics resource utilization on output capacity without considering scale factors; scale efficiency reflects whether resource allocation is aligned with industry scale, and whether the input-output ratio is optimal. Overall efficiency is the product of pure technical efficiency and scale efficiency.

4.1 Overall Efficiency Analysis

In the DEA model, the closer the efficiency value is to 1, the higher the logistics efficiency. When the overall efficiency value is less than 1, DEA is considered ineffective, and there is a need to improve logistics output efficiency. From Table 2, it can be seen that the average overall efficiency value for Sichuan's cities and states from 2011 to 2019 remained below 0.9, with significant differences between cities, indicating that the overall logistics efficiency in Sichuan is low and that there is an imbalance in the development of logistics industries across regions. A detailed analysis shows that only Zigong, Panzhihua, and Leshan have overall logistics efficiency close to 1, indicating that the logistics resources in these regions are being fully utilized. Chengdu's efficiency value was only below 1 in 2019, suggesting that logistics resources in the city were used rationally. Guangyuan and Leshan had an overall efficiency value of 1 in most years, and their overall efficiency has generally shown an upward trend since 2011. This indicates that their logistics industries have been effectively improved. The reason may be that Guangyuan, located at the junction of Sichuan, Shaanxi, and Gansu, has obvious locational advantages, and the development of logistics contributes to its role as a regional logistics hub, which in turn promotes further development in the logistics sector. Leshan, located at the intersection of the Chengdu, South Sichuan, and Panzhihua economic zones, is situated at the connection point between the two major urban clusters of Chengdu and the southern city cluster in the Chengdu-Chongqing economic planning region. It is also at the intersection of the Yangtze River Development Belt and the Chengdu-Mianyang-Leshan Development Belt in the "Double Core, Five Belts" spatial development pattern, and is adjacent to the periphery of the planned Sichuan Tianfu New Area, which serves as the starting point for the "Double Core" waterway transportation corridor in the Chengdu economic area. In 2013, the Provincial Logistics Office officially approved Nanchong as one of Sichuan Province's first modern logistics pilot cities. The Nanchong Modern Logistics Park, covering 13,500 mu, was planned to be fully completed and operational by 2017. After Nanchong's DEA efficiency became effective in 2012, it was not until 2017 that the city regained an effective DEA status, and it has remained stable since, indicating that the logistics reforms implemented in Nanchong from 2013 to 2016 have been effective, and the logistics level has improved. In contrast, most other cities have DEA efficiency values considered ineffective in most years. In particular, cities such as Yibin, Bazhong, Ziyang, and the Ganzi Tibetan Autonomous Prefecture have relatively low overall logistics efficiency, making them key cities that Sichuan Province needs to focus on in order to improve logistics efficiency.

Table 2. Overall logistics efficiency results for Sichuan Province's cities and states (2011-2019)

DMU (city)	2011	2012	2013	2014	2015	2016	2017	2018	2019
Chengdu	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.773
Zigong	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.901	1.000
Panzhihua	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Luzhou	0.645	1.000	0.809	0.931	0.986	0.974	0.977	0.936	0.987
Mianyang	0.468	0.797	0.821	0.702	0.874	0.952	0.993	0.847	0.540
Guangyuan	0.676	0.690	1.000	1.000	1.000	1.000	1.000	1.000	0.731
Suining	0.503	1.000	0.573	0.613	0.568	0.785	0.762	0.845	0.895
Neijiang	0.661	0.873	1.000	0.729	0.700	0.910	0.967	0.897	0.544
Leshan	0.993	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Nanchong	0.310	1.000	0.520	0.770	0.651	0.662	1.000	1.000	1.000
Yibin	0.432	0.320	0.412	0.619	0.589	0.659	0.593	0.537	0.333
Bazhong	0.390	0.487	0.206	0.411	0.311	0.329	0.290	0.332	0.299
Ziyang	0.621	1.000	0.654	0.417	0.414	0.766	0.664	0.607	0.554
Ganzi	0.156	0.454	0.115	0.274	0.370	0.350	0.360	0.354	0.398
Mean	0.633	0.830	0.772	0.748	0.747	0.813	0.829	0.804	0.718

4.2 Pure Technical Efficiency Analysis

Pure technical efficiency refers to the impact of management level, technological capabilities, and other factors on logistics efficiency, without considering scale effects. The closer the pure technical efficiency is to 1, the closer the logistics efficiency is to the optimal state. From Table 3, it can be seen that although the average pure technical efficiency values for these regions decreased slightly in 2012 and 2019, there is an overall upward trend, indicating that the logistics industry has not yet fully utilized technology and management to improve the efficiency of logistics resources. A detailed analysis shows that Chengdu, Zigong, Panzhihua, Luzhou, Guangyuan, Suining, Leshan, and Ganzi Prefecture had a pure technical efficiency value of 1 for most years from 2011 to 2019, indicating that logistics resources in these regions were used rationally. However, Guangyuan's efficiency was relatively low in 2011 and 2012, and Suining's efficiency was low in 2011, which led to lower overall logistics efficiency in those years. Nanchong and Ziyang achieved a pure technical efficiency of 1 in subsequent years, indicating that logistics production activities in these two cities improved, and resources were fully utilized. In contrast, for most other cities, pure technical efficiency was ineffective in many years, with large variations. This indicates that logistics resource input in these regions was not effectively utilized, and there is a need for better resource allocation, improved management, and enhanced technology to increase logistics output.

Table 3. Pure technical efficiency results for Sichuan Province's cities (2011-2019)

DMU (city)	2011	2012	2013	2014	2015	2016	2017	2018	2019
Chengdu	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Zigong	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.949	1.000
Panzhihua	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Luzhou	0.656	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Mianyang	0.508	0.827	1.000	0.943	1.000	0.970	1.000	0.875	0.544
Guangyuan	0.689	0.691	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Suining	0.753	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Neijiang	0.669	0.879	1.000	0.864	0.809	1.000	0.972	0.978	0.834
Leshan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Nanchong	0.315	1.000	0.652	0.804	0.673	0.679	1.000	1.000	1.000
Yibin	0.574	0.389	0.553	0.639	0.638	0.663	0.640	0.626	0.603
Bazhong	0.699	0.817	0.522	0.770	0.666	0.640	0.456	0.685	0.648
Ziyang	0.622	1.000	0.761	0.665	0.833	1.000	1.000	1.000	1.000
Ganzi	1.000	1.000	0.619	0.882	1.000	1.000	1.000	1.000	1.000
Mean	0.749	0.900	0.865	0.898	0.901	0.925	0.933	0.937	0.902

4.3 Scale Efficiency Analysis

Scale efficiency reflects whether the allocation of resources is aligned with the scale of the industry, and whether the input-output ratio reaches an optimal level. The closer the scale efficiency is to 1, the closer the region's actual scale is to the optimal production scale. If the value is less than 1, the region is in a state of scale inefficiency. From Table 4, it can be seen that during the 9 years covered in this study, the scale efficiency of Sichuan Province's regions showed a fluctuating upward trend.

Table 4. Scale efficiency results for Sichuan Province's cities (2011-2019)

DMU (city)	2011	2012	2013	2014	2015	2016	2017	2018	2019
Chengdu	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.773
Zigong	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.950	1.000
Panzhihua	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Luzhou	0.983	1.000	0.809	0.931	0.986	0.974	0.977	0.936	0.987
Mianyang	0.922	0.964	0.821	0.744	0.874	0.981	0.993	0.967	0.993
Guangyuan	0.982	0.999	1.000	1.000	1.000	1.000	1.000	1.000	0.731
Suining	0.668	1.000	0.573	0.613	0.568	0.785	0.762	0.845	0.895
Neijiang	0.988	0.992	1.000	0.844	0.866	0.910	0.995	0.917	0.652
Leshan	0.993	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Nanchong	0.983	1.000	0.798	0.958	0.966	0.976	1.000	1.000	1.000
Yibin	0.752	0.825	0.744	0.968	0.923	0.994	0.926	0.857	0.553
Bazhong	0.558	0.597	0.395	0.534	0.466	0.515	0.637	0.485	0.461
Ziyang	0.999	1.000	0.859	0.627	0.497	0.766	0.664	0.607	0.554
Ganzi	0.156	0.454	0.185	0.311	0.370	0.350	0.360	0.354	0.398
Mean	0.856	0.916	0.799	0.824	0.823	0.875	0.880	0.851	0.785

However, the average scale efficiency value remained below 0.9 in most years. During the period from 2015 to 2019, the lower scale efficiency was the primary reason for the overall lower logistics efficiency in each city and state. This indicates that, at the current levels of technology and productivity, the logistics input-output does not match the optimal scale of production, and there is a need to focus on improving scale efficiency. From the city perspective, only Panzhihua had effective scale efficiency. Chengdu, Luzhou, Guangyuan, Leshan, and Nanchong had scale efficiency above 0.9 in most years, reflecting relatively high scale efficiency. However, in 2019, Chengdu's scale efficiency and in 2018, Zigong's scale efficiency suddenly dropped, which ultimately led to the inefficiency of their overall logistics efficiency. This may be related to changes in local policies. Ganzi Prefecture, on the other hand, had consistently low scale efficiency, despite having a high pure technical efficiency. Therefore, it is necessary to focus on improving scale efficiency to enhance logistics efficiency.

From the perspective of returns to scale, a constant return to scale indicates that the logistics industry in the region is operating at an optimal production scale. If returns to scale are increasing or decreasing, adjustments in input are needed to move towards a state of constant returns to scale. As shown in Table 5, with the exception of Panzhihua, other cities exhibit either increasing or decreasing returns to scale. For instance, in Chengdu, returns to scale remained constant until 2019, when they exhibited decreasing returns to scale. This suggests that there has been an oversupply of resources, and there is a need to adjust the input-output ratio and use resources more efficiently. Similarly, Yibin has consistently experienced increasing returns to scale, indicating that expanding the scale of production through increased investment is necessary. In contrast, Leshan experienced decreasing returns to scale in 2011, but by adjusting the input-output ratio and strengthening management practices, it achieved constant returns to scale thereafter. This serves as a useful reference for other cities.

Table 5. Returns to scale for Sichuan Province's cities (2011-2019)

DMU (city)	2011	2012	2013	2014	2015	2016	2017	2018	2019
Chengdu	-	-	-	-	-	-	-	-	drs
Zigong	-	-	-	-	-	-	-	irs	-
Panzhihua	-	-	-	-	-	-	-	-	-
Luzhou	drs	-	drs	drs	drs	drs	drs	drs	drs
Mianyang	drs	drs	drs	drs	drs	irs	drs	irs	drs
Guangyuan	drs	irs	-	-	-	-	-	-	irs
Suining	irs	-	irs	irs	irs	irs	irs	irs	irs
Neijiang	drs	drs	-	irs	irs	irs	drs	irs	irs
Leshan	drs	-	-	-	-	-	-	-	-
Nanchong	irs	-	irs	irs	drs	drs	-	-	-
Yibin	irs	irs	irs	irs	irs	irs	irs	irs	irs
Bazhong	irs	irs	irs	irs	irs	irs	irs	irs	irs
Ziyang	drs	-	irs	irs	irs	irs	irs	irs	irs
Ganzi Prefecture	irs	irs	irs	irs	irs	irs	irs	irs	irs

5 Analysis of the Influencing Factors of Logistics Efficiency in Sichuan Province Based on the Tobit Model

The previous section presented an empirical study on the logistics efficiency in Sichuan Province and analyzed the variations in the three types of efficiency. However, the factors that contribute to changes in Sichuan's logistics efficiency are still unclear. In this section, a regression model will be constructed to further explore the influencing factors of logistics efficiency.

5.1 Selection of Indicators

In this study, the overall logistics efficiency is selected as the dependent variable. The following independent variables are chosen:

(1) Economic Development Level

The logistics industry is a fundamental, strategic, and leading sector that supports national economic development. The high-quality development of logistics is an important component of economic high-quality development and an essential driving force for economic advancement. This study draws on the research of Gong [10] and uses per capita GDP of each region in Sichuan Province as a measure of the economic development level.

(2) Level of Informatization

The rapid development of the internet economy has accelerated the flow of information. The improvement in the level of informatization has had a significant impact on the logistics industry, stimulating the increase in users and demand. Logistics efficiency continues to improve as it adapts to the development of network and information technologies. The study follows the research of Ge and Yao [19] and uses the volume of postal and telecommunications services as an indicator of the informatization level in each region of Sichuan Province.

(3) Industrial Structure

Industrial structure refers to the allocation and proportional relationships of economic resources across different industries. It reflects the level and direction of a country's economic development. There is a close relationship between industrial structure and logistics efficiency, as the right industrial structure can promote improvements in logistics efficiency. As an important component of the tertiary industry, logistics plays a role in facilitating industrial cooperation and the upgrading of industrial structure. This study uses the proportion of the tertiary industry value to total GDP in each region of Sichuan to measure the industrial structure.

(4) Urbanization Level

Urbanization, while expanding the number and scale of urban areas, also involves population and industrial agglomeration. In the process of urbanization, logistics, being one of the industries most closely related to others, can benefit from urban development to some extent [20]. This study uses the urbanization rate of each region in Sichuan Province as a measure of urbanization level.

(5) Location Factors

Location factors refer to the comprehensive environmental factors such as a region's geographic location, resource distribution, and transportation network. A region with location advantages can establish logistics parks and improve its transportation network, which drives the development of logistics in surrounding areas, thus improving logistics efficiency. Location factors are commonly measured by location entropy. In this study, the location entropy is represented by the ratio of the logistics value of each region's output to the total output value of Sichuan Province [21].

The above data are sourced from the *Sichuan Statistical Yearbook (2011-2019)* and statistical yearbooks and bulletins from each city and district in Sichuan.

5.2 Establishment of the Regression Model

The efficiency values obtained from the DEA model are discrete, and their values range from 0 to 1. Using ordinary least squares (OLS) to perform regression analysis on the values derived from the DEA model results in biased and inconsistent parameter estimates. Therefore, the Tobit regression model, which uses maximum likelihood estimation, is applied for empirical analysis [21], as shown below:

$$Y = \begin{cases} Y^* = \beta X + \mu, & Y^* > 0 \\ 0, & Y^* \leq 0 \end{cases}$$

where, Y^* is the truncated dependent variable; Y is the efficiency value; X represents the independent variables; β represents the regression coefficients; and μ is the error term, where $\mu \sim \left(0, \sigma^2\right)$.

Based on the above analysis, the following regression model is constructed:

$$Y_i = \beta_0 + \beta_1 Z_{1i} + \beta_2 Z_{2i} + \beta_3 Z_{3i} + \beta_4 Z_{4i} + \beta_5 Z_{5i} + \mu$$

where, β_0 is the constant term; $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ are the regression coefficients for each independent variable; i represents the year $(i = 2011, 2012, \ldots, 2021); \mu$ is the error term of the regression function; Y_i is the overall logistics efficiency; Z_{li} represents the per capita GDP of each region in Sichuan Province for year iii; Z_{2i} represents the informatization level of each region for year i; Z_{3i} represents the industrial structure of each region for year i; Z_{4i} represents the urbanization rate of each region for year i; and Z_{5i} represents the location factor of each region for year i.

5.3 Empirical Analysis

The Tobit regression model is estimated using STATA 18.0 software with relevant data, and the results are shown in Table 6.

Table 6. Tobit regression model analysis results

Variable	Coefficient	Standard Error	T-Statistic	Significance Level
Economic Development Level	0.0000127	3.79×10^{-6}	3.36	0.001***
Informatization Level	-7.99×10^{-8}	1.75×10^{-8}	-4.57	0.000***
Industrial Structure	-2.279903	0.6615877	-3.45	0.001***
Urbanization Level	0.0239652	0.0060654	3.95	0.000***
Location Factor	1.034265	0.3953963	2.62	0.01*

Note: * Significant at the 10% significance level; *** Significant at the 1% significance level

From the regression results in Table 6, it can be observed that: Economic development level has a significant positive correlation with overall logistics efficiency, with a coefficient of 0.0000127. This indicates that in most regions of Sichuan Province, economic development has been in a rapid growth phase over the past 9 years. The development of the economy has a marginally increasing effect on logistics efficiency. However, it also suggests that the economic development level in each region does influence regional logistics efficiency, but to a limited extent. Informatization level has a significant negative correlation with overall logistics efficiency, with a coefficient of -7.99×10^{-8}. This finding is consistent with the low technical efficiency observed in many regions, suggesting that informatization does not have a positive driving effect on overall logistics efficiency. Industrial structure has a significant negative correlation with overall efficiency, with a coefficient of -2.279903. This indicates that the proportion of the tertiary industry in the overall industrial structure has a significant negative effect on logistics efficiency. This may be because, while the tertiary industry is rapidly developing, there has been no effective coordinated development within it, and the increase in logistics demand has been slow. Urbanization level has a significant positive effect on overall logistics efficiency, with a coefficient of 0.024. This suggests that for every 1% increase in urbanization level, logistics efficiency increases by 0.024%. As urbanization progresses, corresponding transportation infrastructure and facilities improve, which likely contributes to the increase in logistics efficiency. Location factor has a significant positive correlation with overall logistics efficiency, with the largest positive impact, with a coefficient of 1.03. This indicates that a 1% improvement in location factors will lead to a 1.03% increase in logistics efficiency. Location entropy represents the degree of logistics industry agglomeration and specialization in a region. As Sichuan Province is a major manufacturing province, logistics companies can share information and infrastructure, thereby reducing logistics costs and improving logistics efficiency.

6 Conclusion and Recommendations

6.1 Research Conclusions

This paper evaluates the logistics efficiency of Sichuan Province from 2011 to 2019 using the DEA model. The study found that the overall logistics efficiency in various regions of Sichuan Province is relatively low. During this period, the average efficiency of all regions has consistently remained below 0.9, with significant disparities in the development of the logistics industry across regions. Specifically, Chengdu, Zigong, Panzhihua, Leshan, and Guangyuan exhibit relatively high logistics efficiency, while Suining, Yibin, Ziyang, Bazhong, and Ganzi have relatively low efficiency. From a temporal perspective, the three types of logistics efficiency (overall, pure technical, and scale efficiency) in Sichuan Province generally exhibit fluctuating trends, though the degree of fluctuation varies. In terms of overall logistics efficiency, the fluctuations are larger in cities such as Mianyang, Suining, Neijiang, Nanchong, Yibin, Bazhong, Ziyang, and Ganzi. For pure technical efficiency, cities like Mianyang, Neijiang, and Nanchong show larger fluctuations, while for scale efficiency, Suining, Neijiang, Yibin, Bazhong, and Ziyang exhibit larger fluctuations.

Additionally, through the Tobit model analysis of the factors influencing logistics efficiency, the study found that the current level of informatization and optimization of industrial structure hinder the improvement of logistics efficiency, though the impact of informatization is relatively low. Economic development has a positive impact on logistics efficiency in Sichuan Province. The improvement in urbanization significantly promotes logistics efficiency, while the location factor has the most significant positive effect on logistics efficiency.

6.2 Recommendations

(1) Optimize Logistics Resource Allocation: Compared to pure technical efficiency, the low scale efficiency contributes to the overall low logistics efficiency in Sichuan. This is usually due to insufficient input factors or improper allocation of resources. In cities with excessive resource input, further investment might result in diminishing returns, as seen in Mianyang and Luzhou. On the other hand, areas with insufficient investment may fail to meet the needs of the logistics industry's development. Therefore, regions should optimize the layout of logistics resources, rationally control government investment, and guide enterprises to make rational investments. This will help minimize the occurrence of inefficiencies in scale.

(2) Accelerate Logistics Infrastructure Construction: Sichuan Province is located at the junction of the Silk Road Economic Belt and the Yangtze River Economic Belt, and is a key point of the Belt and Road Initiative. Although its logistics and transportation network is relatively advantageous compared to Central and Eastern European countries, the integration between logistics infrastructures is not tight, and there are insufficient multimodal transport facilities. The logistics infrastructure is not fully developed, and its supporting and driving ability for the industry is inadequate. The Western Land-Sea New Corridor's western section has not yet been fully connected. The logistics facilities in Northwest Sichuan and the Panzhihua-Xichang region are small in scale and face construction challenges. Emergency logistics facilities are also inadequately distributed. Thus, it is crucial to strengthen the construction of logistics infrastructure and improve interconnectivity to enhance logistics efficiency.

(3) Promote the Role of Informatization in Logistics: Several cities in Sichuan, particularly Yibin and Bazhong, have relatively low pure technical efficiency. By improving technical levels, especially through the development of logistics information technology, particularly digital technologies, logistics pure technical efficiency can be improved. Efforts should be made to lead with digital technology, intensify the development of key core technologies, provide integrated supply chain solutions, and encourage traditional logistics companies to expand into value-added and high-end service sectors. Comprehensive innovation in the logistics industry should be promoted to accelerate its development in terms of centralization, intelligence, and standardization.

(4) Optimize the Industrial Structure: The industrial structure has a significant inhibiting effect on logistics efficiency. This is because, in recent years, many cities in Sichuan have undergone a significant shift in industrial structure from being industrially dominated to service-oriented, with a noticeable increase in the share of the tertiary sector. However, the development of the service sector has been lagging, and industrial structure adjustments are still needed. Therefore, Sichuan Province needs to strategically adjust its industrial structure, encourage the transformation of local industries, guide resource allocation in line with scientific development, break traditional monopolies in the service industry, and overcome regional barriers. This will help promote the optimization and adjustment of the tertiary sector.

(5) Fully Leverage Location Advantages: The correlation coefficient between location factors and logistics efficiency is 1.034265, indicating that location factors have the most significant effect on improving logistics efficiency in Sichuan. Sichuan is located at key nodes in initiatives such as the Belt and Road Initiative, the development of the Yangtze River Economic Belt, the western development plan, and the Chengdu-Chongqing economic circle. Taking advantage of this, Sichuan should strengthen transportation connections with surrounding provinces and countries along the Belt and Road. Leveraging key logistics nodes such as the Chengdu International Railway Port, Chengdu Shuangliu International Airport, and Tianfu International Airport, Sichuan can build regional logistics hubs and promote the integrated development of regional logistics.

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Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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