Research on the Input-Output Efficiency of Civil Aviation Industry to Regional Economy in China Based on DEA Modeling

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ABSTRACT

Scientific evaluation of the input-output efficiency of civil aviation industry to regional economy in each province or region of China is an important basis for objectively reflecting the radiation and driving effect of civil aviation industry to regional economy. This paper adopts the DEA-BC2 model to quantitatively analyze the civil aviation transportation inputs and economic development outputs of China’s 31 provinces or regions from 2010 to 2019. Our findings show that the input-output efficiency of China's civil aviation industry to regional economy presents a steady increase in general, but there are significant regional differences among the seven major regions. The levels of comprehensive efficiency, pure technical efficiency and scale efficiency are characterized by a gradient decrease from the coastal areas of East China, North China, and Central and South China to Southwest China, Northeast China, Northwest China, and inland Xinjiang, and there are significant differences in the efficiency levels and growth rates among the provinces. There are also significant differences in the efficiency level and growth rate among provinces or regions. 11 provinces or regions, including Hainan, Gansu, Ningxia, Qinghai, Inner Mongolia, Xinjiang, and Liaoning, all suffer from low levels of technical or scale efficiency, and it can be tentatively assumed that the input-output efficiency level of civil aviation industry o regional economy is low in these provinces, and this needs to be improved. Finally, this paper proposes some policy suggestion, such as increasing capital investment and rationally planning the spatial layout of key industries, to improve the input-output efficiency of civil aviation industry to regional economy. Our findings provide insights into recognizing the differences and patterns of the input-output efficiency of air transport to regional economy in China’s 31 provinces or regions, with an aim to promoting the improvement of the input-output efficiency of civil aviation industry to regional economy in different regions.

Keywords: Civil aviation industry, Regional economy, Input-output efficiency, DEA modeling.

1. Introduction

Due to its advantages in speed, coverage, and flexibility, air transportation has significantly enriched the overall transportation system. It can effectively expand consumer demand, promote the transformation and upgrading of regional industrial structure, and drive the overall development of the economy and society, so it has become an indispensable source of power for regional economic and social development [1]. However, there is a serious mismatch between the existing supply capacity of China's air transportation and the needs of high-quality economic development, which is centrally manifested in the inefficiency of the utilization of air transportation resources and the unsatisfactory overall efficiency [2]. Therefore, in view of the current imbalance and insufficiency problems highlighted in China's civil aviation industry, scientific assessment of the relationship between the inputs of air transportation resources and the outputs of regional economy among provinces and regions is an important basis for testing the ability of air transportation to serve the local economy, promoting the transformation and upgrading of local economic structure, and playing a pioneering role. Studies have shown that there is a close relationship between transportation infrastructure as an input factor and the level of economic activity output [3,4]. There are obvious regional differences in the efficiency of transportation in China [5]. As a consequence, this paper conducts a comparative study of the efficiency between civil aviation inputs and economic outputs in various regions of China, in order to provide a reference for promoting the efficiency of civil aviation inputs and regional economic outputs in different regions.

Existing literature shows that Chinese and international scholars mainly focused on railroads and highways [6-14], and a few scholars studied civil aviation [15].

For this reason, this paper takes air transportation resource inputs as input indicators and the quality of economic development as output indicators [16], and uses the DEA-BC2 method to measure the input-output efficiency of air transportation and regional economy in 31 provinces in China, a comparative study of the civil aviation industry and regional economic input-output efficiency in various regions and provinces in China. The goal of this paper is to analyze the differences and patterns of air transport and regional economic input-output efficiency in 31 provinces in China, and to provide lessons for promoting the improvement of civil aviation and regional economic input-output efficiency in different regions.

2. Model Construction

2.1 Selection of Indicators and Data

This paper selects the indicators for the evaluation of input-output efficiency of air transportation industry on regional economic development in accordance with the principles of science, completeness, operability, low correlation and the same goal. As the level of economic development and the scale of development of civil aviation industry vary greatly among provinces, this paper relativizes the indicators when selecting the inpu-output indicators, as shown in Table 1. For the sake of comparison, this paper divides provinces into six regions according to the regional divisions of the Civil Aviation Administration (Xinjiang and Northwest China are regarded as one region in this research), and at the same time, due to the sudden outbreak of the COVID-19, the air transportation market is facing a great uncertainty, which leads to the difficulty in reflecting the development pattern of the air transportation industry realistically and objectively in the data during the period of 2020-2022. Based on this, the timeframe of this study is defined as 2010-2019, and the data are derived from the Statistical Bulletin on the Development of the Civil Aviation Industry (2011-2020) and the China Statistical Yearbook (2011-2020).

Table 1. System of indicators for air transportation and regional economic development (calculation)

Level 1 indicators	Secondary indicators	Way of measuring	Level 1 indicators	Secondary indicators	Way of measuring
Air transportation resource inputs	Frequency of air travel per capita	Passenger throughput as a percentage of population	Quality of economic development	R&D investment intensity of industrial enterprises above scale (%)	R&D expenditure as a share of GDP
				Patent invention authorization for 10,000 people (items)	Number of patents for inventions at the end of the year (pieces)/year Total population at the end of the year (10,000)
				Per capita disposable income of urban residents (yuan)	(Gross household income of urban residents - contributions Income tax - social security expenditure paid by individuals (- Bookkeeping allowance)/Family size
	Cargo and mail throughput per capita (%)	Cargo and mail throughput as a percentage of population		Per capita disposable income of rural residents (yuan)	(Gross household income of rural inhabitants - contributions to

					Income tax - social security contributions by individuals - accounting for (Account allowance) / family size
				Sulfur dioxide emissions as a share of GDP (%)	Sulfur dioxide emissions as a share of GDP
				Total exports and imports of goods as a share of GDP (%)	Total exports and imports of goods as a percentage of GDP
	Percentage of population working in civil aviation (%)	Number of civil aviation employees as a percentage of the population		GDP per capita (dollars)	Total GDP/average annual population
				Domestic tourism revenue as a share of GDP (%)	Domestic tourism revenue as a share of GDP
				Share of tertiary sector output in GDP (%)	Share of tertiary sector output in GDP

Source: By authors.

2.2 Modeling

In existing research literature, the evaluation methods of resource allocation efficiency are mainly of two types: parametric and non-parametric methods. The parametric method is mainly represented by Stochastic Frontier Production Function Analysis (SFA), and the non-parametric method is represented by Data Envelopment Analysis (DEA). This paper conducts an input-output efficiency analysis of the impact of aviation transportation on regional economies using the DEA method, an effective method for evaluating the relative efficiency of decision-making units (DMUs) with multiple input-output indicators of the same type of [17]. The DEA method is suitable for the evaluation of complex systems with multiple inputs and multiple outputs and does not need to harmonize the scale of each indicator [18]. According to the research content of this paper, the input-output efficiency of air transportation to the regional economy is a complex system with multiple inputs and multiple outputs, and compared with the parametric methods such as SFA, the

DEA model to measure the input-output efficiency doesn't require that all the decision making units (DMUs) adopt the same form of the production function, and satisfy the "multivariate optimization criterion" [19], so this paper believes that DEA is an effective analytical method to measure the efficiency of resource allocation in this study. In the DEA method, the most widely used model is the C2R model, which adopts the assumption of fixed scale and estimates the production boundary by linear programming method to measure the relative efficiency of each decision unit. However, considering that DMUs in this study may be in the state of both increasing and decreasing returns to scale, this paper introduces the BC2 [20] model with variable returns to scale, constructs the DEA-BC2 model, and evaluates the efficiency of decision-making units from the perspective of global optimization, which makes up for the shortcomings and deficiencies of the resource allocation efficiency studies in the existing studies.

The assumption implicit in the DEA method regarding the system's ideal state is that when the system reaches this state, its input-output efficiency is maximized.. When the evaluation value is 1, the input-output system is efficient, i.e., the system is in an ideal state; when it takes the value of 0, the system is the least ideal. 1 and 0 are two extreme states, while most of the results will be the value taken between 0 and 1. When the value tends to be more like 1, i.e., the higher the relative efficiency of the system, the lower the efficiency of the system; and vice versa [21], which is suitable for evaluating complex systems with various inputs and outputs, and does not need to unify the scale of each indicator [22] .

Suppose there are n numbers of decision-making units ($j = 1, \dots, n$), and each decision cell has the same m inputs ($i = 1, \dots, m$) and the same s outputs ($r = 1, \dots, s$), with xij denoting the i-th input of the j-th decision cell, and yrj denoting the j-th output of the j-th decision cell r. Let the first input of decision cell j (iThe weight factor of the input ($i = 1, \dots, m$) have a weighting factor of vi The weight coefficient of the input (r=1,…,s) is r, and the weight coefficient of the output ($r = 1, \dots, s$) has a weight factor of ur, then the comprehensive output of the j is$\sum_{i=1}^{m} v_i x_{ij}$, and the efficiency evaluation index zj is calculated as follows: $z_j = \sum_{r=1}^{s} u_r y_{ij} / \sum_{i=1}^{m} v_i x_{ij}$ ($j = 1,2,3.\dots, n$). With the maximization of the efficiency evaluation index of the j0 (1≤j0 ≤n) decision unit as the objective function, and with the constraint that the efficiency evaluation index of all decision units is less than or equal to 1, the C2 R model of the j0 decision units is first constructed as follows:

$$Z_{j0} = \frac{\sum_{r=1}^{s} u_r y_{rj_0}}{\sum_{i=1}^{m} v_i x_{ij_0}} \qquad \text{[Formular 1]}$$

$$\{\frac{\sum_{r=1}^{s} u_r y_{ij}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \qquad j = 1.2\dots\dots n \qquad vi, ur > 0 \qquad i = 1, \dots, m; r = 1, \dots, s$$

Z_{j_0} stands for the decision-making unitj_0. The comprehensive efficiency of STE_{CCR} which is the comprehensive efficiency of the decision-making units, such that $t = \frac{1}{\sum_{i=1}^{m} \quad v_i x_{ij_0}}$, the original C2 R model is transformed into:

$maxh_{j_0} = \sum_{r=1}^{m} \quad u_r y_{rj_0}$ [Formular 2]

$$\{\sum_{r=1}^{s} \quad u_i y_{rj} - \sum_{r=1}^{m} \quad \omega_i xij \leq 0 \qquad j = 1.2 \ldots\ldots n \qquad \sum_{r=1}^{m} \quad \omega_i x_{ij_0} = 1 \qquad u_r, \omega_i \geq 0 \qquad i = 1, \ldots, m; r = 1, \ldots, s$$

Transforming linear programming problems into dyadic problems:

$S\,TE_{j_0}$ [Formular 3]

$$\{\sum_{j=1}^{n} \quad \lambda_i x_{rj} \leq \ STE_{j_0} x_{ij_0} \qquad i = 1,2 \ldots\ldots m \qquad \sum_{j=1}^{n} \quad \lambda_i y_{rj} y_{rj_0} \qquad r = 1,2 \ldots\ldots s \qquad \lambda_i \geq 0 \qquad j = 1,2, \ldots. n$$

$\sum_{i=1}^{n} \quad \lambda_j$ is the value of returns to scale, and if $\sum_{i=1}^{n} \quad \lambda_j = 1$, then the decision cell is "fixed returns to scale" and the final BC2 model is obtained:$P\,TE_{j_0}$

PTE_{j_0} [Formular 4]

$$\{\sum_{j=1}^{n} \quad \lambda_i x_{rj} \leq \ TE_{j_0} x_{ij_0} \qquad i = 1,2 \ldots\ldots m \qquad \sum_{j=1}^{n} \quad \lambda_i y_{rj} \geq y_{rj_0} \qquad i = 1,2 \ldots\ldots m \qquad \sum_{i=1}^{n} \quad \lambda_i = 1 \qquad \lambda_i \geq 0 \qquad j = 1,2, \ldots. n$$

SinceSTE_{CCR} =PTE_{BCC} × SE, the value of scale efficiency (SE) can be obtained from equation (3) and (4). Scale efficiency reflects the effective degree of the production scale of the object being evaluated, i.e., it reflects whether the object is evaluated in the most appropriate scale of investment. Pure Technical Efficiency (PTE) reflects the effective degree of utilization of existing technologies in the production process, under certain technical conditions and the same input, the higher the PTE, the higher the output rate.

3. Empirical Analysis

3.1 Analysis of Results

Based on the above theoretical analysis and model derivation, DEAP2.1 software is applied to derive the civil aviation industry inputs to the regional economy outputs in terms of comprehensive efficiency, technical efficiency and scale efficiency of each region and province. Due to space limitations, only 2010, 2015 and 2019 are shown.

3.2 Input-Output Efficiency of Civil Aviation to The Regional Economy by Region

The changes in the comprehensive efficiency of the civil aviation industry in the seven regions from 2010 to 2019 are shown in Figure 1.

On the whole, the comprehensive efficiencies of Eastern and North China are significantly better than that of other regions; South Central and Southwest China are next, but also at a high level; and Northeast China and Northwest China and Xinjiang are relatively low.

In terms of annual change, East China is most stable, with little annual change in the level of comprehensive efficiency; Southeast China and Northwest and Xinjiang both showed a steady increase after 2014; and North China and Northeast China saw a sudden increase in the level of comprehensive efficiency in 2019 after experiencing different levels of ups and downs. The comprehensive efficiency growth rates for each region, ranked from highest to lowest, are respectively 7.38% in the Northwest and Xinjiang, 7.31% in North China, 5.98% in Northeast China, 3.06% in Southeast China, 1.15% in East China, and -11.97% in Southwest China.

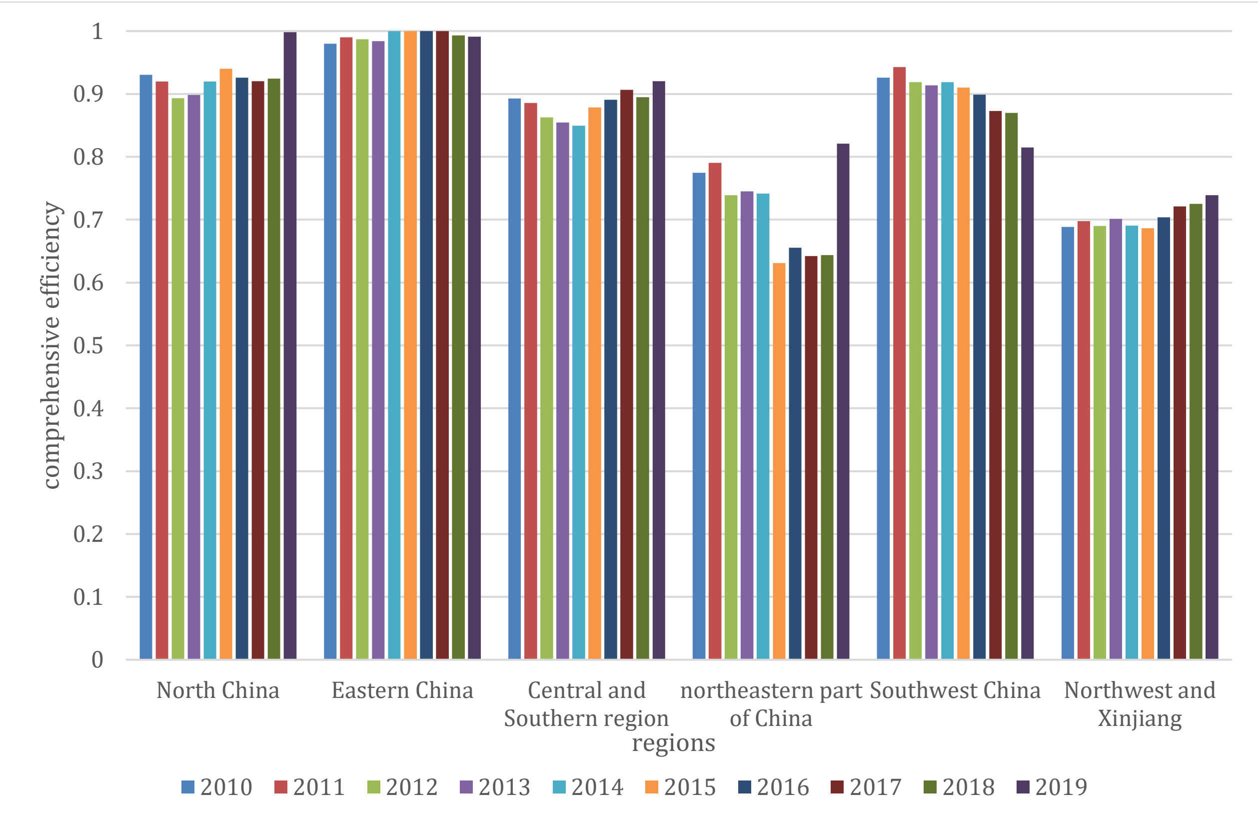

Figure 1. Comprehensive input-output efficiency of the civil aviation industry to the regional economy by region from 2010 to 2019

Source: By authors.

Specifically, we look at the comprehensive efficiency, technical efficiency and scale efficiency of the civil aviation industry inputs on regional economic outputs in China's seven regions, as shown in Table 2.

East China and North China, which have higher levels of comprehensive efficiency, are at higher levels of both technical and scale efficiency and can reach an effective state of 1.000 in some years; South Central China and Southwest China have relatively inferior technical and scale efficiencies, but they are also at higher levels; Northeast China and Northwest China and Xinjiang have higher scale efficiencies but lower levels of technical efficiency. The technical efficiency of the two is greatly improved in 2019, but the scale efficiency is slightly reduced.

Table 2. Input-output efficiency of the civil aviation industry to the regional economy by region

particular year provinces	2010			2015			2019		
DMU	Comprehensive efficiency	Technical efficiency	Scale efficiency	Comprehensive efficiency	Technical efficiency	Scale efficiency	Comprehensive efficiency	Technical efficiency	Scale efficiency
North China	0.930	0.996	0.934	0.940	0.963	0.974	0.998	1.000	0.998
East China	0.980	0.992	0.988	1.000	1.000	1.000	0.991	0.994	0.997
Central and South region	0.893	0.924	0.966	0.878	0.930	0.943	0.920	0.964	0.948
Northeast China	0.775	0.786	0.983	0.631	0.645	0.976	0.821	0.913	0.900
Southwest China	0.926	0.936	0.988	0.910	0.928	0.979	0.815	0.907	0.896
Northwest and Xinjiang	0.688	0.785	0.884	0.686	0.777	0.880	0.739	0.921	0.803
average value	0.865	0.903	0.957	0.841	0.874	0.959	0.881	0.950	0.924

Source: By authors.

3.3 Input-Output Efficiency of Civil Aviation Industry to Regional Economy by Province in Various Regions

3.3.1. Input-output efficiency of the civil aviation industry to the regional economy by province and region within North China

The comprehensive input-output efficiency of the civil aviation industry to regional economy in five provinces in North China from 2010 to 2019 is shown in Figure 2.

On the whole, the comprehensive efficiencies of Beijing and Hebei have been at an effective level of 1.000, followed in turn by Tianjin, Shanxi, and Inner Mongolia.

In terms of annual change, Beijing and Hebei are most stable, with no annual change in the level of comprehensive efficiency; Inner Mongolia shows a steady increase after 2013; Shanxi also shows a steady increase after 2012 and becomes stable after 2014; and Tianjin's comprehensive efficiency shows a decline but gets a big boost in 2019. The comprehensive efficiency growth rate for each province, ranked from highest to lowest, is respectively 24.1% in Inner Mongolia, 15.1% in Shanxi and 1.5% in Tianjin.

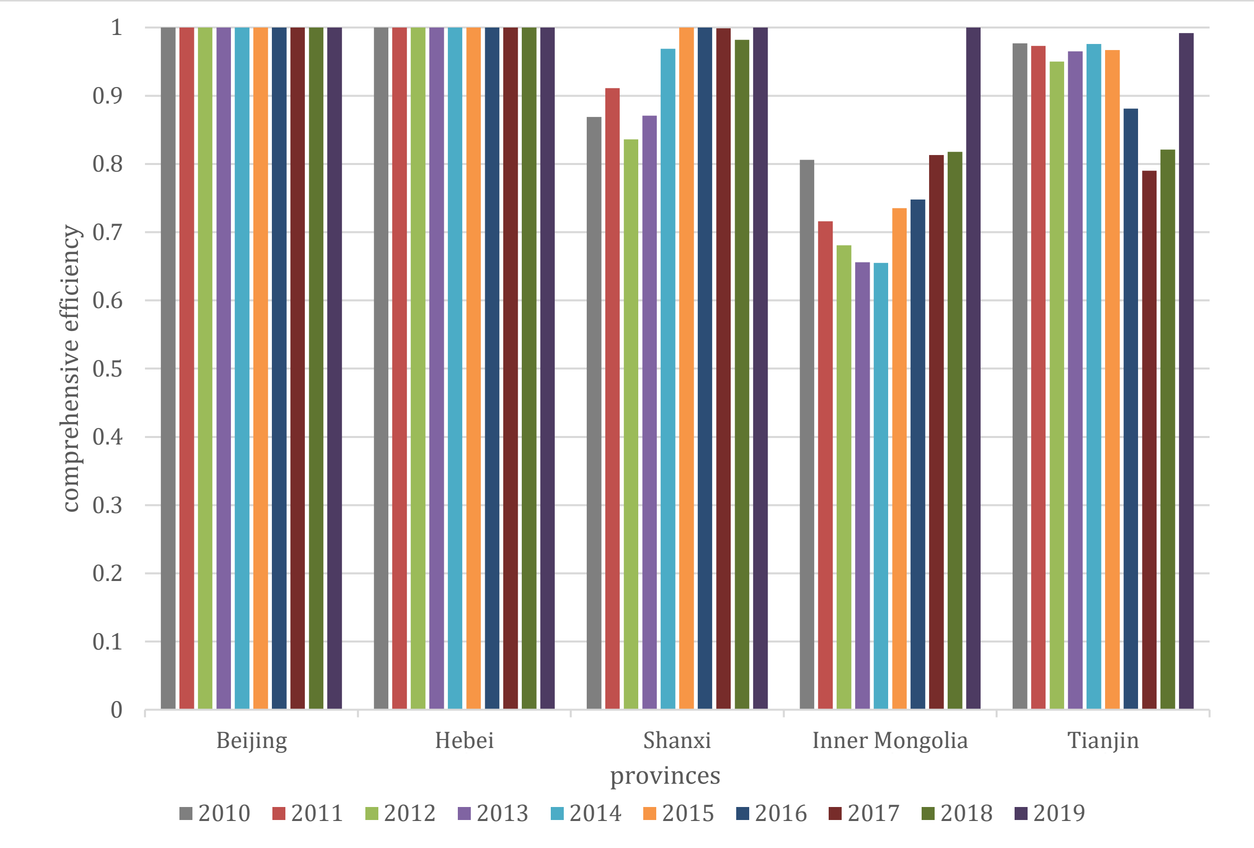

Figure 2. Comprehensive input-output efficiency of civil aviation industry to regional economy in North China by province from 2010 to 2019
Source: By authors.

Specifically, we look at the comprehensive efficiency, technical efficiency and scale efficiency of the civil aviation industry inputs to regional economic outputs in North China, as shown in Table 3.

Beijing and Hebei's technical and scale efficiencies are at the efficient level of 1.000 in all years; Shanxi and Tianjin's technical and scale efficiencies are also at high levels and can reach the efficient level of 1.000 in some years; and Inner Mongolia's technical and scale efficiencies are relatively low, but also reached the efficient value of 1.000 in 2019.

Table 3. Input-output efficiency of civil aviation industry to regional economy by province in North China

particular year provinces	2010			2015			2019		
DMU	Comprehensive efficiency	Technical efficiency	Scale efficiency	Comprehensive efficiency	Technical efficiency	Scale efficiency	Comprehensive efficiency	Technical efficiency	Scale efficiency
Beijing	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hebei	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Shanxi	0.869	0.978	0.889	1.000	1.000	1.000	1.000	1.000	1.000
Inner Mongolia	0.806	1.000	0.806	0.735	0.814	0.903	1.000	1.000	1.000
Tianjin	0.977	1.000	0.977	0.967	1.000	0.967	0.992	1.000	0.992
average value	0.930	0.996	0.934	0.940	0.963	0.974	0.998	1.000	0.998

Source: By authors.

3.3.2 Input-output efficiency of the civil aviation industry to the regional economy by province and region in northeast china

The change in the overall efficiency of the civil aviation industry in the Northeast from 2010 to 2019 is shown in Figure 3.

On the whole, Liaoning Province's overall comprehensive efficiency is better than that of the other regions, then comes Jilin Province and Heilongjiang Province.

In terms of annual change, Liaoning and Heilongjiang provinces showed an overall downward trend in their integrated efficiency values, while Jilin province was more stable. The integrated efficiency of all provinces increased in different degrees in 2019. The comprehensive efficiency growth of each province, from highest to lowest, is respectively 28.9% in Jilin Province, 21.9% in Heilongjiang Province, and -19.8% in Liaoning Province.

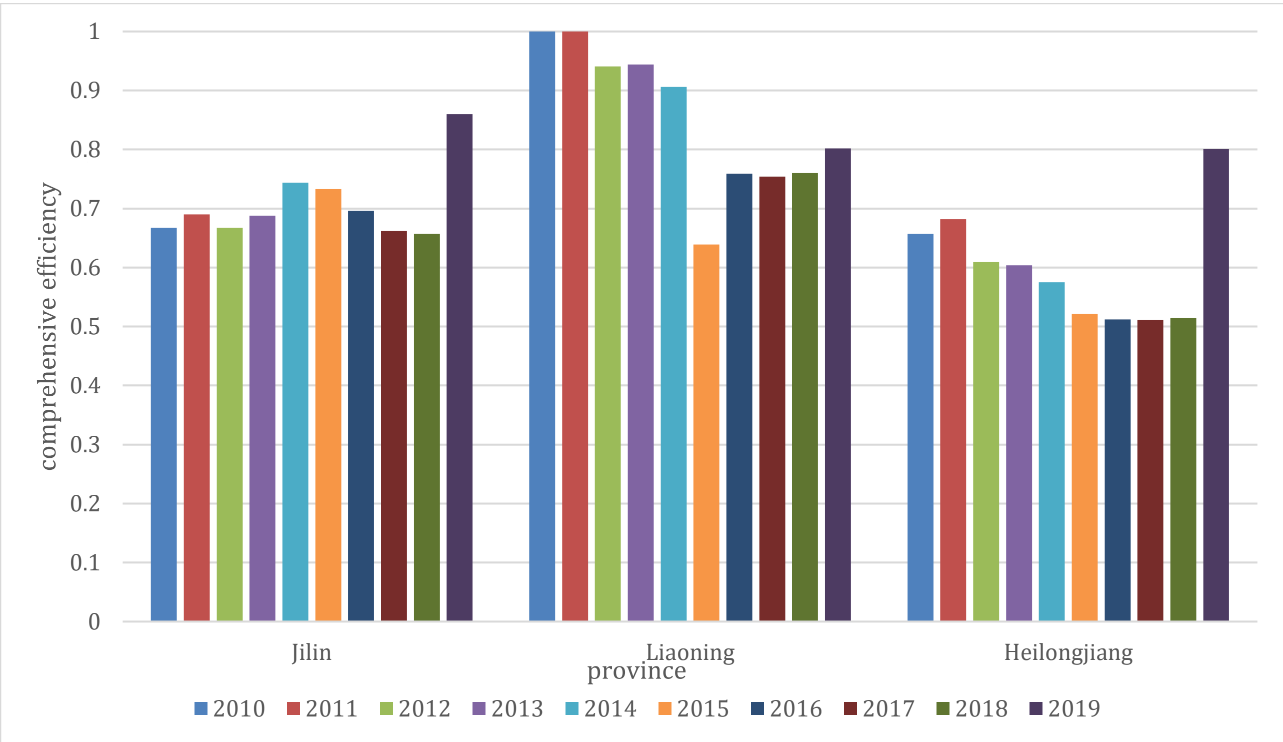

Figure 3. Comprehensive input-output efficiency of civil aviation industry to regional economy by province in Northeast China from 2010 to 2019

Source: By authors.

Specifically, we look at the comprehensive efficiency, technical efficiency and scale efficiency of the civil aviation industry inputs to regional economic outputs in Northeast China, as shown in Table 4.

It can be seen that the comprehensive efficiency of Liaoning Province is better than the other two provinces and is at the highest level, but the scale efficiency is decreasing year by year; the technical efficiency of Jilin Province is not high, but it shows a rising trend year by year and the scale efficiency is higher; the technical efficiency of Heilongjiang Province is increasing in volatility, while the scale efficiency is decreasing year by year.

Table 4. Input-output efficiency of civil aviation industry to the regional economy by province in Northeast China

particular year provinces	2010			2015			2019		
DMU	Comprehensive efficiency	Technical efficiency	Scale efficiency	Comprehensive efficiency	Technical efficiency	Scale efficiency	Comprehensive efficiency	Technical efficiency	Scale efficiency
Jilin	0.667	0.675	0.989	0.733	0.734	1.000	0.860	0.890	0.966
Liaoning	1.000	1.000	1.000	0.639	0.644	0.992	0.802	0.907	0.884
Heilong jiang	0.657	0.684	0.960	0.521	0.557	0.935	0.801	0.941	0.851
average value	0.775	0.786	0.983	0.631	0.645	0.976	0.821	0.913	0.900

Source: By authors.

3.3.3 Input-output efficiency of civil aviation industry to regional economy by province and region in eastern china

Changes in the comprehensive efficiency of the civil aviation industry inputs on regional economic outputs from 2010 to 2019 in East China are shown in Figure 4.

On the whole, the comprehensive efficiency of Shanghai, Jiangsu, Zhejiang and Anhui has been at an effective level of 1.000, while Fujian, Jiangxi and Shandong are relatively low.

In terms of annual change, the overall trend of comprehensive efficiency in Fujian and Jiangxi is increasing, and the overall trend of comprehensive efficiency in Shandong Province is decreasing. The growth rate in comprehensive efficiency by province, from highest to lowest, is respectively 11.6% in Fujian, 3.7% in Jiangxi, 0 in Shanghai, Jiangsu, Zhejiang and Anhui, and -6.1% in Shandong.

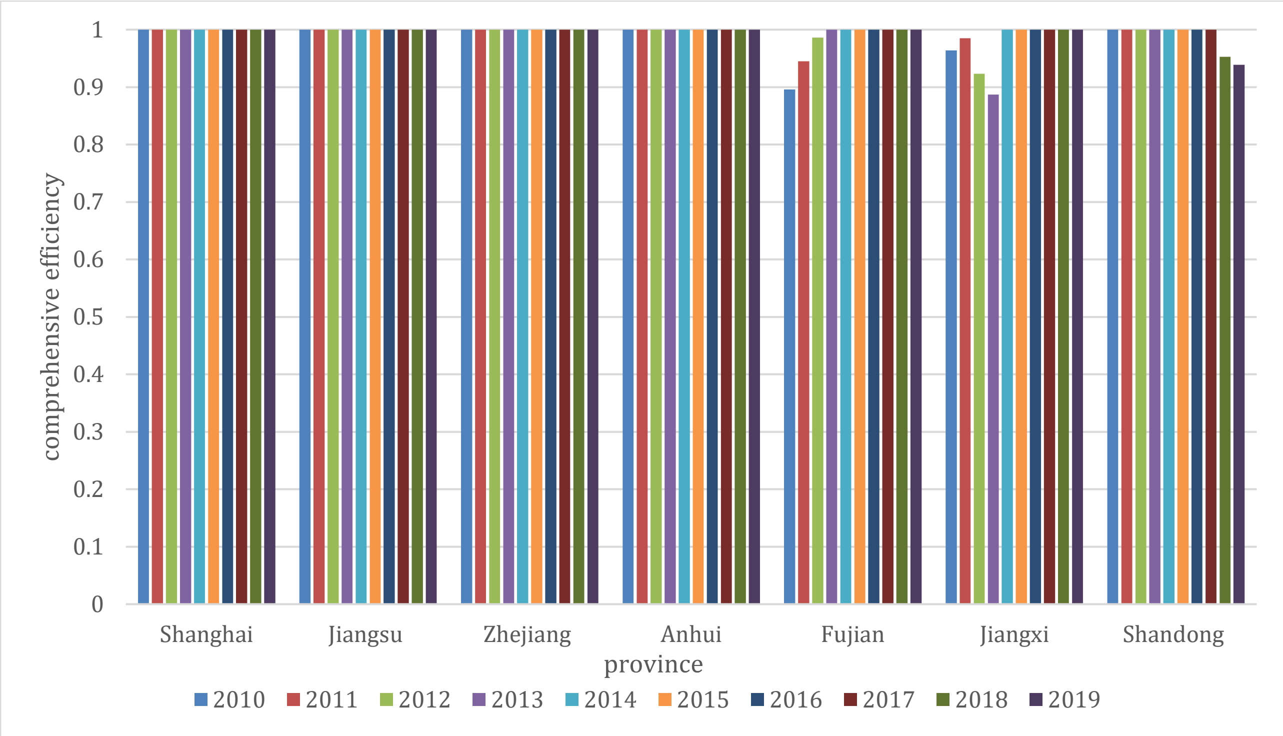

Figure 4. Comprehensive input-output efficiency of civil aviation industry to regional economy by province in East China from 2010 to 2019
Source: By authors.

Specifically, we look at the comprehensive efficiency, technical efficiency and scale efficiency of the civil aviation industry inputs on regional economic outputs in Eastern China, as shown in Table 5.

It can be seen that the technical and scale efficiencies of Shanghai, Jiangsu, Zhejiang and Anhui have been at the effective level of 1.000, so the comprehensive efficiency has been at the effective level of 1.000; the upward trend of the comprehensive efficiency of Fujian Province is due to the improvement of the technical and scale efficiencies; Jiangxi Province is due to the improvement of the technical efficiency; and Shandong Province has a different degree of the technical efficiency and the comprehensive efficiency have declined.

Table 5. Input-output efficiency of the civil aviation industry to the regional economy by province in East China

particular year provinces	2010			2015			2019		
DMU	Comprehensive efficiency	Technical efficiency	Scale efficiency	Comprehensive efficiency	Technical efficiency	Scale efficiency	Comprehensive efficiency	Technical efficiency	Scale efficiency
Shanghai	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Jiangsu	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Zhejiang	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Anhui	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Fujian	0.896	0.978	0.917	1.000	1.000	1.000	1.000	1.000	1.000
Jiangxi	0.964	0.964	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Shandong	1.000	1.000	1.000	1.000	1.000	1.000	0.939	0.960	0.978
average value	0.980	0.992	0.988	1.000	1.000	1.000	0.991	0.994	0.997

Source: By authors

3.3.4 Input-output efficiency of civil aviation industry to regional economy by province and region in Central and South China

Changes in the comprehensive input-output efficiency of civil aviation industry to regional economy from 2010 to 2019 in Central and South China are shown in Figure 5.

On the whole, the comprehensive efficiency of Guangdong has been at an effective level of 1.000, followed by Guangxi, Henan, Hunan and Hubei, and relatively low in Hainan.

In terms of annual change, the comprehensive efficiency of Guangxi, Hunan and Hubei shows an upward trend as a whole, Henan shows a downward trend followed by an upward trend as a whole, and Hainan shows a clear downward trend. The comprehensive efficiency growth rate for each province, ranked from highest to lowest, is respectively 22.3% in Hunan, 19.3% in Guangxi, 14.4% in Hubei, 0 in Guangdong, -0.4% in Henan, and -33.4% in Hainan.

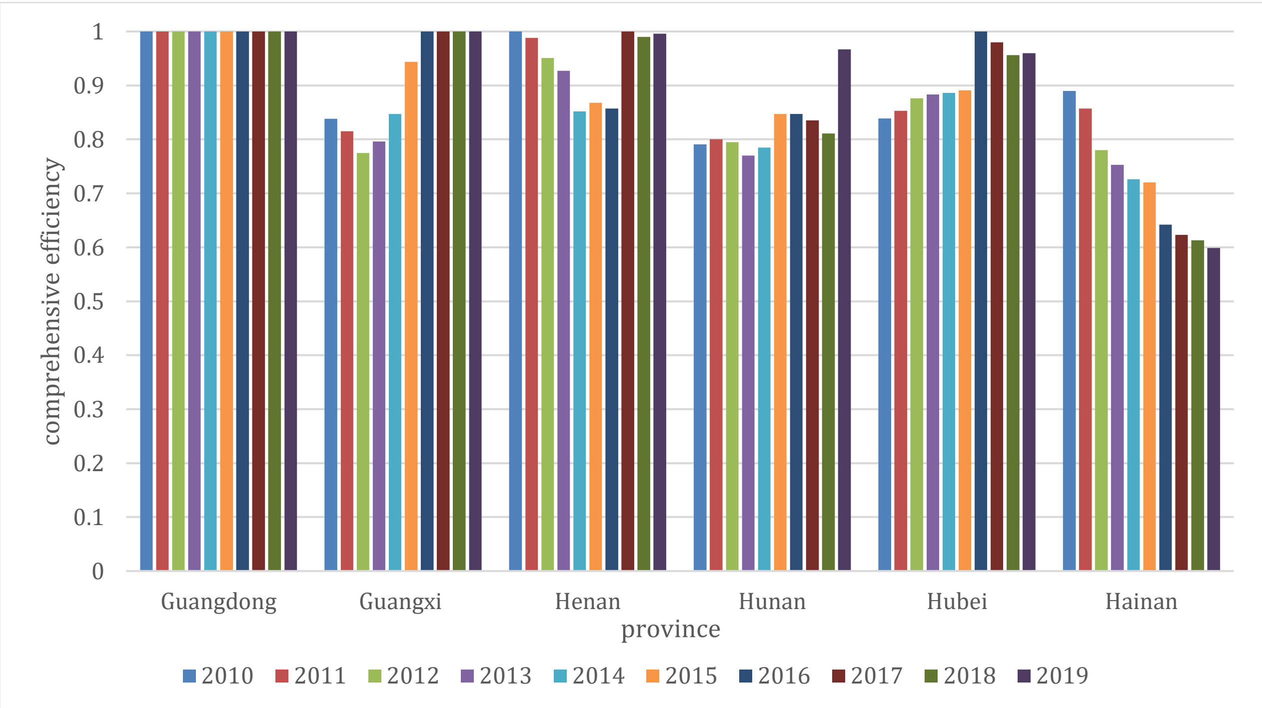

Figure 5. Comprehensive input-output efficiency of civil aviation industry to regional economy by province in Central and South China from 2010 to 2019
Source: By authors.

Specifically, we look at the comprehensive efficiency, technical efficiency and scale efficiency of the civil aviation industry inputs on regional economic outputs in Central and South China, as shown in Table 6.

It can be seen that the technical efficiency and scale efficiency of Guangdong have been at the effective level of 1.000, so the comprehensive efficiency has been at the effective level of 1.000; the comprehensive efficiency of Guangxi, Hunan and Hubei shows an upward trend because the technical efficiency and scale efficiency have been improved in different degrees; the technical efficiency and scale efficiency of Henan firstly decreases, and then rebounds, so that the comprehensive efficiency firstly decreases and then improves; the comprehensive efficiency of Hainan shows a downward trend because the technical efficiency and scale efficiency have both decreased to a large extent. In Henan, the technical efficiency and scale efficiency first decrease and then increase, so its comprehensive efficiency shows a trend of first decreasing and then increasing; in Hainan, the comprehensive efficiency shows a decreasing trend because technical efficiency and scale efficiency both decrease to a large extent.

Table 6. Input-output efficiency of civil aviation industry to regional economy by province in Central and South China

particular year provinces	2010			2015			2019		
DMU	Comprehensive efficiency	Technical efficiency	Scale efficiency	Comprehensive efficiency	Technical efficiency	Scale efficiency	Comprehensive efficiency	Technical efficiency	Scale efficiency
Guangdong	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Guangxi	0.838	0.925	0.906	0.944	0.946	0.998	1.000	1.000	1.000
Henan	1.000	1.000	1.000	0.868	0.901	0.964	0.996	1.000	0.996
Hunan	0.791	0.824	0.960	0.847	0.966	0.878	0.967	0.996	0.971
Hubei	0.839	0.877	0.957	0.891	0.931	0.956	0.960	1.000	0.960
Hainan	0.890	0.916	0.972	0.720	0.836	0.860	0.599	0.790	0.758
average value	0.893	0.924	0.966	0.878	0.930	0.943	0.920	0.964	0.948

Source: By authors.

3.3.5 Input-output efficiency of civil aviation industry to regional economy by province and region in Northwest China and Xinjiang

Changes in the comprehensive efficiency of the civil aviation industry inputs on regional economic outputs from 2010 to 2019 in Northwest China and Xinjiang are shown in Figure 6.

In general, Shaanxi's overall comprehensive efficiency is better than that of other provinces.

In terms of annual change, the trend of changes in all provinces is relatively smooth, with the exception of Xinjiang, which has slightly decreased, and the rest of the provinces as a whole show a steady increase. The comprehensive efficiency growth for each province, from highest to lowest, is respectively 12.1% in Gansu, 10.2% in Shaanxi, 10.3% in Ningxia, 0.8% in Qinghai, and -2.6% in Xinjiang.

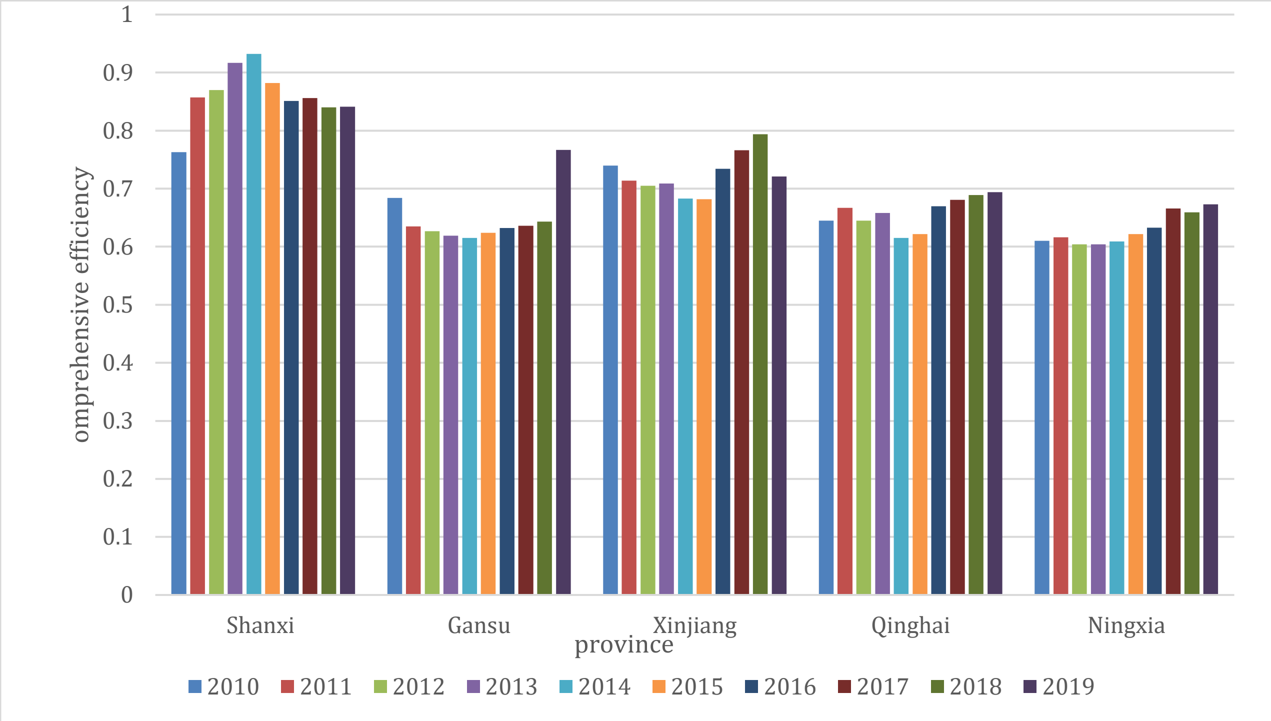

Figure 6. Comprehensive input-output efficiency of civil aviation industry to regional economy by province in Northwest China and Xinjiang from 2010 to 2019
Source: By authors.

Specifically, we look at the comprehensive efficiency, technical efficiency and scale efficiency of the civil aviation industry inputs on regional economic outputs in Northwest China and Xinjiang, as shown in Table 7.

It can be seen that Shaanxi's technical efficiency and scale efficiency are better than other provinces as a whole, and the technical efficiency is increasing year by year, while the scale efficiency is slowly decreasing; Gansu, Qinghai and Ningxia's technical efficiencies are on an overall upward trend; and Xinjiang's technical efficiency declined in 2019 compared with 2010.

Table 7. Input-output efficiency of civil aviation industry to regional economy by province in Northwest China and Xinjiang

particular year provinces	2010			2015			2019		
DMU	Comprehensive efficiency	Technical efficiency	Scale efficiency	Comprehensive efficiency	Technical efficiency	Scale efficiency	Comprehensive efficiency	Technical efficiency	Scale efficiency

Shaanxi	0.763	0.806	0.947	0.882	0.925	0.954	0.841	1.000	0.841
Gansu	0.684	0.788	0.868	0.624	0.708	0.882	0.767	0.873	0.879
Xinjiang	0.740	0.956	0.774	0.682	0.808	0.843	0.721	0.900	0.801
Qinghai	0.645	0.709	0.910	0.622	0.725	0.857	0.694	0.910	0.763
Ningxia	0.610	0.664	0.919	0.622	0.719	0.865	0.673	0.923	0.729
average value	0.688	0.785	0.884	0.686	0.777	0.880	0.739	0.921	0.803

Source: By authors.

3.3.6 Input-output efficiency of civil aviation industry to regional economy by province and region in Southwest China

Changes in the comprehensive input-output efficiency of civil aviation industry to regional economy from 2010 to 2019 in Southwest China are shown in Figure 7.

On the whole, Huizhou’s comprehensive efficiency is better than other provinces as a whole, and has been at an effective level of 1.000 in all years.

In terms of annual change, the overall trend of comprehensive efficiency in Tibet, Sichuan and Chongqing is decreasing, except for 2019 when the overall trend of comprehensive efficiency in Yunnan is increasing. The comprehensive efficiency growth rate for each province from 2010 to 2019, from highest to lowest, is as follows: Guizhou 0%, Yunnan -4.3%, Chongqing -13.3%, Sichuan -15.6%, and Tibet -26.2%.

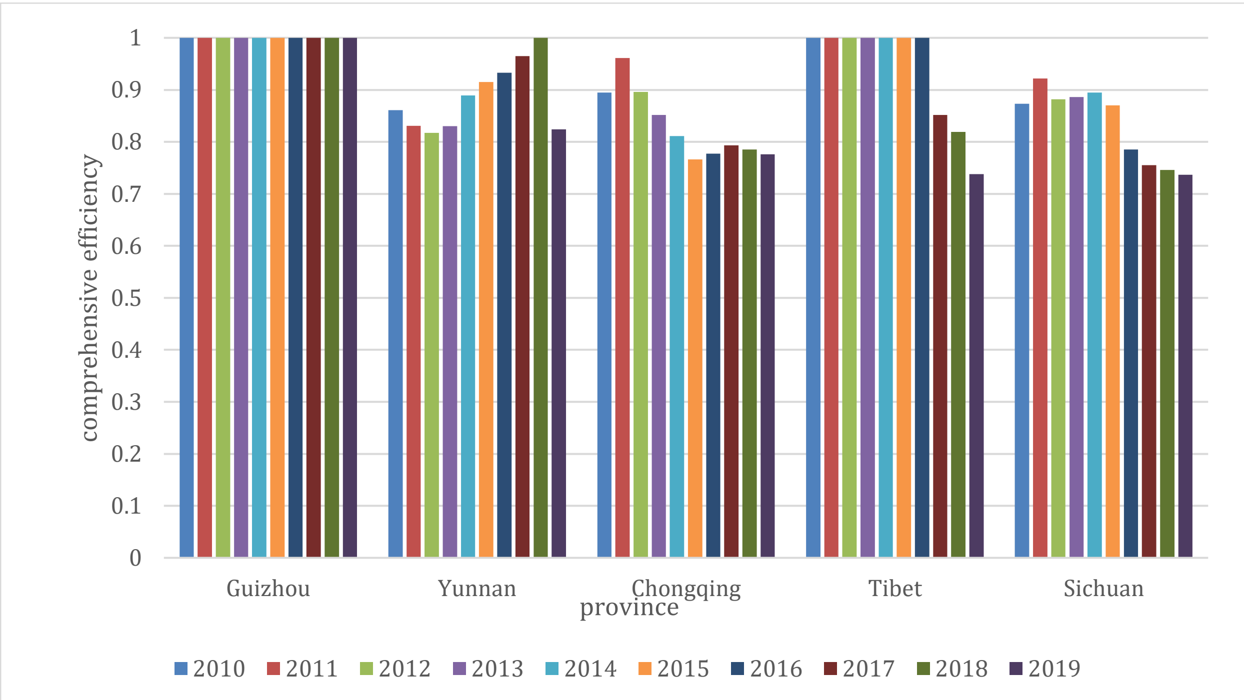

Figure 7. Comprehensive input-output efficiency of civil aviation industry to regional economy by province in Southwest China from 2010 to 2019

Source: By authors.

Specifically, we look at the comprehensive efficiency, technical efficiency and scale efficiency of civil aviation industry inputs to regional economy outputs in Southwest China, as shown in Table 8.

It can be seen that the technical and scale efficiencies of Guizhou have been at the effective level of 1.000, while those of Chongqing, Tibet and Sichuan have been on an upward trend as a whole, and the scale efficiency of Yunnan has declined.

Table 8. Input-output efficiency of civil aviation industry to regional economy by province and region in Southwest China

particular year provinces	2010			2015			2019		
DMU	Comprehensive efficiency	Technical efficiency	Scale efficiency	Comprehensive efficiency	Technical efficiency	Scale efficiency	Comprehensive efficiency	Technical efficiency	Scale efficiency
Guizhou	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Yunnan	0.861	0.874	0.985	0.915	0.930	0.983	0.824	0.906	0.910
Chongqing	0.895	0.899	0.995	0.766	0.829	0.924	0.776	0.874	0.888
Tibet	1.000	1.000	1.000	1.000	1.000	1.000	0.738	0.865	0.853
Sichuan	0.873	0.908	0.962	0.870	0.881	0.988	0.737	0.890	0.828
average value	0.926	0.936	0.988	0.910	0.928	0.979	0.815	0.907	0.896

Source: By authors.

3.4 Changes in the Comprehensive Input-Output Efficiency of Civil Aviation Industry to Regional Economy by Province

Table 9 and Table 10 demonstrate a comparison of the combined efficiency, scale efficiency and technical efficiency of civil aviation industry inputs to regional economy outputs in 31 provinces or regions in China during 2010-2019.

(1) Over the past decade, the comprehensive efficiency, technical efficiency, and scale efficiency of the civil aviation industry in 19 provinces or regions, including Beijing, Hebei, and Shanghai, have successively reached the level of 1.000. Since 1.000 stands for the highest efficiency level, it can be considered that the civil aviation industry in these provinces or regions has achieved effective values of 1.000 in terms of input-output efficiency levels for regional economies. Among them, over the past decade, the comprehensive efficiency of the civil aviation industry in eight provinces or regions, namely Beijing, Hebei, Shanghai, Jiangsu, Zhejiang, Anhui, Guangdong, and Guizhou, has consistently remained at effective levels. The comprehensive efficiency of Shanxi, Inner Mongolia, Fujian, Jiangxi, and Guangxi has also reached effective values of 1.000 after continuous improvements. While Henan, Hubei, and Yunnan have reached effective values in individual years, they show slight fluctuations. However, the efficiency values of Liaoning, Shandong, and Tibet have

shown a declining trend. The comprehensive efficiency of the civil aviation industry in the remaining provinces has not reached the effective value of 1.000.

(2) The average technical and scale efficiencies of Hainan, Gansu, Ningxia, Qinghai, Inner Mongolia, and Xinjiang in 2010-2019 are at a low level; the technical efficiency levels of Liaoning, Sichuan, Chongqing, Jilin, and Heilongjiang are relatively low, and it can be preliminarily concluded that these provinces have a comparatively lower input-output efficiency level of the civil aviation industry to regional economies which needs to be improved.

Table 9. Changes in the comprehensive input-output efficiency of civil aviation industry to regional economy in 31 provinces or regions

Comprehensive efficiency	Provinces (Regions)
1.000	Beijing 2010-2019, Hebei 2010-2019, Shanghai 2010-2019, Jiangsu 2010-2019, Zhejiang 2010-2019, Anhui 2010-2019, Shanxi 2015, 2016, 2019, Inner Mongolia 2019, Liaoning 2010, 2011, Fujian 2013-2019 Jiangxi 2014-2019, Shandong 2010-2017, Henan 2010, 2017, Hubei 2016, Guangdong 2010-2019, Guangxi 2016-2019, Guizhou 2010-2019, Yunnan 2018, Tibet 2010-2016
0.900-0.999	Tianjin 2010-2015, 2019, Shanxi 2011, 2014, 2017, 2018, Liaoning 2012-2014, Fujian 2011-2012, Jiangxi 2010-2012, Shandong 2018-2019, Henan 2011-2013, 2018-2019, Hubei 2017-2019 Chongqing 2011, Sichuan 2011, Guangxi 2015, Yunnan 2015-2017, Shaanxi 2013-2014
0.800-0.900	Tianjin 2016, 2018, Shanxi 2010, 2012-2013, Inner Mongolia 2010, 2017-2018, Liaoning 2019, Jilin 2019, Heilongjiang 2019, Fujian 2010, Jiangxi 2013, Henan 2014-2016, Hubei 2010-2015, Hunan 2011, 2015- 2018, Guangxi 2010-2011, 2014, Hainan 2010-2011, Chongqing 2010, 2012-2014, Sichuan 2010, 2012-2015, Yunnan 2010-2014, 2019, Tibet 2017-2018, Shaanxi 2011-2012, 2015-2019
0.700-0.800	Tianjin 2017, Inner Mongolia 2011, 2015-2016, Liaoning 2016-2018, Jilin 2014-2015, Hunan 2010, 2012-2014, Guangxi 2012-2013, Hainan 2012-2015, Chongqing 2015-2019, Sichuan 2016-2019, Tibet 2019 Shaanxi 2010, Gansu 2019, Xinjiang 2010-2013, 2016-2019
0.600-0.700	Inner Mongolia 2012-2014, Liaoning 2015, Jilin 2010-2013, 2016-2018, Heilongjiang 2010-2013, Hainan 2016-2018, Gansu 2010-2018, Qinghai 2010-2019, Ningxia 2010-2019, Xinjiang 2014-2015
0.500-0.600	Heilongjiang 2014-2018, Hainan 2019

Source: By authors.

Table 10. Average scale and technical input-output efficiencies of civil aviation industry to regional economy in 31 provinces or regions from 2010 to 2019

Provinces (Regions)	Scale efficiency	Provinces (Regions)	Technical efficiency
Beijing	10	Beijing	10
Hebei	10	Tianjin	10
Shanghai	10	Hebei	10
Jiangsu	10	Shanghai	10
Zhejiang	10	Jiangsu	10

Anhui	10	Zhejiang	10
Guangdong	10	Anhui	10
Guizhou	10	Guangdong	10
Jiangxi	9.994	Guizhou	10
Shandong	9.931	Fujian	9.978
Jilin	9.893	Shandong	9.96
Guangxi	9.88	Shanxi	9.795
Fujian	9.848	Jiangxi	9.764
Henan	9.802	Henan	9.613
Yunnan	9.787	Tibet	9.605
Tibet	9.776	Hubei	9.431
Hubei	9.667	Shaanxi	9.22
Shanxi	9.632	Guangxi	9.122
Chongqing	9.517	Yunnan	9.063
Liaoning	9.51	Hunan	9.059
Sichuan	9.457	Inner Mongolia	9.033
Heilongjiang	9.346	Liaoning	8.95
Shaanxi	9.346	Sichuan	8.823
Tianjin	9.292	Xinjiang	8.785
Hunan	9.158	Chongqing	8.725
Hainan	8.834	Hainan	8.126
Gansu	8.741	Qinghai	7.712
Ningxia	8.644	Gansu	7.417
Qinghai	8.564	Ningxia	7.327
Inner Mongolia	8.452	Jilin	7.145
Xinjiang	8.26	Heilongjiang	6.433

Source: By authors.

4. Conclusions

This paper focuses on 31 provinces or regions in China from 2010 to 2019, which are divided into seven major regions according to the classification criteria of the Civil Aviation Administration of China (CAAC). The DEAP 2.1 software was employed to derive comprehensive efficiency, technical efficiency, and scale efficiency of the civil aviation industry inputs to regional economy outputs of each major region and its constituent provinces. The conclusions are as follows:

(1) There are significant regional differences in input-output efficiency of civil aviation industry to regional economy in the seven major regions of China. The average distribution of comprehensive efficiency across these regions is as follows: East China > North China > Central-South China > Southwest China > Northeast China > Northwest and Xinjiang region. The input-output efficiency level of the civil aviation industry in China has exhibited a continuous increase, with efficiency levels gradually decreasing from coastal areas such as East China, North China, and Central-South China towards inland regions like Southwest China, Northeast China, Northwest, and Xinjiang.

In addition, there are significant regional differences in the growth rates across the seven major regions. The growth rates of comprehensive efficiency in the seven major regions are as follows: Northwest and Xinjiang region > North China > Northeast China > Central-South China > East China > Southwest China. The growth trajectory of the input-output comprehensive efficiency of the civil aviation industry in China has shifted from rapid growth to a more stable pace. The growth rates change in a decreasing gradient manner from coastal areas such as East China, North China, and Central-South China towards inland regions like Southwest China, Northeast China, Northwest, and Xinjiang.

(2) There are significant differences in the input-output efficiency of civil aviation industry to regional economy among the provinces within the seven major regions, and the efficiency level also shows a decreasing gradient from coastal provinces within regions such as East China, North China, and Central-South China towards inland provinces within regions such as Southwest China, Northeast China, Northwest China, and Xinjiang.

In addition, there are significant provincial differences in the growth rates of the input-output comprehensive efficiency of the civil aviation industry for regional economies in China. The growth rates present an increasing gradient from coastal provinces in regions such as East China, North China, and Central-South China towards inland provinces in Southwest China, Northeast China, Northwest China, and Xinjiang.

(3) Among China's 31 provinces or regions, the average technical efficiency and scale efficiency of Hainan, Gansu, Ningxia, Qinghai, Inner Mongolia, and Xinjiang during 2010-2019 are at a low level; while the technical efficiency of Liaoning, Sichuan, Chongqing, Jilin, and Heilongjiang is relatively low, and it can be initially assumed that the input-output efficiency level of civil aviation industry to regional economy is low in these provinces and this needs to be improved.

5. Policy suggestions

Based on the above findings, this paper suggests that the input-output efficiency of civil aviation industry to regional economy may be optimized from the following two perspectives.

(1) Increasing capital investment to improve scale efficiencies

The input-output efficiency of China's civil aviation industry has grown rapidly over the past few years, and the civil aviation industry has a strong driving effect on the regional economy. Compared with other types of transportation, the input-output level of civil aviation industry to regional economy ranks in the first place, and the good development of the civil aviation industry can effectively drive the development of the regional economy, so increasing the capital investment in the civil aviation industry will also increase the economic benefits. Xinjiang, Inner Mongolia, Qinghai, Ningxia, Gansu and Hainan have low scale efficiency, and capital investment in the civil aviation industry in these provinces can be appropriately increased in order to improve their scale efficiency and thus enhance economic efficiency.

(2) Rationalizing the spatial layout of key industries to improve technical efficiency

The civil aviation industry is transforming and upgrading. In the past, the civil aviation industry is closely linked with the secondary industry such as petroleum, iron refining, traditional production manufacturing, etc., but now this situation has gradually changed. The civil aviation industry has turned to strengthen the linkage with many emerging industries with high added value and high economic growth potential such as finance, business leasing, high-end production manufacturing, etc., which will become a strong support for the development of the civil aviation industry in Heilongjiang, Jilin, Ningxia, Gansu, Qinghai, Hainan, Chongqing, Xinjiang, Sichuan and Liaoning and other provinces (regions) with low efficiency value should strengthen the spatial layout of the above industries, which is conducive to accelerating the transformation and upgrading of the civil aviation industry and to the win-win interaction between the industries.

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