DEA efficiency-based coupling and coordination analysis of China civil aviation industry and regional economy

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DOI: https://doi.org/10.30212/JITI.202402.007

ABSTRACT

The fundamental role of the air transport sector in promoting the regional economy has become increasingly prominent due to the significant influence of the aviation hub, the international first-class aviation services, and the well-developed general aviation functions. Therefore, it is crucial to evaluate the degree of coordination between the civil aviation industry and the regional economic level. This paper constructs the evaluation index system of civil aviation industry and regional economic development level from the input and output aspects, and develops a coupling coordination degree model for these two sectors based on the DEA-CCR efficiency model, and empirically analyzes the coupling coordination degree of the two and examines the development trends by using the data from 2010-2019. The results of coupling coordination degree of civil aviation industry and regional economy in the seven regions of China shows a steady upward trend. However, there are significant regional differences. Among them, East China and North China exhibit a higher degree of coordination, while Northwest China is in the stage of dysfunction. Using the DEA efficiency model to measure the efficiency over time can effectively classify the coupling coordination degree of different regions into stages. Analyzing the coupling coordination degree of civil aviation industry and regional economy not only enriches the research on the coordinated development of the civil aviation industry and regional economy, but also provides a new insights intothe sustainable development of civil aviation transportation. This analysis offers theoretical support and reference for the future planning of civil aviation construction, which helps to promote the coordinated development of civil aviation industry and regional economy.

Keywords: Civil aviation, Regional economy, Economic development, DEA efficiency, Coupled coordination

1. Introduction

Economic development is the basis for the development of civil aviation, while the development of civil aviation promotes economic development, transformation and upgrading (Zhang Huiyun et al., 2021)[1]. Air transportation is an important support for enhancingthe efficient circulation of resources, information and other production factors between developed and underdeveloped regions, and it is a key mechanism to accelerate the regional economic "internal cycle" and open up the domestic and international double cycle (Liu, P. et al., 2021)[2]. Yu Jian and Guo Yitong (2021)[3] explored the interaction mechanism between civil aviation transportation and regional development in Academic Exchange. They highlighted that the development of civil aviation transportation can promote the growth of regional economy, whilethe prosperity of the regional economy also provides a broader market and better infrastructure for civil aviation transportation. Shen Hui and Zou Ping (2016)[4] also found a positive interaction effect between China's civil aviation industry and economic development. Their study on the synergistic relationship between the two sectors revealed that the rapid development of civil aviation industry helps to improve the overall level of regional economy. Huang Lei et al. (2021)[5] analyzed the impact of civil aviation industry agglomeration on the high-quality development of the economy using the threshold regression model test on provincial panel data, and the results showed that aviation industry agglomeration can effectively promote the high-quality development of the regional economy. Fan Xuexiu et al. (2024)[6] studied the impact of civil aviation transportation on the inbound tourism economy from the perspective of heterogeneity and spatial spillover effect, and found that the development of civil aviation transportation has a significant positive impact on tourism. Similarly, Ma Xiaoke (2017)[7] examined Zhengzhou Air Port as an example to study the coupling mechanism of the airside economy and regional economic development, and found that the development of the airside economy has a significant driving effect on the regional economy. Wu Hengyi (2023) [8] studied the impact of civil aviation on the high-quality development of regional economies, focusing on the mechanism analysis of emergencies, pointing out that although emergencies will impact the civil aviation industry in the short term. However, in the long term, civil aviation can still have a positive impact on the regional economy. Comprehensive studies by the above scholars indicate an obvious positive correlation between the domestic civil aviation industry and the spatial layout of regional economic development, while analyzing the coupling and coordination degree of civil aviation and economic development, promoting the mutual benefit and win-win situation of the two.The approach also provided a new way of thinking for the sustainable development of civil aviation transportation, along with the theoretical support and reference for the future planning of civil aviation construction (Zhao Weiwei, et al., 2018)[9].Such analysis is more conducive to realizing the strategy of high-quality development of civil aviation (Peng Hongqin et al., 2023)[10].

Different scholars had used variousperspectives and methods to study the close connection between civil aviation industry and regional economic development. Fang Zhongquan and Wang Zhangxian (2011)[11] explored the relationship between civil aviation transportation growth and regional economic development through Granger causality test, using Guangzhou Baiyun International Airport as an example. Liang Yinghui, Feng Cheng, and Zheng Pan (2022)[12] signified that the civil aviation transportation industryas an important part of the modern transportation system, that not only facilitates the rapid movement of people and goods, but also drives the development of related industries and provides a new impetus for economic growth. The study by Li and Hu Yaru (2018) [13] found that the development of civil aviation industry can promote the equalization of population distribution, helping to alleviate the population pressure in some regions, and bringing new development opportunities to some underdeveloped regions. Ji Chenyu and Zhang Hanyu (2021) [14]based on the panel data of China's major tourist cities, analyzed and concluded that the civil aviation industry, as an important part of the modern service industry, has a significant pulling effect on the economic growth, while the economic growth also provides a favorable environment for the development of civil aviation industry. Jiang Hong et al. (2020)[15] explored the operation status and development trend of the civil aviation passenger transportation industry by compiling the economic operation boom index of the civil aviation passenger transportation industry to provide a decision-making basis for policy makers.

In the field of civil aviation industry, many scholars haveused the model of DEA to conduct research. Barbara T.H. Yen and Jun-Sheng Li (2020)[16] used the frontier data envelopment analysis method to evaluate the airline's performance based on routes, which provided an international perspective for the airline's efficiency improvement. Arun Saini et al. (2023)[17] combined data envelopment analysis to study the relationship between airline efficiency and environmental impact, providing theoretical support for airlines to achieve green development. Rapposelli A et al. (2020)[18] combined principal component analysis with data envelopment analysis model to assess the operational performance of the Italian airlines, and then later used the model to measure the efficiency in airline routes. Huang Tao and Hao Ya (2019) [19] analyzed the coupling coordination between civil aviation industry and regional economy in Northeast China, and found a strong coupling and coordination relationship between the two.The study indicated that the development of aviation industry can effectively promote the coordinated development of regional economy. Similarly, Zhang Yang Mingyuan and Bai Yang (2018) [20] confirmed the close connection between civil aviation transportation and regional economy by analyzing the correlation between airports and regional economic development in Jiangsu Province. Zeng Bing (2022) [21]evaluated the economic efficiency of Chinese provinces and regions from the perspective of good life by using the DEA-Malmquist model, which provided a reference for improving regional economic efficiency.

Different scholars have adopted various perspectives and methods to study the close connection between the civil aviation industry and regional economic development, which may lead to inconsistency and difficulty in comparing the research results. Drawing on their studies, it can be found that previous studies may not have fully taken into account the differences between different regions in China in terms of the degree of coupling and coordination between the civil aviation industry and regional economic development, and that this paper covers data from 2010-2019, whereas previous studies may not have covered such a long time span Additionally, this paper constructs a comprehensive evaluation index system, including both input and output aspects, which may be more comprehensive and systematic than previous studies. This paper mainly uses the coupled coordination degree model to analyze the relationship between civil aviation industry and regional economic development. The empirical analysis can more accurately reflect the interaction between civil aviation industry and regional economy, which not only supplements to the existing theories, but also may provide theoretical support and references for the future planning of civil aviation construction, which may be lacking in the previous studies.

2. Empirical Design

2.1 Establishment of the indicator system and the coefficient of variation assignment method

Drawing on the research of scholars domestically and internationally, this paper analyzes the coupling and coordination of civil aviation industry and regional economic development. This paper considers 31 provinces (excluding Hong Kong, Macao and Taiwan)in China and categorize the provinces according to the geographic areas under the jurisdiction of the seven regional administrations established by the Civil Aviation Administration of China (CAAC) throughout the country. The span of study period is 2010-2019, and the data are obtained from the 2011-2020 Statistical Yearbook of Civil Aviation of China and the Statistical Yearbook of Cities of China, which were measured in terms of the civil aviation system and the economic development system, respectively. In terms of civil aviation system, the number of employees in the aviation industry in each province and the sum of airport runway area in each province were selected as input indicators. Whereas, the cargo and mail throughput, passenger throughput, and takeoff and landing movements were used as output indicators. The comprehensive efficiency , pure technical efficiency , and scale efficiency of the civil aviation industry were calculated based on the DEA-CCR efficiency model. In terms of the economic development system ,the contribution rate of the three industries to GDP was used as an input indicator. The comprehensive efficiency, pure technical efficiency and scale efficiency of economic development were analyzed by taking various indicators including the investment in fixed assets of the whole society (excluding farmers), domestic tourism income, foreign exchange income from international tourism, gross regional product, and the total amount of imports and exports (the total amount of imports and exports was divided into two categories: the total amount of imports and exports1 is by the location of the operating units, and the total amount of imports and exports2 by the domestic destinations and the sources of goods) as the output indexes. Finally, based on the scale efficiency of civil aviation and economic development, a coupling coordination model was constructed to measure the coupling coordination between civil aviation and economic development in 3l provinces in China. The analysis of the coupling coordination between civil aviation and the economy was analyzed by calculating the average value of each province under the jurisdiction of the seven regional administrations set up by the Civil Aviation Administration of China (CAAC) in the country.

This paper focuses on two systems: the civil aviation industry and economic development, from the input and output levels. It refers to the research of Li Yong et al.'s [22], for considering the characteristics of the both systems and the reliable scientific data, . Data of 2010, 2015 and 2019 are used to construct the indicator system of civil aviation industry and economic development, as detailed in Table 1. The coefficient of variation method is used for calculating the weights of the indicators.

Table 1. Weights of the Civil Aviation Industry and Regional Economic Development Indicator System

Systems	Level 1 indicators	Level 2 indicators	weights		
			2010	2015	2019
Civil aviation industry system	Input indicators	Number of employees in the aviation industry	0.7248	0.7342	0.7504
		Airport runway area	0.2752	0.2658	0.2496
	Output indicators	Cargo and mail throughput	0.5066	0.5247	0.5437
		Passenger throughput	0.2686	0.2667	0.2539
		Take-off and landing sorties	0.2248	0.2086	0.2024
Economic development system	Input indicators	Primary sector contribution to GDP	0.6246	0.5794	0.6035
		Secondary sector contribution to GDP	0.1650	0.2468	0.2423
		Tertiary sector contribution to GDP	0.2105	0.1738	0.1543
	Output indicators	Total fixed asset investment (excluding farm households)	0.0855	0.0928	0.1100
		Domestic tourism revenue	0.1043	0.0912	0.0825
		Foreign exchange earnings from international	0.2052	0.2069	0.2078
		Gross regional product (GDP)	0.1112	0.1143	0.1199
		Total exports and imports 1	0.2424	0.2365	0.2308
		Total exports and imports 2	0.2515	0.2582	0.2491

The coefficient of variation method is used to apply statistical methods to directly calculate the degree of change for each indicator in the system, and the weights assigned to of each indicator obtained through the calculation can eliminate the influence of the measurement scale and the outline of the measurement. The steps for determining the weights of each indicator are as follows:

(1) Calculate the coefficient of variation of each indicator:

$$V_i = \frac{\sigma_i}{\bar{X}_i} \quad (i=1,2,...,n) \ , \qquad (1)$$

where, σ_i is the standard deviation of the ith indicator variable and $\bar{X}_i$ is the mean of the ith indicator variable.

(2) Calculate the weight of each indicator:

$$W_i = \frac{V_i}{\sum_i V_i} (i=1,2,...n) \qquad (2)$$

2.2 DEA-CCR efficiency modeling

Data Envelopment Analysis (DEA) is a non-parametric research method used to assess the efficiency of input-output ratio by determining whether it is on the production frontier or no.t It is a noval research method built on the research of operations research, management science and mathematical economics. Farrell (1957)[23] firstly proposed the concept of efficiency that measured the production frontier by dividing production efficiency into technical efficiency and allocative efficiency. Later, Charnes, Cooper and Rhodes (1978)[24] developed the CCR model. Banker, Charnes and Cooper (1984)[25] further modified the CCR model into the BCC model. Both the CCR and BCC models measure radial efficiency by allowing the input or output terms to increase or decrease in equal proportions. Malmquist (1953) [26] initially proposed the Malmquist index to explain dynamic efficiency. Fare (1994) [27] extended this concept to measure intertemporal efficiency changes. However, these models do not take into account the effects of intertemporal persistent activities and are therefore less suitable for measuring long-term efficiency. Fare and Grosskopf (1996)[28] were first to established the concept of dynamic DEA, devise a form of dynamic analysis, and propose a delayed lag (carryover) variable for dynamic models.

DEA is based on a number of input indicators and a set of output indicators. Using linear programming, a frontier curve is constructed, which then calculates the distance between each decision-making unit and the frontier curve, and the resulting value is used to measure whether the decision-making unit is efficient or not (Wei Quanling et al., 2018) [29]. Among them, the CCR model serves as the foundation of DEA, which is used to measure the overall efficiency under the assumption that each decision-making unit is in a fixed-size compensation situation. The DEA-CCR model is based on the principle of assuming that there are n decision units (j=1,2,.... .n), each decision unit has the same m inputs (i=1,2,.... .m) and the same s-item expenditure (r=1,2,... . s), denote by x_{ij}, the ith input of the jth decision unit, and y_{rj} represent the rth input of the jth decision unit. Let the weight coefficients of the ith input (i=1,2,.... .m) have a weight coefficient of v_i and the rth output (r=1,2,.... .s) with weight coefficient u_r, then the output of the jth decision unit is synthesized as $\sum_{r=1}^{s} u_r y_{rj}$, and the input is synthesized as $\sum_{i=1}^{m} v_i x_{ij}$. Solve the constrained objective planning problem as:

$$\text{Max} Z_{j_0} = \frac{\sum_{r=1}^{s} u_r y_{rj_0}}{\sum_{i=1}^{m} v_i x_{ij_0}} \quad (3)$$

$$\text{s.t.} \begin{cases} \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 & j = 1,2, \ldots n \\ v_i, \ u_r \geq 0 & i = 1,2, \ldots m; \ r = 1,2, \ldots s \end{cases} \quad (4)$$

This is a fractional programming model that needs to be transformed into a linear programming model in order to be solved. To do this, let:

$$t = \frac{1}{\sum_{i=1}^{m} v_i x_{ij_0}}, \quad (5) \quad \text{then} \begin{cases} \mu_r = t \times u_r \\ \omega_i = t \times v_i \end{cases} \quad (6)$$

The original CCR model is transformed:

$$\text{Max} h_{j_0} = \sum_{r=1}^{s} \mu_r y_{r_{j_0}} \quad (7)$$

$$\text{s.t.} \begin{cases} \sum_{i=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} \omega_i x_{ij} \leq 0 & j = 1,2, \ldots n \\ \omega_i, \ \mu_r \geq 0 & i = 1,2, \ldots m; \ r = 1,2, \ldots s \end{cases} \quad (8)$$

2.3 Coupling degree of coordination model

The coupling coordination degree model is used to analyze the coordinated development level of entities, which involves the calculation of three index values, namely the coupling degree (C) and the comprehensive coordination index (T), and the coupling coordination degree (D). The coupling degree reflects the degree of interdependence and mutual constraints between systems, the comprehensive coordination index is a reflection of the degree of good or bad coordination status, which refers to the value of the degree of benign coupling in the coupled interaction relationship, and the degree of coupling coordination can reflect whether there exists a notable level of development between the systems (Huang Jenquan et al., 2022)[32]. Its calculation formula is expressed as:

$$C = \sqrt{\frac{u_1 * u_2}{(u_1+u_2)\hat{}2}} \quad (9)$$

$$T = \alpha u_1 + \beta u_2 \quad (10)$$

$$D = \sqrt{C * T} \quad (11)$$

where, u_1 is the scale efficiency of the civil aviation industry, u_2 is the scale efficiency of the regional economy, α and β are the parameters to be determined, usually taken as α = β = 0.5. In order to further clarify the degree of internal coordination between the civil aviation industry and the regional economic development, the coordination between the civil aviation industry and the regional economic development system has been graded according to the coupling coordination degree. The specific criteria are shown in Table 2.

Table 2. Criteria for the classification of coordination levels

D-value range	(0,0.4]	(0.4,0.5]	(0.5,0.6]	(0.6,0.8]	(0.8,0.9]	(0.9,1]
Level of coordination	Severe disorder	moderate disorder	Mild disorder	Basic coordination	Moderate coordination	High degree of coordination

3. Empirical Analysis

3.1 Efficiency evaluation of civil aviation industry

Using DEA, the scale efficiency of the civil aviation industry in each province of the geographical area under the jurisdiction of the seven regional administrations established by the CAAC in the country from 2010 to 2019 is assessed to reveal its spatio-temporal change characteristics, as shown in Figure 1.

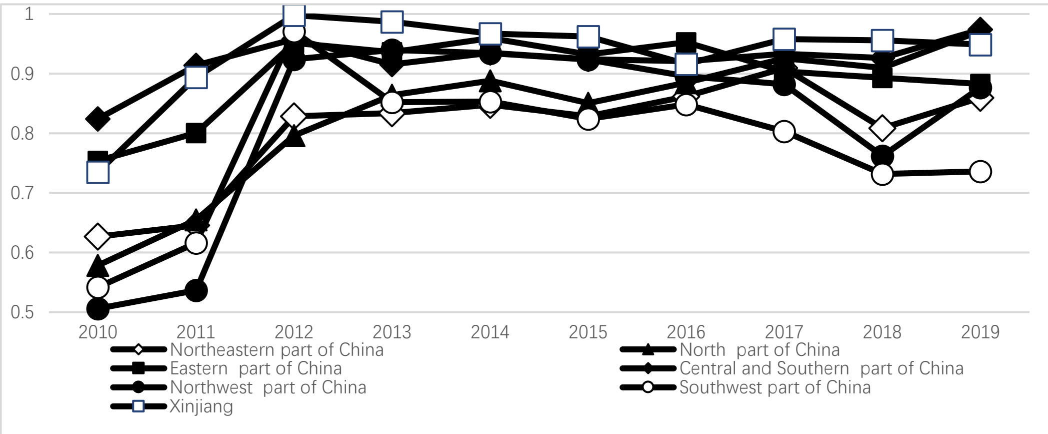

Figure 1. Characteristics of the spatial and temporal changes in the efficiency of the size of the system of the civil aviation industry in the seven regional administrations, 2010-2019

It can be seen from Figure 1 the scale efficiency of China's civil aviation industry in 2010-2019 shows regional differences in both time and space. In terms of time, since 2010, the scale efficiency of the civil aviation industry in each region has shown an upward trend, in which the scale efficiency of Central and South China and East China has continued to rise, alternately leading. The scale efficiency of civil aviation industry in Northwest and Southwest China has shown a significant increase, with the most obvious upward trend in Xinjiang. The scale efficiency of civil aviation industry in North China and Northeast China has fluctuated upward; in terms of space, the scale efficiency of civil aviation industry in each region before 2012 has shown more pronounced differences. Spatially, the differences in the scale efficiency of the civil aviation industry in each region before 2012 are more obvious. The leading advantage of scale efficiency is most prominent in East China and Central and South China, and the differences between the regions gradually narrow after 2012. By calculating the ten-year average scale efficiency of the civil aviation industry system of the seven regional administrations, the level is distributed as follows: Central and South China > East China > Xinjiang > North China > Northeast China > Northwest China > Southwest China.

3.2 Efficiency evaluation of regional economic development

The changes in scale efficiency of economic development in China's seven regions are shown in Figure 2. Accompanied by China's continuous economic, social development and urbanization, the transformation of the economic development model ,industrial transformation and upgrading in various regions, inter-regional economic development is realizing reasonable quantitative growth and steady qualitative improvement. There is a significant increase in the scale efficiency of economic development in each region of the country. Since 2010, the average value of the scale efficiency of economic development in the geographical areas governed by the seven regional administrations established by the CAAC across the country has increased from 0.5378 in 2010 to 0.6252 in 2019, indicating that China's regional economic development level as a whole has been rising during this period of time. However, the differences and imbalances in development still exist and are becoming increasingly evident. Specifically the scale efficiency values in descending order are, East China, North China, Central and South China, Northeast China, Southwest China, Northwest China, and Xinjiang.

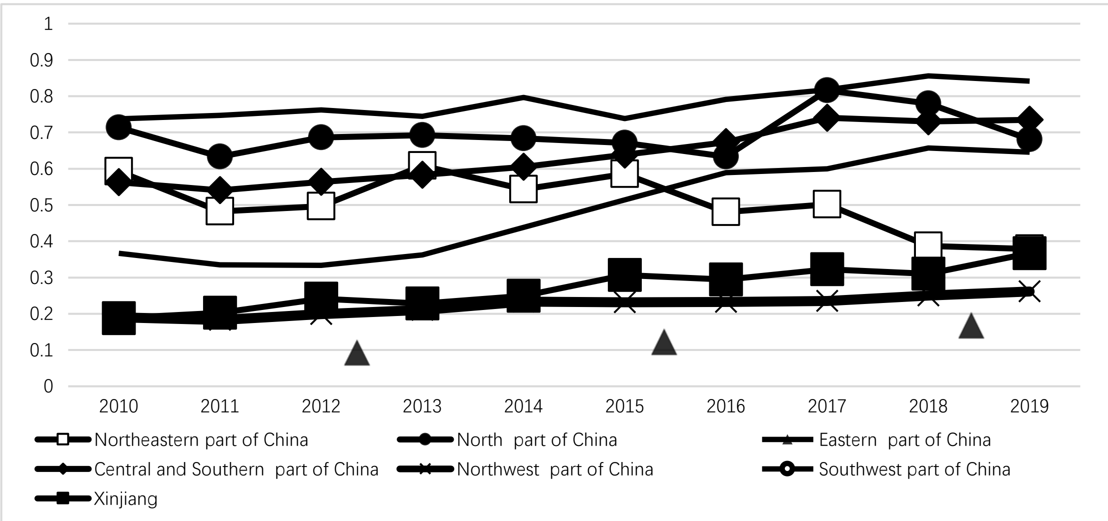

Figure 2. Characteristics of the spatio-temporal evolution of the scale efficiency of the economic development systems of the seven regional administrations, 2010-2019

3.3 Analysis and comparison of the coupling and coordination degree of regional civil aviation

industry and economic development

Based on the scale efficiency, Eq. (9), Eq. (10) and Eq. (11) are used to calculate the degree of coupling between the civil aviation industry and the economic development of the regions governed by the seven regional administrations establishedby the CAAC (the following regions and provinces are listed in pinyin order, with no particular ranking).

3.3.1 Analysis of the coupling coordination degree of civil aviation industry and economic development in the northeast region

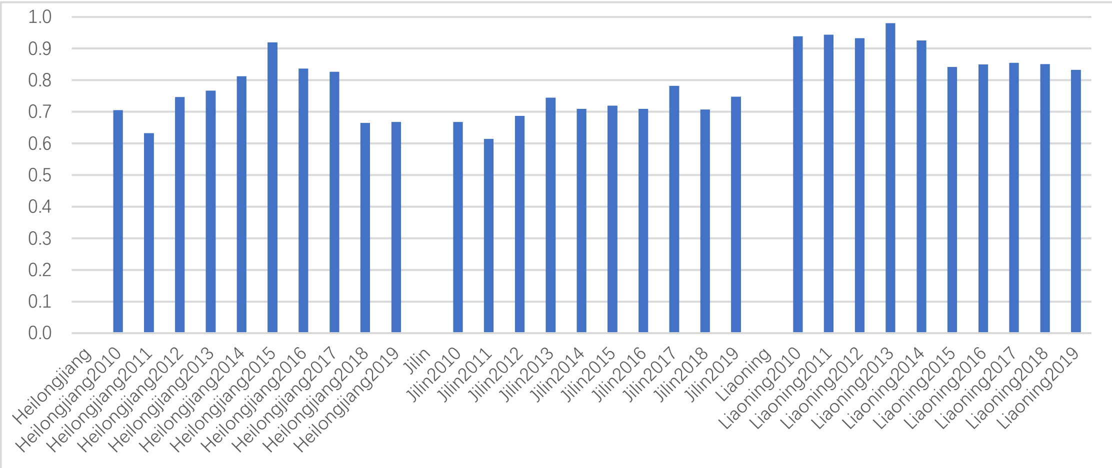

Figure 3. Coupled coordination of civil aviation industry and economic development in Northeast China, 2010-2019

In the Northeast region, the coupling coordination degree of each province has shown a decreasing trend in recent years. The coupling coordination degree of Heilongjiang Province first rose , then declined, reaching the highest in 2015. The coupling coordination degree of Jilin Province has a smaller change, and has been around 0.7 in the past ten years. Meanwhile, coupling coordination degree of Liaoning Province has continuously declined since 2013. These trends indicate that the coupling coordination level of the civil aviation industry and the regional economic development of the Northeast region in recent years has been slow to develop.

3.3.2 Analysis of the coupling and coordination degree of civil aviation industry and economic development in North China

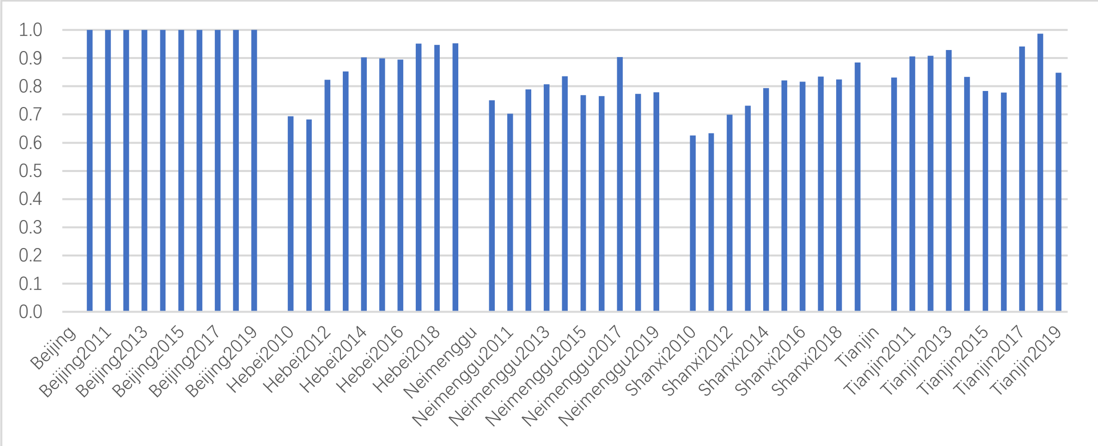

Figure 4. Coupling and harmonization of civil aviation industry and economic development in North China, 2010-2019

As illustrated in Figure 4, the coupling and coordination degree of civil aviation industry and regional economic development in North China has increased year by year from 2010 to 2019. From the perspective of jurisdictional territories, Beijing exhibits highest coupling and coordination degree, maintaining near 1 for many consecutive years. This suggests that its civil aviation industry has a strong internal coordination with regional economic development. The coupling and coordination degree of provinces such as Hebei, Inner Mongolia, and Shanxi has been increasing over time steadily increased. Although Tianjin has fluctuations, but the overall trend remains upward.. Thus, the coupling degree in North China is characterized by a period of stable growth.

3.3.3 Analysis of the coupling degree of coordination between civil aviation industry and economic development in East China

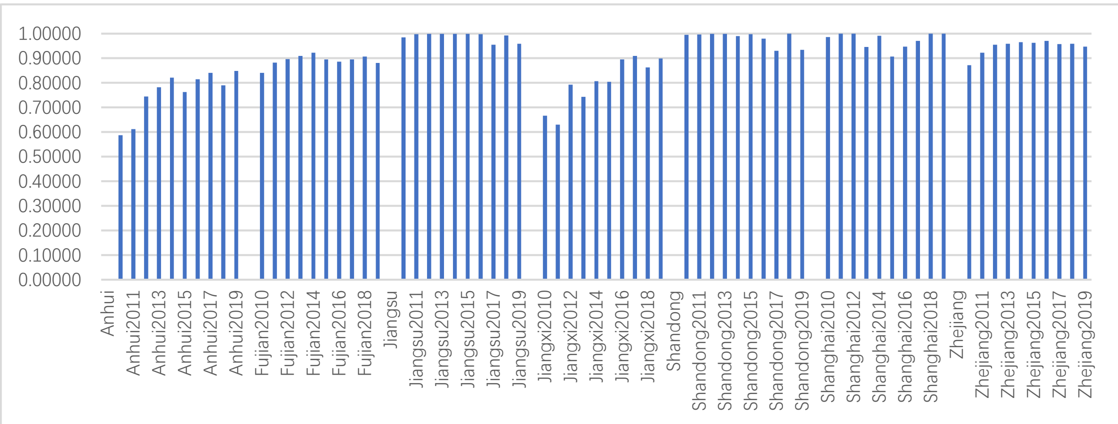

Figure 5. Coupled Coordination of Civil Aviation Industry and Economic Development in East China, 2010-2019

As depicted from Figure 5, the overall level of coupling coordination in East China is higher.

Shandong and Jiangsu have the highest level, although it experienced a decline in 2017. However, the overall level remains in the vicinity of 1. The level of coupling coordination in Fujian and Zhejiang closely follows, stabilizing near 0.9 for many years. Although Shanghai's level of coupling coordination is higher, it exhibits considerable fluctuations. Furthermore, there has been a noticeable upward trend in the degree of coupling coordination in Anhui and Jiangxi since 2013, leading to a rapid increase and gradually narrowing the gap with other provinces in the region.

3.3.4 Analysis of the coupling coordination degree between civil aviation industry and economic development in Northwest China and Xinjiang region

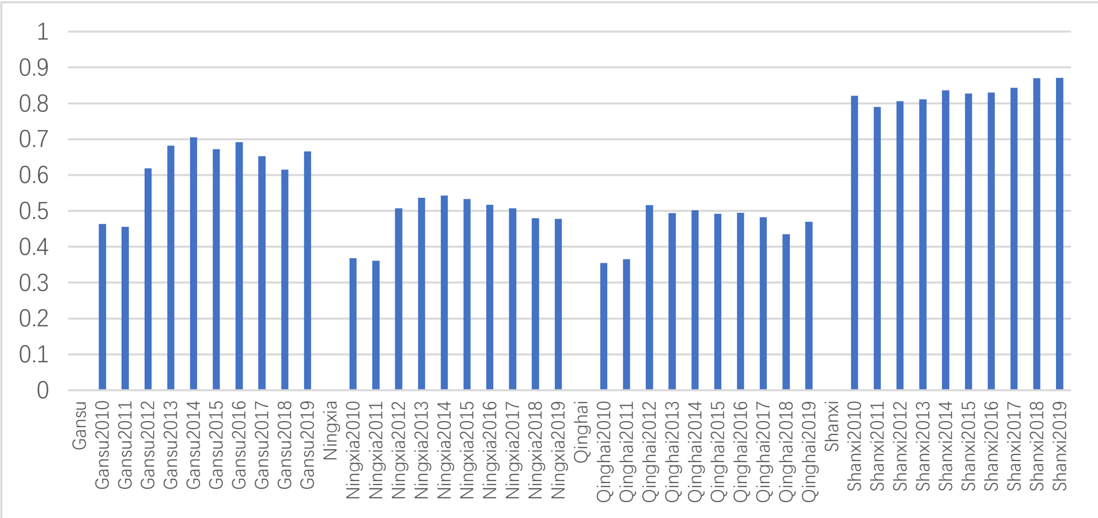

Figure 6. Coupled coordination of civil aviation and economic development in the Northwest Territories, 2010-2019

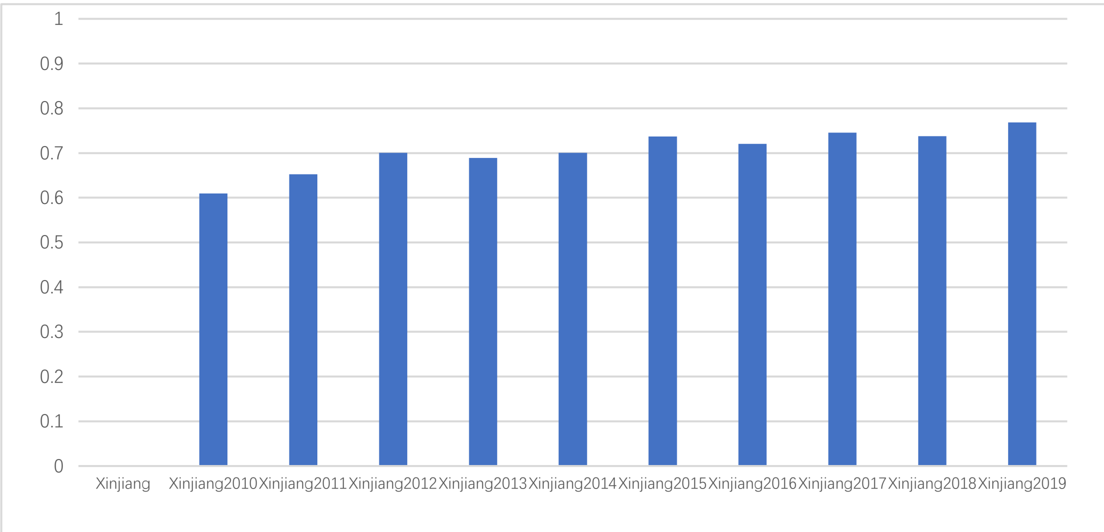

Figure 7 .Coupled coordination degree of civil aviation industry and economic development in Xinjiang region, 2010-2019

The level of coupled coordination degree betweencivil aviation industry and economic development in Northwest China is generally low., However, Shaanxi has the highest level of coupled coordinated development, which is around 0.8 on average. Gansu, Ningxia, and Qinghai have shown rapidly growsince 2012 in an effort to narrow the gap with provinces at higher levels. However, this development has slowed down during the last few years. The overall coupling coordination level of the Northwest region is lagging behind on a national scale. The Xinjiang region's coupling coordination degree has steadily increased , but the overall remains low.

3.3.5 Analysis of the coupling and coordination degree between civil aviation industry and economic development in Southwest Region

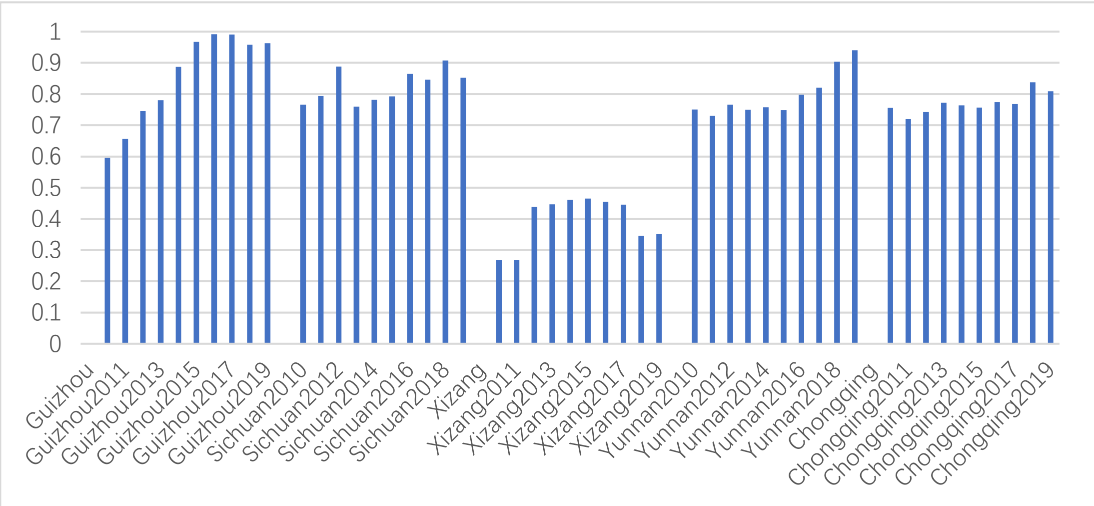

Figure 8. The coupling coordination level of civil aviation and economic development in the southwest region from 2010 to 2019

The overall level of coupling coordination in the southwest region is at the basic coordination stage. However, Tibet Autonomous Region stands out with a significant gap compared to other provinces, indicating a stage of serious dislocation. In contrast, the coupling coordination level of Guizhouand Yunnan has steadily increased over time. Meanwhile, the coupling coordination in the Sichuan and Chongqing region has shown fluctuations with an overall rising trend.

3.3.6 Analysis of the coupling coordination degree of civil aviation industry and economic development in South Central Region

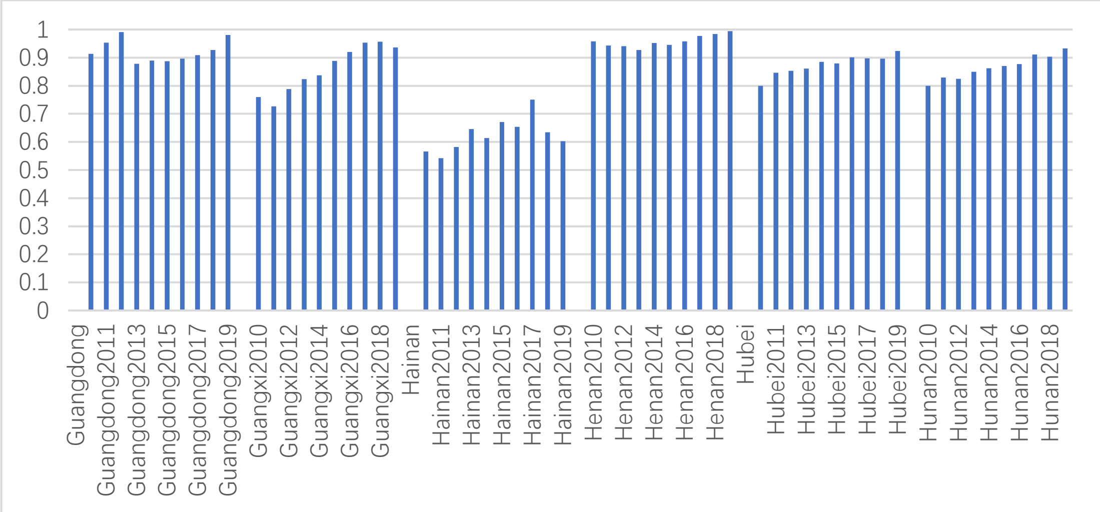

Figure 9. Coupling coordination degree of civil aviation industry and economic development in the central and southern region, 2010-2019

Comparison betweenFigure 8 and Figure 9, reveals significant variations in the overall coupling coordination level of the South Central region and the Southwest region varies significantly. Despite both being part of the southern region. the South Central region shows an upward trend. Apart from Hainan Province, the level of coupling coordination level of the various provinces in the region transitions from medium to high coordination levels. Although Guangdong and Henan have a higher level of coupling coordination level, there still exists a big gap between Guangdong and Henan There also exists a substantial gap between Hainan Province and other provinces.Guangxi province has steadily improved its coupling coordination level in recent years, while Hubei and Hunan provinces have improved but at a slower pace.

3.3.7 Analysis of the coupling coordination degree of national civil aviation industry and economic development

Synthesizing the coupling coordination degree of civil aviation industry and economic development across the seven regions reveals clear spatial differences in China. East China and North China havelargely achieved high and medium coordination. Central and South China are between medium and high coordination. Southwest China has gradually increased its coordination degree and is now between basic and medium coordination, Xinjiang and Northeast China are currently in the basic coordination stage The dislocation in Northwest China has been alleviated,, and it is gradually approaching the stage of mild dislocation.

4.Conclusion

This paper constructs an evaluation index system for the coupling and coordination degree between the civil aviation industry and regional economic development level based on the DEA-CCR efficiency model, using data from 2010-2019. The study investigates the changes in the coupling and coordination degree from both temporal and spatial perspectives., It evaluates the scale efficiency of the civil aviation industry and regional economic development revealing development trends over time. Additionally, it reveals the spatial differences in the degree of coupling and coordination between civil aviation industry and regional economies across different regions of China. The study provides a detailed analysis and comparison of the coupling and coordination degree in each region, examining the characteristics of their respective efficiency changes. The following conclusions are reached:

First, the scale efficiency of China's civil aviation industry from 2010-2019 shows regional differences both temporally and spatially. The average scale efficiency levels of the seven regional administrations established by the Civil Aviation Administration of China (CAAC) over this ten-year period, in descending order are: South Central > East China > Xinjiang > North China > Northeast > Northwest > Southwest. The overall level of China's regional economic development during the sample period has been rising. However, regional differences and imbalances are becoming increasingly evident. The distribution of the average scale efficiency level of the seven regions in the sample period is: East China>North China>Central and South China>Northeast China>Southwest China>Northwest China>Xinjiang.

Second, using the DEA efficiency model, the coupling coordination degree model measures the coupling coordination degree between the civil aviation industry and economic development for the seven regional administrations established by CAAC from 2010 to 2019. Overall, the level of coupled coordination degree of China's civil aviation industry and economic development is rising regionally;

- East China and North China have achieved high and medium coordination.
- Central and South China are between medium and high coordination.
- Southwest China's coordination degree is gradually increasing and is now between basic and medium coordination.
- Xinjiang and Northeast China are currently in the basic coordination stage.
- Northwest China's degree of dysfunctions has eased, gradually approaching the stage of mild dissonance.

Based on the current analysis of the coupling coordination degree, future research can further explore long-term trends and predict future coordination between civil aviation industry and regional economic development. Various factors affecting the coupling and coordination degree of civil aviation industry and regional economy, such as technological innovation, policy environment, market demand, etc., can be analyzed in depth to understand how to promote coordinated development..Additionally, considering environmental and social factors, future research may extend to the international level for cross-regional comparative studies. This approach can help understand the development patterns of different countries and regions under similar circumstances and explore the sustainability of the coordinated development of the civil aviation industry and the regional economy within the context of “dual carbon goals”.

Acknowledgements

This study was supported by the Civil Aviation University of China (CAUC) 2022 Graduate Student Research and Innovation Project, "Study on the Construction of China's Airline Express Network Based on the Accessibility of Hub Airports"（Project No. 2022YJS078);National Natural Science Foundation of China (NSFC) under the project, "Research and validation of key technologies for air-ground security integration in small and medium-sized airport clusters" (Project No. U2333206); the major project of the Key Research Base of Humanities and Social Sciences of the Ministry of Education, "Research on Strategic Transformation and Sustainable Development of State-owned Enterprises under the Perspective of Green Governance" (Project No.22JJD630006); Civil Aviation Security Capacity Building Project "Domestic Air Express Security Supervision" 2024; Tianjin Municipal Education Commission Social Science Major Project, "Study on Optimizing the Business Environment for Private Enterprises in Tianjin"（Project No.2018JWZD52).

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