A Study on the Coupled and Coordinated Development of Air Accessibility and Economic Linkage Strength in International Hub Cities

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ABSTRACT

There is an interactive development relationship between aviation accessibility and the economic driving effect, and the realization of coordinated national regional development requires the coupled development of the two. Based on the weighted average travel time, flight frequency, and city economic indicators, this paper analyses the changes in air accessibility of the top ten international aviation hub cities from 2010 to 2019, adopts the gravity model to measure the economic linkage strength of the top ten international aviation hubs during the ten years, and explores the coupling and coordinating effect between air accessibility and economic linkage strength. The results of the study show that: (1) aviation accessibility among international hub cities shows the phenomenon of "vertical continuous improvement, horizontal class solidification", and the overall distribution pattern of "3+5+2"; (2) The economic driving effect among international hub cities shows the overall phenomenon of The phenomenon of "vertical steady improvement, horizontal polarisation", with the intensity of economic ties between Beijing and Shanghai much higher than that of other regions; (3) The coupling and coordination between air accessibility and economic ties between international hub cities shows an "olive" structure, and can be divided into three types: "leading regional economic development, leading air transport development, and synchronous development of regional economy and air transport". Based on the above empirical results, two development countermeasures are proposed: (1) Differentiated development based on functional positioning; and (2) Integrated regional coordinated development.

Keywords: Air transport, Air accessibility, Economy-led effect, Coupling coordination degree

1. Introduction

Accessibility, also known as reachability, was defined by Hansen (1959) as the magnitude of the forces acting between nodes, which was the first time a specific concept of accessibility was developed [1]. Air accessibility refers to the degree of connection between a region and other regions through air transport modes, which reflects the density of a region's route network and the level of air transport [2]. The economic driving effect is an important concept based on transport accessibility to further characterize the intensity of inter-regional links and interactions, which is a further deepening of the accessibility study [3].

There is an interactive development relationship between aviation accessibility and the economic driving effect, which is a coupled interaction body constituted by mutual influence [4], and the two are coordinated and benignly interact with each other [5]. On the one hand, air accessibility is one of the important factors in promoting the economic driving effect [6], and the improvement of air accessibility will accelerate the transfer of resource elements from neighbouring cities or regions to the central city, and enhance the economic driving effect of the central city on the neighbouring cities or regions [7,8]. On the other hand, the economic driving effect also feeds the development of aviation accessibility, and economic growth, economic integration, and economic openness can promote aviation accessibility by increasing aviation demand and promoting aviation cooperation [9]. Therefore, there is a positive circular effect between aviation accessibility and the economic driving effect, forming a benign interactive relationship [10].

An international aviation hub is not only a kind of transport infrastructure, but also a window for the regional economy to integrate into the global economy and a favorable means to participate in the international division of labor and competition, at the same time, it is also an important carrier to enhance the city's international competitiveness, influence, and an important platform to participate in the allocation of global resources [11]. The coupling effect between aviation accessibility and the local economic environment where the airport is located is the formation mechanism of international aviation hubs with the ability to support, radiate, and drive [12,13].

At present, scholars at home and abroad have studied urban transport accessibility and economic driving effects from different perspectives. Murayama found the integration relationship between transport and inter-city accessibility through the study of urban railways in Japan [14]. James Hooper proposed that distance and cost are often considered the main factors influencing the decision-making process of tourists and borrowed the location theory and the accessibility model to reveal how the accessibility of a destination is affected by the distance to the source of tourism [15]. Kotavaara analyzed road and rail accessibility in Finland and investigated the association between accessibility and human mobility for both types of transport, which proved that the higher the regional accessibility, the more mobile population is attracted [16]. Yang Chunhua compared the changes in railway accessibility in the Beijing-Tianjin-Hebei and Yangtze River Delta regions and the impact on their respective tourism industries [17]. Jiang Huaxiong and Meng Xiaochen used the Beijing-Shanghai high-speed railway as an example to explore the impact of the temporal and frequency effects of high-speed railways on urban spatial interactions [18]. Dai, Xuezhen Quantitative comparison of the magnitude of the contribution of three modes of transport, namely road, ordinary railway, and high-speed railway, to the strength of spatial interaction in Beijing-Tianjin-Hebei by using the gravity model and the potential model [19].In the study of air accessibility, Matisziw, TC utilized a comprehensive dataset on scheduled flight services to apply developed methodologies to the domestic commercial air transport network in the United States, exploring the geographic disparities in accessibility. The results indicated significant variations among core-based statistical areas across the United States [20]. Greig Harvey summarized an approach that combined access time and service frequency as explanatory variables in a multinomial Logit model, deriving an approximate optimal airport choice model for the San Francisco Bay Area [21]. Additionally, Bondzio employed a network-based multinomial Logit model to analyze passenger choices of airports and modes of access [22].

Current research primarily focuses on urban ground transportation systems, while systematic studies on air accessibility, particularly its specific impact on economic driving effects, are still insufficient. Therefore, this study aims to fill this gap by analyzing the air accessibility of international aviation hubs and their economic effects, providing a more comprehensive understanding and insights. At present, regional aviation hubs such as Tianjin and Shenyang have relatively weaker development and radiation capabilities. Consequently, this paper selects ten international aviation hub cities in China as the research subjects to deeply investigate their air accessibility, the development of economic driving effects, and the degree of coupling coordination.

This study is not only significant for theoretical development but also has profound implications for practical applications. On a theoretical level, it innovatively explores the coupling and coordination mechanisms between air accessibility and the strength of economic connections, thereby extending traditional regional economic development theories and providing a new theoretical framework for understanding the economic geography of international hub cities and urban airline network planning under globalization. Practically, the findings can guide the optimization of transportation infrastructure planning. By analyzing the interplay between air accessibility and economic activities, it offers decision support to governments and urban planners, thus optimizing resource allocation and promoting balanced regional economic development. Additionally, the research provides strategic recommendations to enhance the global competitiveness and international cooperation capabilities of international hub cities, strengthening their global influence and potential for economic collaboration. This study not only fills a gap in existing research but also provides valuable scientific underpinnings for urban development, transportation planning, and regional economic integration, positively influencing the ongoing development of cities and regions.

2. Empirical Design

2.1 Research Objects and Data Sources

According to the "14th Five-Year Plan" for Civil Aviation Development in 2021, the research object of this paper is identified as ten international aviation hub cities such as Beijing and Shanghai. Due to the impact of the new crown epidemic in 2020-2022, China's air transport market has been greatly affected, resulting in the relevant data being difficult to truly reflect the development of the civil aviation industry. At the same time, the shorter time span is difficult to reflect the long-term development pattern of the civil aviation industry. Given this, this paper determines the research time span as 2010-2019.

The number of permanent inhabitants (POP) of the international aviation hub city is obtained from the website of the National Statistical Office. Gross Domestic Product (GDP) is obtained from the statistical yearbooks (series of years) of the corresponding cities. The frequency of inter-city flights was obtained from the Civil Aviation Statistics Yearbook of China (2011-2020).

2.2 Air Access Measurement Model

To more accurately measure the level of air hub city accessibility, this paper constructs a weighted average travel time model based on flight frequency based on the traditional weighted average travel time model, drawing on the research results of Lopez E, Tang Enbin, and others, as follows[23,24] :

$$P_j = \sqrt{GDP_j \times POP_j} \qquad [1]$$

$$M_i = \frac{\sum_{j=1}^{n}(T_{ij} \times P_j)}{\sum_{j=1}^{n} P_j} \qquad [2]$$

$$N_i = \frac{\frac{M_i}{n_i} \times \sum_{j=1}^{n}(T_{ij} \times P_j)}{\sum_{j=1}^{n} P_j} \qquad [3]$$

In equation[1], P_j represents the quality of city j, GDP_j represents the gross regional product of city j, and POP_j represents the population of city j.

In equation[2], M_i represents the weighted average travel time (min) of city i, and M_i is inversely related to the accessibility of city i. T_{ij} represents the shortest air travel time (min) from city i to city j. For city pairs with direct or stopover flights, the shortest inter-city flight time is obtained by dividing the straight-line distance between cities by the flight time, where the straight-line distance between cities is simulated by GCMAP, and the flight time is chosen to be the cruise speed of the most popular Boeing 737 at 800 km/h. For city pairs without direct or stopover flights, the shortest inter-city flight time is calculated by the MATLAB model. The optimal transit point is calculated, and the shortest flight time of the two routes is calculated separately by GCMAP, together with the average transit time of 45 minutes, to get its shortest flight time.

In equation[3], N_i represents the weighted average travel time of city i based on the frequency of flights, and N_i is inversely related to the accessibility of city i. The smaller N_i is, the better the accessibility of city i is, and vice versa. Where ni represents the daily frequency of flights in city i, measured as the sum of the daily frequency of flights departing from, stopping at, and arriving at city i.

2.3 Modelling the Measurement of the Economic Driving Effect

The economic driving effect is usually used to describe the ability of a city to influence other cities in the urban spatial interaction network [25]. The gravity model was first proposed by Tinbergen J[26] , and most of the existing literature measures the economic driving effect of cities through the economic gravity model, and this study corrects the economic gravity model based on the existing research to obtain the corrected economic gravity model as follows:

$$R_{ij} = \frac{P_i \times P_j}{T_{ij}^2} \times n_{ij} \qquad [4]$$

$$R_i = \sum_{j=1}^{n} R_{ij} \qquad [5]$$

In equation [4]: R_{ij} is the economic driving effect between cities i and j; P_i, P_j and n_{ij} are the same as before.

In equation [5]: R_i is the sum of economic driving effects between city i and other cities in the region.

2.4 Coupled Coordination Measurement Models

Coupling is an important indicator of the interaction between 2 or more factors in the evaluation system [27]. Due to the large variation in the values of air accessibility and strength of economic linkages in the evaluation system, the relevant data were min-max normalized before analysis.

Given the existence of a positively correlated linear relationship between air accessibility and economic driving effect, the degree of coupling coordination will show a high degree of coordination, and it is difficult to objectively reflect the degree of coordination between the two, so this study makes the following improvements to the evaluation model of the degree of coupling coordination:

$$C = 2 \times \sqrt{\frac{U_1 \times U_2}{(U_1 + U_2)^2}} \quad [6]$$

$$T = \alpha U_1 \times \beta U_2 \quad [7]$$

$$D = \sqrt{C \times T} \quad [8]$$

In equation [6]: C is the coupling index, U_1 is the air accessibility of each city, and U_2 is the economic driving effect of each city.

In equation [7]: T is the coordination index of aviation accessibility and economic driving effect, α and β are weight coefficients, and $\alpha + \beta = 1$. In the related research on the coupled development of regional economy and transport, it is generally considered that the two play equal roles, and $\alpha = \beta = 0.5$ [28].

In equation [8]: D is the coupling coordination degree, taking the value between 0 and 1, and its evaluation level division standard is shown in Table 1 [29].

Table 1 Classification criteria for evaluation level of coupling coordination degree

D-value of coupling coordination	Level of coordination	Type of coupled coordination
(0.0 to 0.1)	1	extreme disorder
[0.1 to 0.2)	2	severe disorder
[0.2 to 0.3)	3	moderate disorder
[0.3 to 0.4)	4	mild disorder
[0.4 to 0.5)	5	on the verge of becoming dysfunctional
[0.5 to 0.6)	6	sue for coordination
[0.6 to 0.7)	7	Primary coordination
[0.7~0.8)	8	Intermediate level coordination
[0.8 to 0.9)	9	good coordination
[0.9 to 1.0)	10	Quality coordination

Source: By reference.

3. Empirical Results

3.1 Characterisation of Air Access to International Aviation Hub Cities

Tables 2 and 3 show the results of air accessibility evaluation and descriptive statistical analysis of the top ten international aviation hub cities from 2010 to 2019.

Table 2 Evaluation results of air accessibility to the top 10 international aviation hub cities, 2010-2019

municipalities	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Shanghai	6.69	5.49	4.30	3.69	3.24	2.76	2.40	2.05	1.84	1.65
Beijing	7.01	5.85	4.54	3.87	3.39	3.08	2.72	2.39	2.14	2.00
Guangzhou	12.03	9.68	5.90	4.92	4.50	4.25	3.65	2.98	2.73	2.43
Xian	18.22	12.68	6.99	6.02	6.63	5.59	4.46	3.43	2.94	2.58
Chongqing	21.92	13.73	7.73	6.21	6.15	5.14	4.24	3.54	3.08	2.61
Shenzhen	19.29	16.25	8.57	6.94	6.50	5.41	4.69	3.63	3.43	3.08

Chengdu	19.49	12.32	8.62	7.44	6.96	5.83	4.84	4.02	3.47	3.11
Kunming	27.96	25.73	15.46	11.05	12.12	10.08	8.21	6.50	5.96	5.52
Harbin	164.76	142.71	62.93	49.87	51.18	42.17	33.16	25.51	21.65	19.76
Urumqi	201.32	158.20	76.73	57.60	69.07	60.30	51.04	42.03	36.17	32.71

Source: By authors.

Table 3 Descriptive statistical analysis of air accessibility evaluation results of the top ten international aviation hub cities, 2010-2019

Statistical indicators	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
maximum values	201.32	158.20	76.73	57.60	69.07	60.30	51.04	42.03	36.17	32.71
minimum value	6.69	5.49	4.30	3.69	3.24	2.76	2.40	2.05	1.84	1.65
average value	49.87	40.27	20.18	15.76	16.98	14.46	11.94	9.61	8.34	7.54
coefficient of variation	1.42	1.45	1.32	1.28	1.37	1.38	1.38	1.39	1.37	1.37

Source: By authors.

As can be seen from the data presented in Tables 2 & 3:

(1) Aviation access to international hub cities shows "steady vertical improvement and horizontal polarisation".

The results in Table 3 show that the maximum value of the accessibility evaluation results of international aviation hub cities decreased from 201.32 in 2010 to 32.71 in 2019, the minimum value decreased from 6.69 in 2010 to 1.65 in 2019, and the average value decreased from 49.87 in 2010 to 7.54 in 2019, which reflects that the 10 international aviation hub cities, as a whole, have shown a significant improvement in their accessibility. accessibility are all showing significant improvement.

From 2010 to 2019, there is still a huge difference between the maximum and minimum values of air accessibility among the 10 international aviation hub cities. In particular, the coefficient of variation of air accessibility among the 10 international aviation hub cities has decreased from 1.42 in 2010 to 1.37 in 2019, but remains at a high level, indicating that there is an obvious "polarisation" problem among the international aviation hub cities.

(2) The air accessibility of international hub cities shows a clear "3+5+2" echelon pattern.

In terms of air accessibility results, the three international aviation hub cities of Shanghai, Beijing, and Guangzhou belong to the first echelon, and their air accessibility is significantly higher than that of the other cities; in the 2010-2019 air accessibility rankings, for example, Shanghai, Beijing and Guangzhou are in the first echelon of continuous leadership, while Harbin and Urumqi are in the third echelon of continuous lagging behind. Xi'an, Shenzhen, Chengdu, Chongqing, and Kunming are in the middle of the second tier, while the other five cities are unstable within the tier in terms of air accessibility ranking over the decade.

Under the overall "3+5+2" echelon pattern, the composition of the cities in each echelon shows a relatively stable pattern, and it is difficult for the cities in the lagging echelon to enter the higher echelon. In the horizontal comparison between the top ten international aviation hubs, Beijing and Shanghai in the first echelon are in an unsurpassed position, and their air accessibility is numerically far ahead of other cities. Harbin and Urumqi, in the third tier, are still far behind the other cities in terms of air accessibility.

3.2 Characterisation of the Economic Driving Effect of International Aviation Hub Cities

Table 4 presents the evaluation results of the economic driving effects of international aviation hubs and the results of descriptive statistical analysis. Due to space constraints, only a subset of the data is displayed in this section. Considering the consistency and availability of the data, the years 2010, 2014, and 2019 represent the beginning, middle, and end of the study period, respectively. Data from these equidistant time points provide a clear trend of changes and facilitate analysis. Furthermore, significant events such as the global economic recovery post-2010, regional policy adjustments in 2014, and economic fluctuations in 2019 have had substantial impacts on the study's theme. Therefore, only data from 2010, 2014, and 2019 are presented in Tables 4 and 5.

Table 4 Evaluation results of the economic driving effect of the ten major international aviation hubs and results of descriptive statistical analysis, 2010-2019

municipalities	2010	2014	2019	2010-2019 Average	percentage
Shanghai	1739997759	3407108064	6686657844	3910946692	26.19 per cent
Beijing	1498950601	2711419139	4802130804	3098309958	20.75 per cent
Chongqing	277596643	1670356355	3185303786	1835544711	12.29 per cent
Guangzhou	651034145	1626426950	3092935226	1801844678	12.07 per cent
Shenzhen	539782396	1441231272	3059096061	1686689694	11.29 per cent
Chengdu	282137765	945628364	1936809790	1084451286	7.26 per cent
Xian	332137457	684551051	1284035509	845599063	5.66 per cent
Kunming	83470232	396223874	735077104	419289034	2.81 per cent
Harbin	128739147	227722089	275436464	230373996	1.54 per cent
Urumqi	7950024	18209091	31937680	20075430	0.13 per cent
average value	554179617	1312887625	2508942027		
coefficient of variation	1.0775	0.8347	0.8393		

Source: By authors.

As can be seen from the data presented in Table 4:

(1) The economic driving effect of international hub cities has been steadily increasing vertically.

The results in Table 4 show that the maximum value of the evaluation results of the economic driving effect of the ten international aviation hub cities increased from 1739997759 in 2010 to 6686657844 in 2019, the minimum value increased from 7950024 in 2010 to 31937580 in 2019, and the average value increased from 554179617 in 2010 to 2508942027. indicating that the top ten international aviation hub cities as a whole and their economic linkage intensity are all showing significant improvement.

(2) Polarisation of the Economic Driving Effect of International Hub Cities in Cross-Sectional Comparisons.

The results in Table 4 show that the total economic driving effect of international aviation hub cities in 2010-2019 is 58.45%, 46.60%, and 46.94% in Shanghai and Beijing in 2010, 2014, and 2019, respectively. At the same time, in Harbin, Urumqi in 2010, 2014, and 2019, the total economic driving effect of the total share of 2.47%, 1.23%, and 1.68%, respectively. It can be seen that the economic driving effect of Shanghai and Beijing has long been ahead of the remaining eight international aviation hub cities, while the economic driving effect of Harbin and Urumqi has long lagged behind the remaining eight international aviation hub cities.

There is a huge difference between the maximum and minimum values of the economic driving effect among the 10 international aviation hub cities, and the maximum value of the economic driving effect has risen from 1739997759 in 2010 to 6686657844 in 2019, and the minimum value has also risen from 7950024 in 2010 to 2508942027 in 2019, which indicates that there is still a huge difference between the maximum and minimum values of the economic driving effect among the 10 international aviation hub cities, and that there is still a huge difference between the maximum and minimum values of the economic driving effect among the 10 international aviation hub cities. There is still a huge difference between the maximum and minimum values of the leading effect. Especially from the view of the coefficient of variation of economic driving effect among 10 international aviation hub cities, although it also declined from 1.0775 in 2010 to 0.8393 in 2019, it remains at a high level, indicating that there is an obvious "polarisation" problem among international aviation hub cities.

3.3 Characterisation of the Coupling of Air Accessibility and Strength of Economic Linkages in International Hub Cities

Table 5 shows the results of the coupled coordination measure of air accessibility and economic driving effect of the top ten international aviation hub cities.

Table 5 Degree of harmonization of the coupling of air accessibility and strength of economic linkages

municipalities	degree of coupling coordination							
	2010	Type of coordination	2014	Type of coordination	2019	Type of coordination	10-year average	Type of coordination
Shanghai	0.9950	Quality	0.9950	Quality	0.9950	Quality	0.9950	Quality
Beijing	0.9584	Quality	0.9395	Quality	0.9139	Quality	0.9415	Quality
Guangzhou	0.7746	Intermediate	0.8242	good	0.8167	good	0.8103	good
Chongqing	0.6207	Primary	0.8243	good	0.8214	good	0.7999	good
Shenzhen	0.7326	Intermediate	0.7937	Intermediate	0.8101	good	0.7857	Intermediate
Chengdu	0.6253	Primary	0.7141	Intermediate	0.7237	Intermediate	0.7090	Intermediate
Xian	0.6516	Primary	0.6606	Primary	0.6574	Primary	0.6725	Primary
Kunming	0.4645	on the verge of becoming dysfunctional	0.5656	sue for coordination	0.5603	sue for coordination	0.5457	sue for coordination
Harbin	0.3512	mild disorder	0.3737	mild disorder	0.3722	mild disorder	0.3641	mild disorder
Urumqi	0.1000	severe disorder	0.1000	severe disorder	0.1000	severe disorder	0.1000	severe disorder

Source: By authors.

It can be found from the data presented in Table 5:

(1) International hub city aviation accessibility and economic driving effect coupled with a comprehensive degree of coordination, and the overall showing "olive" structure.

The results in Table 5 show that the overall degree of coordination between air accessibility and the economic driving effect of the 10 international aviation hub cities presents an "olive-shaped" structure. Among them, from 2010 to 2019, the average values of the coupling and coordination degree of Shanghai and Beijing's aviation accessibility and economic driving effect are 0.9950 and 0.9415 respectively, which belong to the type of "high-quality coordination", significantly better than the rest of the international aviation hub cities, and are in the upper pole of the "olive shape"; the average values of Guangzhou and Chongqing are 0.9950 and 0.9415 respectively. The average values of Guangzhou and Chongqing are 0.8103 and 0.7999 respectively, belonging to "good coordination", while the average values of Shenzhen and Chengdu are 0.7857 and 0.7090 respectively, belonging to "intermediate coordination", and the average values of Xi'an and Kunming are 0.7857 and 0.7090 respectively, belonging to "intermediate coordination". Xi'an and Kunming are 0.6725 and 0.5457 respectively, belonging to "primary coordination" and "barely coordinated"; Harbin and Urumqi are 0.3641 and 0.1000 respectively, belonging to "dysfunction". Harbin and Urumqi are 0.3641 and 0.1000 respectively, belonging to the type of "disorder" and the lower pole of "olive shape".

(2) International hub cities are of three types: "leading regional economic development, leading air transport development, and synchronizing regional economic and air transport development".

Although the overall trend of the coupling degree of air accessibility and economy-led effect is fluctuating and increasing, there are still some cities that belong to the "out-of-phase" type during 2010-2019. Given the differences in the positional order of the economic driving effect and air accessibility, the coupling degree of coordination is further classified into three types: "leading regional economic development, leading air transport development, and the same development of regional economy and air transport" [30].

Between 2010 and 2019, the rankings of Shanghai, Beijing, Kunming, Harbin, and Urumqi in terms of air accessibility and economic driving effect are stable, with no obvious fluctuation changes, and belong to the type of "synchronization between regional economic and air transport development". Among them, the rankings of Shanghai and Beijing in terms of air accessibility and economic driving effect are at a higher position, which is a high level of synchronous development, while the rankings of Kunming, Harbin, and Urumqi in terms of air accessibility and economic driving effect are at a lower position, which is a low level of synchronous development. The rankings of Shenzhen, Chongqing, and Chengdu are higher than the rankings of air accessibility, indicating that their regional economic development is constrained by the development of air transport, which belongs to the type of "leading regional economic development", among which, the rankings of Chongqing's economic driving effect are much higher than that of its air accessibility rankings, indicating that the constraints of its air transport on the development of the regional economy are more serious. Chongqing's economic driving effect is much higher than its air accessibility ranking, indicating that its air transport constraints on regional economic development are more serious. Guangzhou and Xi'an's air accessibility rankings are higher than their economic driving effect rankings, indicating that their air transport development still has a high potential to drive regional economic development, and belongs to the type of "leading air transport development", of which Xi'an's economic driving effect ranking is much lower than its air accessibility ranking, indicating that its regional economy is seriously lagging behind its air transport development. Xi'an's economic driving effect is much lower than its air accessibility ranking, indicating that its regional economy is seriously lagging behind air transport development.

4. Conclusion and Discussion

The rapid expansion of the airline network has greatly advanced the process of regional commuting and economic activities and reshaped the spatial pattern of economic geography. This paper takes 10 international aviation hub cities as the research object, uses the air accessibility model based on flight frequency and the economic driving effect model, analyses the results of air accessibility and economic driving effect of aviation hub cities from 2010 to 2019, and measures the coupling coordination level of the two, aiming to classify the development of the 10 international aviation hubs in the context of the coordinated development of air transport and regional economy Provide development suggestions.

The research results show that: (1) Air accessibility between international hub cities presents the phenomenon of "vertical continuous improvement, horizontal class solidification", and the overall distribution pattern of "3+5+2"; (2) The economic driving effect between international hub cities generally shows the phenomenon of "vertical steady improvement, horizontal polarisation", and the intensity of economic ties between Beijing and Shanghai is much higher than that of other regions; (3) The coupling and coordination degree between air transport accessibility and the intensity of economic ties between international hub cities shows the "olive-shaped" structure, and It can be divided into three types: "leading regional economic development, leading air transport development, and synchronous development of regional economy and air transport".

Based on the above findings, this paper proposes the following two countermeasures:

(1) Differentiation based on functional positioning.

The first is to create "international gateway and hub cities". For Beijing, Shanghai, and Guangzhou, to create international gateway and hub cities, based on the "14th Five-Year Plan for Civil Aviation Development", will focus on the two major functions of "gateway" and "hub", and will focus on building an important pivot point in the domestic general circulation and an important strategic link in the domestic and international dual circulation. It will focus on the two functions of "gateway" and "hub", focusing on the construction of an important pivot point of the domestic general circulation and an important strategic link of the domestic and international double circulation, to build an international gateway hub city serving the whole country and radiating to the world. The second is to build a "regional transit hub city". For Chengdu, Urumqi, Harbin, etc., to create a regional transit hub city, Chengdu, Xi'an, Shenzhen, and other cities as important nodes, to the east of Japan and South Korea, north of Mongolia and Russia, south of the ASEAN, west of the "Belt and Road" along the country as a point, the establishment of regional interoperability and interconnectivity mechanism, speed up the development of the linkage with the neighbouring countries, take the initiative to radiation drive the neighbouring countries, and jointly play a role in the international aviation industry. It will accelerate the linkage development with neighbouring countries, take the initiative to radiate and drive the neighbouring countries, and jointly play the functions of "transit" and "directionality" of an international aviation hub city.

(2)Based on the development status to achieve classified development

Based on the coupling characteristics of air accessibility and economic linkage strength in international hub cities, this paper proposes tailored development plans for cities with different development statuses. For cities where regional economy and air transport develop in sync, such as Shanghai and Beijing, it is recommended to continue strengthening infrastructure construction, promoting technological innovation, and enhancing international cooperation to maintain their leading positions in the global aviation network. Additionally, for cities where regional economic development leads, such as Shenzhen, Chongqing, and Chengdu, it is essential to accelerate the improvement of aviation infrastructure and optimization of airline networks to lift the constraints that air transport places on economic development, thereby fostering coordinated growth between the economy and air transport. For cities where air transport development leads, like Guangzhou and Xi'an, it is advised to promote economic diversification and enhance regional cooperation to boost economic vitality, ensuring that the advantages of air transport effectively translate into drivers of economic growth. These strategies not only enhance the competitiveness of individual cities but also strengthen the overall coordinated development of regional economies, providing a scientific basis and policy guidance for urban development and regional economic integration.

(3) Coordinated Regional Development.

The results of calculating and analyzing the relationship between the coupling coordination degree among the ten major international aviation hubs show that although the level of air accessibility and the economic driving effect have both changed during the decade, the development of the two is not synchronous. At the macro level, the adjustment of Beijing, Shanghai, and Guangzhou should focus on improving the inter-regional economic driving effect based on promoting the construction of international and domestic route networks and enhancing the capacity of international and domestic connectivity. For the remaining international aviation hubs, the scale of the hinterland market should be expanded to enhance the economic driving effect of the international hub cities, and the coverage capacity of the hinterland market should be enhanced using improving the airport infrastructure and service capacity and reinforcing the comparative advantages in air transport. At the micro level, the comparative advantages of air transport have not given full play to the driving effect on the regional economy, and the coupled and coordinated development among the ten international aviation hubs also shows a big difference. For the remaining international hub cities other than Beijing, Shanghai, and Guangzhou, the connection with cities with excellent coupling coordination performance such as Beijing, Shanghai, and Guangzhou should be strengthened. Beijing, Shanghai, and Guangzhou should give full play to their "support" ability, drive economic cooperation and exchange among the ten international aviation hub cities, and enhance the level of economic driving effect among the ten international aviation hub cities.

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