Evaluation of Competition and Co-operation of Hub Airport Route Networks in the Yangtze River Delta

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ABSTRACT

To scientifically evaluate the competition-cooperation pattern of the route network market in an airport cluster, we focused on the Yangtze River Delta (YRD) hub airports as the research subject. We constructed a quantitative model of the route network of the YRD hub airports from both the holistic and the interactive markets perspectives. We estimated the competition indices of the waypoints, routes, and travelers' in the route network. The results show that: 1) From the perspective of a holistic market, the competition among waypoints in the Yangtze River Delta hub airports mainly manifests as competition, with the number of waypoints and the regional layout being more homogeneous. The degree of route competition shows an overall decreasing trend and the overall trend of the passenger competition pattern is consistent with that of the route market. 2) From the perspective of the interactive market, the interactive market of waypoints generally belongs to the competitive market; the interactive pattern of routes also belongs to the competitive market. The passenger interactive market is trasitioning from cooperative to competitive. This study measures the degree of competition in the airline network using quantitative methods, provides accurate market analysis, enhances understanding of the structural changes in the aviation market, and helps promote the healthy development of the aviation market in the Yangtze River Delta region and beyond.

Keywords: Yangtze River Delta, Airport clusters, Hub airports, Competition-cooperation, Route network evaluation

1. Introduction

As an important growth pole for China's economic and social development and a global hub and gateway, the route network layout of airports in the Yangtze River Delta (YRD) region is directly related to the level of regional internal and external transport facilitation [1]. With the competing development of airports in Shanghai, Hangzhou, Nanjing, Hefei, and others, the allocation of route resources and market competition dynamics are becoming increasingly complex. In 2019, the total

passenger throughput of airports in the YRD Airport Group reached 267 million, a growth rate of 7.0% compared to 2018. In comparison, the passenger throughput of airports in the Guangdong-Hong Kong-Macao Greater Bay Area was 153 million (7.9% growth)., and in the Beijing-Tianjin-Hebei region, it was 142 million (2.2% growth).The YRD airport cluster also has the characteristics of the largest route network, the highest isomorphism, the weaker resistance to disruption, and the most homogeneous internal routes, making the competition the most intense [2,3].

In the airport cluster, due to the "siphon effect" of regional hub airports, air traffic is more likely to be concentrated in the hub airports. These hubs not only carry a large amount of air traffic but also significantly affect the transport organization efficiency of the entire aviation network [4,5]. In 2019, the passenger throughput of the seven hub airports (Shanghai, Hangzhou, Nanjing, Ningbo, Wenzhou and Hefei) accounted for the largest share of the total passenger throughput of the entire aviation network. These airports accounted for 86.4% of the passenger throughput of the entire YRD region, while the other 16 airports accounted for only 13.6%. The route network is an important part of the air transport system, a crucial production factor for hub airports, and a key element for differentiated positioning among airports. The Yangtze River Delta airport cluster has formed a spatial pattern with the two major airports in Shanghai serving as the Asia-Pacific international hub, airports in Hangzhou, Nanjing, and Hefei as regional hubs, and airports in Ningbo and Wenzhou as the main nodes [6]. On the one hand, due to geographic proximity, some of the short and medium-haul routes have structural duplication, resulting in disorderly competition. On the other hand, because of the different stages of development and functional positioning, there is an urgent need to strengthen the division of labor in the route network and resources allocation. Based on the current situation, it is necessary to systematically assess the route network of major hub airports in the Yangtze River Delta, identify the problems, and propose optimization measures to promote the high-quality development of air transport in the entire region.

Current research on the evaluation of airport cluster route network competition is limited to the Guangdong-Hong Kong-Macao Greater Bay Area, with a lack of studies on other airport clusters, and insufficient development of evaluation indexes. Therefore, based on existing research, this paper selects the Yangtze River Delta Airport Cluster hub airports as the focus of study. From the perspectives of the holistic market and the interactive market, and based on the three indexes (waypoint, number of flights, and the number of passengers transported) we derive the results for the waypoints, flight routes, and passenger traffic volume. These indexes of waypoints, flight routes, and passenger competitiveness are derived to explore the competition pattern between airports within the cluster and with external airports. This study aims to determine the current status of competition in the route network of the Yangtze River Delta hub airports, optimize the spatial layout of the route network, and to provide references for the differentiated positioning of the hub airports in the Yangtze River Delta.

2. Literature Review

Before the evaluation of route network competition, research on regional airport competition and its homogenization has been prominent, with many scholars focusing on various evaluation method. Peng Yubing et al. focus on the operational characteristics of hub airports, establish an index system for evaluating the hub airport competitiveness,, and demonstrate empirically that their method can objectively reflect overall hub airport competitiveness [7]. Jiang Yonglei et al. assess the level of homogeneity in airport development across the Yangtze River Delta (YRD) region using refined similarity coefficients. They construct an airport homogeneity network and conclude a significant

degree of homogeneity among YRD airport, with hub airports exhibiting the highest level of homogeneity. Feng Xia et al. enhance the evaluation of airport homogeneity by integrating airport attributes and networks, proposing a cascade analysis method for accessing airport cluster homogeneity [9] He Xiangni et al. focus on direct and transit routes, passenger demand, transit traffic, and other factors to develop an optimization model for route network in dual-hub airports competition scenario. These models aims to reduces delays and route overlap, comprehensively addressing hub airport competition [10]. A European airports survey via questionnaire reveals an evident competitive behavior among airports[11]. Analyzing data from 59 U.S. hub airports over a decade (2009-2019), a study employs a Cliff-Ord spatial model to investigate airports competition, highlighting the impact of their management structures on airport performance[12]. Another study utilizes passenger ground access flow data from four major airports around London to construct a spatial interaction model , elucidating the passenger flow patterns dominated by these airports in their respective areas, with intense competition in the central London market. The model performed well for scheduled flights but was less effective for charter traffic [13]. This study assessed the competitive landscape. A comprehensive assessment of European hub airports evaluates market concentration using the Herfindahl-Hirschman Index, indicating dominant positions held by most European hub airports in their respective markets [14].

The established studies mostly focus on the competition of route networks, overlooking the significance of route cooperation as a pivotal factor in market development. From the perspective of travelers' behavior in choosing airports, Chen Pangjin et al. get that convenience is a necessary condition for the cooperation between Macao and Zhuhai airports in the Guangdong-Hong Kong-Macao Greater Bay Area Airport Cluster, with cost-effectiveness exerting the second-most significant influence [15,16].Zhang Ying et al. from the perspective of the airspace resource tension and conflicting interests between Hong Kong and Shenzhen airports in the Guangdong-Hong Kong-Macao Greater Bay Area, put forward suggestions on the space for cooperation, consensus on cooperation, and mechanisms for cooperation between airports of these two regions [17]; Zhu Jia et al. conducted a study on the cooperation between small and medium-sized airports and airlines, and found that this cooperation can not only increase the market share but also yield residual profits [18]. By considering the differences between airports and developing a coordinated development strategy for a multi-airport system, studies suggest that the spatial clustering of airports of the same efficiency may not improve the overall efficiency [19]. This study aims to assess the impact of strategic cooperation between airport operators and airlines on airline performance and to address various aspects of this collaboration. Through interviews with middle management and panel regression analysis, the research reveals the effects of such collaborations [20]. The study optimizes subsidy strategies using a bi-level game theory model to promote the coordinated development of multi-airport route networks, deeply analyzing the interactions between passengers, airlines, and airports. The results indicate that targeted subsidy strategies can enhance route coordination among airports [21].

Regarding the study on the competitiveness and cooperation of regional airport clusters, research on the competitive characteristics of airports in metropolitan areas/metropolitan regions is mostly based on questionnaires and from the micro perspective of passenger traveling [22,23,24]. Lin Siqi et al. included airport output and input, and the level of urban development in the evaluation of the competitiveness of airports within the airport clusters. They concluded the competitive relationship between hub airports in the Guangdong-Hong Kong-Macao Greater Bay Area Airport Cluster [25]. With the continuous improvement of the research methodology, it has become a major

trend to study the competitive relationship of airport clusters from both the overall and nodal perspectives. It has been concluded that the overall cohesion of the Beijing-Tianjin-Hebei Airport Cluster is low, with insufficient co-operation among airports and increased competition among hub airports in the Guangdong-Hong Kong-Macao Greater Bay Area Airport Cluster, along with significant disparities between airports of various tiers [26,27,28]. Focusing on round-trip and transit passengers in the international market, the Hirschman and Entropy indices were used to indicate the internal competition in the round-trip market at global air hub airports. These studies indicate high levels of internal cooperation in the transit market among these airports [29].

3. Research Design

3.1 Network Model and Variable Definitions

3.1.1 Network Model: The route network is represented as a bipartite graph $N=(G,K,E)$*:*

G: Set of nodes representing the airport group, denoted as $G=\{V_i : i=1,2,\cdots,m\}$, where m is the number of airports.

K: Set of nodes representing destinations, denoted as $K=\{V_j : j=1,2,\cdots,n\}$, where n is the number of destinations.

E: Set of edges representing connections between airports in the group and their destinations, denoted as $E=\{e_{ij} : i\in G, j\in K\}$. If there is a direct route, e_{ij} = 1, otherwise e_{ij} = 0.

Edge Weight f_{ij}: Represents the weight of edge e_{ij}, such as flight frequency or available seats.

3.1.2 Simplified Processing

(1) Use cities with multiple airports as single nodes by merging data for these airports (e.g., merge data for Shanghai Pudong and Hongqiao airports).

(2) The network is treated as symmetric (undirected network), implying that if there is a flight from city A to city B, there is also a corresponding flight from city B to city A.

3.2 Quantitative Evaluation Model

3.2.1 Overall Competitive-Cooperative Evaluation

(1) Degree of Airport j （k_j）:

$$k_j=\sum_{i\in G} e_{ij} \qquad (1)$$

Represents the degree value of airport j.

(2) Standardized Degree K_j:

$$K_j=\frac{k_j}{m}\ , \qquad (2)$$

where 1/m < K_j < 1, indicating the market competition-cooperation type:

K_j =1: Fully competitive market; K_j =1/m: Fully monopolistic market; $K_j \neq 1$: Classified into strong cooperative market (K_j < 0.25), weak cooperative market (0.25< K_j < 0.5), weak competitive market (0.5 < K_j < 0.75), and strong competitive market (K_j > 0.75).

(3) Market Weight Competition-Cooperation Index RCI_j:

$$RCI_j = \max\left\{f_{ij}\right\} / \sum_i f_{ij} \quad , \tag{3}$$

where $1/m \leqslant RCI_j \leqslant 1$, defining market types:

$RCI_j \geqslant 1/m \times 1.5$: Monopolistic competitive market. Other cases: Coordinated competitive market.

3.2.2 Interactive Competitive-Cooperative Evaluation

(1) Route Competitive Index between Two Airports A and B NCI_{AB}

$$NCI_{AB} = \frac{|A \cap B|}{|A \cup B|} \tag{4}$$

where $0 \leq NCI_{AB} \leq 1$:

$NCI_{AB}=1$: Fully competitive market, $NCI_{AB}=0$: Fully cooperative and complementary market. $NCI_{AB} \leq 0.25$: Strong cooperative market, $0.25 < NCI_{AB} \leq 0.5$: Weak cooperative market, $0.5 < NCI_{AB} \leq 0.75$: Weak competitive market, $NCI_{AB} > 0.75$: Strong competitive market.

(2) Interactive Competitive-Cooperative Index Based on Connection Strength

$$S_{AB} = \frac{\sum_{A \cap B} f_{ij}}{\sum_{A \cup B} f_{ij}} \tag{5}$$

$$C_{AB}^{*} = \frac{1}{|A \cap B|} \times \sum_{V_j \in A \cap B} \left[\sum_{V_i \in \{V_a, V_b\}} \left(\frac{f_{ij}}{\sum_i f_{ij}} \right)^2 \right] \tag{6}$$

$$NCI_{AB}^{*} = S_{AB} \times \left(1 - C_{AB}^{*}\right) \tag{7}$$

S_{AB}: Proportion of the common market in the total market.

C_{AB}^{*}: Arithmetic mean of the concentration of all routes in the common market.

NCI_{AB}^{*}: Interactive competitive-cooperative index of the route network between the two airports based on connection strength.

where $0 \leqslant NCI_{AB}^{*} \leqslant 1$, defining market types:

$NCI_{AB}^{*} \leqslant 0.25$:Strong cooperative market;$0.25 < NCI_{AB}^{*} \leqslant 0.5$:Weak cooperative market;$0.5 < NCI_{AB}^{*} \leqslant 0.75$: Weak competitive market; $NCI_{AB}^{*} > 0.75$: Strong competitive market.

3.3 Data Sources

The route network data for the empirical analysis in this paper is based on the OAG (Official Aviation Guide) global route flight database and the Civil Aviation Administration of China (CAAC) airport business volume statistics. The route network data pertains to 2015 and 2019 and includes only passenger flights. The route attribute data includes flight volume (annual flight volume of no less than 52 flights, i.e., at least one flight per week in one direction) and passenger traffic (excluding annual flights of fewer than 52).

The selection of airports encompasses hub airports within the cluster of six cities: Shanghai (Pudong International Airport and Hongqiao International Airport combined), Hangzhou, Nanjing, Hefei, Ningbo, and Wenzhou. It also encompassess airports in Beijing (Capital International Airport and Daxing International Airport combined), Chengdu (Tianfu International Airport and Shuangliu International Airport combined), Dalian, Guangzhou, Guiyang, Guilin, Harbin, Haikou, Hohhot, Kunming, Nanning, Qingdao, Sanya, Xiamen, Shenzhen, Shenyang, Shijiazhuang, Taiyuan, Tianjin, Xi'an, Yinchuan, Changchun, Chongqing, Jinan, Lanzhou, Wuhan, Xining, Changsha, Zhengzhou,

Fuzhou, Nanchang, Urumqi, and Lhasa, as well as other hub airports outside of the cluster in 33 cities.

4. Empirical Analysis of Hub Airports in the Yangtze River Delta

4.1 Holistic Competition and Co-operation Patterns

4.1.1 Waypoint

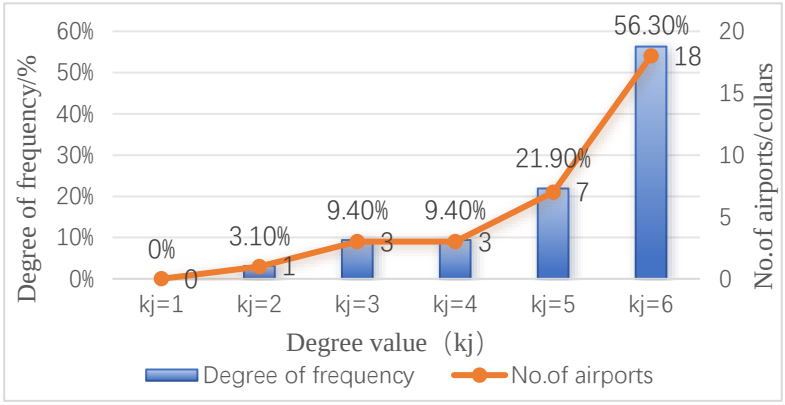

Figure 1. Competitive Pattern of Hub Airport Destinations in Yangtze River Delta in 2015

Source: By authors.

From the competitive perspective (Figure 1), in 2015, the Yangtze River Delta hub airports did not have a fully monopolistic or strong cooperation market. The weak cooperation market included four airports: Urumqi, Jinan, Xining, and Yinchuan, with a share of the navigation market p(k) of 12.5%. The weak competition market included Hohhot, Lanzhou, and Wuhan airports, with a market share of 9.4%. The strong competition market included Fuzhou, Guiyang, Nanchang, Nanning, Xiamen, Shijiazhuang, and Tianjin airports, with a market share of 12.5%. The fully competitive market included 18 airports: Beijing, Chengdu, Dalian, Guangzhou, Guilin, Harbin, Haikou, Kunming, Qingdao, Sanya, Shenzhen, Shenyang, Taiyuan, Xi'an, Changchun, Changsha, Zhengzhou, and Chongqing, accounting for 56.3% of the aviation market.

Overall, the analysis highlights the different levels of competition among the Yangtze River Delta hub airports, with varying degrees of market share and competition intensity.

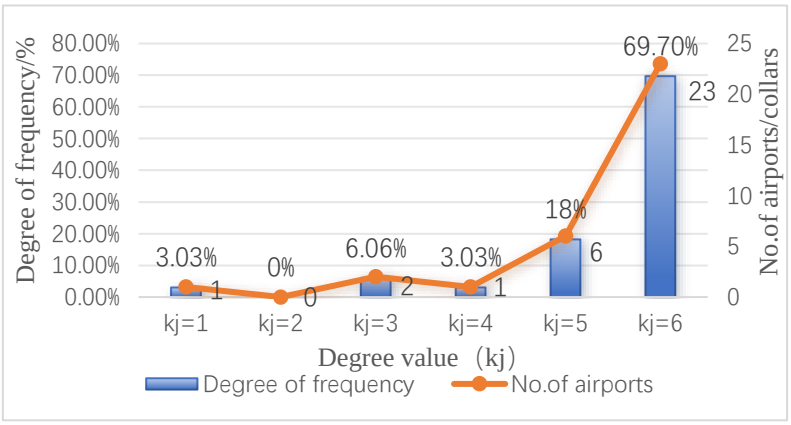

Figure 2. Competitive Pattern of Hub Airport Destinations in Yangtze River Delta in 2019

Source: By authors.

In the 2019, Yangtze River Delta hub airport waypoint competition (Figure 2), the fully monopolistic market includes only one airport, Lhasa, with a 3.0% share of the navigation market. This represents an increase of one navigation point and a 3.0% rise in market share compared to 2015.

The weak cooperation market comprises two airports, Fuzhou and Nanchang, with a 6.0% share of the navigation market, reflecting a decrease of two navigation points and a 6.4% decline in market share compared to 2015, indicating a decline rate of over 50%. The weakly competitive market includes only one airport, Urumqi, with a 3.0% share of the navigation market, showing a decrease of two navigation points and a 6.4% reduction in market share since 2015, representing a decline rate of nearly 70%. The strongly competitive market includes six airports—Jinan, Lanzhou, Wuhan, Xining, Changsha, and Zhengzhou—with an 18.2% share of the navigation market, a decrease of one navigation point and a 3.7% drop in market share, representing a decline rate of 14.3%. The fully competitive market encompasses 23 airports: Beijing, Chengdu, Dalian, Guangzhou, Guiyang, Guilin, Harbin, Haikou, Hohhot, Kunming, Nanning, Qingdao, Sanya, Xiamen, Shenzhen, Shenyang, Shijiazhuang, Taiyuan, Tianjin, Xi'an, Yinchuan, Changchun, and Chongqing, with a 69.7% share of the throughput market, an increase of five throughput points and a 13.4% rise in market share from 2015, representing a growth rate of 27.8%.

The competition market among hub airports in the Yangtze River Delta airspace is primarily characterized by strong competition and fully competitive markets. Overall, it covers major cities in China, although significant homogeneity exists in the number of airports and regional layout, focusing on connecting to economically developed regions. Coverage is relatively weak for the central and western regions while the type of market competition has shifted most significantly from strong competition to full competition, with an intensifying trend in competition.

4.1.2 Routes

From the analysis of route competition based on flight frequency, it was found that routes from the Yangtze River Delta hub airports to 33 hub airports across the country (except for Lhasa, which holds the complete monopoly) exhibit monopoly-like competitive conditions. However, the monopoly-competitive indexes vary significantly among these routes, reflecting substantial variability and complexity in the competition.

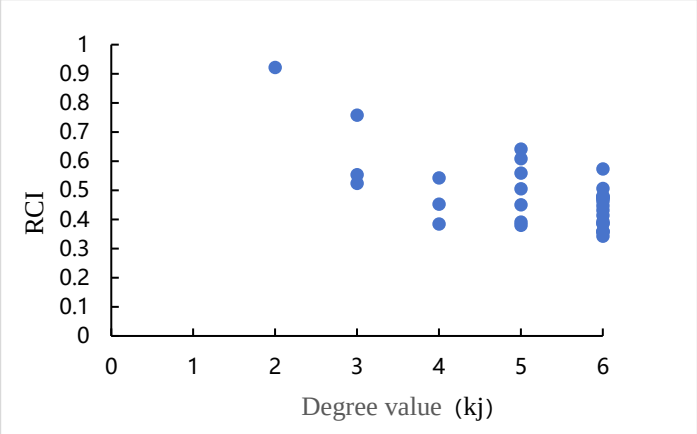

Figure 3. Route Competition Index Distribution of Hub Airports in Yangtze River Delta, 2015
Source: By authors.

In the 2015 route market of the Yangtze River Delta hub airports (Figure 3), at the degree value (2) route market, the routes of Urumqi airport are monopolistically competitive. At the degree value (3) route market, the routes of three airports-—including Jinan, Xining, and Yinchuan —are monopolistically competitive. At the degree value (4) route market, the routes of three airports —including Hohhot, Lanzhou, and Wuhan—are monopolistically competitive. At the degree value (5)

route market, the routes of seven airports—including Fuzhou, Guiyang, and Nanchang —are monopolistically competitive markets. Finally, at the degree value (6) route market, the routes of 18 airports —including Beijing, Chengdu, and Guangzhou—are monopolistically competitive markets.

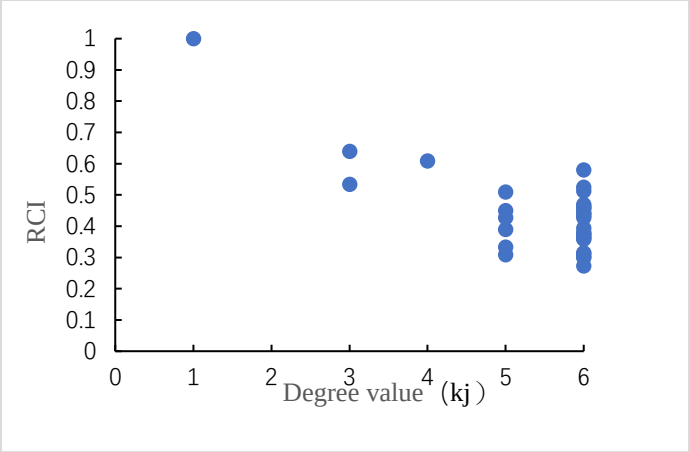

Figure 4. Route Competition Index Distribution of Hub Airports in Yangtze River Delta, 2019
Source: By authors.

In the 2019, route market of Yangtze River Delta hub airports (Figure 4), at the degree value (1) route market, the routes of Lhasa airport are monopolistically competitive. At the degree value (3) route market, the routes of two airports —Fuzhou and Nanchang —are monopolistically competitive. At the degree value (4) route market, the routes of Urumqi airport are monopolistically competitive. At the degree value (5) route market, the routes of six airports —including Jinan, Lanzhou, and Wuhan —are monopolistically competitive. In the degree value (6) route market, the routes of 23 airports —including Beijing, Chengdu, and Guangzhou —are monopolistically competitive.

Comparative analysis of the route competition indices at different degree values in 2015 and 2019 reveals that, as the degree value of airports increases (except for degree value (6)), the difference between the maximum and minimum indices for each degree value in 2019 is smaller than in 2015. This indicates that the degree of competition in the route market is decreasing over time.

Table 1. Route Competition Index and Changes in 2019 and 2015

waypoint	RCI_{2019}	RCI_{2015}	difference	waypoint	RCI_{2019}	RCI_{2015}	difference
Beijing	0.4695	0.4764	-0.0068	Sanya	0.4406	0.4747	-0.0342
Chengdu	0.4579	0.4623	-0.0044	Xiamen	0.5129	0.5592	-0.0462
Dalian	0.4643	0.4473	0.0170	Shenzhen	0.4332	0.4316	0.0016
Fuzhou	0.6392	0.6091	0.0301	Shenyang	0.4420	0.5741	-0.1321
Guangzhou	0.3603	0.3569	0.0033	Shijiazhuang	0.3772	0.3805	-0.0033
Guiyang	0.2727	0.3910	-0.1184	Taiyuan	0.3798	0.3593	0.0205
Guilin	0.3673	0.4708	-0.1035	Urumqi	0.5807	0.6413	-0.0606
Harbin	0.4567	0.4809	-0.0241	Urumqi	0.6088	0.9216	-0.3128
Haikou	0.3022	0.3424	-0.0402	Wuhan	0.5100	0.4529	0.0571
Hohhot	0.2994	0.3843	-0.0849	Xi'an	0.3590	0.3867	-0.0277
Jinan	0.4497	0.7585	-0.3088	Xining	0.3338	0.5534	-0.2196

Kunming	0.3131	0.3590	-0.0459	Yinchuan	0.3700	0.5245	-0.1546
Lasa	1.0000	0.0000	1.0000	Changchun	0.4274	0.5060	-0.0786
Lanzhou	0.3090	0.5423	-0.2333	Changsha	0.4278	0.3854	0.0424
Nanchang	0.5339	0.5050	0.0289	Zhengzhou	0.3901	0.3933	-0.0032
Nanning	0.3148	0.4504	-0.1356	Chongqing	0.3933	0.4138	-0.0205
Qingdao	0.5247	0.4781	0.0465				

Source: By authors.

Regarding the differences in the route competition index (Table 1), the degree of competition from the Yangtze River Delta hub airports to 23 airports—including Beijing, Chengdu, Guiyang, Guilin, Harbin, Haikou, Hohhot, Jinan, Kunming, Lanzhou, Nanning, Sanya, Xiamen, Shenyang, Shijiazhuang, Tianjin, Urumqi, Xi'an, Xining, Yinchuan, Changchun, Zhengzhou, and Chongqing—has weakened from 2015 to 2019. Conversely, competition to airports—including Dalian, Fuzhou, Guangzhou, Lhasa, Nanchang, Qingdao, Shenzhen, Taiyuan, Wuhan, and Changsha—has increased.

4.1.3 Passenger Market

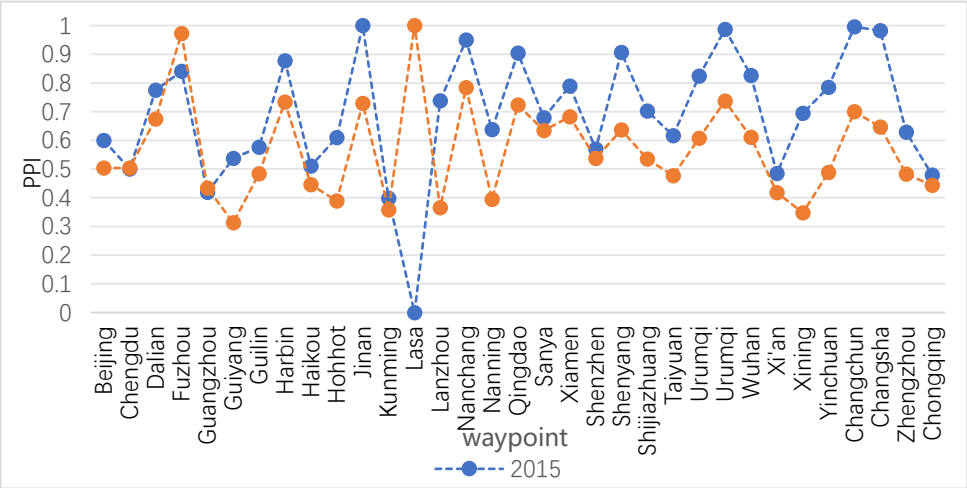

Figure 5. Passenger Competition Index for 33 Hub Airports, 2015 and 2019

Source: By authors.

Considering that flight volume does not fully reflect market competition, passenger traffic volume in the civil aviation market is used as a measure to verify the accuracy of this study. As illustrated by the passenger market-weighted competition index (Figure 5), the passenger market from the Yangtze River Delta hub airports to the 32 hub airports in China (except Jinan, which is a monopoly) was entirely monopolistically competitive in 2015. Similarly, in 2019, the passenger market (except Lhasa, which is a monopoly) was also entirely monopolistically competitive.

Analyzing the differences in the passenger market-weighted competition index between 2015 and 2019 reveals that the degree of competition in the passenger market from the Yangtze River Delta hub airports to three airports—Chengdu, Fuzhou, and Guangzhou—is increasing. Conversely, the competition in the passenger market to 30 airports—Beijing, Dalian, and Guiyang—is weakening. This finding aligns overall with the observed trend in the route market.

From a holistic market perspective, it can be concluded that the current route network destinations of hub airports in the Yangtze River Delta exhibit homogeneous competition. The competition in both the route and passenger markets tends to ease, gradually developing towards

cooperation.

4.2 Interactive Competitive and Co-operative Evaluation

4.2.1 Waypoint

Table 2. Interactive Competitive Index Distribution of Hub Airport Waypoint in the Yangtze River Delta, 2015 and 2019

Index	Shanghai	Hangzhou	Ningbo	Nanjing	Hefei	Wenzhou
Shanghai	——	**0.9688**	**0.9063**	**1**	**0.7879**	**0.8750**
Hangzhou	0.9375	——	**0.8750**	**0.9688**	**0.8125**	**0.9032**
Ningbo	0.6875	0.6774	——	**0.9063**	**0.7500**	**0.9000**
Nanjing	0.9375	0.8750	0.6774	——	**0.7879**	**0.8750**
Hefei	0.8125	0.8065	0.7143	0.8667	——	**0.7742**
Wenzhou	0.8125	0.8065	0.7778	0.7500	0.7931	——

Note: The top half of the matrix diagonal (in bold) represents the 2019 scenario and the bottom half represents the 2015 scenario. Tables 2 and 3 are identical.
Source: By authors.

From the analysis of the waypoint interactive competition index in 2015, no airports exhibited full cooperation and complementary markets (NCI = 0), strong cooperative markets (NCI ≤ 0.25), weak cooperative markets (0.25 < NCI ≤ 0.5), or full competition markets (NCI = 1). There are five pairs of airports—Ningbo-Shanghai, Ningbo-Hangzhou, Nanjing-Ningbo, Hefei-Ningbo, and Wenzhou-Nanjing—that were characterized as weakly competitive markets (0.5 < NCI ≤ 0.75). Additionally, ten pairs of airports—Hangzhou-Shanghai, Nanjing-Shanghai, Hefei-Shanghai, Wenzhou-Shanghai, Nanjing-Hangzhou, Hefei-Hangzhou, Wenzhou-Hangzhou, Wenzhou-Ningbo, Hefei-Nanjing, and Wenzhou-Hefei—exhibited strong competitive markets (NCI > 0.75).

By 2019, there were no airports in fully cooperative complementary markets, strong cooperative markets, or weak cooperative markets. Only one pair of airports, Ningbo-Hefei, exhibited a weak competitive market. Thirteen pairs of airports—Shanghai-Hangzhou, Shanghai-Ningbo, Shanghai-Hefei, Shanghai-Fuzhou, Hangzhou-Ningbo, Hangzhou-Nanjing, Hangzhou-Hefei, Hangzhou-Wenzhou, Ningbo-Nanjing, Ningbo-Wenzhou, Nanjing-Hefei, Nanjing-Wenzhou, and Hefei-Wenzhou—were in strong competitive markets. Additionally, one pair of airports, Shanghai-Nanjing, was characterized as a perfectly competitive market.

The destinations of Shanghai, Nanjing, and Hangzhou airports on domestic routes show significant overlap, especially for economically developed cities. The overall waypoint interactive competition market of the route network of the Yangtze River Delta hub airports is classified as a competitive market. In 2015, the waypoint competition market consisted of both weak and strong competition segments. By 2019, it was primarily composed of strong competitive markets, with the Shanghai-Nanjing airports transitioning from strong competition to fully competitive markets. Overall, the interactive competition index for waypoints at hub airports has shown a growth trend, indicating an increase in market competition.

4.2.2 Routes

Analyzed by the Route Interactive Competition Index, in 2015, three pairs of airports—Ningbo-Shanghai, Hefei-Shanghai, and Wenzhou-Shanghai—exhibited a weak cooperative market. Eight

pairs of airports—including Nanjing-Shanghai, Ningbo-Hangzhou, Hefei-Hangzhou, Wenzhou-Hangzhou, Nanjing-Ningbo, Hefei-Ningbo, Hefei-Nanjing, and Wenzhou-Nanjing—displayed a weak competitive market. Additionally, four pairs of airports—Hangzhou-Shanghai, Nanjing-Hangzhou, Wenzhou-Ningbo, and Wenzhou-Hefei—demonstrated strong competitive markets.

Table 3. Interactive Competitive Index Distribution of Hub Airport Routes in the Yangtze River Delta, 2015 and 2019

Index	Shanghai	Hangzhou	Ningbo	Nanjing	Hefei	Wenzhou
Shanghai	——-	**0.8440**	**0.4540**	**0.8047**	**0.5140**	**0.4770**
Hangzhou	0.8240	——-	**0.6633**	**0.9066**	**0.7376**	**0.6945**
Ningbo	0.3578	0.5523	——-	**0.6968**	**0.7470**	**0.8749**
Nanjing	0.7479	0.8944	0.6003	——-	**0.7676**	**0.6926**
Hefei	0.3911	0.6255	0.7356	0.7221	——-	**0.7695**
Wenzhou	0.3863	0.6221	0.7771	0.6372	0.7863	——-

Source: By authors.

In 2019, two pairs of airports, Shanghai-Ningbo and Shanghai-Wenzhou, exhibited weak cooperative markets. Seven pairs of airports—Shanghai-Hefei, Hangzhou-Ningbo, Hangzhou-Hefei, Hangzhou-Wenzhou, Ningbo-Nanjing, Ningbo-Hefei, and Nanjing-Wenzhou—demonstrated weakly competitive markets. Additionally, six pairs of airports—Shanghai-Hangzhou, Shanghai-Nanjing, Hangzhou-Nanjing, Ningbo-Wenzhou, Nanjing-Hefei, and Hefei-Wenzhou—displayed strong competitive markets.

Analyzing the trend of the interactive competition index for each airport route between 2015 and 2019, it can be concluded that, except for the Hefei-Wenzhou route, the degree of competition among the remaining 14 pairs of airports is weakening. In contrast, competition among these 14 pairs has increased to varying degrees, with three pairs—Shanghai-Hefei, Hangzhou-Ningbo, and Hangzhou-Hefei—showing the most significant growth. Overall, the route market's interactive competition predominantly falls into the competitive market category.

The trend toward stronger interactive competition in the route market may be attributed to the uncontrolled competition and structural duplication of routes among hub airports.

4.2.3 Passenger Market

Table4. Interactive Competitive Index Distribution of Passenger Markets in Hub Airports in Yangtze River Delta, 2015 and 2019

Index	Shanghai	Hangzhou	Ningbo	Nanjing	Hefei	Wenzhou
Shanghai	——	**0.7333**	**0.3444**	**0.5552**	**0.3010**	**0.3370**
Hangzhou	0.6054	——	**0.6214**	**0.7798**	**0.5525**	**0.5826**
Ningbo	0.1288	0.3710	——	**0.5853**	**0.6565**	**0.8269**
Nanjing	0.3421	0.6747	0.4760	——	**0.6879**	**0.5715**
Hefei	0.1919	0.4966	0.6479	0.7473	——	**0.6898**
Wenzhou	0.2018	0.5018	0.6978	0.6370	0.6648	——

Source: By authors.

Analyzed by the Passenger Interactive Competitive Index, in 2015, three pairs of airports—

Ningbo-Shanghai, Hefei-Shanghai, and Wenzhou-Shanghai—exhibited strong cooperative markets. Four pairs of airports—Nanjing-Shanghai, Ningbo-Hangzhou, Hefei-Hangzhou, and Nanjing-Ningbo—demonstrated weakly cooperative markets. Additionally, eight pairs of airports, including Hangzhou-Shanghai, Nanjing-Hangzhou, Wenzhou-Hangzhou, Hefei-Ningbo, Wenzhou-Ningbo, Hefei-Nanjing, Wenzhou-Nanjing, and Wenzhou-Hefei, indicated weak competitive markets.

By 2019, three pairs of airports—Shanghai-Ningbo, Shanghai-Hefei, and Shanghai-Wenzhou—had transitioned to weakly cooperative markets. Ten pairs of airports, such as Shanghai-Hangzhou, Shanghai-Nanjing, Hangzhou-Ningbo, Hangzhou-Hefei, Hangzhou-Wenzhou, Ningbo-Nanjing, Ningbo-Hefei, Nanjing-Hefei, Nanjing-Wenzhou, and Hefei-Wenzhou, displayed weakly competitive markets. Two pairs of airports, specifically Hangzhou-Nanjing and Ningbo-Wenzhou, were classified as strongly competitive markets.

Based on the trend observed in the Passenger Interactive Competitive Index, it is evident that the interactive passenger market is transitioning from cooperation to competition. Except for the Nanjing-Hefei and Nanjing-Wenzhou airport pairs, where passenger competition is diminishing, the remaining 13 pairs of airports are experiencing increased competition. This trend is particularly evident in the Shanghai-Ningbo, Shanghai-Nanjing, and Hangzhou-Ningbo airport pairs, which are showing significant growth in competitiveness. The trend toward stronger interactive competition in the passenger market may be attributed to hub airports in the Yangtze River Delta attracting a substantial number of transshipment passengers, bolstered by enhanced external radiation capacity and the clustering effect of various high-end resources.

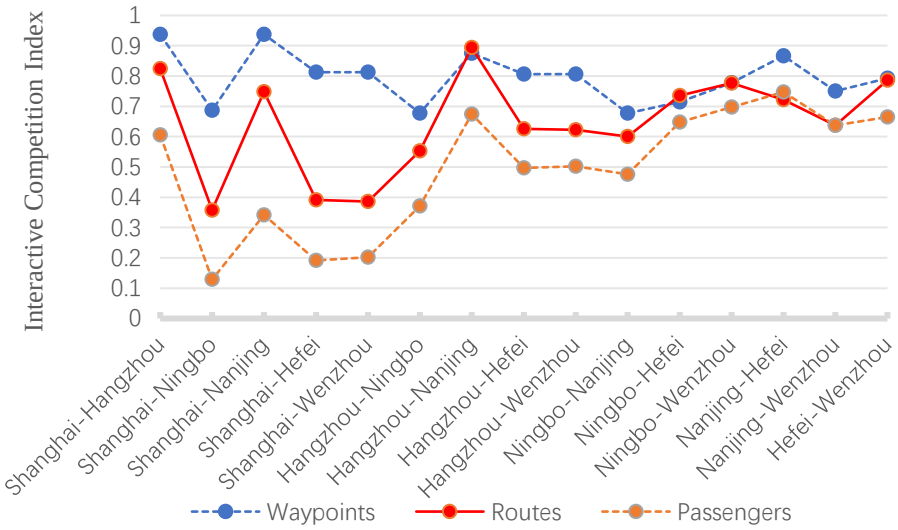

Figure 6. Interactive Competitive Index of Hub Airports in the Yangtze River Delta for Destination, Route and Passenger Markets, 2015

Source: By authors.

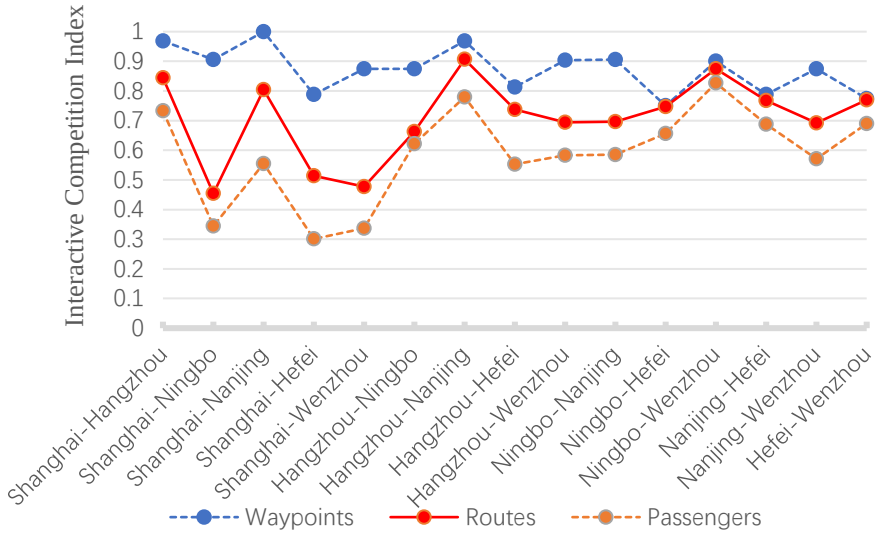

Figure 7. Interactive Competitive Index of Hub Airports in the Yangtze River Delta for Destination, Route and Passenger Markets, 2019

Source: By authors.

Comparative analysis of the interactive competition indices for waypoints and routes reveals that the competition intensity in the waypoint market at hub airports surpasses that in the route market, and notably exceeds overall competition in the passenger market. This indicates that the strategy for developing route networks prioritizes waypoints over routes and routes over passengers.

From an interactive market perspective, it can be concluded that the current hub airports in the Yangtze River Delta have adopted a development model characterized by simultaneous competition across the waypoint, route, and passenger markets. This model reflects an evident mutual influence and spatial diffusion in route network development.

5. Results and Discussion

(1) Overall Competition-Cooperation Pattern Analysis:

Waypoint Market: The waypoint market exhibits predominantly competitive, with a high degree of homogeneity in the number of waypoints and regional layouts, it primarily focuses on connecting economically developed regions, with limited coverage in central and western regions. The competition trend is intensifying.

Route Market: With the exception for Lhasa, which operates a complete monopoly, other routes are monopolistic competitive, with varying indices. The overall degree of competition is decreasing, showing significant differences and complexity.

Passenger Market: The trend is consistent with the route market. Currently, the route network destinations of YRD hub airports show homogeneous competition, but competition in the route and passenger markets is moderating and it is gradually developing towards cooperation.

(2) Interactive Competition-Cooperation Pattern Study:

Waypoint Market: The overall market is competitive In 2015, it featured both weak and strong competitive segments,, whereas by 2019, it primarily consisted of strong competitive markets. The competition index is rising, indicating an increase in market competition.

Route Market: This market is characterized as a competitive market, with an increasing degree of interactive competition. This trend may be due to irrational situations such as uncontrolled competition and structural duplication of routes among hub airports.

Passenger Market: This market is transitioning from cooperative to competitive. The increasing trend in interactive competition may result from the strengthened external radiation capacity and aggregation effect of high-end resources at YRD hub airports, attracting a significant numbers of transshipment passengers. Currently, the YRD hub airports have adopted a development model of simultaneous competition in waypoints, routes, and passenger markets, demonstrating significant mutual influence in spatial diffusion.

The research focuses on quantitatively measuring competition and cooperation indices of destinations, routes and passenger markets in the air route network. It aims to delineate the development pattern of the air route network atthe Yangtze River Delta airports and to promote the coordinated and integrated development of the hub airports.Beyond expanding the application of the competition and cooperation theory in the aviation market,it also provides theoretical and empirical support for the regional economic integration process.

Future research and practice can focus on the following areas:

(1)Waypoint layout optimization: Further research is needed to optimize waypoint layout, improve the coverage of the central and western regions, and reduce homogenized competition.

(2)Route market regulation: Explore effective market regulation mechanism, avoid disorderly competition and repeated opening of routes, thereby improving the utilization efficiency of route resources.

(3)Passenger market development: Strengthen the service and management of transit passengers, improve the overall service quality of the airport, and promote the healthy development of the passenger market.

(4)Multi-dimensional concurrence model: Develop a more detailed and multi-dimensional concurrence quantitative model to more accurately evaluate market dynamics and formulate corresponding strategies.

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