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Research Article

Analysis of Competition Relationship of Multiairport Regional Airport Market Based on Deep Learning

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At present, China's civil aviation industry is in a period of rapid development. The passenger traffic is increasing year by year. The contradiction between the demand and supply of flight resources is becoming more and more prominent, and the competition between airports is becoming more and more fierce. Driven by local development and the country's overall planning, there are more and more multiairport areas, so how to analyze the airport market competition in multiairport areas needs to be further realized. This paper constructs a two-dimensional Hotelling model based on flight frequency and passenger travel cost to analyze the internal mechanism of market competition among multiple airports. It is assumed that, in a multiairport area, two airports are distributed at both ends of a linear straight line, and the other airport is in between, and each airport provides displacement services connecting the same destination airport. The research shows that, (1) with the increase of the flight frequency of the airports at both ends, its equilibrium profit shows a trend of decreasing first and then increasing; the difference of the flight frequencies of the airports at both ends affects the equilibrium profit of the middle airport. (2) With the gradual increase of flight frequency, the reduction of passenger travel cost will make the equilibrium market share and equilibrium profit show a trend of first decreasing and then increasing. (3) Taking the Yangtze River Delta regional airport as an example, it is found after verification that increasing flight frequency or reducing passenger travel costs can increase the balanced profit and market share of Hangzhou Xiaoshan Airport and Nanjing Lukou Airport; increasing flight frequency can improve the balanced profit and balanced market share of Sunan Shuofang Airport.

1. Introduction

Under the joint promotion of market demand and relevant national policies, a multiairport area has been formed. There are many problems in the multiairport area: the distribution of aviation resources is uneven, a few airports in the area are oversaturated, most airports are underutilized, there is market overlap, and differentiated development is not obvious. Airport competition in multiairport areas is becoming increasingly fierce. Therefore, it is necessary to study the market competition relationship between airports in the multiairport area, clarify the relationship between flight frequency, passenger travel cost, and airport market share and interests, and provide development suggestions for the competition between airports, which is conducive to the formation of good form of competition. This paper uses the Hotelling model to describe the market competition behavior between airports in a multiairport area. Lian JI and Rønnevik J found through investigation that the market share of Norwegian regional airports has gradually shifted to nearby major airports, regional airports have lost more passengers, and airport competition is more intense [1–6]. Woong et al. analyzed the operation of major multiairport systems in the world's metropolises and obtained the main direction for the efficient development of the multiairport system in Korea. There is no absolute and unique solution to the operation of the multiairport system. Decisions should be made according to local conditions. At the same time, it can be seen from the multiairport system operation failure cases in some countries that the comprehensive formulation of multiairport system operation policies is beneficial to the development of the national economy and the people [7]. Carstens takes the Italian multiairport system as an example, analyzes the sustainability of airport development, and believes that a multiairport system model with correlation can overcome economic and financial problems and provide sustainable infrastructure management strategies. A multiairport system can make a significant contribution to the management and development of infrastructure in a sustainable manner [8]. Wang et al. took the Guangdong-Hong Kong-Macao Greater Bay Area as the research object and discussed the competition among airports in the multiairport area according to the airport competition at the airline level and its impact on passengers' choice of airports. The competition among airlines is not just that of airlines in a single airport [9]. King-Yin Cheung et al. believe that, in a multiairport area, if the relevant departments in charge of the airport want to promote the better development of the airport, they need to take into account the competition and cooperation factors of the nearby airports [10]. By sorting out relevant literature at home and abroad, it can be seen that the Hotelling model is widely used to analyze the impact of product differentiation on the development of enterprises. A small number of literatures study the Hotelling model in airline pricing and game strategies. A Hotelling game model under duopoly situation is established. Research shows that when only one airline provides service and the service cost factor is lower, another airline can easily be eliminated by the market. When both airlines provide services, the service cost factor should be guaranteed to increase revenue within a reasonable range. In summary, it is found that the Hotelling model is rarely used in the market competition research between airports. To this end, this paper uses the Hotelling model to analyze the internal mechanism of market competition among multiple airports in the region and explores the relationship between airport flight frequency and passenger travel costs on airport passenger demand and airport profits, providing advice on healthy competition and ultimately complying with the national airport group coordinated development strategy to achieve the common development of regional airports [11–13].

2. Hotelling Model of Airport Passenger Source Competition

The original Hotelling model: some consumers are evenly distributed in a long x linear city, and there are two manufacturers at the same time, assuming that the products of the two manufacturers are homogeneous, the price is given exogenously p, and consumers only buy unit product; in addition, the transportation cost is a linear function of the distance from the consumer to the manufacturer and the unit transportation cost is 1, so every rational consumer will go to the manufacturer closer to him to buy the product. The original one-dimensional Hotelling model is suitable for analyzing the issues of location selection, competition, and pricing between two manufacturers, and the discussion objects are limited to two. In reality, there are generally more than two manufacturers of the same product. Therefore, the introduction of a two-dimensional Hotelling model can be more fundamentally close to reality and make the research more representative. Therefore, this paper expands the original Hotelling model into a two-dimensional Hotelling model to study the market competition behavior between airports in multiple airport areas.

2.1. Model Assumptions

(1) It is assumed that there are x 3 airports distributed on the axis [0, 1], Airport 1 is located at the x (0, 0) position on the axis, Airport 2 is located at the x (a, 0) position on the axis, and Airport 3 is located at the x (1, 0) position on the axis, and the positions do not overlap each other, that is, $0 < a < 1$.

(2) The passenger travel cost and the distance to the destination airport have a quadratic function relationship. The cost per unit distance from the passenger to the airport is that the passengers are distributed in the t enclosed graph (x, y) with the same density (as shown in Figure 1) $(0, 0)$, $(0, 1)$, $(1, 1)$, $(1, 0)$ which is the location where the passengers are distributed.

(3) The $i\,(i = 1, 2, 3)$ price of the air ticket from the airport to the same destination is $pi\,(i = 1, 2, 3)$, and the revenue obtained by the airline's unit product is all c.

(4) $Ui\,(i = 1, 2, 3)$, i represents the utility function when the passenger chooses the airport to travel, and $U0$ represents the inherent benefit before the passenger chooses the airport to travel.

(5) Assuming that passenger demand is evenly distributed, the average planned delay time per passenger is $s\ d = T/4fi$ [12]. Among them, T represents the flight operation time on a certain route, and $fi\,(fi > 0)$ represents the frequency of flights from the airport i to the same destination airport. The larger the fi value, the smaller the planned delay cost per passenger on average. In order to measure the utility value of passengers choosing an airport, let $\theta = 4/T$, the larger f is, the stronger the i preference for choosing an airport to travel is.

(6) $Di\,(i = 1, 2, 3)$ is the passenger demand at the airport i.

(7) $\pi i\,(i = 1, 2, 3)$ is the profit of the airport i.

2.2. Model Establishment. Therefore, the utility of (x, y) passengers at the location choosing Airport 1, Airport 2, and Airport 3 is

$$U1 = U0 + \theta f1 - t\left(x^2 + y^2\right) - p1, \tag{1}$$

$$U2 = U0 + \theta f2 - t\left[(x - a)^2 + y^2\right] - p2, \tag{2}$$

$$U3 = U0 + \theta f3 - t\left[(1 - x)^2 + y^2\right] - p3. \tag{3}$$

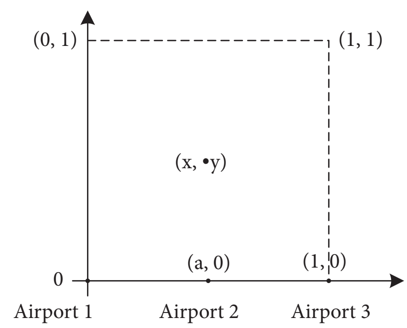

Figure 1: Schematic diagram of the two-dimensional Hotelling model.

There is no difference in the utility of passengers choosing Airport 1 and Airport 2, that is, $x1\,(0 < x1 < a)$:

$$U1 = U2. \quad (4)$$

Solutions are as follows:

$$x1 = \frac{1}{2at}\left[a^2 t + \theta(f1 - f2) + (p2 - p1)\right]. \quad (5)$$

Similarly, assuming that the passenger's abscissa is, there is no difference in the utility of passengers choosing Airport 2 and Airport 3, that is, $x2\,(a < x2 < 1)$:

$$U2 = U3. \quad (6)$$

Solutions are as follows:

$$x2 = \frac{1}{2(1-a)t}\left[(1-a)(1+a)t + \theta(f2 - f3) + (p3 - p2)\right]. \quad (7)$$

When the abscissa of the passenger is, the passenger will choose airport $x < x1$ 1 to take the plane; when the abscissa of the passenger is, the passenger will choose Airport 2 to take the plane; when the abscissa of the passenger is $x1 < x < x2x > x2$, the passenger will choose Airport 3 to take the plane. Then, the respective market shares of the three airports $D1, D2$, and $D3$ are summed as follows:

$$\begin{aligned}
D1 &= \int_0^1 \int_0^{x1} \mathrm{d}x\mathrm{d}y = x1 = \frac{1}{2at}\left[a^2 t + \theta(f1 - f2) + (p2 - p1)\right],\\
D2 &= \int_0^1 \int_{x1}^{x2} \mathrm{d}x\mathrm{d}y = x2 - x1 = \frac{1}{2(1-a)at}\begin{bmatrix} a(1-a)t + a\theta(f1 - f3) - \\ \theta(f1 - f2) + a(p3 - p1) - (p2 - p1) \end{bmatrix},\\
D3 &= \int_0^1 \int_{x2}^{1} \mathrm{d}x\mathrm{d}y = 1 - x2 = \frac{1}{2(1-a)t}\left[(1-a)^2 t - \theta(f2 - f3) - (p3 - p2)\right].
\end{aligned} \quad (8)$$

Then, the profit functions of the three airports are as follows:

$$\begin{aligned}
\pi 1 &= D1 \cdot (p1 - c) = \frac{(p1 - c)}{2at}\left[a^2 t + \theta(f1 - f2) + (p2 - p1)\right],\\
\pi 2 &= D2 \cdot (p2 - c) = \frac{(p2 - c)}{2(1-a)at}\left[a(1-a)t + a\theta(f1 - f3) - \theta(f1 - f2) + a(p3 - p1) - (p2 - p1)\right],\\
\pi 3 &= D3 \cdot (p3 - c) = \frac{(p3 - c)}{2(1-a)t}\left[(1-a)^2 t - \theta(f2 - f3) - (p3 - p2)\right].
\end{aligned} \quad (9)$$

2.3. Model Solution. Under the condition of complete information, because Airport 1, Airport 2, and Airport 3 are in a competitive relationship, the three aim to maximize their own profits and solve the model, as follows:

$$\frac{\partial \pi 1}{\partial p 1}=\frac{1}{2at}\left[a^2t+\theta(f1-f2)+(p2-2p1)+c\right]=0,$$
$$\frac{\partial \pi 2}{\partial p 2}=\frac{1}{2(1-a)at}\left[a(1-a)t+a\theta(f1-f3)-\theta(f1-f2)+a(p3-p1)-(2p2-p1)+c\right]=0, \quad (10)$$
$$\frac{\partial \pi 3}{\partial p 3}=\frac{1}{2(1-a)t}\left[(1-a)^2t-\theta(f2-f3)-(2p3-p2)+c\right]=0.$$

Solving the three equations in (10), simultaneously, the equilibrium prices of the three airports are obtained as follows:

$$p^*1=\frac{1}{6}[3at+3\theta(f1-f2)+a\theta(f1-f3)+6c],$$
$$p^*2=\frac{1}{3}[3(1-a)at+a\theta(f1-f3)+3c],$$
$$p^*3=\frac{1}{6}[3(1-a)t+3\theta(f3-f2)-a\theta(f3-f1)+6c]. \quad (11)$$

The equilibrium market shares of the three airports are

$$D1^*=\frac{1}{12at}[3at+3\theta(f1-f2)+a\theta(f1-f3)],$$
$$D2^*=\frac{1}{12(1-a)t}[6(1-a)at+2a\theta(f1-f3)-3\theta(f1-f2)],$$
$$D3^*=\frac{1}{12(1-a)t}[3(1-a)t+3\theta(f3-f2)-a\theta(f3-f1)]. \quad (12)$$

The equilibrium profits of the three airports are

$$\pi1^*=\frac{1}{72at}[3at+3\theta(f1-f2)+a\theta(f1-f3)]^2,$$
$$\pi2^*=\frac{2[3(1-a)at+a\theta(f1-f3)]^2-3\theta(f1-f2)[3(1-a)at+a\theta(f1-f3)]}{36(1-a)t}, \quad (13)$$
$$\pi3^*=\frac{1}{72(1-a)t}[3(1-a)t+3\theta(f3-f2)-a\theta(f3-f1)]^2.$$

3. Hotelling Model Analysis of Airport Market Competition

The form of airport market competition is to compete for passengers to the greatest extent, and flight frequency can affect the planned delay cost of passengers and become one of the important factors for passengers to choose an airport. Therefore, the market competition between airports is largely dependent on airline flights. Therefore, this paper selects the two main factors of flight frequency and passenger travel cost to analyze the manifestations of airport market competition in multiairport areas.

3.1. Airport Equilibrium Market Share Analysis. According to the model results, it can be seen that the equilibrium market share of the airport mainly depends on the location of the airport, the travel cost of passengers θ, and the flight frequency of each airport. The equilibrium market share of the three airports is analyzed separately, as follows.

3.1.1. The Relationship between Equilibrium Market Share and Flight Frequency. Analysis of the relationship between the equilibrium market share of Airport 1 and flight frequency: the airport's equilibrium market share is proportional to its own flight frequency and inversely proportional to the flight frequency of Airport 2 and Airport 3.

Proof. Derivation of $fi\,(i=1,2,3)$ is as follows:

$$\begin{cases} \dfrac{\partial D\ 1^*}{\partial f\ 1}=\dfrac{(3+a)\theta}{12at}, \\ \dfrac{\partial D\ 1^*}{\partial f\ 2}=-\dfrac{\theta}{4at}, \\ \dfrac{\partial D\ 1^*}{\partial f\ 3}=-\dfrac{\theta}{12t}. \end{cases} \quad (14)$$

We obtain from formula (14) that the equilibrium market share of Airport 1 is proportional to its own flight frequency and inversely proportional to the flight frequency of Airport 2 and Airport 3.

If the flight frequency of Airport 1 increases, the market share of Airport 1 when it maximizes its own profit will increase; if the flight frequency of Airport 2 and Airport 3 increases, the market share of Airport 1 when it maximizes its own profit will decrease.

Analysis of the relationship between the equilibrium market share of Airport 2 and flight frequency: the airport's equilibrium market share is proportional to its own flight frequency and inversely proportional to the flight frequency of Airport 1 and Airport 3. □

Proof. Formula (12) $Si\,(i = 1, 2, 3)$ can be derived separately as follows:

$$\begin{cases} \dfrac{\partial D\ 2^*}{\partial f\ 1} = \dfrac{(2a-3)\theta}{12(1-a)t}, \\[2ex] \dfrac{\partial D\ 2^*}{\partial f\ 2} = \dfrac{3\theta}{12(1-a)t}, \\[2ex] \dfrac{\partial D\ 2^*}{\partial f\ 3} = -\dfrac{2a\theta}{12(1-a)t}. \end{cases} \tag{15}$$

We obtain from formula (15) that, due to , $0 < a < 1$then the equilibrium market share of Airport 2 is proportional to its own flight frequency and inversely proportional to the flight frequencies of Airport 1 and Airport 3.

If the flight frequency of Airport 2 increases, the market share of Airport 2 when it maximizes its own profit will increase; if the flight frequency of Airport 1 and Airport 3 increases, the market share of Airport 2 when it maximizes its own profit will decrease.

Analysis of the relationship between the equilibrium market share of Airport 3 and flight frequency: the airport's equilibrium market share is proportional to its own flight frequency and inversely proportional to the flight frequency of Airport 1 and Airport 2. □

Proof. Derivation of formula (12) $fi\,(i = 1, 2, 3)$ is as follows:

$$\begin{cases} \dfrac{\partial D\ 3^*}{\partial f\ 1} = \dfrac{a\theta}{12(1-a)t}, \\[2ex] \dfrac{\partial D\ 3^*}{\partial f\ 2} = -\dfrac{3\theta}{12(1-a)t}, \\[2ex] \dfrac{\partial D\ 3^*}{\partial f\ 3} = \dfrac{(3-a)\theta}{12(1-a)t}. \end{cases} \tag{16}$$

We obtain from formula (16) that the equilibrium market share of Airport 3 is proportional to its own flight frequency and the flight frequency of Airport 1 and is inversely proportional to the flight frequency of Airport 2.

If the flight frequency of Airport 3 itself increases, the market share of Airport 3 when it maximizes its own profit will increase; if the flight frequency of Airport 1 itself increases, the market share of Airport 3 when it maximizes its own profit will increase; if the flight frequency of Airport 2 increases, then the market share of Airport 3 when it maximizes its own profit will decrease. □

3.1.2. The Relationship between Equilibrium Market Share and Passenger Travel Costs. Analysis of the relationship between the equilibrium market share of Airport 1 and the cost of passenger travel: thanks to $\partial D\ 1^*/\partial t = -(3+a)\theta f1 - 3\theta f2 - a\theta f3/12at^2$, then at that time, $f1 < 3f2 + af3/3 + a\partial D\ 1^*/\partial t > 0$, the equilibrium market share of Airport 1 is proportional to the travel cost of passengers; at that time, $f1 > 3f2 + af3/3 + a\partial D\ 1^*/\partial t < 0$, that is, the equilibrium market share of Airport 1 is inversely proportional to the travel cost of passengers.

If $f1 < 3f2 + af3/3 + a$ and when the passenger travel cost increases, the market share of Airport 1 when it maximizes its own profit will increase; if $f1 > 3f2 + af3/3 + a$ and when the passenger travel cost increases, the market share when Airport 1 maximizes its own profit will decrease.

Analysis of the relationship between the equilibrium market share of Airport 2 and the cost of passenger travel: thanks to $\partial D\ 2^*/\partial t = -(3-2a)\theta f1 - 3\theta f2 + 2a\theta f3/12(1-a)t^2$, then at that time, $f2 < (3-2a)f1 + 2af3\ /3\partial D\ 2^*/\partial t\ > 0$, the equilibrium market share of Airport 2 is proportional to the travel cost of passengers; at that time, $f2 > (3-2a)f1 + 2af3/3\partial D\ 2^*/\partial t < 0$, that is, the equilibrium market share of Airport 2 is inversely proportional to the travel cost of passengers.

If $f2 < (3-2a)f1 + 2af3/3$ and the passenger travel cost increases, the market share of Airport 2 when it maximizes its own profit will increase; if $f2 > (3-2a)f1 + 2af3/3$ and when the passenger travel cost increases, the market share of Airport 1 when it maximizes its own profit will decrease.

Analysis of the relationship between the equilibrium market share of Airport 3 and passenger travel costs: thanks to $\partial D\ 3^*/\partial t = -a\theta f1 - 3\theta f2 + (3-a)\theta f3/12(1-a)t^2$, then at that time, $f3 < 3f2 - af1/3 - a\partial D\ 3^*/\partial t > 0$, the equilibrium market share of Airport 3 is proportional to the travel cost of passengers; at that time, $f3 > 3f2 - af1/3 - a\partial D\ 3^*/\partial t < 0$, that is, the equilibrium market share of Airport 3 is inversely proportional to the travel cost of passengers.

If $f3 < 3f2 - af1/3 - a$ and the passenger travel cost increases, the market share of Airport 3 to maximize its own profit will increase; if $f3 > 3f2 - af1/3 - a$ and the passenger travel cost increases, the market share of Airport 3 to maximize its own profit will decrease.

The specific changes in equilibrium market share and passenger travel costs are shown in Table 1.

It can be seen from Table 1 that when the flight frequency of the airport is less than the algebraic sum of the flight frequencies of the other two fields, in order to increase the equilibrium market share of the airport, it is only necessary to increase the travel cost of passengers to achieve more market share. When the flight frequency is greater than the algebraic sum of the other two flight frequencies, in order to increase the equilibrium market share of the airport, it is only necessary to reduce the travel cost of passengers to achieve more market share.

3.2. Analysis of Airport Equilibrium Profit. According to the model results, it can be seen that the equilibrium profit of the airport mainly depends on the location of the airport, the travel cost of passengers θ, and the flight frequency of each airport. The equilibrium profits of the three airports are analyzed separately, as follows.

3.2.1. The Relationship between Airport Equilibrium Profit and Flight Frequency. Analysis of the relationship between the equilibrium profit of Airport 1 and the flight frequency: thanks to $\partial\pi\ 1^*/\partial f\ 1 = (3+a)\theta[3at + 3\theta(f1-f2) + a\theta(f1-f3)]/36at$, then at that time, $f1 > 3\theta f2 + a\theta f3 - 3at/(3+a)\theta\partial\pi\ 1^*/\partial f\ 1 > 0$, the equilibrium profit of Airport 1 is proportional to the flight frequency of the airport itself; at that time, $f1 < 3\theta f2 + a\theta f3 - 3at/(3+a)\theta$ $\partial\pi\ 1^*/\partial f\ 1 < 0$, that is, the equilibrium profit of Airport 1 is inversely proportional to the flight frequency of the airport itself.

If $f1 > 3\theta f2 + a\theta f3 - 3at/(3+a)\theta$ and the flight frequency of Airport 1 increases, the equilibrium profit of Airport 1 will increase. At this time, Airport 1 can increase its own flight frequency to improve its own equilibrium profit and achieve the purpose of improving its own competitiveness; if $f1 < 3\theta f2 + a\theta f3 - 3at/(3+a)\theta$ and when the flight frequency of Airport 1 increases, the equilibrium profit of Airport 1 will decrease. At this time, Airport 1 can reduce its own flight frequency to improve its equilibrium profit and achieve the purpose of improving its own competitiveness.

Airport 2 and flight frequency: thanks to $\partial\pi\ 2^*/\partial f\ 2 = \theta[3(1-a)at + a\theta(f1-f3)]/12at$, then at that time, $f3 - f1 < 3(1-a)t/\theta\partial\pi\ 2^*/\partial f\ 2 > 0$, the equilibrium profit of Airport 2 is proportional to the flight frequency of the airport itself; at that time, $f3 - f1 > 3(1-a)t/\theta\partial\pi\ 2^*/\partial f\ 2 < 0$, that is, the equilibrium profit of Airport 2 is inversely proportional to the flight frequency of the airport itself.

If $f3 - f1 < 3(1-a)t/\theta$ and the flight frequency of Airport 2 increases, the equilibrium profit of Airport 2 will increase. At this time, Airport 2 can increase its own flight frequency to improve its own equilibrium profit and achieve the purpose of improving its own competitiveness; if $f3 - f1 > 3(1-a)t/\theta$ and when the flight frequency of 2 increases, the equilibrium profit of Airport 2 will decrease. At this time, Airport 2 can reduce its own flight frequency to increase its equilibrium profit and achieve the purpose of improving its own competitiveness.

Airport 3 and flight frequency: thanks to $\partial\pi\ 3^*/\partial f\ 3 = (3-a)\theta[3(1-a)t + 3\theta(f3-f2) - a\theta\ (f3-f1)]/36(1-a)t$, then at that time, $f3 > 3\ (1-a)t + a\theta f1 - 3\theta f2/(a-3)\theta\partial\pi\ 3^*/\partial f\ 3 > 0$, the equilibrium profit of Airport 3 is proportional to the flight frequency of the airport itself; at that time, $f3 < 3(1-a)t + a\theta f1 - 3\theta f2/(a-3)\theta\partial\pi\ 3^*/\partial f\ 3 < 0$, that is, the equilibrium profit of Airport 3 is inversely proportional to the flight frequency of the airport itself.

If $f3 > 3(1-a)t + a\theta f1 - 3\theta f2/(a-3)\theta$ and the flight frequency of Airport 3 increases, the equilibrium profit of Airport 3 will increase. At this time, Airport 3 can increase its own flight frequency to improve its own equilibrium profit and achieve the purpose of improving its own competitiveness; if $f3 < 3(1-a)t + a\theta f1 - 3\theta f2/(a-3)\theta$ and when the flight frequency of 3 increases, the equilibrium profit of Airport 3 will decrease. At this time, Airport 3 can reduce its own flight frequency to improve its equilibrium profit and achieve the purpose of improving its own competitiveness.

The specific changes of airport equilibrium profit and flight frequency are shown in Table 2.

It can be seen from Table 2 that, for the airports at both ends, when the flight frequency of its own airport is greater than the algebraic sum of the flight frequencies of the other two airports, the airport can increase the flight frequency to improve the airport's equilibrium profit; when the flight frequency of its own airport is less than the algebraic sum of the flight frequencies of the two airports, the airport can improve the equilibrium profit of the airport by reducing the flight frequency. For intermediate airports, when the difference between the airports at both ends is less than a certain constant value, the airport can increase the flight frequency to improve the airport's equilibrium profit; when the difference between the airports at both ends is greater than a certain constant value, the airport can reduce the frequency of flights to improve the equilibrium profit of the airport.

3.2.2. The Relationship between Airport Equilibrium Profit and Passenger Travel Cost. Airport 1 and the travel cost of passengers: thanks to $\partial\pi\ 1^*/\partial t = [3at + 3\theta f2 + a\theta f3 - (3+a)\theta f1] \times [3at - 3\theta f2 - a\theta f3 + (3+a)\theta f1]/72at^2$, then at that time, $3\theta f2 + a\theta f3 - 3at/(3+a)\theta < f1 < 3\theta f2 + a\theta f3 + 3at/(3+a)\theta\partial\pi\ 1^*/\partial t > 0$, the equilibrium profit of Airport 1 is proportional to the travel cost of passengers; when $f1 > 3\theta f2 + a\theta f3 + 3at/(3+a)\theta$ or $f1 < 3\theta f2 + a\theta\ f3 - 3at/(3+a)\theta$, $\partial\pi\ 1^*/\partial t < 0$, that is, the equilibrium profit of Airport 1 is inversely proportional to the travel cost of passengers.

If $3\theta f2 + a\theta f3 - 3at/(3+a)\theta < f1 < 3\theta f2 + a\theta f3 + 3at/(3+a)\theta$ and the passenger travel cost increases, the equilibrium profit of Airport 1 will increase. At this time, Airport 1 can increase its own equilibrium profit by increasing the passenger travel cost to achieve the purpose of improving its own competitiveness; if $f1 > 3\theta f2 + a\theta f3 + 3at/(3+a)\theta$ or $f1 < 3\theta f2 + a\theta f3 - 3at/(3+a)\theta$ and the passenger travel cost increases, the equilibrium profit of Airport 1 will decrease. At this time, Airport 1 can increase its own equilibrium profit by reducing the travel cost of passengers and achieve the purpose of improving its own competitiveness.

Airport 2 and the travel cost of passengers: thanks to $\partial\pi\ 2^*/\partial t = [-a\theta(f1-f3)] \times [2 - 3\theta(f1-f2)]/36(1-a)t^2$, then when $f1 > f3$, $f2 < 3\theta f1 - 2/3\theta$ or $f1 < f3$, $f2 > 3\theta f1 - 2/3\theta$, $\partial\pi\ 2^*/\partial t > 0$, that is, the equilibrium profit of Airport 2 is proportional to the travel cost of passengers; when $f1 > f3$, $f2 > 3\theta f1 - 2/3\theta$ or $f1 < f3$, $f2 < 3\theta f1 - 2/3\theta$, when $\partial\pi\ 2^*/\partial t < 0$, that is, the equilibrium profit of Airport 2 is inversely proportional to the travel cost of passengers.

TABLE 1: The relationship between equilibrium market share and passenger travel cost.

$f1 < 3f2 + af3/3 + a$, $\partial D\ 1^*/\partial t > 0$	$f2 < (3-2a)f1 + 2af3/3$, $\partial D\ 2^*/\partial t > 0$	$f3 < 3f2 - af1/3 - a$, $\partial D\ 3^*/\partial t > 0$
$f1 > 3f2 + af3/3 + a$, $\partial D\ 1^*/\partial t < 0$	$f2 > (3-2a)f1 + 2af3/3$, $\partial D\ 2^*/\partial t < 0$	$f3 > 3f2 - af1/3 - a$, $\partial D\ 3^*/\partial t < 0$

TABLE 2: The relationship between airport equilibrium profit and flight frequency.

$f1 > 3\theta f2 + a\theta f3 - 3at/(3+a)\theta$, $\partial \pi\ 1^*/\partial f\ 1 > 0$;	$f3 - f1 < 3(1-a)t/\theta$, $\partial \pi\ 2^*/\partial f\ 2 > 0$;	$f3 > 3(1-a)t + a\theta f1 - 3\theta f2/(a-3)\theta$, $\partial \pi\ 3^*/\partial f\ 3 > 0$;
$f1 < 3\theta f2 + a\theta f3 - 3at/(3+a)\theta$, $\partial \pi\ 1^*/\partial f\ 1 < 0$	$f3 - f1 > 3(1-a)t/\theta$, $\partial \pi\ 2^*/\partial f\ 2 < 0$	$f3 < 3(1-a)t + a\theta f1 - 3\theta f2/(a-3)\theta$, $\partial \pi\ 3^*/\partial f\ 3 < 0$

If $f1 > f3$, $f2 < 3\theta f1 - 2/3\theta$, or $f1 < f3$, $f2 > 3\theta f1 - 2/3\theta$, and when the travel cost of passengers increases, the equilibrium profit of Airport 2 will increase. At this time, Airport 2 can increase its own equilibrium profit by increasing the travel cost of passengers to achieve the purpose of improving its own competitiveness; if $f1 > f3$, $f2 > 3\theta f1 - 2/3\theta$, or $f1 < f3$, $f2 < 3\theta f1 - 2/3\theta$, and when the travel cost of passengers increases, the equilibrium profit of Airport 2 will decrease. At this time, Airport 2 can improve its own equilibrium profit by reducing the travel cost of passengers and achieve the purpose of improving its own competitiveness.

Airport 3 and the travel cost of passengers: thanks to $\partial \pi\ 3^*/\partial t = [3(1-a)t + 3\theta f2 - a\theta f1 - (3-a)\theta f1] \times [3(1-a)t - 3\theta f2 + a\theta f1 + (3-a)\theta f1]/72\ (1-a)t^2$, then at that time, $3\theta f2 - a\theta f1 - 3(1-a)t/(3-a)\theta < f3 < 3\theta f2 - a\theta f1 + 3(1-a)t/(3-a)\theta \partial \pi\ 3^*/\partial t > 0$, the equilibrium profit of Airport 3 is proportional to the travel cost of passengers; when $f3 > 3\theta f2 - a\theta f1 + 3(1-a)t/(3-a)\theta$ or $f3 < 3\theta f2 - a\theta f1 - 3(1-a)t/(3-a)\theta$, $\partial \pi\ 3^*/\partial t < 0$, that is, the equilibrium profit of Airport 3 is inversely proportional to the travel cost of passengers.

If $3\theta f2 - a\theta f1 - 3(1-a)t/(3-a)\theta < f3 < 3\theta f2 - a\theta f1 + 3(1-a)t/(3-a)\theta$ and when the travel cost of passengers increases, the equilibrium profit of Airport 3 will increase. At this time, Airport 3 can increase its own equilibrium profit by increasing the travel cost of passengers to achieve the purpose of improving its own competitiveness; if $f3 > 3\theta f2 - a\theta f1 + 3(1-a)t/(3-a)\theta$ or $f3 < 3\theta f2 - a\theta f1 - 3(1-a)t/(3-a)\theta$ and the travel cost of passengers increases, the equilibrium profit of Airport 3 will decrease. At this time, Airport 3 can increase its own equilibrium profit by reducing the travel cost of passengers, so as to achieve the purpose of improving its own competitiveness.

The specific changes of airport equilibrium profit and passenger travel cost are shown in Table 3.

For the airports at both ends, when the flight frequency of its own airport is within a certain range, the airport can increase its own equilibrium profit by increasing the travel cost of passengers; when the flight frequency of its own airport is outside a certain range, the airport can reduce passengers travel costs to increase its own equilibrium profit. For intermediate airports, the equilibrium profit is related to the frequency of flights at all three airports.

4. Empirical Analysis

Based on the analysis results of the competitiveness evaluation of 16 airports in the Yangtze River Delta region, this paper selects Nanjing Lukou Airport and Hangzhou Xiaoshan Airport with similar levels of competitiveness, as well as the distance between the two airports and the level of competitiveness. The passenger throughput, cargo and mail throughput, and aircraft take-offs and landings in the article are all from the statistics on the official website of the Civil Aviation Administration. The airport's outbound flights come from the Feichang Zhun big data platform. The statistics of the outbound flights are from three airports in Chongqing, respectively. Example is monthly flight operation data verification at Jiangbei Airport in July 2019. The passenger throughput, cargo and mail throughput, number of aircraft take-offs and landings, and the number of outbound flights of the three airports are shown in Table 4.

According to the information, the three airports belong to the Yangtze River Delta region. Sunan Shuofang Airport is located between Nanjing Lukou Airport and Hangzhou Xiaoshan Airport. Wuxi is about 200 km away from Hangzhou, and about 1.5 hours by high-speed rail. Wuxi is about 174 km away from Nanjing, and about 0.8 hours by high-speed rail. The road traffic system between the three airport cities is perfect, the urban traffic in the urban area is perfect, and the passengers flow among them, and the market competition is severe.

The article makes Hangzhou Xiaoshan Airport the left end airport, that is, $(0, 0)$, $a = 0.5347$. Nanjing Lukou Airport is the right end $(1, 0)$ airport $(a, 0)$; according to the existing data, the travel cost of passengers is 0.46 yuan per kilometer, which can be known $t = 172$; if the order is $T = 4$, there is $\theta = 1$; the flight frequency of the airport refers to the number of flights that provide travel services for passengers at the airport. This article refers to the number of flights in which the airport provides travel services for passengers, so the article selects the number of outbound flights from each airport as the flight frequency of each airport.

Table 5 can be obtained by representing the data as in Table 1.

From the analysis of Table 5, it can be seen that, at present $f1 = 520 > 188$, the equilibrium market share of Hangzhou Xiaoshan Airport is inversely proportional to the travel cost of passengers. At this time, if the airport wants to

Table 3: The relationship between airport equilibrium profit and passenger travel cost.

$3\theta f2 + a\theta f3 - 3at/(3+a)\theta < f1 < 3\theta f2 + a\theta f3 + 3at/(3+a)\theta$, $\partial\pi\ 1^*/\partial t > 0$; $f1 > 3\theta f2 + a\theta f3 + 3at/(3+a)\theta$ or $f1 < 3\theta f2 + a\theta f3 - 3at/(3+a)\theta$, $\partial\pi\ 1^*/\partial t < 0$
$f1 > f3$, $f2 < 3\theta f1 - 2/3\theta$ or $f1 < f3$, $f2 > 3\theta f1 - 2/3\theta$, $\partial\pi\ 2^*/\partial t > 0$; $f1 > f3$, $f2 > 3\theta f1 - 2/3\theta$ or $f1 < f3$, $f2 < 3\theta f1 - 2/3\theta$, $\partial\pi\ 2^*/\partial t < 0$
$3\theta f2 - a\theta f1 - 3(1-a)t/(3-a)\theta < f3 < 3\theta f2 - a\theta f1 + 3(1-a)t/(3-a)\theta$, $\partial\pi\ 3^*/\partial t > 0$; $f3 > 3\theta f2 - a\theta f1 + 3(1-a)t/(3-a)\theta$ or $f3 < 3\theta f2 - a\theta f1 - 3(1-a)t/(3-a)\theta$, $\partial\pi\ 3^*/\partial t < 0$

Table 4: The details of each indicator of the three airports in July 2019.

	Passenger throughput (person-time)	Cargo throughput (tons)	Aircraft take-off and landing (sorting)	Number of outbound flights (flights)
Hangzhou Xiaoshan Airport	3536434	53321.8	25252	520
Sunan Shuofang Airport	714051	12027	5545	149
Nanjing Lukou Airport	2795043	30241.3	21192	406

Table 5: The relationship between equilibrium market share and passenger travel costs.

$f1 < 188$, $\partial D\ 1^*/\partial t > 0$; $f1 > 188$, $\partial D\ 1^*/\partial t < 0$	$f2 < 479$, $\partial D\ 2^*/\partial t > 0$; $f2 > 479$, $\partial D\ 2^*/\partial t < 0$	$f3 < 69$, $\partial D\ 3^*/\partial t > 0$; $f3 > 69$, $\partial D\ 3^*/\partial t < 0$

Table 6: The relationship between equilibrium profit and airport flight frequency.

$f1 > 110$, $\partial\pi\ 1^*/\partial f\ 1 > 0$; $f1 < 110$, $\partial\pi\ 1^*/\partial f\ 1 < 0$	$f3 - f1 < 240$, $\partial\pi\ 2^*/\partial f\ 2 > 0$; $f3 - f1 > 240$, $\partial\pi\ 2^*/\partial f\ 2 < 0$	$f3 > -29$, $\partial\pi\ 3^*/\partial f\ 3 > 0$; $f3 < -29$, $\partial\pi\ 3^*/\partial f\ 3 < 0$ (rounding)

increase its equilibrium market share, it only needs to reduce the travel cost of passengers, $f2 = 149 < 479$. The equilibrium market share of the airport is directly proportional to the travel cost of passengers. At this time, if the airport wants to increase its equilibrium market share, it only needs to increase the travel cost of passengers, $f3 = 406 > 69$. At this time, the equilibrium market share of Nanjing Lukou Airport is inversely proportional to the travel cost of passengers. At this time, if the airport wants to increase its equilibrium market share, it only needs to reduce the travel cost of passengers.

Substitute the data into Table 2 to get Table 6.

From the analysis of Table 6, it can be seen that, at present, the $f1 = 520 > 110$ equilibrium profit of Hangzhou Xiaoshan Airport is directly proportional to the flight frequency. At this time, if the airport wants to improve its equilibrium profit, it only needs to increase the flight frequency of the $f3 - f1 = -114 < 240$ airport. Equilibrium profit is proportional to flight frequency. At this time, if the airport wants to improve its equilibrium profit, it only needs to increase the airport's flight frequency, $f3 = 406 > -29$. At this time, the equilibrium profit of Nanjing Lukou Airport is proportional to the flight frequency. At this time, the airport wants to improve its own the equilibrium profit, simply by increasing the frequency of flights at the airport.

In the process of market competition, flight frequency and market share show an S-curve relationship [12], and the specific relationship is shown in Figure 2.

Substitute the data into Table 3 to get Table 7.

From the analysis of Table 7, it can be obtained that since $f1 = 520 > 266$ the equilibrium profit of Hangzhou Xiaoshan Airport is inversely proportional to the travel cost of passengers at this time, if the airport wants to improve its equilibrium profit, it only needs to reduce the travel cost of passengers, $f1 > f3$, $f2 = 149 < 519$. The equilibrium profit of Nanjing Lukou Airport is proportional to the travel cost of passengers. At this time, if the airport wants to improve its equilibrium profit, it only needs to increase the travel cost of passengers, $f3 = 406 > 166$. At this time, the equilibrium profit of Nanjing Lukou Airport is inversely proportional to the travel cost of passengers. To improve your own equilibrium profit, you only need to reduce the travel cost of passengers.

The status of the three airports is shown in Table 8.

As can be seen from Table 8, as far as the existing airports are concerned, if Hangzhou Xiaoshan Airport and Nanjing Lukou Airport want to increase their own balanced market share and balanced profit, they only need to reduce the travel cost of passengers and increase the flight frequency of the airport. The current operating scale of the airport is not comparable to that of Hangzhou Xiaoshan Airport and Nanjing Lukou Airport. If you want to increase your own balanced market share and balanced profit and increase the cost of passenger travel, this goal can be achieved, but excessive regulation of the travel cost of passengers will reduce the possibility of passengers traveling at Sunan Shuofang Airport. Therefore, a small increase in passenger travel costs and increased flight frequency can improve its own balanced market share and balanced profit.

Table 7: The relationship between equilibrium profit and passenger travel cost.

$110 < f1 < 266, \frac{\partial \pi 1^*}{\partial t} > 0;\ f1 > 266$ or $f1 < 110, \frac{\partial \pi 1^*}{\partial t} < 0$
$f1 > f3,\ f2 < 519$ or $f1 < f3,\ f2 > 519, \frac{\partial \pi 2^*}{\partial t} > 0$
$f1 > f3,\ f2 < 519$ or $f1 < f3,\ f2 > 519, \frac{\partial \pi 2^*}{\partial t} > 0$
$-29 < f3 < 166, \partial \pi 3^*/\partial t > 0;\ f3 > 166$ or $f3 < -29$ (rounding), $\frac{\partial \pi 3^*}{\partial t} < 0$

Table 8: Status table of the three airports.

	Hangzhou Xiaoshan Airport	Sunan Shuofang Airport	Nanjing Lukou Airport
$\partial D/\partial t$	—	+	—
$\partial \pi/\partial t$	—	+	—
$\partial \pi/\partial f$	+	+	+

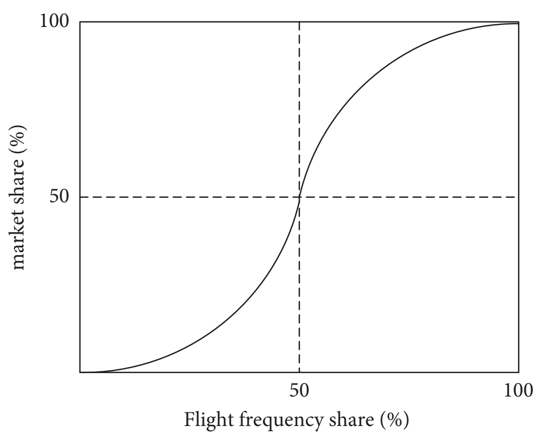

Figure 2: S-Curve diagram.

5. Conclusion

This paper uses the Hotelling model to analyze the market competition game relationship between airports in multiple airport areas, takes Hangzhou Xiaoshan Airport, Nanjing Lukou Airport, and Sunan Shuofang Airport as examples for empirical analysis, and draws the following conclusions. (1) The changes of the airport's equilibrium market share, equilibrium profit, and passenger travel cost vary with the change of the airport's flight frequency. Generally speaking, when the flight frequency is small, the equilibrium market share and the equilibrium profit are proportional to the passenger travel cost. At this time, the market share and profit can be increased by increasing the passenger travel cost; when the flight frequency is relatively large, the equilibrium market share and equilibrium profits are inversely proportional to passenger travel costs, and market share and profits can be increased by reducing passenger travel costs. (2) The change of equilibrium profit and flight frequency is as follows: for the airports at both ends, when the flight frequency is small, the equilibrium profit is inversely proportional to the flight frequency, and the equilibrium profit can be increased by reducing the flight frequency. When it is larger, the equilibrium profit is proportional to the flight frequency. At this time, the equilibrium profit can be increased by increasing the flight frequency; the difference between the flight frequencies of the two airports affects the equilibrium profit of the middle airport. (3) Taking the Yangtze River Delta Regional Airport as an example, it is found that, by increasing the flight frequency or reducing the travel cost of passengers, the balanced profit and market share of Hangzhou Xiaoshan Airport and Nanjing Lukou Airport can be improved; by increasing the flight frequency, the balanced profit and market share of Sunan Shuofang Airport can be improved.

Data Availability

The dataset can be accessed upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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