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Research Article

Competition between High-Speed Rail and Airline Based on Game Theory

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The coexistence of high-speed rail (HSR) and airline in a busy transportation corridor generates competition between the two transportation modes. An unfair competition between HSR and airline not only reduces both revenues, but also triggers a series of social problems. Based on generalized costs, this paper proposes combining an improved gray prediction model, modified gravity model, and Logit model to predict the average passenger flow, induced passenger flow, and transfer passenger flow. According to the predicted results, we establish a game model that considers different stages of the HSR development. For demonstrative purposes, the approach is applied to an empirical study in China, that is, the competition between Beijing-Shenyang HSR and airline. Malignant fare war will make both parties lose out. Either mode that improves service quality will generate more revenue. If both parties improve the level of service, all incomes of the HSR, airline, and community increase. Results show the HSR contribution is greater than the airline in the case study.

1. Introduction

As an expanding mode of intercity passenger transportation, high-speed rail (HSR) has been selected as the travel mode by more and more travelers due to its convenient, fast, and safe features. In 1957, Japan proposed a construction plan of HSR and built the first HSR in the world, which opened the door of a new era for the world's HSR. Then France, Germany, UK, and other developed countries entered the era of HSR and constructed national or cross-border HSR lines that improved the national infrastructure and promoted the overall economic development. In the literature [1, 2], many scholars were devoted to assessing the direct and other indirect effects of HSR.

The emergence of HSR will inevitably have an adverse impact on other modes of transportation. Plenty of studies focus on the competition between HSR and other modes. For example, the study that involved competition between rail and road transportation was first proposed by Eade and Hardy [3], drawing the conclusion that if the railway pursued to become more competitive, it must change its inherent physical properties by comparing their economic characteristics and physical structure. The relative impact of HSR was considered to be more significant in smaller cities than large metropolitan areas because of the shorter travel time [4]. From the environmental perspective, private cars depended on the supply of energy and the environmental cost was uncompetitive compared with HSR [5]. In addition, many studies explored the relationship between HSR and other transportation modes [6–10].

With many similar advantages (e.g., safety, punctuality, speed, convenience), HSR has greatly impacted on the aviation market. Up to 2013, the total number of civil aviation airports in China reached 206 and the total number of civil aviation airports will reach 244 by 2020 [11]. A number of regional airports are designed in the affected area of HSR. In response to the competition of HSR, airline adopts the strategy of discount fare to attract travelers, while the low-fare strategy makes the revenue of the HSR line decline. With a continuous progress of HSR mileage, the competition would be more intense between HSR and aviation [12, 13]. How to balance competition has been a hot research topic [14–19]. HSR is more popular in a small city because of the short travel time, where the airline's service is not available nor dominant. When the travel time is within 2–4 hours, the market share of HSR would be increasing rapidly.

Many methods and models have also been proposed to analyze the competition, for example, stated preference techniques [20], static traffic assignment methods [21], traffic equilibrium models [22, 23], and the optimal location of transportation facilities [24, 25]. The integrated intercity travel demand model developed by Yao and Morikawa [17] was used to estimate induced intercity travel demand; the result showed that HSR could reduce travel cost and travel time and improve service. The mode choice model was established to analyze the potential competition of the HSR with the air transportation [26]. The route choice model played a crucial role in many transportation related areas [27]. However, these methods cannot effectively solve the competitive situation between the HSR and other modes of transportation especially aviation. The emergence of game theory brings a new perspective in this research field.

Game theory is a mathematical method to study the phenomenon with competitive properties. The epochal masterpiece "Game Theory and Economic Behavior" produced by Von Neumann and Morgenstern [28] had been systematically applied in the economic field. Since then, game theory entered a rapid development period and many classic literatures had been published [29–31]. The two-stage Nash best-response game model was built to calculate the largest airline revenue based on passenger allocation conditions. Since then, game theory had been widely used to decide all aspects of competition between HSR and aviation, including pricing strategy [32], choice of hubs [33–35], coalition [36], service frequency [37], plane size [38, 39], and stop location [37]. Game theory was first applied to China's transportation problems by Li et al. [40], establishing a game model based on the global transportation problem. Hsu et al. [41] developed Taiwan HSR fare optimization strategies by solving the Nash equilibrium model. Many studies were also committed to using a variety of methods to study the competitive relationship between HSR and airline, for example, Logit model [42], analytic hierarchy process [43], and information entropy theory [44].

Although, in the competition field of HSR and aviation, many models and theories have been proposed and established, these theories are mainly from the operator's perspective and the purpose is to achieve a maximum benefit. In this paper, we use game theory to study competition between HSR and aviation on the basis of previous experiences. The game between airline and HSR is divided into two stages. In the first stage of the game, when HSR initially participates in the competition, we establish a revenue model to achieve the goal of maximizing their own benefits of HSR and aviation. In the second stage of the game, when the HSR market is mature and the government begins to intervene in the game between HSR and airline, it has the goal to achieve the maximum social revenue.

This paper is organized as follows: Section 2 proposes a two-stage game model. Section 3 describes the data used in the model and presents the results. Section 4 draws conclusions and outlooks the future research.

2. Methodology

2.1. Game Process. In this section, a new game model of HSR and airline will be established. China Railway Corporation is state-owned enterprise managed by the central government of China. HSR operators consider both the HSR profit and consumer benefit. We divide the game model into two stages: (i) game between the two companies, which are all profit maximizers; (ii) game under the government policy; that is, the HSR operator maximizes both profit and social welfare, and airlines maximize profit and meanwhile consider the social welfare in order to obtain more benefits.

Travelers will choose the transportation mode with fewer costs. As the main game participants, HSR and airline adjust fair to attract more passengers in order to maximize revenue. The competitive process between HSR and airline is a multistage game; the game process is shown in Figure 1.

2.2. Model Construction. A new game model is proposed based on maximizing benefit between HSR and airline, and the principle assumptions of the model are as follows:

(i) Under a competitive condition in the market, both HSR and airline can be free to pricing in a certain limit.

(ii) The total supply of HSR and airline is greater than the travel demand, which is influenced by the fare.

(iii) Different routes of HSR and airline do not affect each other.

(iv) Ignore the heterogeneity of passengers, such as gender, age, and income.

(1) The First Game Stage. When HSR is in operation, set the fare P_h^0 according to the initial airline fare P_a^0 and its revenue model. Airline has two alternatives, that is, accept or reject. If accept, the market share of airline is $1 - T_h^0$ when the market share of HSR is T_h^0. Otherwise, airline modifies the fare to P_a^1. HSR may accept or reject. If accept, the market share is $1 - T_a^1$ when the airline market share is T_a^1. After a few times of game, the equilibrium fare (P_h^*, P_a^*) and the equilibrium market share $(T_h^*, 1 - T_h^*)$ can be reached. HSR and airline revenue models are as follows.

(i) HSR Revenue Model

$$\begin{aligned}\pi_h^k &= P_h^k Q_h^k - C_h^k \\ &= P_h^k \times \left(Q^{k-1} + \Delta Q^k\right) \times T_h^k \\ &\quad - \left[A_h + \left(Q^{k-1} + \Delta Q^k\right) \times T_h^k \times B_h\right],\end{aligned} \tag{1}$$

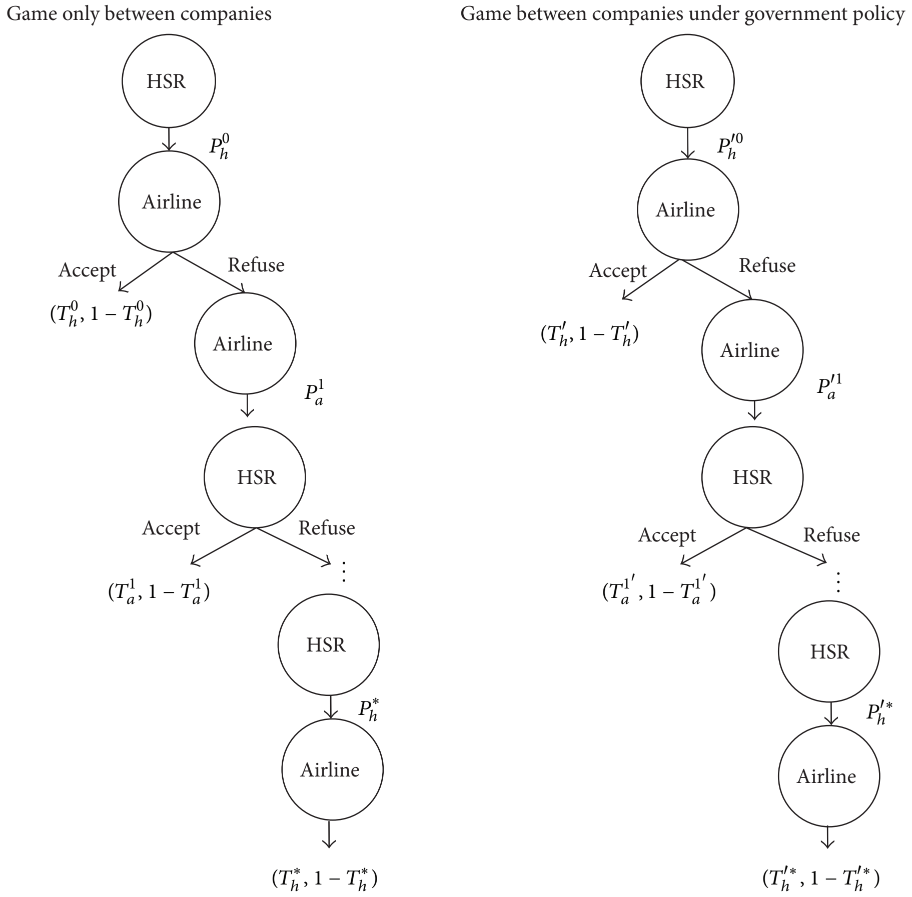

Figure 1: Game process between HSR and airline.

where π_h^k is HSR revenue after k times of game; P_h^k is HSR price after k times of game; Q_h^k is HSR passenger volume after k times of game; Q^{k-1} is total passenger volume of various transportation modes of $k-1$ times of game; ΔQ^k is total induced passenger volume of various transportation modes of k times of game; C_h^k is total HSR passenger cost after k times of game; T_h^k is HSR share rate after k times of game; A_h is total HSR passenger fixed cost; B_h is HSR passenger unit variable cost.

(ii) Airline Revenue Model

$$\begin{aligned}\pi_a^k &= P_a^k Q_a^k - C_a^k \\ &= P_a^k \times \left(Q^{k-1} + \Delta Q^k\right) \times T_a^k \\ &\quad - \left[A_a + \left(Q^{k-1} + \Delta Q^k\right) \times T_a^k \times B_a\right],\end{aligned} \tag{2}$$

where π_a^k is airline revenue after k times of game; P_a^k is airline price after k times of game; Q_a^k is airline passenger volume of k times of game; Q^{k-1} is airline passenger volume after $k-1$ times of game; C_a^k is total airline passenger cost after k times of game; T_a^k is airline share rate after k times of game; A_a is total airline passenger fixed cost; B_a is airline passenger unit variable cost.

(2) The Second Game Stage. In the second stage, the game process is similar with the first stage, but the objectives are modified. HSR operators consider not only the profit but also the social welfare, and airlines also consider consumer benefits because of the government policy. Objectives are represented as follows:

$$\begin{aligned}U^k &= U_h^k + U_a^k = \left(\pi_h^k + u_h^k\right) + \left(\pi_a^k + u_a^k\right), \\ u_h^k &= \left(Q^{k-1} + \Delta Q^k\right) \times T_h^k \times \left(V_{\max}^k - V_h^k\right), \\ u_a^k &= \left(Q^{k-1} + \Delta Q^k\right) \times T_a^k \times \left(V_{\max}^k - V_a^k\right), \\ U_h^k &= P_h^k \times \left(Q^{k-1} + \Delta Q^k\right) \times T_h^k \\ &\quad - \left(A_h + \left(Q^{k-1} + \Delta Q^k\right) \times T_h^k \times B_h\right) \\ &\quad + \left(Q^{k-1} + \Delta Q^k\right) \times T_h^k \times \left(V_{\max}^k - V_h^k\right), \\ U_a^k &= P_a^k \times \left(Q^{k-1} + \Delta Q^k\right) \times T_a^k \\ &\quad - \left(A_a + \left(Q^{k-1} + \Delta Q^k\right) \times T_a^k \times B_a\right) \\ &\quad + \left(Q^{k-1} + \Delta Q^k\right) \times T_a^k \times \left(V_{\max}^k - V_a^k\right),\end{aligned} \tag{3}$$

where U^k is total social benefit after k times of game; u_h^k is HSR additional benefits after k times of game; u_a^k is airline additional benefits after k times of game; U_h^k is HSR contribution value for social benefit after k times of game; $V_{\max}^k$ is total generalized cost of various transportation mode after k times of game; V_h^k is HSR generalized cost after k times of game; V_a^k is airline generalized cost after k times of game.

2.3. Passenger Flow Forecasting Model. The passenger demand in our study consists of three parts: the trend of passenger demand, induced passenger demand, and transfer passenger demand. The trend passenger demand refers to the demand which increases naturally without HSR due to the population growth, economic development, land use changes, improved quality of life, and so forth. The induced passenger demand represents the potential passenger demand induced by the development of the HSR network. The transfer passenger demand is the redistribution of passengers in the transportation systems. Passengers transfer not only from one transportation mode to another mode, but also from a route to another in the same mode. The generalized cost is a foundation to calculate the induced passenger demand and transfer passenger demand.

(i) Generalized Cost. The definition of the generalized cost that takes into account the trip economy, trip time, convenience, comfort, and safety is given by

$$V_j(n) = \frac{\left(\theta_1 E_j + \theta_2 F_j + \theta_3 C_j + \theta_4 M_j\right)}{S_j} + \varepsilon_j, \tag{4}$$

where $V_j(n)$ represents generalized cost of taking travel mode j $(m + 1 \geq j \geq 1)$ in year n. E_j represents the trip price. F_j represents the trip time which is the sum of operating time, waiting time, pick-up time, and drop-off time. C_j represents the trip convenience, which includes transit time and booking time. M_j represents comfort which is measured with recovery time from fatigue situation. S_j is the safety degree which is often measured with the accident rate. ε_j is the corresponding constant. θ_1, θ_2, θ_3, and θ_4 are service characteristic parameters.

(ii) Trend Passenger Volume. To predict the trend passenger volume, this paper proposes an improved gray Gompertz model [45]. According to the basis of the sequence, we use the gray Gompertz model to predict data which is added to the base sequence as new data, excluding the old data in the original columns, and get new foundation columns. Once again, we use the gray Gompertz model to predict. Repeat the above steps until the desired time data have been predicted, as explained in the following steps.

Step 1. Calculate the average daily passenger volume of each year, given by

$$Q(t) = \sum_{i=1}^{m} \frac{Q_i(t)}{365} \quad (t = 1, 2, \ldots, l), \tag{5}$$

where $Q_i(t)$ is passenger volume of transportation mode i in year t and $Q(t)$ is average daily passenger volume of all the transportation modes in year t.

The initial sequence is obtained; that is,

$$Q = \{Q(1), Q(2), \ldots, Q(l)\}. \tag{6}$$

Step 2. Obtain the logarithm of the initial sequence and incremental process

$$\begin{gathered} Q^{(0)}(t) = \ln[Q(t)], \\ Q^{(1)} = \left\{Q^{(1)}(1), Q^{(1)}(2), \ldots, Q^{(1)}(l)\right\}, \end{gathered} \tag{7}$$

where $(Q^{(1)}(t) = \sum_{k=1}^{t} Q^{(0)}(k)\ (t = 1, 2, \ldots, l))$.

Step 3. Obtain the least-square solution by calculating p_2, p_3, and p_4. Use $p_2 = -e^a$ to calculate a; then get b and c though $Q^{(0)}(t) = be^{-at} + c$.

$$\begin{gathered} \begin{bmatrix} Q^{(1)}(2) + Q^{(1)}(3) & 2 & 1 \\ Q^{(1)}(3) + Q^{(1)}(4) & 3 & 1 \\ M & M & M \\ Q^{(1)}(l-1) + Q^{(1)}(l) & l-1 & 1 \end{bmatrix} \begin{bmatrix} p_2 \\ p_3 \\ p_4 \end{bmatrix} \\ = \begin{bmatrix} Q^{(0)}(2) \\ Q^{(0)}(3) \\ M \\ Q^{(0)}(l-1) \end{bmatrix} - 2 \begin{bmatrix} Q^{(1)}(2) \\ Q^{(1)}(3) \\ M \\ Q^{(1)}(l-1) \end{bmatrix}. \end{gathered} \tag{8}$$

Step 4. $Q(t)$ is obtained according to the Gompertz reduction model

$$Q(t) = e^{be^{-at}+c}. \tag{9}$$

Step 5. Add the prediction data in one year to the basic data, instead of the first annual data; the new initial sequence is formed as

$$Q' = \{Q(2), Q(3), \ldots, Q(l+1)\}. \tag{10}$$

According to Steps 2–5, the average daily passenger of year $l + 2$ can be predicted, which will be added to the base sequence, and get new foundation columns. Repeat Steps 1–5 until the desired year data have been predicted.

(iii) Induced Passenger Volume. The induced passenger volume is that the improvement of traffic conditions and reduction of travel costs attract new traffic passenger volume. In this paper, we measure the induced passenger volume base on the gravity model.

In year n, we assume the generalized cost of transportation mode i is $V_i^{\prime 0}(n)$ without HSR and generalized cost of transportation mode j is $V_j^0(n)$ with HSR. $\Delta Q^0(n)$ represents the average daily induced passenger volume after HSR's operation. $Q^0(n)$ represents the average daily total passenger volume after HSR's operation. $Q^{0'}(n)$ represents the average daily total passenger volume before HSR operation. Then the induced passenger volume due to HSR's operation can be calculated by

$$\begin{aligned}\Delta Q^{0}(n) &= Q^{0}(n) - Q^{0'}(n) \\ &= K \times \frac{[SE(n)]^{\alpha}}{\left[\sum_{j=1}^{m+1} V_i^{0}(n)/(m+1)\right]^{\beta}} - K \\ &\quad \times \frac{[SE(n)]^{\alpha}}{\left[\sum_{i=1}^{m} V_i^{0'}(n)/m\right]^{\beta}} \\ &= K \times \frac{[SE(n)]^{\alpha}}{\left[\sum_{i=1}^{m} V_i^{0'}(n)/m\right]^{\beta}} \\ &\quad \times \left[\left(\frac{\sum_{i=1}^{m} V_i^{0'}(n)}{\sum_{j=1}^{m+1} V_i^{0}(n)} \times \frac{m+1}{m}\right)^{\beta} - 1\right] \\ &= Q^{0'}(n) \\ &\quad \times \left[\left(\frac{\sum_{i=1}^{m} V_i^{0'}(n)}{\sum_{j=1}^{m+1} V_i^{0}(n)} \times \frac{m+1}{m}\right)^{\beta} - 1\right].\end{aligned} \tag{11}$$

Through the game between HSR and airline, both service levels are improved, and generalized costs decrease. Assume the generalized costs of transportation j is $V_j^{k-1}(n)$ in time $k-1$ and $V_j^{k}(n)$ in time k, respectively. $Q^{k-1}(n)$ represents the average daily total passenger volume in the $(k-1)$th stage of the game. $Q^{k}(n)$ represents the value of the kth stage of the game; then the induced passenger volume $\Delta Q^{k}(n)$ due to the increased service level is calculated by

$$\begin{aligned}\Delta Q^{k}(n) &= Q^{k}(n) - Q^{k-1}(n) \\ &= K \times \frac{[SE(n)]^{\alpha}}{\left[\sum_{j=1}^{m+1} V_j^{k}(n)/(m+1)\right]^{\beta}} - K \\ &\quad \times \frac{[SE(n)]^{\alpha}}{\left[\sum_{j=1}^{m+1} V_i^{k-1}(n)/(m+1)\right]^{\beta}} \\ &= K \times \frac{[SE(n)]^{\alpha}}{\left[\sum_{j=1}^{m+1} V_j^{k-1}(n)/m\right]^{\beta}} \\ &\quad \times \left[\left(\frac{\sum_{j=1}^{m+1} V_j^{k-1}(n)}{\sum_{j=1}^{m+1} V_j^{k}(n)}\right)^{\beta} - 1\right] \\ &= Q^{k-1}(n) \times \left[\left(\frac{\sum_{j=1}^{m+1} V_j^{k-1}(n)}{\sum_{j=1}^{m+1} V_i^{k}(n)}\right)^{\beta} - 1\right].\end{aligned} \tag{12}$$

The total induced passenger volume is the sum of the following two parts:

$$Q(n) = \Delta Q^{0}(n) + \Delta Q^{k}(n). \tag{13}$$

(iv) Transfer Passenger Volume. The transfer passenger volume is the result of changes in the internal transportation system. The generalized cost is a major factor that affects travelers to choose travel mode. The Logit model is used to predict the transfer passenger volume.

$$Q_j^{k+1}(n) = \left[Q^{k}(n) + \Delta Q^{k+1}(n)\right] \times T_j^{k+1}(n), \tag{14}$$

where $Q_j^{k+1}(n)$ is average daily transfer passenger volume of transportation mode j in the $(k+1)$th stage game after decreasing the generalized cost; $Q^{k}(n)$ is average daily total passenger volume in the kth stage game after decreasing the generalized cost; $T_j^{k+1}(n)$ is share rates of transportation mode j in the $(k+1)$th stage game, which is calculated by

$$\begin{aligned}T_j(n) &= \frac{\exp\left(-V_j(n)/\overline{V}(n)\right)}{\sum_{j=1}^{m+1}\exp\left(-V_j(n)/\overline{V}(n)\right)}, \\ \overline{V}(n) &= \sum_{j=1}^{m+1}\frac{V_j(n)}{(m+1)},\end{aligned} \tag{15}$$

where $T_j(n)$ is transportation sharing rate of taking transportation mode j in year n; $V_j(n)$ is the generalized cost of taking transportation mode j in year n; $\overline{V}(n)$ is the average generalized cost in year n.

2.4. Passenger Costs Model

(i) HSR Passenger Costs. HSR passenger costs include six components: wages, power, materials, depreciation, capital costs, and other expenses. HSR passenger costs can also be separated into two parts: variable costs and fixed costs. Variable costs refer to the costs that will change when passenger volume changes, including HSR line investment costs, train purchase costs, and maintenance costs. Fixed costs refer to the costs of maintenance, including energy costs, wages, and other costs.

$$C_h^{k} = A_h + Q_h^{k}B_h, \tag{16}$$

where C_h^{k} is total HSR passenger costs of the kth time game; A_h is total HSR passenger fixed costs; B_h is HSR passenger unit variable cost; Q_h^{k} is HSR passenger volume of the kth time game.

(ii) Airline Passenger Costs. Civil aviation passenger costs can be divided into two parts: operation costs and expenses for the study period. Operation costs include various expanses occurring in the production process, including indirect operation costs and direct operation costs. Similar to HSR, airline passenger costs can be divided into two parts: variable costs and fixed costs. Variable costs consist of airline infrastructure costs, land use costs, aircraft purchase costs, and aircraft maintenance costs. Fixed costs include energy costs, wages, and other costs.

$$C_a^{k} = A_a + Q_a^{k}B_a, \tag{17}$$

where C_a^k is total airline passenger costs of the kth time game; A_a is total airline passenger fixed cost; B_a is airline passenger unit variable cost; Q_a^k is airline passenger volume of the kth time game.

3. Data and Case Study

Beijing, the capital of China, is the national center of politics, culture, science, and education. Shenyang, the capital of Liaoning province, is a regional center of economic circles in Northeast Asia and the region surrounding Bohai Sea. The communications between the two large cities are quite frequent, triggering high travel demands in this corridor. The game between HSR and airline is a typical case to study the competition.

Beijing-Shenyang HSR is a key construction project in the China's HSR planning. The design speed is 350 km/h, and the operation speed is 300 km/h. After its completion of the Beijing-Shenyang HSR, the travel time will be only two hours from Beijing to Shenyang. It will greatly promote the regional economy of Northeastern China.

The origin of the Beijing-Shenyang airline is the Capital International Airport, and the endpoint is Taoxian Airport. There are about 20 flights per day. The flight distance from Beijing to Shenyang is about 610 km; the flight time is about 1 hour 30 minutes, so the average travel speed is about 407 km/h. The full air fare is about 700 RMB, but there are discount deals. Currently, there are three airlines in operation, that is, China International Airlines, China Eastern Airlines, and China Southern Airlines.

Firstly, the costs of HSR and airline are calculated; then the generalized costs of multimodal transportation are calculated (e.g., HSR, airline, road traffic, and railway). Secondly, we forecast the passenger demand that includes the trend passenger demand, induced passenger demand, and transfer passenger demand, which are foundation of the game between HSR and airline. Equilibrium results of the first stage game between Beijing-Shenyang HSR and airline are shown in Table 1.

Table 1: The first-stage game equilibrium results.

Item	HSR	Airline
Fare (RMB)	420	584 (including fuel costs)
Fare rate (RMB/km)	0.60	0.82
Daily passenger volume	11,433	5,072
Revenue (RMB)	2,572,600	1,075,303

Note: exchange rate: US $1 = 6.22 RMB.

Table 1 indicates that, after the opening of Beijing-Shenyang HSR, the competition between HSR and airline will become more intense. When the equilibrium is reached, the HSR fare is about 420 RMB, the fare rate is about 0.6 RMB/km, the passenger volume will reach 11,433 (about 69% of the total passenger volume of both HSR and airline), and the HSR daily revenue will reach 2,572,600 RMB. The air fare is about 584 RMB, including the airport construction fee (50 RMB) and fuel surcharge (30 RMB). The fare rate is about 0.82 RMB/km, the passenger volume will reach 5,072 (31% of the total passenger volume), and the airline daily revenue will reach 1,075,303 RMB.

Equilibrium results of the second stage game are shown in Table 2.

Table 2: The second-stage game equilibrium results.

Item	HSR	Airline
Fare (RMB)	386	562 (including fuel costs)
Fare rate (RMB/km)	0.55	0.79
Daily passenger volume	12,315	5,665
Revenue (RMB)	2,352,165	1,076,350
Passenger revenue (RMB)	463,854	
Government revenue (RMB)	3,873,369	

Table 2 shows that when the Beijing-Shenyang HSR is mature, government will intervene in the competition between HSR and airline. When the game reaches equilibrium again, the HSR fare is about 386 RMB, the fare rate is about 0.55 RMB/km, the daily passenger volume will reach 12,315 (68% of the total passenger volume), and the HSR daily revenue will reach 2,352,165 RMB. The Beijing-Shenyang airline fare is about 562 RMB. The fare rate is about 0.79 RMB/km, the daily passenger volume will reach 5,665 (32% of the total passenger volume), and the airline daily revenue will reach 1,076,350 RMB. The daily revenue will reach 463,854 RMB and the government daily revenue will reach 3,873,369 RMB.

When the competition between HSR and airline in the second stage reaches equilibrium, they will implement some new measures to attract passengers, for example, increasing train frequency and reducing station checking links in order to improve the speed and convenience. The change of the total time and convenience brings the exaltation of passenger volume and revenue, as shown in Table 3.

Table 3 indicates equilibrium results of the second stage game for different scenarios. When the total time of airline remains consistent, if the total time of HSR reduces 0.5 hours, its passenger volume will increase. Both passenger daily revenue and government daily revenue will increase. When the total time of HSR remains stable, if the total time of airline reduces 0.5 h, its passenger volume will increase. Either passenger daily revenue or the government daily revenue will reduce. When both the total time of HSR and airline decrease 0.5 h, the passenger volume of both HSR and airline will increase, as well as the passenger and government daily revenue.

When the second stage competition game reaches equilibrium, HSR will improve passenger service such as comfort to gain a larger market share. This paper uses passenger fatigue recovery time to represent comfort and calculates the change of passenger volume and revenue with comfort. Table 4 shows the sensitivity of comfort. All scenarios of equilibrium are compared. When the fatigue recovery time of airline does not change, if the recovery time of HSR decreases 0.5 h, the passenger volume of HSR will increase

Table 3: Sensitivity of passenger volume and revenue with respect to the total time.

Total time (h)		Passenger volume		Revenue (RMB)	
HSR	Airline	HSR	Airline	Passenger	Government
4.1	4.3	12,315	5,665	463,850	3,892,365
3.6	4.3	13,929	4,827	705,720	4,283,289
4.1	3.8	11,739	7,076	289,550	3,876,139
3.6	3.8	13,397	6,514	504,610	4,301,097

Note: exchange rate: US $1 = 6.22 RMB.

Table 4: Sensitivity of passenger volume and revenue with respect to comfort.

Fatigue recovery time (h)		Passenger volume		Revenue (RMB)	
HSR	Airline	HSR	Airline	Passenger	Government
0.81	0.53	12,315	5,665	463,850	3,892,365
0.31	0.53	13,410	5,136	598,970	4,136,120
0.81	0.20	11,813	6,739	397,690	3,934,383
0.31	0.20	13,041	6,146	530,320	4,188,891

and the passenger volume of airline will decline. Both of the passenger daily revenue and government daily revenue will increase. When the recovery time of HSR does not change, if that of airline decreases 0.33 h, the passenger volume of HSR will reduce and the passenger volume of airline will increase. Passenger daily revenue will reduce and government daily revenue will increase. When both the recovery time of HSR and airline are reduced, the passenger volume of HSR and airline will all increase. Passenger daily revenue and government daily revenue will all increase, too.

4. Conclusions

With the development of HSR, the competition between HSR and airline cannot be ignored, because HSR and aviation have similar characteristics, such as convenience, high speed, and safety. How to balance the competition between them is vital to both the academic community and industry.

(i) This paper applies game theory to study the competition between HSR and aviation. The game model is established based on the different development stages of HSR. The game between airline and HSR is divided into two stages. In the first stage of the game, we establish a linear model to achieve the goal of maximum social welfare and make the decision on each cost and tax standard. The second stage is the game between each carrier based on the maximized profit, adjusting one's marketing strategy by anticipating competitors' marketing strategies. The strategy is to evaluate the combination including fare, service frequency, and the number of seats. Heuristic algorithms can be used to solve the optimization.

(ii) In the case study, when the competition reaches equilibrium, either in the first stage or in the second stage, HSR fare is lower than airline fare and HSR passenger travel demand is more than airline passenger travel demand.

(iii) In the first stage, although HSR passenger demand is more than the airline's, HSR revenue is less than the airline's.

(iv) In the second stage game between Beijing-Shenyang HSR and Beijing-Shenyang airline, when it reaches equilibrium, the two transportation modes can also improve their speeds and convenience to increase the passenger revenue and social revenue. The government can appropriately raise HSR and airline frequencies, by reducing checking links and improving the convenience, finally the social revenue will be improved. It proves that the game model of HSR and airline is rational and effective to increase total revenue including HSR, airline, passenger, and social welfare in China.

Besides, this article still has some limitations. In the case study, the flight distance from Beijing to Shenyang is about 610 km, which is a middle-distance case. In China, the nonoperation time of each trip for HSR and civil aviation is about 1.5 h and 2.5 h, respectively. The average operation speed of HSR is about 300 km/h, while the average speed of civil aviation is about 500 km/h. If the travel distance reaches 1,500 km, the total travel time for passengers of HSR and civil aviation is estimated to be 6.5 h and 5.5 h, respectively. Travel monetary costs of both modes are comparable. So when the travel distance is over 1,500 km, civil aviation has a competitive advantage in the competition with HSR. The conditions of night and vacation travels have not been considered. People traveling at night require more comfortable environment. People traveling in holidays pay more attention to fare. What is more, the established model has not been applied in practice because the HSR is still under construction.

Disclosure

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Competing Interests

The authors declare that they have no competing interests.

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