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Price comparison of high-speed rail and civil aviation based on efficiency price

Junya Liu[1,a,*], Ziyu Guo[2,b], Mingfang Hu[2,c,*]

[1]*School of Economics, China-ASEAN Institute of Financial Cooperation, Guangxi University, Nanning, China*
[2]*Guangxi Vocational and Technical College of Communications, Nanning, China*
[a]*591361227@qq.com*, [b]*Gziyu163@163.com*, [c]*475795460@qq.com*
[*]*Corresponding author*

Abstract: *As the economy develops, transportation also experiences significant changes. High-speed rail started late but has developed rapidly, which has also affected civil aviation. This paper compares the second-class seat of high-speed rail with the economy class of civil aviation, and first-class seat of high-speed rail and first-class cabin of civil aviation; uses the dimensionless method to calculate the efficiency–price ratio according to the performance index; and analyzes the competition between high-speed rail and civil aviation, as well as the rationality of their respective pricing. Lastly, this study presents opinions and suggestions for future pricing.*

Keywords: *efficiency price, high-speed rail, civil aviation, pricing*

1. Introduction

With the rapid development of the economy, increasingly faster pace of life, and world population growth, people’s requirements for transportation are also increasing and competition in transportation is becoming fierce. According to the different countries’ respective economic strengths, scientific and technological advantages, population distribution, and other specific national conditions, these countries have focused on different means of transport based on the actual needs of their citizens. At present, China’s high-speed railway is developing rapidly, and the construction of new airports has also started a new era of cooperation and competition.

High-speed railways and civil aviation are modern modes of transport and play a key role in facilitating people's travel and promoting the exchange and development of China's economy. They compete with each other in the market but use their respective strengths to handle millions of passenger trips. Although China's high-speed railway started late, it has developed rapidly, which has also affected civil aviation. To deal with the competition of high-speed railways, civil aviation uses discounted-fare air travel to attract passengers, resulting in the continuous low passenger occupancy rate of some high-speed rail lines and serious operating losses. Since the opening of the Beijing–Shanghai high-speed railway on June 30, 2011, civil aviation routes along the railway have been substantially affected. The Beijing–Shanghai route experienced slow growth after 2011. In particular, 2011 to 2014 was the period with the slowest growth. Although growth has increased since 2015, the actual growth rate was lower than the average growth rate of the aviation market.

The preceding discussion indicates that price can reflect the advantages and disadvantages of resource allocation. Moreover, research on the performance comparison of different seats of high-speed railway and civil aviation can evaluate whether or not the current resource allocation in China is ideal and reasonable. Transport prices play an important role in the competition between different modes of transportation. In China, current high-speed railways and civil aviation have their respective independent pricing systems. Without regard to the differences in their costs and services, they cannot form a reasonable price relationship. This paper attempts to explore the efficiency–price relationship between high-speed railway and civil aviation from the perspectives of fare cost and efficiency level, and judge the rationality of the existing price relationship. The research results can promote the reasonable development of high-speed railway and maximize its advantages, and also have significance in improving the overall efficiency of the transportation system and optimizing the transportation structure layout.

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2. Literature review

This paper will review the previous literature from three levels. The first level is on the general relevant layer for setting efficiency price. It involves research on the basic situation of transportation and price setting. The second level is on the further relevant level, including research on the relationship between competition and mutual influence on transportation products. The third level is on the closely related level and involves research on the efficiency and price comparison of different transportation modes. The three incremental levels facilitate the process, and this paper generalizes from the current research results.

In "Theory of the Properties of Transportation Products," Ou Guoli (2004)[1] takes transportation product as the research object. He makes an in-depth analysis of its six inherent characteristics, which fills in the gap in previous research on transportation products and their properties. Li Xiaopeng (2011) [2]analyzes the basic situation of competition between China's civil aviation and high-speed rail in "The Enlightenment of European Air-Rail Intermodal Transport Mode to China's Civil Aviation." He states that "civil aviation is facing severe challenges." Thereafter, he analyzes the European air–rail multimodal transportation. He concludes that the construction of comprehensive transportation system is inevitable, construction needs should be considered from the national strategy, and that civil aviation plays an active role in the construction. Ma Chongyan (2014) [3]uses theory of high-speed railway transportation cost in "Research on the Cost of High-speed Railway Transportation." He adopts the activity-based costing method and identifies the influencing factors of transportation cost. He measures and analyzes the cost of the Beijing–Shenzhen high-speed railway and proposes measures to manage transportation costs. In "Experience of High-speed Rail Fare Adjustment in Developed Countries and Its Enlightenment to China," Yu Xinyu et al. (2017) [4]analyze the high-speed rail fare adjustment in Japan, France, Germany, and other developed countries. They conclude that stronger laws and regulations, stricter hearing system, clearer supervision mechanism, dynamic adjustment strategies, and various preferential measures of fare are needed for fare adjustment in China.

In comparing the different transportation modes, Dai Lingling (2009) [5]analyzes the economic characteristics of different modes of transportation and the domestic macro environment in "Research on the Competitive Relationship between High-speed Railway and Other Modes of Transportation." He takes the Beijing–Shanghai line as an example and concludes that the most competitive price of high-speed rail is 0.4 yuan per person and kilometer. Thereafter, he analyzes the factors affecting people's travel patterns and studies the competitiveness of high-speed rail by using the LOGIT model. In "Game engineering as tool for cost-benefit analysis," Nicole Adler, Eric Pels, and Chris Nash (2010) [6]establish a game model of high-speed railway against civil aviation based on the passenger flow equilibrium model of high-speed railway operators, traditional civil aviation companies, and low-cost civil aviation companies. They also select different parameters, such as fares, operating frequency, transportation capacity, and environmental costs, to construct the efficiency functions of high-speed railway operators, civil aviation companies, and the government.

Lastly, this paper reviews the efficiency price research of different transportation modes. In "A study on the relationship between fares of urban rail transit and conventional public transport," Chen Shuhong (2007) [7]uses labor value, equilibrium price, and transportation value theories. She uses the price parity model as basis in analyzing the principle of formulating reasonable fare parity and level of public transport fare parity. Moreover, she designs the fare parity process. In "Research on the Price Comparison between China's High-speed Railway and Other Modes of Transportation," Hao Yi (2010) [8]uses market structure and transportation structure theories and adopts the model method of the transportation price relationship to study the price relationship between domestic and foreign transportation modes. She starts with the competitive environment of the market and determines the problems in China's current price comparison. Taking the Beijing–Shanghai line as an example, she gives a reasonable price comparison range and provides short- and long-term suggestions.

3. Empirical research

3.1 Research steps

High-speed rail and civil aviation have different efficiency price ratios owing to differences in external performance factors, such as speed, safety, and comfort,see Figure 1 for details.Owing to their different prices, passengers will also choose the suitable way according to their income. This paper analyzes performance indicators, such as safety, comfort, convenience, and quickness, and carries out dimensionless processing thereafter. We obtain the efficiency value after weighted average by means of expert scoring and weight assignment under the analytic hierarchy process (AHP) [9].

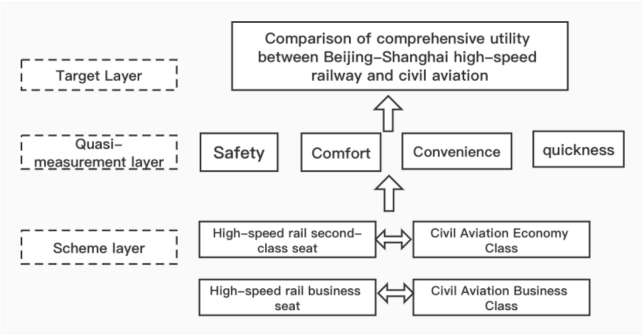

Figure 1: Efficiency comparison model under AHP

3.2 Data processing

This paper selects data of the Beijing–Shanghai high-speed rail line in 2020, which involves safety, comfort, convenience, and quickness.

(1) Safety, for traffic safety, this paper selects serious and major accident and death rates.(See Table 1 for details).

Table 1 Indicator data on Safety

Transportation	High-speed rail	Civil aviation
Accident rate (per 10 thousand people)	0.32 %	0.057%
Death rate (per 10 thousand people)	0.29 %	0.031 %

Data sources: “2020 Railway Statistical Bulletin”

(2)Comfort is determined by seat size per capita, punctuality, travel time, and passenger satisfaction[10].(See Table 2 for details).

Table 2 Indicator data on Comfort

Transportation	High-speed rail business seat	Civil aviation business class	High-speed rail second-class seat	Civil aviation economy class
Area	3.6720	1.9319	0.4095	0.5151
Passenger satisfaction	0.9	0.88	0.8	0.7
Travel time	4.5	2.25	4.5	2.25

Data sources: Beijing Railway Bureau, VariFlight Statistical Data, Wang Xiaoxuan. Research on public satisfaction evaluation and service optimization of high-speed rail services [D], "2020 Civil Aviation Industry Development Statistical Bulletin"

(3)Convenience is reflected in the density of departures or flights and passenger capacity.(See Table 3 for details).

Table 3 Indicator data on Convenience

Transportation	High-speed rail	Civil aviation
Departures and flight density	101	112
Passenger capacity	2277.4	1200

Source of data: “Beijing–Shanghai high-speed railway research report: Passenger business performance is gradually being restored, and the flexibility of price increases is gradually emerging.”

(4)Quickness lies in the travel time and punctuality of the journey[11].(See Table 4 for details).

Table 4 Indicator data on Quickness

Transportation	High-speed rail	civil aviation
Average driving speed	350 km/h	850 km/h
Punctuality	98.8%	76.74%

Data source: Feichangzhun, 12306App

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3.3 Dimensionless processing of model indicators

First, we divide efficiency into different levels.(See Table 5 for details).

Table 5 Efficiency in different levels

Efficiency levels	First level	Second level	Third level	Fourth level	Fifth level
Value range	0.8–1	0.6–0.8	0.4–0.6	0.2–0.4	0.0–0.2

Second, we can obtain the transport quality index.(See Table 6 for details).

Table 6 Transport quality index

Projects	Accident-rate(%)	Death rate(%)	Area	Passenger satisfaction	Travel time	Departures and flight density	Passenger capacity	Average driving speed	Punctuality
High-speed-rail business seat	0.32	0.29	3.67	0.9	4.5	101	2277.4	35	98.8%
Civil-aviation business class	0.057	0.03	1.93	0.88	2.25	112	1200	85	76.74%
High-speed rail-second-class seat	0.32	0.29	0.41	0.8	4.5	101	2277.4	35	98.8%
Civil-aviation economy-class	0.057	0.03	0.52	0.7	2.25	112	1200	85	76.74%

Third, we set the index data to form the following matrix: $x=(x_{ij})=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{np} \end{bmatrix}$

That is, we set the quantity of transportation modes and parameters as n and p, respectively, and use the following formula:

$$z_{ij}=\frac{x_{ij}-x_j}{s_j}\quad (i=1,2...n;j=1,2...p),\text{in}\quad x_j=n^{-1}\sum_{i=1}^{n}x_{ij},\quad s_j=\left[n^{-1}\sum_{i=1}^{n}\left(x_{ij}-x_j\right)^2\right]^{-\frac{1}{2}}.$$

The following normalized matrix can be obtained:

$$z=\left(z_{ij}\right)=\begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1p} \\ z_{21} & z_{22} & \cdots & z_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ z_{n1} & z_{n2} & \cdots & z_{np} \end{bmatrix}.$$

We calculate the correlation coefficient between each two indicators after standardization and obtain the correlation coefficient matrix R[12]: $R=(n-1)^{-1}z'z$.

We calculate the eigenvalues of the correlation coefficient matrix R and the corresponding eigenvectors. The P characteristic roots obtained from the equation are arranged from small to large. It is obtained by the equation corresponding to $|KE-R|=0$ $\lambda_1 \ge \lambda_2 \ge \lambda_3 ... \ge \lambda_p \ge 0$ $(KE-R)x=0$

The eigenvectors of the p eigenvalues are, where is the unit eigenvector corresponding to the eigenvalues . $T=\left(t_1,t_2...,t_p\right)^T$ t_i λ

Thereafter, principal component scores are calculated. To ensure that the information contained in the original data of z is extracted by the new principal component, the principle of extracting the principal component is considered the cumulative contribution rate of 90 %. Set as the extracted its principal component score, Y_i is as follows:

$$Y_i=z\times t_i=\begin{bmatrix} z_{11}t_{1i}+z_{12}t_{2i}+...+z_{1p}t_{pi} \\ z_{21}t_{1i}+z_{22}t_{2i}+...+z_{2p}t_{pi} \\ \cdots \\ z_{n1}t_{1i}+z_{n2}t_{2i}+...+z_{np}t_{pi} \end{bmatrix}.$$

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Lastly, the comprehensive score value of each component can be calculated. Taking the information contribution rate of each principal component as weight, the weighted summation of the extracted scores of each principal component is used to obtain the comprehensive score value of each component.

3.4 Obtaining the final result

According to the principal component analysis method, we will assign weights of 0.2 for safety, 0.05 for comfort, 0.45 for convenience, and 0.3 for convenience according to the scores of relevant experts [13].(See Table 7 for details).

Table 7 The final result

	Safety		Comfort			Convenience		Quickness		score
	0.20		0.05			0.45		0.3		
High-speed rail business seat	1.32	2.35	-290196.92	-612.17	-5.12083E-07	-680.82	-0.42	0.0073	415.29	-14721.6893
Civil aviation business class	0.19	0.35	290196.92	612.17	-7.66836E-07	680.82	0.42	0.0037	-415.29	14722.53534
High-speed rail second-class seat	-0.79	-1.41	-290196.92	-612.17	4.8575E-06	-680.82	-0.42	-0.003	-7626.25	-17135.33041
Civil aviation economy class	-0.72	-1.29	290196.92	612.17	3.51306E-06	680.82	0.42	-0.013	-8456.83	12309.55714

3.5 Analysis of results

We can determine that the price–efficiency ratio of civil aviation business class and high-speed rail business seat is 1.00005747, and the efficiency ratio of civil aviation economy class and high-speed rail second-class seat is 0.718372908. That is, the efficiency price of civil aviation to high-speed rail equals 0.7684 to 1.0001. This result shows that under the current situation, efficiency prices of high-speed rail and civil aviation business seats are similar, but the efficiency price of civil aviation economy class is not as high as that of high-speed rail second-class seats.

According to software such as 12306, we know that the prices of high-speed rail business seat is 2,318 yuan, second-class high-speed rail seat is 626 yuan, civil aviation business class is about 4,170 yuan, and civil aviation economy class is about 1,394 yuan. Pricing of civil aviation to the price of high-speed rail equals 1.7990 to 2.2268. Compared with cost pricing, real pricing is deviated, and pricing of second-class high-speed rail seats is relatively low, and the price of business seats is high.

We use hierarchical efficiency price comparison to calculate efficiency prices. This method eliminates the problems that will arise in cost data and selects some exogenous variables. We know that the efficiency–price ratio of civil aviation to high-speed rail equals 0.7684 to 1.0001. Compared with real price, efficiency price of second-class seat is appropriately increased, and the price of business seat is appropriately reduced. Efficiency prices consider the technical and operational characteristics of the two transportation modes, and coordinate the competition between external effects and the two transportation modes.

4. Recommendations

According to the preceding conclusions, considering the application of the range of parity relationship, we consider future developments from short- and long-term perspectives.

(1) In the near term, enhancing intermodal transport with high-speed rail can be achieved by tailoring road networks in various cities based on national guidelines and local needs. This approach can boost connectivity, convenience, and accessibility, leading to more city-to-city train services and reduced travel times, thus enhancing high-speed rail's appeal.Mid-term strategies should consider easing price restrictions on high-speed rail, adopting a semi-market pricing mechanism to align fares with efficiency and market demands. While state subsidies make high-speed rail affordable, semi-market adjustments can balance affordability with profitability and operational efficiency, ultimately serving the public interest by optimizing market welfare.

(2) For long-term planning, China should implement a macro-control system for high-speed rail fares, ensuring rational and standardized pricing adjustments based on a fair price parity relationship.

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By optimizing resource allocation, China can foster the coordinated and efficient development of various transport modes, with high-speed rail becoming a key player. Different transport modes should leverage their efficiency and pricing to highlight their advantages, steering the high-speed rail sector towards a balanced and sustainable fare structure. For instance, high-speed rail could set reasonable fares for varying distances to align with its developmental goals. For short distances, traditional trains could remain the primary option, while high-speed rail could command higher fares for medium distances due to its central role. For long-distance travel, where air travel is more prevalent, high-speed rail could adjust prices downwards to stimulate demand, thus aiding the growth of China's transport industry. The current situation suggests that China's high-speed rail has a low efficiency-to-price ratio, with a singular model lacking market-oriented adjustments to technological advancements and customer needs. This not only burdens the government but also fails to optimize efficiency, leading to an inefficient use of resources and a loss of social welfare. Therefore, establishing a reasonable high-speed rail pricing strategy is crucial for the sustainable development and overall improvement of China's transportation network.

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