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*Research Article*

# A Study on High-Speed Rail Pricing Strategy in the Context of Modes Competition

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High-speed rail (HSR) has developed rapidly in China over the recent years, for the less pollution, faster speed, comfort, and safety. However, there is still an issue on how to improve the seat occupancy rates for some HSR lines. This research analyzes the pricing strategy for HSR in Wuhan-Guangzhou corridor based on the competition among different transport modes with the aim of improving occupancy rates. It starts with the theoretical analysis of relationship between market share and ticket fare, and then disaggregate choice models with nested structure based on stated preference (SP) data are established to obtain the market share of HSR under specific ticket fare. Finally, a pricing strategy is proposed to improve the occupancy rates for Wuhan-Guangzhou HSR. The results confirm that a pricing strategy with floating fare should be accepted to improve the profit of HSR; to be specific, the ticket fare should be set in lower level on weekdays and higher level on holidays.

## 1. Introduction

High-speed rail (HSR) is currently regarded as one of the most significant technological breakthroughs in passenger transport developed in the second half of the 20th century [1]. Due to the advantages of rapidness, comfort, convenience, safety, and reliability [2], China has witnessed rapid development of HSR over the past years. However, its performance in operation is still restricted by the pricing strategy under the intense competition among various transport modes. The traditional fixed pricing strategy gives up the induced passenger flow generated by fares change [3] and the high pricing of HSR leads to low occupancy rates and resources waste. For example, statistics shows that the average occupancy rates of Wuhan-Guangzhou HSR can be as low as 20% except for the spring festival which is not satisfactory as expected. The lower the occupancy rate is, the less the profit is. Therefore reasonable pricing strategy should be researched to solve the pricing problems for HSR.

In order to solve the problem of pricing strategy, a number of recent researchers have been devoted to studying reasonable methodology for passenger transport pricing. Li and Tayur [4] and Labbé et al. [5] applied the Bilevel programming to the optimal pricing. Zeng et al. [6] put forward a new thought of combining the value of travel time and Bilevel programming to maximize the benefit of the railway agencies and the passengers' utility. Hsu et al. [7] and Adler et al. [8], based on game theory, analyzed the competition between two modes of transport and get optimal pricing in order to maximize the profits of operator. Zhou et al. [9] studied the pricing model for parallel rail lines under the situation of diversified property rights through considering the main influencing factors of the rail network pricing, including cost and supply.

Though extensive researches have been undertaken to search for optimal passenger transport pricing, few researchers have been devoted to studying the relationship between ticket fare and market share of transport mode. However, the demand (market share) for certain mode changes along with passenger pricing policy [10]; that is, certain mode price variation will affect the market share while market share variation will affect ticket fare in case of maximizing

Table 1: Mode split in the sample for different income levels.

| | Sample size | | | | | The ratio of income level (%) |
|---|---|---|---|---|---|---|
| | HSR | Conventional rail | Air | Road | Total | |
| Low-income group (lower than 30,000 CNY) | 529 | 207 | 275 | 11 | **1022** | 33.20 |
| Middle-income group (between 30,000 CNY and 100,000 CNY) | 710 | 204 | 507 | 10 | **1431** | 46.49 |
| High-income group (higher than 100,000 CNY) | 279 | 56 | 287 | 3 | **625** | 20.31 |

operators' profits. Therefore, ticket fare and market share cannot be separated from each other.

This paper analyzes a pricing strategy for high speed rail (HSR) based on the quantitative relationship between ticket fare and market share. The rest of this paper is organized as follows. In the second section, nested choice models for different income levels are established. The model parameters are estimated and individual preferences are analyzed in the third section. The fourth section studies the quantitative relationship between market share and ticket fare, and then a pricing strategy aimed to improve the occupancy rates of HSR is proposed. The conclusions are given in the fifth section.

## 2. Nested Choice Model

Disaggregate choice analyses, based on SP (stated preference), RP (revealed preference), or mixed data, are usually advocated by researchers as a proper methodology to assess and compare the preferences of travelers in the context of model competition [11]. To analyze the market share of HSR, disaggregate choice models based on the SP information provided by the survey are estimated for this study.

*2.1. The Data.* A questionnaire survey in Wuhan-Guangzhou corridor was conducted to obtain stated preference (SP) data for the model estimation. Questionnaires were distributed to public transport users in railway station, airport, and so on. The SP data was obtained by presenting 9 profiles, in which the attributes of HSR such as travel time and travel cost were varied. And the attributes of current alternatives were left unchanged. In each profile, respondents were asked to make a choice from the given alternatives: HSR, conventional rail, air, and road transport. Besides, personal information was also asked for in the SP survey such as age, profession, trip purpose, and income.

A total of 3078 valid observations were obtained from the questionnaire survey. Considering that the sensitivities to multiple attributes are different under various income levels, the obtained data can be divided into three datasets according to annual income: low-income group, middle-income group, and high-income group. And three models with different datasets are established, respectively. The distribution of income levels and the mode split in the sample are described in Table 1.

From the available information in the sample, HSR has an absolute advantage in attracting passengers and the new alternative will capture passenger flow from existing modes.

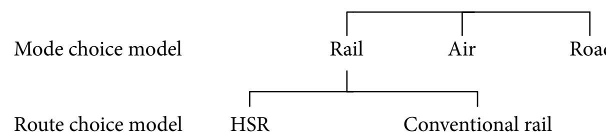


Figure 1: Structure of nested mode/route choice model.

*2.2. Model Formulation.* Multinomial logit (MNL) model is the traditional and popular tool used among logit models. However, MNL model exhibits the independence from irrelevant alternative (IIA) property so that it fails to account for the existence of similarities among choice alternatives [12]. The nested logit (NL) model overcomes the problem by grouping alternatives into nests, and interdependence between the pairs of alternatives is allowed in the same layer to satisfy the IIA property [13–15]. A nested choice model is considered and the model structure is shown in Figure 1. The travel modes considered in this study are rail, air, and road. The rail mode is divided into two alternatives: HSR and conventional rail.

Disaggregate choice model has theoretical basis on the assumption of utility maximization. The probability that individual $n$ chooses alternative $i$ is given by

$$\begin{aligned} P_{in} &= P\left(U_{in} > U_{jn},\ i \neq j\right) \\ &= P\left(V_{in} + \varepsilon_{in} > V_{jn} + \varepsilon_{jn},\ i \neq j\right), \end{aligned} \tag{1}$$

where $U_{in}$ is the utility of alternative $i$ for individual $n$; $V_{in}$ is the deterministic term in the utility function of alternative $i$ for individual $n$; $\varepsilon_{in}$ presents the random term.

When the random terms obey the distribution of Gumble, the probability that individual $n$ chooses an alternative is shown from (2) to (4). The probability of mode $m$ being chosen can be calculated by (2). The conditional probability of choosing route $r$ given that mode $m$ is chosen can be described by (3). Furthermore, (4) gives the probability that a route $r$ is chosen. Consider the following:

$$P_n(m) = \frac{e^{\lambda(V_{mn}+V^*_{mn})}}{\sum_{m'=1}^{M_n} e^{\lambda(V_{m'n}+V^*_{m'n})}}, \tag{2}$$

$$P_n(r \mid m) = \frac{e^{(V_{r|m})_n}}{\sum_{r'=1}^{R_{mn}} e^{(V_{r'|m})_n}}, \tag{3}$$

$$P_n(rm) = P_n(r \mid m)\, P_n(m), \tag{4}$$

Table 2: Dummy variables used in the utility function.

| | HSR | Conventional rail | Air | Road |
|---|---|---|---|---|
| Age | | | | |
| Over forty | 1 | 0 | 0 | 0 |
| Other | 0 | 0 | 0 | 0 |
| Profession | | | | |
| Civil servants or managers | 1 | 0 | 1 | 0 |
| Workers | 0 | 1 | 0 | 0 |
| Other | 0 | 0 | 0 | 0 |
| Trip purpose | | | | |
| Business purpose | 1 | 0 | 1 | 0 |
| Other | 0 | 0 | 0 | 0 |

where $\lambda$ is the scale parameter; $M_n$ are the set of modes that exist in mode $m$; $R_{mn}$ are the set of alternatives that exist in route $r$; $V_{(r|m)_n}$ is the fixed term in the utility function that varies with the combination of $m$ and $rm$; $V_{mn}$ is the fixed term in the utility function that has nothing to do with $r$ and only varies with $m$; $V^*_{mn}$ is the utility composited based on the fixed term of $rm$. And the composed utility can be described in

$$V^*_{mn} = \ln \sum_{r=1}^{R_{mn}} \exp\left(V_{(r|m)_n}\right). \quad (5)$$

For each of the utility functions in the three models, we take account for some attributes such as travel time, travel cost, profession, age, and trip purpose. As for the service attributes of transport modes (i.e., travel time and travel cost), the same parameter is applied to travel time of HSR and air and the same parameter is used to travel cost of HSR and air too. Given the airport location, a terminal time is taken into account in the utility of air transport. To take advantage of other attributes, it is essential to express the attributes as concrete numbers when used in the utility function. Through analyzing individual preferences of the sample, it is assumed that passengers over forty and those traveling for business purpose have a general preference for HSR and passengers with a variety of professions show different preferences for certain mode. For example, civil servants and managers prefer to choose HSR or air for travelling. On the contrary, workers are more willing to choose conventional rail. The dummy variables used in the utility function are shown in Table 2.

## 3. Estimation Results

With various influence factors considered in the utility function, maximum likelihood estimations for different income groups are presented in Tables 3, 4, and 5. Some conclusions can be summarized by analyzing and comparing the results in different tables.

(1) The facts that all absolute $t$-values are greater than 1.96 indicate that, for all coefficients, we can reject the null hypothesis that the true value is zero at the 0.05 significance level. Meanwhile, the likelihood ratio indexes for all models are over 0.2 which can be regarded as satisfactory goodness of fit.

(2) For all models, parameters of travel time and travel cost have a negative impact on the utility function. This is consistent with common sense that passengers try their best to reduce travel time and cost when traveling. Besides, parameters of travel time keep increasing from Table 3 to Table 5, which shows that passengers become more sensitive to the variation of travel time as the income level rises.

(3) From the estimation results of all models, the parameters of profession, age, and trip purpose have a positive impact on the utility function. It means that HSR is very attractive for passengers traveling for business purpose as well as those in old age. Civil servants and managers show a general preference for HSR and air. On the contrary, workers prefer to choose conventional rail for travelling.

(4) As for the value of travel time (VOTT) of HSR, represented by the single ratio between travel time and travel cost, it appears that the VOTT keeps increasing as the income level varies. The results indicate that high-income passengers are willing to pay more money in exchange for the decrease of travel time when they choose HSR for travelling.

## 4. High-Speed Rail Pricing

In this section, a pricing strategy with the aim of improving occupancy rates for Wuhan-Guangzhou HSR is discussed. Firstly, the quantitative relationship between ticket fare and market share of HSR can be obtained based on the dataset calculated through calibrated NL models, and then the pricing strategy is presented through considering the different passenger flow between weekdays and holidays.

*4.1. The Relationship between Market Share and Ticket Fare.* Based on the NL models with parameters calibrated, the HSR market share under specific fare can be calculated by (6). And it is composed of the market share of low-income group, middle-income group, and high-income group (i.e., $P^1_{\text{hsr}}$, $P^2_{\text{hsr}}$, and $P^3_{\text{hsr}}$). And the market shares of different income groups can be obtained respectively from the following:

$$P_{\text{hsr}} = \frac{1}{i}\sum_{i=1}^{3}\theta_i P^i_{\text{hsr}}, \quad (6)$$

$$P^1_{\text{hsr}} = \frac{1}{n}\sum_{n=1}^{K} P_n^{\text{low}'}, \quad (7)$$

$$P^2_{\text{hsr}} = \frac{1}{n}\sum_{n=1}^{K} P_n^{\text{mid}'}, \quad (8)$$

$$P^3_{\text{hsr}} = \frac{1}{n}\sum_{n=1}^{K} P_n^{\text{high}'}, \quad (9)$$

Table 3: Estimations of low-income group ($t$-statistics are in parentheses).

| | HSR | Conventional rail | Air | Road |
|---|---|---|---|---|
| Constant | | | 2.0170 (5.326) | |
| Travel time (h) | −0.4972 (−6.105) | −0.3671 (−2.684) | −0.4972 (−6.105) | −0.3671 (−2.684) |
| Travel cost (CNY/100) | −0.8435 (−6.431) | −0.9741 (−2.055) | −0.8435 (−6.431) | −0.9741 (−2.055) |
| Profession | 0.6348 (2.489) | 0.6348 (2.489) | 0.6348 (2.489) | |
| Age | 0.4877 (3.664) | | | |
| Logsum | | 1.5026 (5.763) | | |
| $\rho^2$ | | 0.2846 | | |
| Sample size | | 1022 | | |
| VOTT (CNY/h) | 58.94 | | | |

Table 4: Estimations of middle-income group ($t$-statistics are in parentheses).

| | HSR | Conventional rail | Air | Road |
|---|---|---|---|---|
| Constant | | | 2.3909 (6.881) | |
| Travel time (h) | −0.7663 (−8.914) | −0.4649 (−3.718) | −0.7663 (−8.914) | −0.4649 (−3.718) |
| Travel cost (CNY/100) | −1.0534 (−8.885) | −1.4410 (−3.208) | −1.0534 (−8.885) | −1.4410 (−3.208) |
| Profession | 0.3680 (2.329) | 0.3680 (2.329) | 0.3680 (2.329) | |
| Trip purpose | 0.3809 (2.583) | | 0.3809 (2.583) | |
| Logsum | | 1.3068 (8.266) | | |
| $\rho^2$ | | 0.3368 | | |
| Sample size | | 1431 | | |
| VOTT (CNY/h) | 72.75 | | | |

Table 5: Estimations of high-income group ($t$-statistics are in parentheses).

| | HSR | Conventional rail | Air | Road |
|---|---|---|---|---|
| Constant | | | 3.3348 (4.809) | |
| Travel time (h) | −1.0467 (−6.205) | −0.4139 (−2.114) | −1.0467 (−6.205) | −0.4139 (−2.114) |
| Travel cost (CNY/100) | −1.2753 (−5.490) | −2.6309 (−3.746) | −1.2753 (−5.490) | −2.6309 (−3.746) |
| Trip purpose | 0.7519 (3.963) | | | |
| Logsum | | 1.3077 (5.694) | | |
| $\rho^2$ | | 0.4255 | | |
| Sample size | | 625 | | |
| VOTT (CNY/h) | 82.07 | | | |

where $\theta_i$ is the weight measured by the distribution of income levels shown in Table 1; $P_n^{\text{low}'}$ is the probability of choosing HSR for a low-income passenger; $P_n^{\text{mid}'}$ is the probability of choosing HSR for a middle-income passenger; $P_n^{\text{high}'}$ is the probability of choosing HSR for a high-income passenger.

To analyze the relationship between market share and ticket fare, 41 ticket fares are picked from 390 CNY to 590 CNY in order. And the later fare is increased by 5 CNY than the former one. Then the market shares under specific ticket fares are calculated. Based on the regression analysis method, the quantitative relationship is shown in Figure 2. The adjusted $R^2$ is up to 0.997, which indicates that logarithmic regression model is suitable to describe the relationship between the parameters. Given that the market share is a variable between 0 and 1, the ticket fare should range from 294 CNY to 673 CNY to make sure that the equation is effective. The relation equation is shown in (10) and the value range of $x$ is described in the parentheses. Consider the following:

$$y = -1.21 \ln(x) + 7.879, \quad (294 < x < 673), \tag{10}$$

where $y$ is the HSR market share; $x$ is the HSR ticket fare, CNY.

*4.2. Pricing Strategy.* Based on the quantitative relationship obtained, a pricing strategy to improve the occupancy rates between Wuhan and Guangzhou is researched. It is assumed that the rate of passenger transport demand from Wuhan to Guangzhou ranges from 20% to 35% in the corridor. With the aim of 100% occupancy rate, the pricing strategy for HSR is shown in Table 6.

From the estimation results, 100% occupancy rate can be implemented when the fare is set at 407 CNY in weekdays and 533.5 CNY (or 420 CNY) in holidays. In weekdays, the fare

Table 6: Estimations of HSR pricing.

| Operation scheme | Weekdays | Holidays | |
|---|---|---|---|
| | 8 carriages, 43 trains | 8 carriages, 43 trains | 16 carriages, 43 trains |
| Assumption of travel demand (day) | 8000 | 30000 | 30000 |
| HSR pricing (CNY) | 407 | 533.5 | 420 |

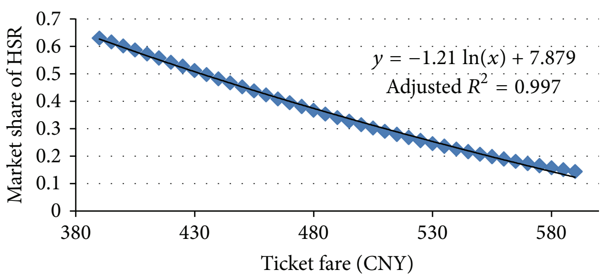


Figure 2: Regression analysis results.

is 50 CNY lower than the current one (465 CNY), so it will be beneficial to decrease the fare appropriately in exchange for the increase of occupancy rates. In holidays, the operation scheme in weekdays even cannot meet the transport demand. But when the carriages of each train are increased to 16, 420 CNY should be the satisfying fare for obtaining the 100% seat occupancy rate. Comparatively speaking, a strategy with floating pricing should be more positive to improve the earnings. Ticket fare should be set in lower level in order to attract more passengers in weekdays. As for the pricing strategy in holidays, both the rise of ticket fare and the adjustment in operation scheme could be effective.

## 5. Conclusions

This paper provides a pricing strategy for Wuhan-Guangzhou HSR based on the quantitative relationship between rail pricing and market share of HSR. Through considering the service attributes of transport mode and personal attributes, NL models using SP data are built to obtain the market share of HSR under specific fare. This method not only suits for assessing and comparing the individual preferences under the context of mode competition but also gives a pricing strategy to relieve the situation of low occupancy rates for some HSR lines. The results of nested choice model confirm that the sensitivities to multiple influencing factors are diverse as income level varies and passengers with high income pay more attention to the travel time of transport mode other than personal properties. Besides, the results of pricing strategy show that floating ticket fare will be more positive to improve the occupancy rates for HSR and to meet transport demand. The pricing strategy obtained could be beneficial to the full play of economic and social benefits under the rapid development of HSR in China.

## Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of the paper.

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