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Modeling traveler mode choice behavior of a new high-speed rail corridor in China

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This study examines mode choice behavior for intercity business and personal/recreational trips. It uses multinomial logit and nested logit methods to analyze revealed preference data provided by travelers along the Yong-Tai-Wen multimodal corridor in Zhejiang, China. Income levels are found to be positively correlated with mode share increases for high-speed rail (HSR), expressway-based bus, and auto modes, while travel time and trip costs are negatively correlated with modal shift. Longer distance trips trigger modal shifts to HSR services but prevent modal shift to expressway-based auto use due to escalation of fuel cost and toll charges. Travelers are less elastic in their travel time and cost for trips by nonexpressway-based auto use modes. The magnitude of elasticity for travel time is higher than trip costs for business trips and lower for personal/recreational trips. The study provides some policy suggestions for transportation planners and decision-makers.

Keywords: high-speed rail; nested logit model; mode choice behavior; intercity travel; short corridor; China

Introduction

The 282-km Yong-Tai-Wen high-speed rail (HSR) route, linking the cities of Ningbo, Taizhou, and Wenzhou in Zhejiang Province on the eastern coast of China, opened to traffic in September 2009. Subsequently, the China Central Government issued a fuel tax-for-fee policy that mandates the cancellation of tolls on all provincial nonexpressways (referred to as Class II highways) in the country. As a result, toll collection on Provincial Route 214, a Class II highway that runs parallel to the HSR corridor, was terminated in February 2010, reducing out-of-pocket costs for both auto and bus users. With respect to travel demand, however, the additional passenger capacity provided by the HSR induced additional passenger demand along this corridor that also increases along with economic development. Thus, travelers in the Yong-Tai-Wen corridor could choose to use the newly opened HSR (trains), the tolled expressway (autos and express buses), or the untolled

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Table 1. HSR corridors investigated in some notable studies.

Study year	Corridor	Country	Length (km)	Alternative modes
1995, 1998	Toronto–Montreal	Canada	505	HSR/air/auto
1996, 1997, 1998	Sydney–Canberra	Australia	300	HSR/air/auto
2002	Toukaidou–Shinkansen	Japan	515	HSR/air/rail/express bus/auto
2003	Madrid–Barcelona	Spain	600	HSR/auto
2004	Seoul–Busan	Korea	418	HSR/air/auto
2004	Seoul–MokPo	Korea	405	HSR/air/rail/bus/auto
2005	Seoul–Daegu	Korea	293	HSR/air
2006	Seoul–Busan	Korea	418	HSR/air/rail/bus/auto
2009	London–Paris	UK	492	HSR/air

Source: http://www.uic.org/spip.php?article573.

Class II Provincial Route 214 (autos) to complete their trips. Greater total passenger travel demand along the corridor, coupled by the addition of new HSR services and the cancellation of tolls on Route 214, would inevitably result in redistribution of modal shares among the competing travel modes. Thus, this corridor provides a unique opportunity to examine travel behavior and mode shifts among travelers when faced with meaningful choices between conventional transportation modes such as autos and buses, and high-quality alternatives such as HSR, express bus, and tolled expressways.

Over the last two decades, a number of studies have investigated travel choices following the introduction of HSR services. Table 1 lists some of the notable studies. As can be seen, most of the HSR lines operate on long corridors over 300 km and even close to 600 km. The findings of those studies might not manifest changes in traveler mode choices concerning the Yong-Tai-Wen HSR corridor since this corridor has a shorter operating length, relatively higher travel demand, and more practical transportation alternatives available. These conditions also make the Yong-Tai-Wen corridor an excellent case study for examining travel behavior and mode choices under competitive conditions. Thus, this study investigates the mode choice behavior of intercity passenger travel, identifies factors influencing modal shift, and provides some policy guidance for effective means to promote desired mode split changes along similar corridors relevant to China and elsewhere.

The study is organized as follows: Section 1 provides a brief review of the pertinent literature on mode choice behavior and HSR. In Section 2, a methodology is proposed for applying multinomial logit model and nested logit models to key questions of travel behavior and mode choice. Section 3 presents data collection, preliminary data processing and analysis. Section 4 focuses on the application of the methodology for calibrating the multinomial logit and nested logit models for different trip purposes. In addition, the elasticity of travel demand in response to changes in in-vehicle travel time and out-of-pocket costs are calculated to help propose policy guidance as an effective means to promote desired mode split changes. Finally, Section 5 presents some conclusions.

Related work

Methods used in studies on mode choice of intercity travel involving HSR services can be classified into three categories: network assignment, neural network, and discrete choice models. Chang and Chang (2004) formulated a network assignment model that deals with train, air, and auto modes to assess modal shifts after introducing HSR services. They concluded that a higher percentage of mode shift to HSR from air and train modes appears when travel distance is greater than 300 km. Nijkamp, Reggiani, and Tritapepe (1996) studied travel choices between rail and auto modes using neural network techniques. This research revealed that the neural network model requires a large amount of data and time to identify the most suitable model structure in order to achieve marginally improved model estimation results over the use of more conventional methods.

One of the major limitations of the above models was that they lacked rigorous treatments of disaggregated behavior such as individual traveler mode choice behavior. As a result, discrete choice models (McFadden 1973, 1978; Domencich and McFadden 1975; Maddala 1983; Ben-Akiva and Lerman 1985) that could capture disaggregate-level behavior of individual travelers became more popular for examining modal shift. For instance, González-Savignat (2004) developed a binary logit model to quantify mode shares between HSR and auto modes. This research revealed that the HSR mode is preferred for recreational travel and travel alone. In another study, Park and Ha (2006) examined mode shares between HSR and air travel using the binary logit technique and found that the elasticity of travel demand is larger for trip cost than for out-of-vehicle travel time and travel frequency. Bhat (1995) introduced multinomial logit, nested logit, and heteroscedastic extreme value models for travel mode choice analysis and found that the heteroscedastic extreme value model could provide better mode share estimation results. An improvement of current rail services would alleviate air-traffic congestion at airports more so than alleviating auto congestion on roads. However, he further concluded that the multinomial logit model would overestimate the increase in HSR passenger ridership. Some researchers developed multinomial logit and heteroscedastic extreme value models for mode choices among auto, HSR, and air travelers with different fare levels and concluded that high-income and long-distance users would prefer HSR and air modes although some large groups would be more willing to select a cheaper mode (Vickerman 1997; Hensher 1997; Cheng 2010). In a separate study, Bhat (1998) used multinomial logit, fixed-coefficient logit, and random-coefficient logit models to determine mode shares among air, HSR, and auto modes and analyzed their cross-variable sensitivity. He found that high-income users, men, and single travelers prefer air modes while women and groups favor HSR. Travelers with trip origins and destinations in large cities are also more likely to select the HSR mode. Single travelers and women also tend to be more sensitive to trip frequency. Yao et al. (2002) formulated a nested logit model to establish mode shares among HSR, conventional rail, air, express bus, and auto modes and concluded that HSR is capable of attracting users from other competing modes, especially from conventional rail.

Based on existing studies, it seems that gender, income level, trip purpose, travel time, trip cost, frequency, length, and travel group size are primary factors that could affect traveler mode choice behavior. For multimodal corridors, the multinomial logit and nested logit models have been most widely used. With respect to the Yong-Tai-Wen corridor, three travel modes (train, auto, and express bus) and three types of service facilities (HSR, expressway, and Class II highway) are available. When travelers make travel mode choice decisions, they may first consider service facilities and then select the appropriate mode, or they could first select travel modes and then consider service facilities. As a result, the nested logit model structure appears to be more appropriate to model the nested decision-making process. In this study, data on revealed preference (RP) collected from the Yong-Tai-Wen corridor will be applied to different types of nested logit model to determine the impacts of modal shift caused by the addition of HSR and the cancellation of Class II highway tolling. The authors also wish to find which model performs the best among different types of nested logit model and multinomial logit model, whether the impact factors are similar to prior studies for this shorter distance corridor and how they affect modal shift.

Proposed methodology

The multinomial logit model (Yao et al. 2002; Lee, Chon, and Park 2004), which has a simple model form and structure, has been widely used for analyzing intercity travel mode choice behavior following the introduction of HSR services (Domencich and McFadden 1975; Park and Ha 2006; Suh and Yang 2005; Lee and Chang 2006; Greene 2007). Further, some researchers developed the nested logit model to address the issue of the Independence of Irrelevant Alternatives encountered in the mode choice analysis where it could not be explicitly handled by the multinomial logit model (Bhat 1995, 1998). The following section describes the two types of discrete choice models that are based on utility maximum theory (Ben-Akiva and Lerman 1985).

In multinomial logit and nested logit models, a decision-maker is modeled as selecting the alternative with the highest utility among those available at the time a choice is made. Generally, the utility function for traveler n selecting travel mode i can be specified as follows:

$$U_{in} = V_{in} + \varepsilon_{in}(i \in C_n) \tag{1}$$

where V_{in} is called the systematic components of utility of traveler n selecting travel mode i, and ε_{in} is the random components that represent traveler preference, C_n is the selection sets for traveler n can be generally expressed in linear form as follow:

$$V_{in} = \sum_k \beta' X_{kin} \tag{2}$$

where X_{kin} is the kth variable and β' is the parameter needs to be estimated.

According to utility maximum theory, the probability of traveler n selecting travel mode i can be expressed as follows:

$$P_{in} = \Pr(U_{in} \geq \max(U_{jn}); \forall j \in C_n, j \neq i) \tag{3}$$

If the utility random component satisfies the Independent Identical Distribution condition, the multinomial logit model can be written as:

$$P_{in} = \frac{\exp(\beta' X_{kin})}{\sum_{j \in C_n} \exp(\beta' X_{kjn})} \tag{4}$$

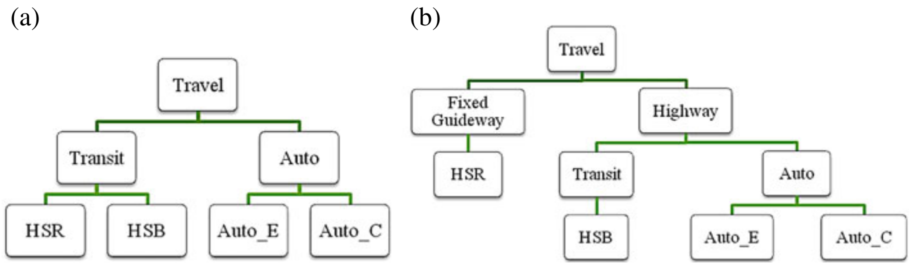

Figure 1. Two possible types of nested logit models for current study. (a) Trips grouped by travel mode. (b) Trips grouped by facility type.

Assuming the utility random component satisfies only the identical distribution condition but is not independent, we can obtain the nested logit model. The probabilities of a doubly nested logit model P_{in} can be expressed as the multiplication of conditional probability $P\ (k/j)$ and marginal probability $P_{(j)}$,

$$P_i = \frac{\exp\left(\alpha_{(i/j)} + \beta' X_{(i/j)}\right)}{\sum_{m=1}^{k=j} \exp(\alpha_{(m/j)} + \beta' X_{(m/j)})} \times \frac{\exp\left(\lambda_j\left(\gamma' Y_{(j)} + IV_{(j)}\right)\right)}{\sum_{b=1}^{B} \exp\left(\lambda_b\left(\gamma' Y_{(b)} + IV_{(b)}\right)\right)} \quad (5)$$

where β' and γ' are model coefficients, $IV(j) = \ln\left[\sum_{m=1}^{k/j} \exp\left(\alpha_{(m/j)} + \beta' X_{(m/j)}\right)\right]$, and λ_j is the logsum or inclusive value parameter.

The unique character of the Yong-Tai-Wen corridor includes multiple types of service facilities and alternative travel modes, allowing the application of both multinomial logit and nested logit models. For the nested logit model, two types of nesting may be constructed. As shown in Figure 1, the first type splits travel demand by transit and auto mode. Within the transit mode, two sub-modes can be considered according to facility types – HSR and the express bus using the expressway (high-speed bus [HSB]). On the auto side, two sub-modes could be classified depending upon the use of the expressway (Auto_E) and Class II highway (Auto_C). In the second nested logit model, travel demand could be split first by fixed guideway and highway as two different types of facilities. Within the fixed guideway facility, HSR is the only travel mode. With respect to the highway facility, travel demand can be separated for transit and auto modes. With the highway-based transit mode, express bus (HSB) is the only travel mode. Within the highway-based auto mode, two sub-modes can be classified: auto travel on the expressway (Auto_E) and auto travel on Class II highway (Auto_C).

Methodology application

Data collection

In China, HSR has a maximum operating speed more than 200–250 km/h and makes few stops with the average spacing of stations ranging from 80 km to 110 km. The express bus services in this study focus on intercity buses that travel are mostly along expressways and have a similar speed to autos. In July 2010, a questionnaire survey was administered to collect data on RPs for transportation mode choices among travelers using HSR, expressway, and Class II highway facilities along the Yong-Tai-Wen corridor.

Alternative travel modes included HSR on the HSR facility, HSB and Auto_E on the expressway, and Auto_C on the Class II highway. For HSR users, the questionnaire was distributed at Ningbo and Wenzhou HSR stations. For HSB users, the questionnaire was distributed at Ningbo and Wenzhou intercity bus stations. For auto users, the questionnaire was distributed at Taizhou Rest Area on the Yong-Tai-Wen Expressway and at Fenghua Weigh Station on Provincial Route 214 (Class II highway). The survey participants were selected randomly by the investigator who stratified the sample and kept the sample balanced by gender and age attributes. If a selected user did not respond, the investigator shifted to the next available respondent. The questionnaire focused on collecting information on individual traveler's socioeconomic attributes (occupation and income) and travel characteristics (travel purpose, origin–destination [OD], access and egress modes, travel time, and trip costs). Table 2 summarizes basic information on the sampled data-set concerning the four travel modes classified by occupation, income, and trip purpose. For each mode, more than 700 respondents completed the survey, adding up to a total of 2950 respondents in the survey data-set, in which there are 1068 business travelers, 1753 personal/recreational purpose travelers, and 129 nonrespondents.

For the choice of the HSR mode, 53.2% of survey participants were university students. This is because the survey was conducted immediately after the beginning of summer breaks. The HSR was chosen by university students to reach their home destinations. Corresponding to the student participants, their monthly income levels varied from less than RMB 1000 to RMB 2000–3000 (RMB 1000:USD160). As for HSR travel by trip purpose, 38.6% of business trips and 23.8% of return-to-home trips were by HSR. For access/egress modes, 44.6 and 20.5% of respondents used bus and taxi modes. The weighted average time for all access/egress modes was about 51 minutes. For the HSB mode, 41.5% of survey participants were enterprise employees and about 30% were university students. Approximately two-thirds of respondents did not explicitly indicate their income levels. In total, 44% of business trips and 24.9% of return-to-home trips were by HSB. Similar to the HSR mode, about 43.5 and 31.7% of respondents were by bus and taxi as for access/egress modes. Lower than the weighted average time of HSR access/egress modes, it was only 41 minutes. For Auto_E mode, approximately 48.1% of respondents were enterprise and government employees and 40.4% of survey participants were self-employed. Similar to the HSB mode, two-thirds of respondents did not explicitly indicate their income levels. In total, 57.7% of business trips and 13.1% of recreational trips were by Auto_E mode. For the choice of Auto_C mode, 46.1% of respondents were self-employed. About 40% of respondents did not explicitly indicate their income levels. In total, 79.1% of government and private business trips were by Auto_C mode.

Table 2 also provides summary statistics of level of service for main city OD pairs along this corridor in terms of three important travel attributes: travel time, trip costs, and trip distance. By simultaneously referencing the information on travel time and trip distance statistics, it reveals that HSR maintains the highest average travel speed at 171 km per hour, followed by expressway-based auto at 73 km per hour, expressway-based buses at 65 km per hour, and Class II highway-based autos at 52 km per hour. Trip costs per kilometer in ascending order were RMB 0.17 per km for Class II highway-based autos, RMB 0.28 per km for expressway-based autos, RMB 0.34 per km for HSR, and RMB 0.38 per km for expressway-based buses.

Table 2. Summary information on data-set sample.

	Alternative mode		HSR	HSB	Auto_E	Auto_C
Attributes	Occupation	Enterprise employee	149	299	236	108
		Government employee	35	67	135	98
		Student	404	215	9	7
		Self-employed	92	64	311	323
		Other	74	58	67	89
		No response	6	17	12	75
	Monthly income (RMB)	<1000	172	39	13	127
		1000–2000	87	36	15	151
		2000–3000	76	73	41	132
		3000–5000	49	66	55	95
		5000–8000	38	37	47	106
		8000–10,000	13	5	23	68
		>10,000	13	9	81	10
		No response	312	455	495	281
	Trip purpose	Home-to-work	29	84	22	45
		Home-to-school	27	17	2	5
		Government business	144	227	444	253
		Private business	150	90	66	301
		Recreational	69	58	101	65
		Return-to-home	181	179	29	12
		Other	151	52	10	8
		No response	9	13	96	11
	Access/egress modes	Bus	339	313	–	–
		Taxi	156	228	–	–
		Auto	82	61	–	–
		Walk	21	14	–	–
		No response	162	104	–	–
		Sample size	760	720	770	700
Summary statistics for main OD pairs	Travel time (hrs)	Ningbo–Taizhou	0.9	2.28	1.97	2.7
		Taizhou–Wenzhou	0.75	2.14	1.94	3.7
		Ningbo–Wenzhou	1.65	4.42	3.91	6.4
	Trip costs (RMB)	Ningbo–Taizhou	50	54	40	25
		Taizhou–Wenzhou	45	54	40	31
		Ningbo–Wenzhou	95	108	80	56
	Trip distance (km)	Ningbo–Taizhou	156	143	143	148
		Taizhou–Wenzhou	126	142	142	185
		Ningbo–Wenzhou	282	285	285	333

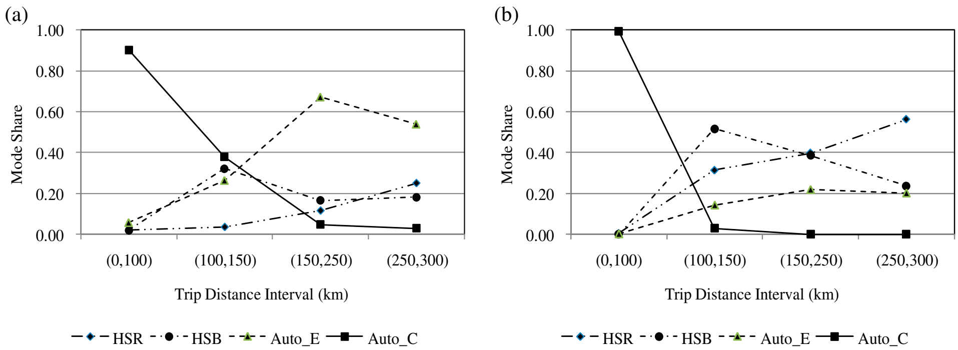

Figure 2. Mode share by distance interval. (a) Business trip purpose. (b) Personal/recreational purpose.

Preliminary data analysis

As shown in Figure 2(a) and (b), modal split among HSR, HSB, Auto_E, and Auto_C modes for business trips and for personal/recreational trips varied significantly by trip distance. For business trip purposes, the mode share of Auto_C was about 90% when trip distance was within 100 km. With the increase in trip distance to nearly 150 km, the modal shares of HSR, HSB, and Auto_C were at an equal level of about 30%. When trip distance was longer than 150 km and approaching 250 km, the mode share of Auto_E increased considerably and reached around 65%. When trip distance for business trips was longer than 300 km, the mode share of Auto_C became negligible.

For personal/recreational trip purposes, Auto_C was the dominant mode of travel choice when trip distance was shorter than 100 km. With the increase in trip distance, the shares of the other three modes increased gradually. When trip distance increased from 100 km to 150 km, the share of HSB reached 50% and the share of HSR increased to 30%. For trip distances up to 250 km, HSB and HSR shared the same level of travel demand, reaching 40% for each mode. However, when trip distance was longer than 250 km, HSR became the dominant mode with which the modal share exceeded 50% that is slightly higher than the combined mode shares of HSB and Auto_E. When trip distance for personal/recreational trips was longer than 300 km, the mode share of Auto_C became negligible.

Model calibration

As part of model calibration, a number of variables that have been identified to be statistically significant in prior studies were considered. Considering the difference in travel behavior affected by distance that shows significantly in two trip routes which are travel route of distance longer than corridor length (280 km) and shorter than corridor length and the revealed significant changes in mode shares for business trips and personal/recreational trips by trip distance, a dummy variable was first created for a trip distance that was longer than 280 km corresponding to the length of the Yong-Tai-Wen HSR corridor. A similar variable also appears in previous studies (Hensher 1997). The second variable considered was a dummy variable for monthly income less than RMB 5000 to differentiate the travel choice behavior between low/medium-income groups and the high-income group. The third variable considered trip costs. The costs for HSR and expressway-based HSB users include fare charges. The costs for expressway-based Auto_E consist of toll, fuel cost, and vehicle depreciation cost. For Class II highway-based Auto_C, the costs comprised of fuel cost and vehicle depreciation cost. In general, the fuel cost of cars used for government business purpose trips is fully reimbursed. Thus, fuel cost does not represent out-of-pocket costs for these users. Hence, only vehicle depreciation cost is considered for Auto_C involved with government business trips. In this study, average auto acquisition cost is assumed to be RMB 100,000 and with a 5% salvage value after 15 years of typical service life. Using the sum-of-year digits depreciation method, the auto depreciation cost could be estimated as RMB 25.2 per trip.

NLogit 4.0 proprietary software (Greene 2007) was employed for calibrating the multinomial logit model and two types of nested logit model that predict changes in model split after introducing the HSR services and canceling tolls on Class II highways. The maximum likelihood estimation technique was used to estimate model coefficients. The explanatory variables at the 5% significance level included: income level, trip distance, travel time, and trip costs. The following section briefly discusses model calibration results.

Calibrated intercity mode choice model for business trips

Table 3 presents details of the calibrated intercity mode choice model for business trips. There are 401 uncompleted business samples, so they will be rejected in all models. The McFadden Pseudo R^2 values are between 0.67 and 0.75. Of the three models calibrated, the two nested logit models are with better model fits compared with the multinomial logit mode. Between the two nested models, the nested logit model with trips grouped by facility type has shown a marginally better fit.

The constants are all relative to Auto_C which is the base mode, and the base mode whose constant is zero. The signs of the constant term associated with HSR, HSB, and Auto_E modes in all calibrated models are negative. This reveals that even after HSR services were introduced and tolls on Class II highways were canceled, the Class II highway was still a more preferred mode without considering impacts of income levels, trip distance, and trip costs. Another possible reason why significant changes in modal choice preferences were not observed may be that the data collection for the current study was conducted soon after the introduction of HSR services. A longer time period may be necessary before business trip travelers gain sufficient experience with the benefits of using HSR to trigger a change in modal choice. Nevertheless, this finding is consistent with the results of previous studies (Hensher 1996; González-Savignat 2004) in which the probability of choosing the current mode would continue to increase after introducing HSR services.

In all three models, the signs of the coefficient related to the median-income dummy variable are always positive. This indicates that, all other factors being equal, travelers with median incomes greater than RMB 5000 per month prefer to choose express buses on the expressway or HSR and to drive cars on the expressway rather than on the Class II highway. This finding is similar to those documented in the existing literature where higher income users would be willing to select air or other more expensive and efficient travel modes (Bhat 1995; Vickerman 1997; Hensher 1997; Yao et al. 2002; Cheng 2010).

Further, positive signs were found for the coefficients on the long-distance dummy variable concerning the HSR mode. Conversely, negative signs are found for the Auto_E mode. This suggests that if trip distance is longer than 280 km (equivalent to the total length of the Yong-Tai-Wen corridor), travelers prefer to choose HSR over driving cars on a Class II highway. This finding is consistent with the conclusions reached in previous

Table 3. Calibrated intercity mode choice models for business trips.

		Multinomial logit model		Nested logit model with trips grouped by: Travel mode		Nested logit model with trips grouped by: Facility type	
Variable (Auto_C as base mode)	Alternative mode	Coefficient	*t*-statistic	Coefficient	*t*-statistic	Coefficient	*t*-statistic
Constant	HSR	−5.815	−6.07	−6.330	−6.06	−10.689	−4.94
	HSB	−0.559	−1.59	−1.056	−2.24	−0.863	−1.04
	Auto_E	−2.234	−2.28	−0.660	−1.21	−2.923	−4.94
Dummy variable for median income >5000	HSR	2.105	3.29	2.689	3.74	1.287	2.11
	HSB	2.210	4.51	2.760	4.78	1.165	3.63
	Auto_E	1.295	2.14	1.239	2.25	–	–
Dummy variable for trip distance >280 km	HSR	2.149	5.63	2.576	6.15	2.723	2.86
	HSB						
	Auto_E	−1.417	−3.80			−1.838	−4.23
Travel time	All	−2.245	−5.34	−1.904	−4.91	−3.799	−9.45
Trip costs	All	−0.061	*−3.85*	−0.125	−6.11	−0.045	−1.98
Inclusive value parameters	Transit			0.806	6.23		
	Auto			1.000	Fixed		
	Fixed guideway					0.521	4.63
	Highway					0.545	5.52
Value of time (RMB per hour)		36		15		84	
Log likelihood function		−293.32		−283.95		−290.60	
R^2		0.67		0.69		0.75	
Observations		667		667		667	

studies (Hensher 1997). However, for such a longer distance, users are not willing to drive cars on an expressway as compared to driving cars on a Class II highway. One explanation for this is that the toll charges on the use of the Yong-Tai-Wen Expressway are rather high. The significantly augmented total trip costs from long-distance travel due to high toll charges could prevent travelers from selecting the Auto_E mode.

The signs of both trip costs and travel time for all modes relative to the Auto_C mode are negative and the absolute value of the coefficients for the travel time variable is significantly greater than that of trip costs. This indicates that, all other things being equal, increases in trip costs and travel time associated with HSR, HSB, and Auto_E modes relative to Auto_C mode would discourage modal shifts toward those modes. Unusually, the trip cost coefficient for the travel mode nested logit model is higher (−0.125) because there is no trip distance dummy in this model. For the two different trip purpose models, the in-vehicle time and trip cost variables are negative, which show the negative effects for mode choice. With model coefficients calibrated in the three types of model, the value of time for business trips could be estimated in the range of RMB 15–84 per hour, respectively. The rather low value of time estimated by the nested logit model with trips grouped by travel mode requires further examination.

Calibrated intercity modal choice model for personal/recreational trips

Table 4 presents details of the calibrated intercity mode choice model for personal/recreational trip purposes. There are 381 uncompleted personal/recreational responses, so they were rejected in all models. Because of a relatively small sample regarding the information on user's income levels in the data-set, the median-income level variable was removed during the course of model calibration. The R^2 values are between 0.67 and 0.74. Similar to the models calibrated for business trip purposes, the two nested logit models still provide better model fits compared with the multinomial logit model. Between the two nested models, the nested logit model with trips grouped by facility type shows a slightly better fit.

The signs of the constant term associated with HSR and Auto_E modes in all calibrated models are negative, whereas the signs are positive for the HSB mode. This suggests that after introducing HSR services and removing Class II highway tolls, driving on the Class II highway is still a more preferred mode compared to HSR and driving on expressways. However, similar to the concerns regarding the findings of the models calibrated for business trips, it may also take more time for personal/recreational trip travelers to gain experiences on the benefits of using HSR and then possibly switch travel modes. Nevertheless, riding express buses seems to be a more preferred mode of choice than driving on a Class II highway for personal/recreational trips after the introduction of HSR services. One explanation for this might be that after the HSR deployment, the quality of service provided by the express buses improved to remain competitive. Consequently, express bus ridership increased.

The impacts of long trip distances are only found to be significant for the HSR mode. The positive signs obtained from all three models reveal that if a traveler's trip distance is longer than the total length of the Yong-Tai-Wen corridor (i.e., 280 km), they prefer to choose HSR over driving cars on a Class II highway for personal/recreational trips. Similar to the models calibrated for business trips, the signs of both trip costs and travel time for all modes relative to Auto_C mode are negative. With model coefficients calibrated in the three types of model, the value of time for personal/recreational trips can be estimated in the range of RMB 20–26 per hour, respectively.

Table 4. Calibrated intercity mode choice models for personal/recreational trips.

				Nested logit model with trips grouped by			
		Multinomial logit model		Travel mode		Facility type	
Variable (Auto_C as base mode)	Alternative mode	Coefficient	*t*-statistic	Coefficient	*t*-statistic	Coefficient	*t*-statistic
Constant	HSR	−3.388	−7.88	−0.071	−0.06	−5.254	−4.18
	HSB	0.251	1.71	3.421	3.11	0.356	0.67
	Auto_E	−3.061	−21.13	−3.796	−15.35	−3.552	−4.69
Dummy variable for trip distance >280 km	HSR	1.815	7.40	2.020	7.98	2.759	3.91
	HSB						
	Auto_E						
Travel time	All	−1.799	−8.29	−1.507	−4.88	−2.328	−3.76
Trip costs	All	−0.070	−6.16	−0.061	−3.13	−0.119	−4.96
Inclusive value parameters	Transit			0.678	4.99		
	Auto			0.565	4.54		
	Fixed guideway					0.469	6.27
	Highway					0.486	6.61
Value of time (RMB per hour)		26		21		20	
Log likelihood function		−536.37		−524.21		−523.27	
R^2		0.67		0.72		0.74	
Observations		1372		1372		1372	

With the best fit mode choice models for business trips and personal/recreational trips, the value of time for business trips is found to be around 4.2 times the value of time for personal/recreational trips (RMB 84 per hour vs. RMB 20 per hour). According to the existing literature (cf. Vickerman 1997; Hensher 1997; Cheng 2010), the value of in-vehicle time is about USD14.5–29.5 for business trips and USD10.1–10.9 for nonbusiness trips. This gives a ratio of 1.4–2.7 in terms of value of time for the two types of trip purpose. The significant differences in the ratio of the value of time for business and nonbusiness trips estimated in the current study may be attributable to the data-set used for model calibration, where a significant portion of survey respondents were university students who as a group are associated with a lower level of value of time.

Comparison of mode choice behavior for business and personal/recreational trips

Table 5 summarizes a comparison of the predicted and actual market shares of HSR, HSB, Auto_E, and Auto_C modes for business and personal/recreational trips along the Yong-Tai-Wen corridor where the actual mode shares were collected from local transport agencies and predicted mode shares were obtained directly from NLogit 4.0 simulation models that were calibrated based on the RP survey data. The comparison is made in accordance with the nested logit models with trips grouped by facility type for business trips and personal/recreational trips, respectively.

A high consistency level is achieved between the actual and predicted modal splits for business and personal/recreational trips. For business trips, the dominant modes of choice are Auto_C and Auto_E in accordance with the predicted mode shares of 38% for Auto_C and 28% for Auto_E. In other words, driving cars on a toll-free Class II highway and on the tolled Yong-Tai-Wen Expressway are the primary choice for business trips. As for personal/recreational trips, the dominant modes of choice are HSR and Auto_C according to mode share predictions of 38% for HSR and 32% for Auto_C.

Most transportation policy analysis and investment decisions are carried out using forecasts of aggregate demand (González-Savignat 2004). Elasticity measures of the responsiveness of demand to changes in policy-relevant variables are of greater importance for discrete choice models. These models provide the responsiveness of the individual choice probabilities (P_i) to a change in an explanatory variable X_k. Dunne (1984) pointed out the importance of considering the distribution of elasticity across the sample to obtain

Table 5. Comparison of actual and predicted mode shares.

	Business purpose		Personal/recreational purpose	
Mode	Actual	Predicted	Actual	Predicted
HSR	0.17	0.16	0.37	0.36
HSB	0.20	0.18	0.22	0.23
Auto_E	0.30	0.28	0.08	0.09
Auto_C	0.33	0.38	0.33	0.32
Total	1.00	1.00	1.00	1.00

unbiased results if the sample is not composed of homogeneous individuals. Following this approach, aggregate direct or own-point elasticity is derived in the form:

$$E_{X_{jkn}}^{P_n^i} = \frac{\sum_{n=1}^{N} E^{P_n^i} \beta_{jkn} X_{jkn} (\partial_{ij} - P_n^j)}{\sum_{n=1}^{N} P_n^i}. \tag{6}$$

where k is the variable, n is the individual traveler, and ∂_{ij} is equal to 1 if $i = j$ (direct-point elasticity) and equal to 0 if $i \neq j$ (cross-point elasticity). This is a weighted average of the individual elasticity where the weights are the individual proportions of the total probability.

Using the calibrated multinomial logit and nested logit models with trips grouped by facility type, the direct elasticity of travel demand on the use of HSR, HSB, Auto_E, and Auto_C modes caused by changes in travel time and trip costs is estimated for business and personal/recreational trips, respectively.

As seen in Table 6, the elasticity of business trips with respect to travel time is the highest for HSB at −2.954 to −4.224, followed by Auto_E at −2.016 to −2.73 and HSR at −1.582 to −1.859, and the lowest for Auto_C at −0.699 to −1.07. Furthermore, the elasticity of business trips with respect to trip costs is the highest for HSB at −1.788 to −2.123, followed by Auto_E at −1.079 to −1.354 and HSR at −1.068 to −2.121, and the lowest for Auto_C at −0.152 to −0.169. These results suggest two major conclusions. First, travel time appears to be more sensitive than trip costs in affecting mode shares for business trips. Second, the impacts of travel time and trip costs on mode shares for business trips are elastic for HSR, HSB, and Auto_E modes. However, they are inelastic for Auto_C mode. This reveals that if the transportation agency wishes to increase the mode share of HSR, reducing travel time is more effective that reducing trip costs. In addition, the potential increases in the HSR mode share are likely from the modal shifts of HSB and Auto_E modes and unlikely from the modal shift of Auto_C mode. As such, the reduction in trip costs associated with a Class II highway due to toll cancellation has trivial impacts on attracting more business trips to the Class II highway.

As summarized in Table 6, the elasticity of personal/recreational trips with respect to travel time is the highest for Auto_E at −3.321 to −3.783, followed by HSB at −2.071 to −2.30 and HSR at −0.63 to −1.055, and the lowest for Auto_C at −0.781 to −0.986. Moreover, the elasticity of personal/recreational trips regarding trip costs is the highest for Auto_E at −4.146 to −6.334, followed by HSB at −2.406 to −2.893 and HSR at −1.324 to −1.649, and the lowest for Auto_C at −0.457 to −0.764. Overall, the elasticity of travel cost (except for Auto_E of personal/recreational trips) in this study is to be found between −0.764 and −2.893, which are similar to the findings of previous studies in which the elasticity is between −0.233 and −3.907. The elasticities of travel time in this study are between −0.630 and −3.783 (except for HSB of business trips) that in previous studies are between −0.159 and −3.390 (Bhat 1995; Park and Ha 2006; Cascetta et al. 2011). Contrary to the business trip case, travelers are more sensitive to trip costs than travel time in affecting mode shares for personal/recreational trips. The impacts of travel time and trip costs on mode shares for business trips are elastic for HSR, HSB, and Auto_E modes and inelastic for Auto_C mode. Hence, if a transportation agency intends to increase the mode share of personal/recreational trips by HSR, reducing trip costs is more effective that reducing travel time. Also, the potential increases in the mode share of HSR are likely from the modal shifts of Auto_E and HSB, rather than Auto_C. To this end, the reduction in trip costs on the use of a Class II highway after canceling tolls is unlikely to attract more personal/recreational

Table 6. Elasticity of travel time and trip cost by trip purpose and travel mode.

		Multinomial logit model				Nested logit model by facility type			
Trip purpose	Variable	HSR	HSB	Auto_E	Auto_C	HSR	HSB	Auto_E	Auto_C
Business	Travel time	−1.859	−2.954	−2.016	−0.699	−1.582	−4.224	−2.730	−1.070
	Trip costs	−2.121	−2.123	−1.354	−0.169	−1.068	−1.788	−1.079	−0.152
Personal/recreational	Travel time	−1.055	−2.300	−3.321	−0.781	−0.630	−2.071	−3.783	−0.986
	Trip costs	−1.649	−2.406	−4.146	−0.457	−1.324	−2.893	−6.334	−0.764

trips to the Class II highway. Another illogical result also shows in the multinomial logit model, where business travelers are more travel cost-sensitive than personal/recreational travelers and more sensitive to travel cost than travel time. But in the nested logit model, all elasticity values are intuitively plausible, so the nested logit model seems to be more appropriate to analyze this multimodal shorter corridor.

Conclusions

This study has used multinomial logit and nested logit methods to analyze RP data associated with the Yong-Tai-Wen corridor in Zhejiang, China (with regard to HSR, expressway, and Class II highway facilities and HSR, express bus, and auto carriers) and examined mode choice behavior for intercity passenger travel. The maximum likelihood estimation technique was utilized to calibrate model coefficients for intercity business trips and personal/recreational trips, respectively. Factors that were statistically significant in affecting modal shifts to HSR, expressway-based buses, and expressway-based autos relative to Class II highway-based autos include: income levels, trip distance, travel time, and trip costs of individual travelers.

Specifically, this study found that the nested logit model by facility type seems to be more appropriate for analyzing this multimodal shorter corridor. The McFadden Pseudo R^2 reached 0.74–0.75, and all elasticity values resulted from this model were intuitively plausible. More specifically, further useful findings included:

- The constant terms of all nested logit model by facility type were negative and minimum for HSR, indicating that the current modes were still preferred without considering the combined impacts of income levels, trip distance, travel time, and trip costs. Similarly, Hensher (1997) found that HSR was less preferred to the car. However, Yao et al. (2002) and González-Savignat (2004) found that HSR is more preferred to current modes.
- The signs of the coefficient related to the median-income dummy variable were always positive in the models dealing with business trips, suggesting that, all other things being equal, travelers with a median income of at least RMB 5000 per month tended to choose HSR, expressway-based buses, and expressway-based autos over Class II highway-based autos. This finding is similar to those documented in the existing literature where higher income users would be willing to select air or other more expensive and efficient travel modes (Bhat 1995; Vickerman 1997; Hensher 1997; Yao et al. 2002; Cheng 2010).
- HSR was preferred over Class II highway-based autos and expressway-based autos as long as the trip length exceeded the total length of the 280 km long Yong-Tai-Wen corridor regardless of whether the trips were for business or personal/recreational purposes. Previous studies conducted by Hensher (1997, 1998) had similar conclusions. Especially, we found the expressway-based auto mode was less preferred compared with the Class II highway-based auto mode for a trip length longer than 280 km. This may be attributable to the high fuel cost and toll charges for the use of the Yong-Tai-Wen Expressway.
- As to travel time and trip costs, the negative signs on the estimated coefficients for all models that dealt with business and personal/recreational trips suggest that increases in the amount of travel time or trip costs on the use of HSR, expressway-

based buses, and expressway-based autos would inevitably prevent modal shifts from Class II highway-based autos to these modes.

- The direct elasticities of travel time and trip costs were different between personal/recreational trips and business trips. The magnitude of elasticity for travel time was larger than that of trip costs for business trips. However, it was the contrary case for personal/recreational trips. This result is similar to findings in the existing literature (Hensher 1997). This study specially found that the elasticity with respect to travel time and trip costs for Class II highway-based auto mode was the lowest and nearly inelastic.

Cross comparisons were made on actual and predicted mode shares for business and personal/recreational trips using the calibrated nested logit models with which trips are grouped by facility type. The direct elasticity of travel time and trip costs was computed for business and personal/recreational trips by travel mode using the calibrated multinomial logit and nested logit models with trips grouped by facility type. For business trips, the elasticity with respect to travel time and trip costs was higher for expressway-based buses, expressway-based autos, and HSR in descending order and lower for the Class II highway-based auto mode. However, the magnitude of elasticity for travel time was larger than that for trip costs. For personal/recreational trips, the elasticity with respect to travel time and trip costs was elastic for expressway-based autos, expressway-based buses, and HSR in descending order and was inelastic for the Class II highway-based auto mode. Contrary to business trips, the magnitude of elasticity for personal/recreational trips was larger for trip costs compared with that of travel time.

The study findings have several policy implications. For business or personal trips, travel time, and trip costs were inelastic in affecting modal shifts concerning the Class II highway-based auto mode. Consequently, the reduction in trip costs on the use of Class II highway after canceling tolls is unlikely to attract more business or personal/recreational trips to the Class II highway. For business trips, reductions in travel time appeared to be more effective than reductions in trip costs in increasing mode shares for expressway-based buses, expressway-based autos, and HSR, respectively. For personal/recreational trips, decreases in trip costs could be more effective than shortening of travel time in increasing mode shares for expressway-based autos, expressway-based buses, and HSR, respectively. Particular to the goal of improving HSR ridership, reducing travel time and while also lowering trip costs could increase both business trips and personal/recreational trips that account for nearly one-half of the HSR ridership. Furthermore, flexibility in ticket purchase, operational speed, and frequency of HSR services can be used to segment the market. During peak periods, a higher ticket fare, increased frequency, and improved speeds of HSR could be used to further reduce travel time and attract more business travelers. In off-peak periods, HSR could offer cheaper fares, reduced operational speeds, and lower frequency that achieve cost-savings for the railway operator but increase competitiveness to attract personal/recreational passengers.

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