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Analyzing Competition between the High Speed Train and Alternative Modes. The Case of the Madrid-Zaragoza-Barcelona Corridor

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Abstract

While there have been many studies of urban travel demand, little attention has been paid to the analysis of inter-urban rail travel demand. Studies of inter-urban rail demand usually focus on assessment through the conventional cost benefit analysis of this type of investments, in which the emphasis is on the cost side. However, the analysis of the potential benefits, bearing in mind the intermodal competition, is usually neglected. This paper analyzes the potential competition of the high speed train (HST) with the main competing modes on the Madrid-Barcelona route, where a new HST infrastructure has been recently built. The analysis is based on the estimation of disaggregated Nested Logit models using information provided by travellers in the main corridors: Madrid-Zaragoza and Madrid-Barcelona. The utility specification considers the effect of the main level-of-service attributes as well as some latent variables on modal choice. We analyze demand response to various policy scenarios that consider the potential competition between HST and other modes as well as the willingness to pay for improved levels of service. The results highlight the low level of competition that the HST could exert over air transport services in Madrid-Barcelona corridor, showing that policy makers may have been very optimistic about the figures of traffic diversion from air that could be attained.

Keywords: Intermodal Competition Stated Preference (SP), Mixed RP/SP data, HST Elasticities, Willingness to pay

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1 Introduction

Trans-European Transport Networks constitute one of the basic policy instruments applied in the EU to achieve growth, competitiveness and employment. European transport policy has always called for an integrated approach combining, inter alia, measures to revitalize the rail sector, and special emphasis has been placed on the development of high speed train (HST) corridors. These corridors are characterized by dense flows of rail passengers at speeds of 300 km/hr between the principal cities of the EU. European policy makers have tried to revitalize railways, their aim being for HST routes to take virtually all traffic away from air sectors, with more convenient travel times between the core central business districts of the cities.

A good example of this type of infrastructure is the new Madrid-Barcelona HST line. The line began operations in the Madrid-Zaragoza-Lleida corridor in 2003 and the complete Madrid-Barcelona line came into commercial service at the beginning of 2008, covering the 625 km between these two cities in under three hours,. Nationally, this line will connect with the Madrid-Seville HST, which entered service in 1992, and, internationally, will produce substantial reductions in travel time between the main cities of the Iberian Peninsula and the principal European cities once the extension to the French border is completed.

Madrid and Barcelona are the two largest Spanish cities, with more than 5 and 3 million inhabitants, respectively. From a demographic perspective, Zaragoza (700,000 inhabitants) is the main city located on the corridor linking those two cities. Madrid and Barcelona are also important economic centres of Spain, and the air shuttle between these two cities constitutes one of the most important domestic markets in the world (4.7 million passengers in 2006). The main airlines operating in this market offer a total of more than sixty flights per day, making air transport an attractive alternative, especially in the business-trip segment. In addition, the airport facilities in both cities are well connected to public transport services.

The impacts of investments in HSTs can be analyzed in a number of ways. However, at present, the majority of the projects are, in the best of the cases, only assessed at national level, and existing contributions differ regarding coverage and perspective. The papers fall into the following groups: general assessments (Laird *et al.* 2005; Martín 1997; Nash 1991; Sichelschmidt 1999; Short and Kopp 2005; van Exel *et al.* 2002; Vickerman 1997); evaluations of the economic profitability of particular corridors or areas (de Rus and Inglada (1993, 1997), for the HST Madrid-Seville; Levinson *et al.* (1997) for Los Angeles-San Francisco; de Rus and Román (2006) for the HST Madrid-Zaragoza-Barcelona; Steer Davies Gleave (2004) and Atkins (2004) for the case of the UK; de Rus and Nombela (2004) for the European Union; and Martín and Nombela (2007) for the case of Spain); assessments of the regional effects (Blum *et al.* 1997; Haynes 1997; Plassard 1994; Vickerman 1995); studies of the impacts on accessibility (Fröidh 2005; Gutiérrez *et al.* 1996; Gutiérrez 2001; Martín *et al.* 2004; Vickerman *et al.* 1999); and, finally, regarding intermodal competition, Combes and Linnemer (2000) study the impacts of the creation of a new infrastructure connecting two points and coexisting with old network infrastructure (like roads) using a game-theoretic approach.

The analysis of the passengers' perceptions of and preferences in interurban transport is not new in the literature. Discrete 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 passengers in the context of modal competition. Ahern and Tapley (2008) evaluated the preferences and perceptions of bus and train passengers in Ireland using both SP and RP techniques. González-Savignat (2004) analyzed the potential of the high speed train to compete with the airline market. That author used SP techniques proposing a hypothetical market with relevant information, given that the high speed train alternative was not then available on the Madrid-Barcelona route. Ortúzar and Simonetti (2008) developed an SP experiment to evaluate the modal competition of airplanes and a fictitious high-speed train between Santiago and Concepción in Chile. They used a factorial fractional design of four variables - travel time, fare, comfort, and service delay. They incorporated RP data, obtained in a previous study, including bus, train and airplane travellers. Mixed RP/SP models were estimated and compared with those obtained from the stated preference data alone. Rigas (2009) studied the characteristics and perceptions of leisure passengers identifying the effects on modal choice between boats and air. The analysis was conducted by constructing a Multinomial Logit model, in which the dependent variable was the probability of a passenger choosing to travel by boat.

This paper contributes to the empirical literature on HST effects by analyzing the potential competition between the high speed train (HST) and the alternative modes in the Madrid-Zaragoza-Barcelona corridor, focusing both on modelling issues and on policy analysis. Effort is concentrated on the Madrid-Zaragoza and Madrid-Barcelona routes, where the HST could attract more traffic. In contrast with the existing literature, private transport modes (car as driver and car as passenger) are also included as competing alternatives. This is especially relevant in the case of the first route where traffic diversion basically comes from car and conventional trains[1] while, in the second, the HST enters the market with the objective of diverting traffic from air transport. The inclusion of the different components of the total journey length (in-vehicle, waiting, and access+egress time) also represents a novel aspect of the model specification.

The analysis is based on the estimation of disaggregated mode choice models using RP and mixed RP/SP datasets collected during 2004. At that time, the HST was already operating between Madrid and Zaragoza (where we collected only RP data), but rail services between Madrid and Barcelona were still provided by conventional trains; thus, in addition to RP data, we obtained SP information about the new alternative.

In general, the joint use of RP/SP datasets exploits the advantages and overcomes the limitations of each type of data. RP data are based on individuals' choices and allow researchers to characterize actual travel behaviour while SP data are based on individuals' stated choice behaviour in hypothetical scenarios and are useful when the problem is to analyze the demand for new alternatives and/or measure the effect of latent variables and their interactions with other attributes. Our model specification considers how the main level-of-service attributes (such as travel cost, travel time components and service frequency) and latent variables[2] (such as comfort and reliability) affect modal choice; the income variable (which is frequently not included in the specification of mode choice models) is included in the utility specification following the recommendations of the literature when the share of income spent in transport is no negligible. Substitution patterns among groups of alternatives are also analyzed through the estimation of Nested Logit models. Measures for the willingness to pay for improving the level of service, elasticity values and demand response to different policy scenarios are obtained.

The rest of the paper is organized as follows. Section 2 presents the theoretical framework on which the research is based. Section 3 describes the main characteristics of the databases used in the analysis and Section 4 provides the steps followed in the modelling process as well as estimation results. Model applications are shown in Section 5 and, finally, the main conclusions are presented in Section 6.

2 Theoretical Framework

Discrete choice models represent the behaviour of individuals when they choose from a finite set of alternatives (e.g. mode choice for interurban trips) and are derived under the assumption of utility maximization by the decision maker. The theoretical basis for their econometric specification is the random utility theory (McFadden 1974), which states that the utility of alternative *j* for individual *q* has the expression:

$$U_{jq} = V_{jq} + \varepsilon_{jq} \tag{1}$$

Where V_{jq} is the representative or systematic utility (observed by the analyst) of individual *q* for alternative A_j and ε_{jq} is a random term that includes unobserved effects. V_{jq} depends on the observable attributes $\vec{X}_{jq}$ of alternative *j* as well as on the socio-economic characteristics of individual *q*. In fact, V_{jq} is the conditional indirect utility function that includes the role of the constraints faced by the individual when he chooses both the amount of continuous goods and one of the discrete alternatives which, following Lancaster (1966), is represented by a vector of characteristics (see Jara-Díaz 1998, for more details about the consumer theory of discrete choice).

The dependent variable represents individual behaviour and is a discrete variable. We have, therefore, a probabilistic model. From the model estimation we can obtain the probability and distribution of the dependent variable for each individual observation. Hence the probability that individual *q* chooses alternative *j* is given by the expression:

$$P_{jq} = P(V_{jq} + \varepsilon_{jq} \geq V_{iq} + \varepsilon_{iq} \quad \forall\ i \neq j) = P(\varepsilon_{iq} \leq \varepsilon_{jq} + (V_{jq} - V_{iq}) \quad \forall\ i \neq j) \tag{2}$$

The derivation of choice probabilities will depend on the different assumptions formulated about the distribution of the unobserved portion of utility ε_{jq}. In this regard, the famous Multinomial Logit (MNL) Nested Logit (NL) models are obtained when ε_{jq} are iid extreme value and a type of generalized extreme value, respectively (see Train 2003 and Ortúzar and Willumsen 2001 for more details about the derivation of choice probabilities in random utility models).

The use of RP/SP data to estimate choice models requires that the variances of the error terms in RP and SP satisfy the following expression (Ben-Akiva and Morikawa 1990):

$$\sigma_{\varepsilon}^2 = \mu^2 \sigma_{\eta}^2 \tag{3}$$

where μ is an unknown parameter, and ε and η are the error terms of the RP and SP utilities respectively. Hence, in order to mix the data the following utility functions for a given alternative *j* are postulated:

$$U_j^{RP} = V_j^{RP} + \varepsilon_j = \theta X_j^{RP} + \alpha Y_j^{RP} + \varepsilon_j$$
$$\mu U_j^{SP} = \mu(V_j^{SP} + \eta_j) = \mu(\theta X_j^{SP} + \omega Z_j^{SP} + \eta_j) \tag{4}$$

where θ, α and ω are parameters to be estimated; X_j^{RP} and X_j^{SP} are common attributes to the RP and SP data sets, respectively; and Y_j^{RP} and Z_j^{SP} are attributes that only belong to the designated data set.

Bradley and Daly (1997) proposed an estimation method based on the construction of an artificial NL structure where RP alternatives are placed just below the root and each SP alternative is placed in a single-alternative nest with a common scale parameter μ .

3 The Data

3.1 Madrid-Zaragoza Corridor

The analysis of demand in the Madrid-Zaragoza corridor is based on a revealed preference (RP) survey that gathered information about travel behaviour in the principal modes: car as driver, car as passenger, bus, high speed train (HST) and plane. The main interest was to analyze individual preferences in the market situation created after the introduction of the new HST line in this corridor.

The survey was conducted during April and May 2004. Bus users were interviewed in the Avenida de America bus station while air transport users were approached at the corresponding boarding gates at Barajas Airport. People travelling by HST were interviewed on board the train, and finally car users were interviewed in the petrol stations strategically located on the national road A-II. The survey was administered to bus, HST and plane users by means of personal interviews, while car users were asked to complete a questionnaire and mail it back. In all cases, the questionnaire was divided into four sections of questions: identification data, trip information, household information and personal information. Trip information includes questions related not only to chosen alternative for the reference trip but also to available modes not chosen by the individual.

We obtained a total of 226 valid observations. Table 1 shows the modal split in the sample for this corridor.

Table 1. Modal split in the sample. Madrid-Zaragoza

Mode	Travellers	%
Car-driver	59	26.11
Car-passenger	17	7.52
Bus	57	25.22
HST	75	33.19
Plane	18	7.96

The dominant modes are car and HST with market shares of around 33%, followed by bus (25.22%) and plane (7.96%). Modal shares in the sample were determined by trying to replicate modal shares in the population, given the available information at the time the surveys were carried out and considering a maximum error of 10%

(Ortúzar and Willumsen 2001). The market share in the sample for the HST was increased (and the share of car reduced) under the assumption that the new alternative will capture traffic from the car alternatives.

Table 2 shows the level-of-service attributes as well as the socioeconomic characteristics of the sample. Total travel time has been divided into its main components: access time, waiting time, in-vehicle-time, and egress time. It is worth highlighting that the total duration of the trip is similar for the HST and the car (212 minutes approximately) although there may be differences in the perception of these modes. While travelling by car provides a higher accessibility to travellers, it has the inconvenience of driving (for the car driver) during the whole trip. Total time by plane is about 15 minutes less than by HST, but access and waiting time (which are usually more negatively perceived by travellers) in this mode comprise nearly 72% of total travel time. 46% of the trips were made for work or education purposes and almost 56% of the individuals were men. We also observe differences in per capita weekly income, ranging from 208 € for bus users to 318 € for HST users; and expenditure rate[3], which ranges from 1.56 for bus users to 2.46 for HST/plane users.

3.2 Madrid-Barcelona Corridor

Demand analysis in the Madrid-Barcelona corridor is based on a mixed RP/SP database. RP data were obtained from a survey that gathered information about travel behaviour in the principal modes: car as driver, car as passenger, bus, conventional train and plane. The main interest was focused on analyzing individuals' preferences in the future market situation that would be created after the introduction of the new HST line in this corridor. At the moment of data collection, the cities connected by the HST line were Madrid, Zaragoza and Lleida. At that time, the line connecting Barcelona and other cities in Catalonia was expected to be finished by the end of 2007. Finally, the HST line to Barcelona was inaugurated in February 2008.

Our study also aimed to analyze the effect of the latent variables on mode choice decisions. Although latent variables are not usually included in the utility specification (because, in practice, their measurement is not straightforward), they may play an important role in individuals' choices. SP experiments represent the appropriate tool to analyze these situations because the analyst has the opportunity to present a detailed description of these variables in the experiment. Therefore, plane users, who represented the main source of traffic diversion, were faced with a stated choice experiment between the plane (the dominant mode) and the new HST alternative. As all the participants in the exercise were actually travelling in the corridor, the no-travelling option was not considered. The mixed or joint estimation method proposed by Bradley and Daly (1997), combining RP and SP data, enabled us to estimate the utility of the new alternative as well as the utility of the already existing options.

Table 2. Descriptive analysis of the sample. Madrid-Zaragoza

	Chosen mode					
	Car driver	*Car passenger*	*Bus*	*HST*	*Plane*	*Total*
Choice	59	17	57	75	18	226
Availability	164	92	189	218	171	-
LEVEL-OF-SERVICE ATTRIBUTES (Average per available alternative)						
Access time (minutes)	-	-	29	27	37	-
Waiting time (minutes)	-	-	30	23	60	-
In-vehicle-time (minutes)	213	208	256	129	57	-
Egress time (minutes)	-	-	29	34	42	-
Travel cost/Fuel (€)	26.80	15.04	12.84	43.81	69.62	-
Toll (€)	2.90	1.60	-	-	-	-
Access cost (€)	-	-	3.29	3.33	6.91	-
Egress cost (€)	-	-	3.80	5.23	8.20	-
Headway (minutes)	-	-	60	75	658	-
SOCIOECONOMIC CHARACTERISTICS (Classification per chosen mode)						
Trip purpose: work or education	20 (34%)	8 (47%)	14 (25%)	52 (69%)	10 (56%)	104 (46%)
Trip purpose: Other	39 (66%)	9 (53%)	43 (75%)	23 (31%)	8 (44%)	122 (54%)
Access+egress time <60'	-	-	47 (82%)	55 (73%)	16 (89%)	118 (52%)
Access+egress time >60'	-	-	10 (18%)	20 (27%)	2 (11%)	32 (14%)
Men	44 (75%)	7 (41%)	17 (30%)	51 (68%)	13 (72%)	132 (58%)
Women	15 (25%)	10 (59%)	40 (70%)	24 (32%)	5 (28%)	94 (42%)
Age (average)	37	35	32	38	34	36
Per capita weekly income (average €)	263.98	298.71	207.66	318.36	314.53	274.46
Expenditure rate (average)	2.10	2.25	1.56	2.46	2.46	2.13

With regard to data gathering, we used the same procedure as in the corridor Madrid-Zaragoza with the exception of the SP experiment, which was conducted at the corresponding boarding gates at the airport. We used computers to interview plane users, which allowed us to gain realism and adapt the SP experiment to the individuals' experience. Table 3 shows the sample's modal split corresponding to the RP survey, where the plane was the dominant mode with a share of close to 67%.

The descriptive analysis of the sample is shown in Table 4. In this corridor, total travel time by plane is substantially less than in the rest of the modes but again the proportion of access and waiting time is very high (nearly 70%).

Car is the second fastest mode with a total travel time of 70 minutes less than the train. Almost 56% of trips were mandatory (work or education) and 54% of travellers were men. We also observed differences in per capita weekly income, ranging from 167 € for car passengers to 351 € for plane users. And finally, the expenditure rate ranges from 1.23 for car passengers to 2.81 for plane users.

The SP survey included two latent variables: reliability and comfort. The former was included to account for the negative effect of delay over scheduled departure time and the latter to analyze the effect of having more space in plane seats. The experiment also included other typical level-of-service attributes, such as travel time, access time, travel cost and headway (time between two consecutive services), which helped us define the overall quality of the alternative. In order to gain realism, the levels assigned to some attributes in the SP exercise were customized to each respondent experience by pivoting the information provided by the RP questions around the reference alternative (the plane, in this case). Thus, the levels of travel cost (c_v) and access+egress time (t_a) were defined in terms (as plausible percentage variations according to the available information about future fares and access time for the HST) of the values experienced by the respondents, and the levels of the service headway varied with the departure time. In a recent research Rose et al. (2008) suggest the construction of D-efficient designs pivoting attribute levels around a reference alternative. Train and Wilson (2008) also analyze the dependence between the SP attributes and unobserved factors.

Table 5 shows a detailed definition of the attribute levels included in the experiment. A main effect factorial fractional design consisting of six attributes (four defined at three levels and two at two levels) and nine scenarios for each alternative was created using the WINMINT[4] software. A special code was created for that purpose, which allowed us to obtain RP and SP data in the same survey. Each respondent (the 295 plane users) was faced with nine choice sets that were created automatically by the program, obtaining a total of 2,655 SP observations. After removing 179 inconsistent observations[5], we obtained a mixed RP/SP data base of 2,917 observations.

Table 3. Modal split in the sample. Madrid-Barcelona

Mode	Travellers	%
Car-driver	38	8.62
Car-passenger	18	4.08
Bus	39	8.84
Train (conventional)	51	11.56
Plane	295	66.89

Table 4. Descriptive analysis of the sample. Madrid-Barcelona

	Chosen mode					
	Car Driver	*Car passenger*	*Bus*	*Train*	*Plane*	*Total*
Choice	38	18	39	51	295	441
Availability	165	92	165	288	435	-
LEVEL-OF-SERVICE ATTRIBUTES (Average per available alternative)						
Access time (minutes)	-	-	27	29	36	-
Waiting time (minutes)	-	-	40	28	58	-
In-vehicle-time (minutes)	357	369	477	332	59	-
Egress time (minutes)	-	-	33	39	37	-
Travel cost/Fuel (€)	46.07	22.70	25.13	62.33	95.19	-
Toll (€)	18.32	4.45	-	-	-	-
Access cost (€)	-	-	2.66	5.47	7.31	-
Egress cost (€)	-	-	3.50	7.07	7.91	-
Headway (minutes)	-	-	46	150	33	-
SOCIOECONOMIC CHARACTERISTICS (Classification per chosen mode)						
Trip purpose: work or education	16 (42%)	3 (17%)	10 (26%)	31 (61%)	187 (63%)	247 (56%)
Trip purpose: Other	22 (58%)	15 (83%)	29 (74%)	20 (39%)	108 (37%)	194 (44%)
Access+egress time <60'			28 (72%)	45 (88%)	240 (81%)	313 (71%)
Access+egress time >60'			11 (28%)	6 (12%)	55 (19%)	72 (16%)
Men	26 (68%)	8 (44%)	15 (38%)	28 (55%)	160 (54%)	237 (54%)
Women	12 (32%)	10 (56%)	24 (62%)	23 (45%)	135 (46%)	204 (46%)
Age (average)	41	31	28	39	36	36
Per capita weekly income (average €)	355.93	166.89	188.25	341.57	350.68	328.88
Expenditure rate (average)	2.86	1.23	1.41	2.68	2.81	2.62

4 The Model

4.1 Madrid-Zaragoza Corridor

To analyze demand in the Madrid-Zaragoza corridor, we estimated a disaggregate mode choice model based on the RP information provided by the surveys. We specified modal utility in terms of the main level-of-service attributes, as well as various socioeconomic characteristics of the individuals. We considered a linear-in-the-parameter (but not linear-in-the-attributes) specification that included transport costs divided by the expenditure rate (Jara-Díaz and Farah, 1987). Since we obtained a significant proportion of money spent on transport, ranging from 5% to 27% for the different modes, we also included cost squared terms as recommended in Jara-Díaz (1998)[6].

We also defined interactions between some socioeconomic variables and level-of-service attributes to analyze systematic taste variation (Rizzi and Ortúzar 2003). We found that there was significant interaction of *T* (trip purpose) with travel time. Thus, it was possible to analyze the perception of travel time in terms of the trip purpose. We also analyzed the interaction of access+egress time with a dummy variable *Ta*<60 (1, if access+egress time was less than 60 min, 0 otherwise[7]), which captures the time intensity of this component of travel time.

Table 5. Attributes and levels of the SP experiment

Attributes	**Levels**	**Mode**			
		Plane		**HST**	
Travel cost (c_v)	0	$c_v \times 1.10$		c_v	
	1	c_v		$c_v \times 0.90$	
	2	$c_v \times 0.90$		$c_v \times 0.80$	
Travel time	0	1h 20 min		2h 45 min	
	1	1h 10 min		2h 30 min	
	2	1h		2h 15 min	
Access+Egress time (t_a)	0	$t_a \times 1.20$		t_a	
	1	t_a		$t_a \times 0.90$	
	2	$t_a \times 0.80$		$t_a \times 0.80$	
Frequency (Headway) (*f*)		*Departure before 9:00*	*Departure after 9:00*	*Departure before 9:00*	*Departure after 9:00*
	0	Every 30 min	Every 60 min	Every 60 min	Every 90 min
	1	Every 15 min	Every 30 min	Every 30 min	Every 60 min
Reliability (*r*)	0	30 min delay (Inside the plane)		10 min delay	
	1	15 min delay (in the boarding gate)		5 min delay	
	2	Departure on time		Departure on time	
Comfort (*CA*)	0	Low: Little legroom Narrow seats			
	1	High: Ample legroom Wide seats		High: Ample legroom Wide seats	

c_v=Travel cost in plane
t_a=Access+Egress time in plane

Thus, the specification of the utility for the RP alternatives in this corridor is given by:

$$V^{RP}_{car-driver} = C_{cc} + (\theta_{t_v} + \theta_{t_v\_T} T)t_v + \theta_{c_v/g}\frac{c_v}{g} + \theta_{c_v^2/gI}\frac{{c_v}^2}{gI}$$

$$V^{RP}_{car-passenger} = C_{ca} + (\theta_{t_v} + \theta_{t_v\_T} T)t_v + \theta_{c_v/g}\frac{c_v}{g} + \theta_{c_v^2/gI}\frac{{c_v}^2}{gI}$$

$$V^{RP}_{bus} = C_{bus} + (\theta_{t_a} + \theta_{t_a\_T_{a<60}} T_{a<60})t_a + \theta_{t_e} t_e + (\theta_{t_v} + \theta_{t_v\_T} T)t_v + \theta_{c_v/g}\frac{c_v}{g} + \theta_{c_v^2/gI}\frac{{c_v}^2}{gI} + \theta_f f$$

$$V^{RP}_{train-HST} = C_{train-HST} + (\theta_{t_a} + \theta_{t_a\_T_{a<60}} T_{a<60})t_a + \theta_{t_e} t_e + (\theta_{t_v} + \theta_{t_v\_T} T)t_v + \theta_{c_v/g}\frac{c_v}{g} + \theta_{c_v^2/gI}\frac{{c_v}^2}{gI} + \theta_f f$$

$$V^{RP}_{plane} = (\theta_{t_a} + \theta_{t_a\_T_{a<60}} T_{a<60})t_a + \theta_{t_e} t_e + (\theta_{t_v} + \theta_{t_v\_T} T)t_v + \theta_{c_v/g}\frac{c_v}{g} + \theta_{c_v^2/gI}\frac{{c_v}^2}{gI} + \theta_f f \qquad (5)$$

where C_is are the alternative specific constants of the different modes, t_v is travel time, t_a is access+egress time, t_e is waiting time, c_v is travel cost, f is the service headway (i.e. time between two consecutive services) g is the expenditure rate, I is per capita family income and θs are unknown parameters.

We use different Nested Logit specifications to test the substitution patterns between the alternatives. In the final specification we found correlation between bus, HST and plane. Figure 1 shows the tree structure used in our model.

The estimation results are displayed in Table 6. All parameter estimates have the expected sign and were significant at the 95% confidence level, with the exception of the car constant, the waiting time[8], and the interaction of access+egress time with $T_a<60$.

Only the specific constants of car alternatives were significant and with a negative sign. This indicates that public transport alternatives are preferred if the effect of the other attributes is zero. These constants could include the effect of accident risks and inconvenience of driving. However, these aspects deserve a more detailed analysis. The specification of a model with the full set of constants (with two

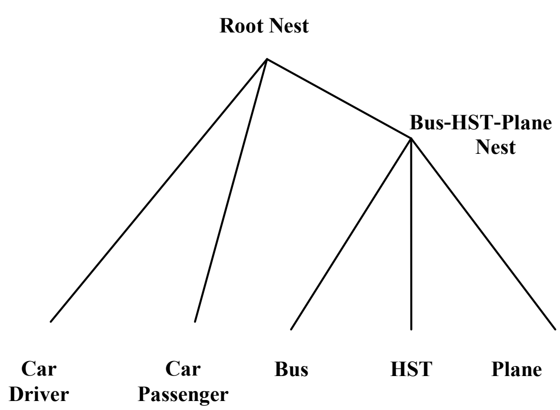

Figure 1. Tree structure. Madrid-Zaragoza

of them not significant) provided a non satisfactory result for the waiting time parameter, which was not significant but presented a positive sign. The likelihood ratio test allowed us to conclude (at the 99% confidence level) that the restricted model specifying only two constants was not significantly different from the more general one, so the simpler model should be preferred.

Finally, the estimation results show, in general, that travel time produces more disutility for mandatory trips (work or education). Despite the low level of significance, we observe that access+egress time produces more disutility to individuals with access+egress time greater than 60 minutes.

4.2 Madrid-Barcelona Corridor

In the Madrid-Barcelona corridor, the utility specification for the RP alternatives followed the same structure as those used in the corridor Madrid-Zaragoza (see Equation 5), where the fourth alternative in this corridor was the conventional train (note that the new HST was not operating on this corridor at that moment). In this case, the proportion of income spent on transport is also very significant, again justifying the inclusion of the cost squared term.

The utility for the SP alternatives (the new HST, and plane) was specified in accordance with the attributes included in the choice experiment: travel time (t_v), travel cost (c_v), access+egress time (t_a), service headway (f), reliability (r),expressed in terms of the delay time and comfort (CA). Comfort was specified interacting with travel time in order to obtain the perception of comfort in terms of the duration of the trip as well as the perception of travel time in terms of level of comfort. The utilities for the SP are alternatives are given by:

$$V_{HST}^{SP} = C_{HST} + (\theta_{t_a} + \theta_{t_a\_T_{a<60}} T_{a<60})t_a + (\theta_{t_v} + \theta_{t_v\_T} T)t_v + \theta_{c_v/g}\frac{c_v}{g} + \theta_{c_v^2/gI}\frac{c_v^2}{gI} + \theta_f f + \theta_r r$$

$$V_{plane}^{SP} = (\theta_{t_a} + \theta_{t_a\_T_{a<60}} T_{a<60})t_a + (\theta_{t_v} + \theta_{t_v\_T} T)t_v + \theta_{c_v/g}\frac{c_v}{g} + \theta_{c_v^2/gI}\frac{c_v^2}{gI} + \theta_f f + \cdots$$

$$\cdots + \theta_r r + \theta_{CA\_t_v} CA \cdot t_v \tag{6}$$

where C_{HST} is the alternative specific constant for the HST alternative and CA is equal to 1 if the level of comfort is high as defined in the SP experiment.

After testing different substitution patterns between the alternatives using Nested Logit models, in this case we only found a correlation between train and plane. This indicates that, in the individuals' decision making process, there is a higher level of substitution between these two alternatives. Figure 2 shows the artificial tree structure used in the RP/SP model. For more details about this estimation method see Ortúzar and Willumsen (2001). Although authors are aware that the Nested Logit model does not allow the inclusion of correlations among observations belonging to the same individual, we must mention that we were not able to estimate a sensible error component Mixed Logit Model specification accounting for this effect.

Table 6. Estimation results. Madrid-Zaragoza

Parameter		**Estimates (*t*-test)**
Car-driver constant	C_{cc}	-3.1890 (-1.7)
Car-passenger constant	C_{ca}	-6.7130 (-1.9)
Travel time (t_v)	θ_{tv}	-0.0097 (-2.7)
Travel cost/g (C_v/g)	$\theta_{cv/g}$	-0.1130 (-4.7)
Headway (f)	θ_f	-0.0019 (-2.3)
Travel cost^2/gI (c_v^2/gI)	$\theta_{cv2/gI}$	0.0764 (4.4)
Access+egress time (t_a)	θ_{ta}	-0.0217 (-3.3)
Waiting time (t_e)	θ_{te}	-0.0059 (-0.5)
Travel time_Work+education (t_v×T)	θ_{tv_T}	-0.0137 (-4.1)
Access+egress time_T acc+egr<60 ($T_{a<60}$×t_a)	$\theta_{ta\_Ta<60}$	0.0030 (0.4)
Nest parameter	μ	0.1965 (1.8) [-7.4]*
Model Fit Statistics		
l (0)*		-273.4453
l (C)*		-258.5531
l (θ)*		-213.3112
Observations		210

**t-test with respect to* μ*=1*

The estimation results are shown in Table 7. All parameter estimates have the expected sign and are significant at a 95% confidence level, with the exception of the headway, the waiting time, and the interaction of travel time with trip purpose. All the alternative specific constants (considering the plane as reference) for the RP alternatives are significant with a negative sign, indicating that plane would be preferred if the effect of the other attributes were zero. To check the advisability of including the alternative specific constant for the HST in the specification, we applied the likelihood ratio test. The restricted model (considering C_{HST}=0) is not significantly different at the 97% confidence level from the more general one (C_{HST}≠0) so the simpler specification is preferred for parsimony. In this corridor, travel time also produces more disutility for mandatory trips.

As comfort was specified interacting with travel time, we were able to analyze the disutility of travel time in terms of the level of comfort. We found that the disutility produced by travel time increases as the level of comfort diminishes. We also observed that access+egress time produces more disutility to individuals with access+egress time longer than 60 minutes.

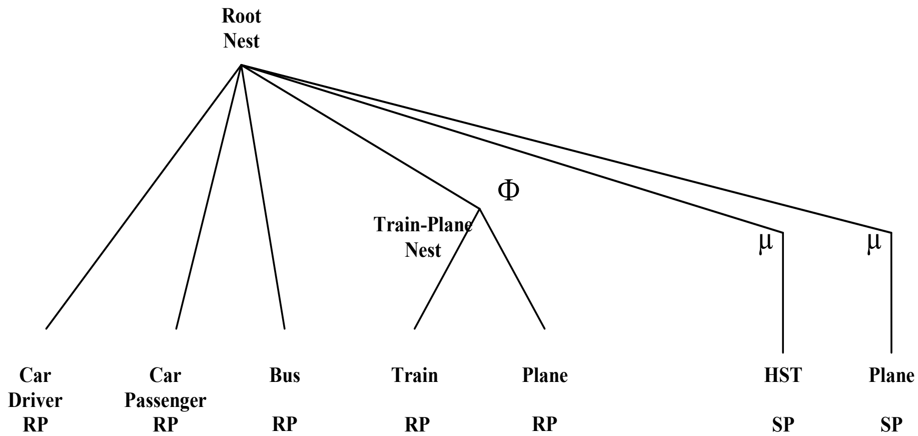

Figure 2. Artificial tree structure. Madrid-Barcelona

Table 7. Estimation results. Madrid-Barcelona

Parameter		Estimates (*t*-test)
Car-driver constant	C_{cc}	-3.8060 (-3.1)
Car-passenger constant	C_{ca}	-4.7120 (-3.4)
Bus constant	C_b	-2.5810 (-2.5)
Train constant	C_t	-1.0000 (-2.5)
Travel time (t_v)	θ_{tv}	-0.0047 (-2.8)
Travel cost/g (C_v/g)	$\theta_{cv/g}$	-0.0572 (-4.7)
Headway (f)	θ_f	-0.0011 (-0.5)
Travel cost^2*/gI* (c_v^2/gI)	$\theta_{cv2/gI}$	0.0174 (3.9)
Access+egress time (t_a)	θ_{ta}	-0.0199 (-4.9)
Waiting time (t_e)	θ_{te}	-0.0028 (-0.4)
Travel time_Work+education ($t_v \times T$)	θ_{tv_T}	-0.0009 (-1.0)
Access+egress time_T acc+egr<60 ($T_{a<60} \times t_a$)	$\theta_{ta\ Ta<60}$	0.0096 (2.5)
Reliability (delay) (r)	θ_r	-0.0180 (-2.6)
Travel time × Comfort high ($CA \times t_v$)	θ_{CA_tv}	0.0026 (1.8)
HST-Plane nest parameter	Φ	0.3651 (3.2) [-5.62]*
Scale factor SP	μ	0.9026 (3.2) [-0.34]*
Model Fit Statistics		
*l *(0)*		-2124.7995
l (C)*		-2074.5049
l(θ)*		-1997.3985
Observations		2917

**t-test with respect to* Φ*=1 y* μ*=1*

5 Applications

5.1 Derivation of the Willingness To Pay Measures

Measures of willingness to pay (WTP) express, in monetary terms, changes in the utility that are caused by changes in attributes. They are also referred to as the subjective value of a given attribute q_{kj} (e.g. the subjective value of time), and are derived from the estimation of discrete choice models as the ratio between the marginal utility of this attribute and the marginal utility of travel cost, which coincides with minus the marginal utility of income $\left(\frac{\partial V_j / \partial q_{kj}}{\partial V_j / \partial c_j}\right)$. Specifications of the representative utility, introducing income (e.g. dividing travel cost by the expenditure rate), interactions and quadratic terms yield more complex specifications of the marginal utilities that could take different values for every individual in the sample. This kind of specification also made the computation of confidence intervals for the WTP measures more complex since their distribution is generally unknown and the use of simulation techniques is normally required (Espino *et al.* 2006b).

Aggregate WTP were computed using the sample enumeration method, obtained as the average WTP for the individuals in the sample (see Ortúzar and Willumsen 2001 for more details about the application of this method). It should be pointed out that more complex specifications of the utility (e.g. random parameters) would need to simulate the distribution of the coefficients before applying the sample enumeration method. Table 8 shows the WTP measures obtained in the Madrid-Zaragoza corridor.

In general, WTP for travel time savings is greater for mandatory trips (work or education) than for other trip purposes, and takes the highest value for plane users, followed by HST, car and bus. Access+egress time is less valued by individuals for whom this figure is below 60 minutes. These are individuals living in the capital city or surrounding vicinities, however this difference should be interpreted with caution because the parameter corresponding to the incremental term (interaction) was not significant in the estimation process. In this corridor, the relationship SVAT>SVTT>SVWT[9] is satisfied for all modes. This means that individuals are more

Table 8. Willingness to pay measures. Madrid-Zaragoza

Subjective value of	Car driver	Car passenger	Bus	HST	Plane
travel time (€/hour)	25.28	20.54	19.10	25.68	34.22
- Work/education motive	36.13	33.24	29.81	38.89	51.18
- Other motive	13.31	11.19	10.53	14.19	20.66
access+egress time (€/hour)	-	-	22.76	30.50	41.14
- access+egress <60'	-	-	22.53	29.05	37.84
- access+egress>60'	-	-	23.32	33.48	46.06
waiting time (€/hour)	-	-	-	9.14	20.24
headway (€/hour)	-	-	2.17	2.88	6.39

willing to pay for saving access+egress time than for saving travel time, as happens in the majority of both interurban and urban trips. However, waiting time is less valued than travel time, in contrast to what happens in most urban trips, where waiting time (e.g. at the bus stop) is more related to the frequency of the service. For scheduled interurban trips, there is normally a minimum period of waiting time that is subject to the regulation imposed by the operation of the transport system (e.g. passengers must check in at the airport 40 minutes before departure of the flight), but in these cases individuals have the opportunity to undertake many different activities at the transport terminal (e.g. shopping, use a laptop, take meals or drinks, etc.) and do not have such a negative perception of the waiting time.

In the Madrid- Barcelona corridor, WTP measures were obtained from a hybrid utility containing common and non-common RP/SP parameters as in equation (4) (see Louviere *et al.* 2000 for more details). If attributes are defined only for the SP case (i.e. comfort, and reliability), their parameters must be scaled by μ . However, those corresponding to attributes measured in the RP data base do not need to be scaled even if they only appear in the SP utility (Cherchi and Ortúzar 2004). In this case, the sample enumeration method was only applied to individuals in the RP data base.

Table 9 presents the WTP measures for the Madrid-Barcelona corridor. Once again, the WTP for travel time savings is higher for mandatory trips. We also found that the value increases as the level of comfort is lower. When the level of plane comfort is low, the subjective value of time is similar to that obtained for the HST users. However, if the comfort for plane travellers is increased, their WTP for reduced travel time is substantially lower. The relationship SVAT>SVTT>SVWT is also maintained for travellers in this corridor. As the duration of the journey in this corridor is higher, the perception of waiting time is less negative, and consequently the WTP for waiting time savings is lower. However, it is important to note that this attribute presented a very low significance and these figures must be interpreted with caution.

We also obtained a high WTP for reductions in delay time, it being higher in the case of the HST than in that of the plane. In trips where departure times are scheduled and known in advance, delay time produces more disutility. In many of these cases passengers receive no compensation when delays occur, although it is becoming common practice for transport companies wishing to mitigate the inconveniences associated with delays to offer compensation programs as competitive strategies. Although it is beyond the scope of this paper, it may also be possible to analyze whether there are behavioural differences among travellers regarding the departure time (early versus late services). Thus, the importance of properly quantifying the WTP for more reliable transport services is highlighted. The omission of factors, such as delay, in the specification of the utility may bias other WTP measures related to travel time. In this regard, it is possible that the high figures for the value of time obtained in González-Savignat (2004) could be influenced by this factor.

We also obtained the WTP for improvements in comfort in the plane alternative. In the SP experiment we aimed to define a level of comfort for the plane similar to that for HST travellers. In our model, comfort was specified as interacting with travel time, thus the WTP for improved comfort varies with the duration of the trip. This was 8.45 euros for trips of approximately one hour in-vehicle. Although this is not a very high figure compared with other WTP, the impact of comfort attributes on the perception of time is not negligible.

Table 9. Willingness to pay measures. Madrid-Barcelona Corridor

Subjective value of	Car driver	Car passenger	Bus	Train	Plane		HST
					Comfort high	Comfort low	
travel time (€/hour)	17.59	12.37	12.39	14.97	10.55	19.29	19.33
- Work/education motive	18.91	15.48	15.03	17.77	12.96	22.50	22.41
- Other motive	15.24	10.46	10.72	12.18	7.52	15.27	14.00
access+egress time (€/hour)	-	-	30.34	37.14	46.44		46.45
- access+egress <60'	-	-	25.96	30.69	40.13		39.50
- access+egress>60'	-	-	42.78	51.79	61.31		61.60
waiting time (€/hour)	-	-	6.75	7.98	10.17		-
headway (€/hour)	-	-	2.64	3.12	3.98		3.92
delay (€/hour)	-	-	-	-	59.34		64.83
improving comfort from low to high (€)	-	-	-	-	8.54		-

For mandatory trips, the WTP for travel time savings was substantially higher in the Madrid-Zaragoza corridor. In this corridor, business travellers presented an average weekly income 75€ higher than those in the Madrid-Barcelona corridor. Thus, for these individuals the marginal utility of income is lower and the WTP is consequently higher.

5.2 Elasticity Values

The sample enumeration method was used to obtain the aggregated elasticities of the new HST alternative (Ortúzar and Willumsen 2001). Table 10 presents direct and cross elasticities of the probability of choosing the HST. These are computed as the arc elasticity considering 1% variation in the corresponding attribute. The same method could be applied for more complex models, like Mixed Logit, taking into consideration that parameters could be random variables and that probabilities are now integrals that must be approached using simulation.

In the Madrid-Zaragoza corridor, cross elasticities were computed with respect to car attributes (travel time and travel cost) while in the Madrid-Barcelona corridor they referred to plane attributes. In all the cases analyzed, we obtained figures below 1, i.e. demand for the HST is inelastic. This means that a one percent increase, for example, in travel cost will reduce demand for the HST in a lower proportion. We have shown that demand for the HST is, in general, more elastic in the Madrid-Barcelona corridor the only exception being travel time. Cross elasticities with respect to car attributes (for Madrid-Zaragoza) are very low, and these figures are consistent with the policy analysis presented in the next section.

Table 10. Elasticity values for HST

Direct elasticities of the probability of choosing HST		
Attribute	**Madrid-Zaragoza**	**Madrid-Barcelona**
Travel cost	-0.55	-0.72
Travel time	-0.59	-0.38
Access+egress time	-0.36	-0.44
Headway	-0.05	-0.07
Cross elasticities of the probability of choosing HST		
Attribute	**Madrid-Zaragoza (with respect to car attributes)**	**Madrid-Barcelona (with respect to plane attributes)**
Travel cost	0.12	0.7
Travel time	0.04	0.11
Access+egress time	-	0.51
Headway	-	0.01

Demand Response and Policy Analysis

Demand response to the application of different policies is represented by the percentage change in the aggregate market share of alternative *j* with respect to the initial situation:

$$\Delta P_j = \frac{P_j^1 - P_j^0}{P_j^0} \cdot 100 \tag{7}$$

Where P_j^1 is the aggregate share of alternative j once the policy is applied, and P_j^0 is the initial (base year) aggregate share of alternative *j*. Aggregate market shares are obtained as the average probabilities across the individuals in the sample (i.e. applying the sample enumeration method).

We are mainly interested in analyzing the new HST's potential competition with the alternative modes (especially car and plane). Table 11 shows the policy scenarios analyzed in the two corridors. All the policies refer to a base scenario, which represents the current situation, i.e. considering the new HST for Madrid-Zaragoza and the conventional train for Madrid-Barcelona.

In the Madrid-Zaragoza corridor, these policies consider increments in travel cost for the car alternatives (scenarios 1, 2 and 3), and the combination of a 100% increase in car cost with a 25% reduction in HST travel time (scenario 4) and a 10% reduction in HST fares (scenario 5). Figure 3 shows the percentage variation in the predicted market shares with respect to the base situation resulting from the application of the different policies. We find that policies consisting only of penalizing the car alternatives (increasing their travel costs) do not produce substantial increases (in all the cases these figures were below 5%) in the market shares of the alternative public transport competitors. However, a 25% reduction in travel time for the HST in

Table 11. Policy scenarios

ATTRIBUTE	SCENARIOS						
	BASE	1	2	3	4	5	6
Madrid-Zaragoza							
Car cost	Actual	+10%	+50%	+100%	+100%	+100%	-
HST cost	Actual	Actual	Actual	Actual	Actual	-10%	-
Delay (train/HST)	0 min	0 min	0 min	0 min	0 min	0 min	-
Access time (plane)	Actual	Actual	Actual	Actual	Actual	Actual	-
Waiting time (plane)	Actual	Actual	Actual	Actual	Actual	Actual	-
Travel time (HST)	Actual (HST)	Actual (HST)	Actual (HST)	Actual (HST)	-25%	Actual (HST)	-
Madrid-Barcelona							
Comfort	Actual (level 0)	Actual (level 0)	More space and legroom (level 1)	Actual (level 0)	Actual (level 0)	Actual (level 0)	Actual (level 0)
Delay (plane)	0 min	0 min	0 min	30 min	0 min	0 min	0 min
Delay (train/HST)	0 min	0 min	0 min	0 min	10 min	0 min	0 min
Access time (plane)	Actual	Actual	Actual	Actual	Actual	+10%	Actual
Waiting time (plane)	Actual	Actual	Actual	Actual	Actual	Actual	+50%
Travel time (train/HST)	Actual (Conventional train)	-50% (HST)	-50% (HST)	-50% (HST)	-50% (HST)	-50% (HST)	-50% (HST)

combination with a 100% increment in car costs will produce the highest gains for the HST.

All the scenarios analyzed in the Madrid-Barcelona corridor considered a 50% reduction in travel time for the new HST. Since the plane is the principal competitor to this new alternative, the different policies are focused on plane attributes. Thus, scenario 1 considers only the reductions in travel time for the HST. Scenarios 2 to 5 consider, ceteris paribus, improvements in plane comfort, increases in delay for plane and train; and increases in access and waiting time for plane, respectively.

Demand response to the different scenarios is presented in Figure 4. Reductions in the plane's market share due to the introduction of the new HST do not exceed 15%, in any of the cases analyzed; the plane being the dominant mode in this corridor with predicted market share close to 65%. Demand for the HST was more sensitive to those policies that penalize time attributes of the plane (delay, access time and waiting time in scenarios 3, 5 and 6). Thus, airlines and airports must operate efficiently in order to maintain air transport as a competitive alternative in medium distance corridors. Although, comfort is an important indicator of service quality for air passengers, it is strongly related to the duration of the trip. In this kind of corridor, improvements in the level of comfort, providing planes with more space between seats, do not produce significant variations in market shares.

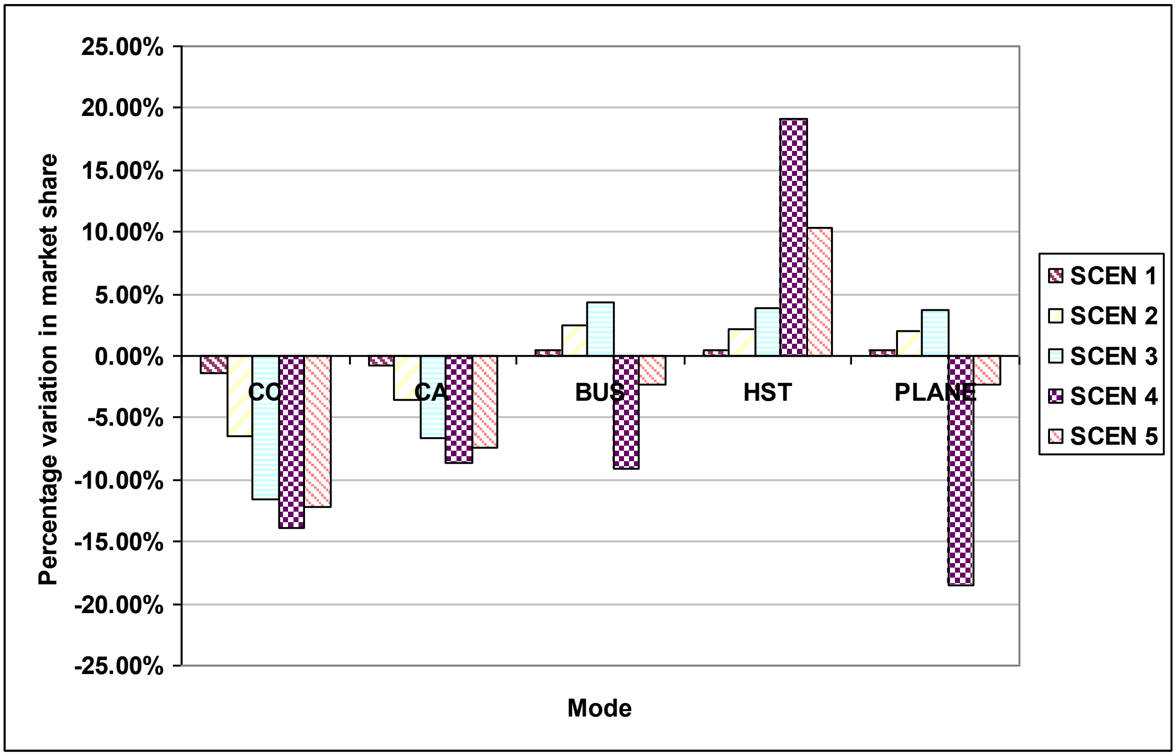

Figure 3. Demand response. Madrid-Zaragoza

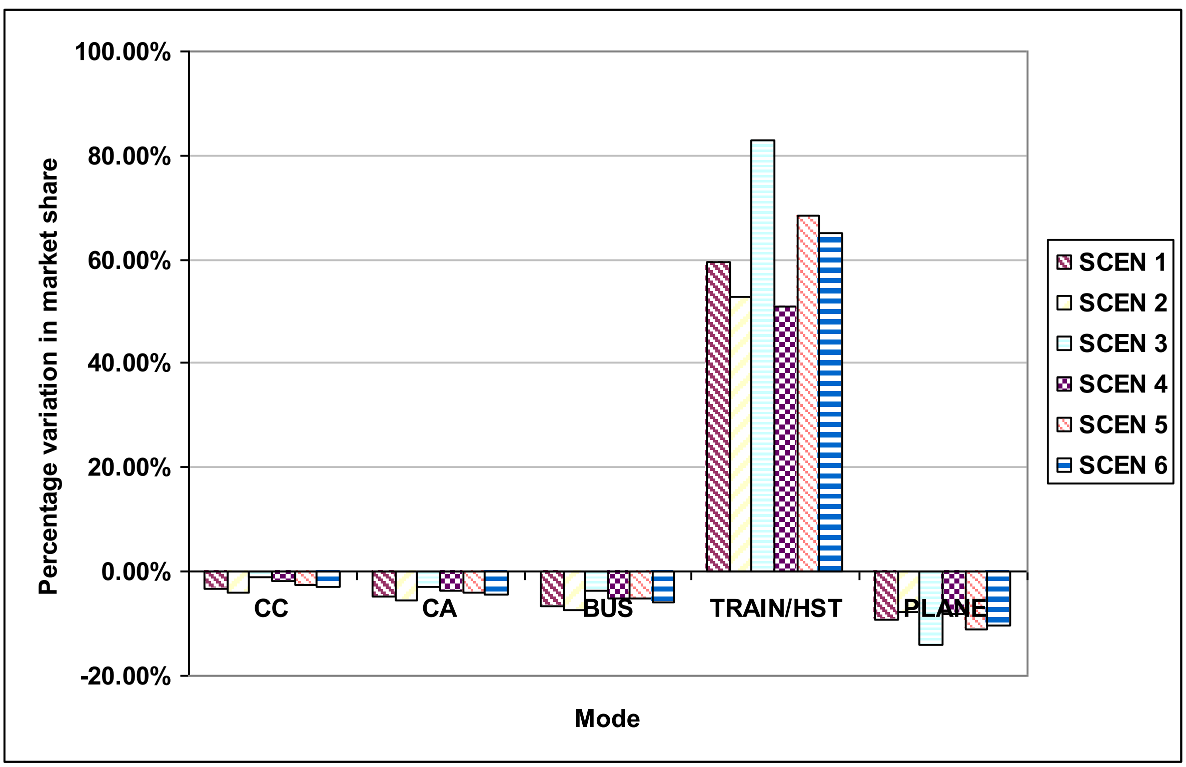

Figure 4. Demand response. Madrid-Barcelona

6 Conclusions

In this paper, we analyzed competition of the HST with the main competing modes in the Madrid-Zaragoza-Barcelona corridor. The analysis was based on the estimation of disaggregate demand models using both RP and mixed RP/SP databases. Modal utilities for the RP and SP alternatives were defined in terms of the main level-of-service attributes and various socioeconomic characteristics of the individuals. The model specification aims to explain the changes in the demand for HST as a result of changes in travel times, travel costs, access+egress times, headway, reliability and comfort across all the modes that compete in this corridor. In particular we found the interaction of travel time with the travel purpose and comfort (only in the case Madrid-Barcelona) very interesting. Regarding the structure, our models also capture the existence of correlations between bus, train and plane (in Madrid-Zaragoza) and between train and plane in the case of the RP alternatives in the Madrid-Barcelona corridor. In this case, the correlation is expected to be higher when the new mode starts to operate in the corridor because the HST is a closer substitute to the plane than the conventional train.

We obtained different measures of willingness to pay for improved service quality. In general, WTP for travel time savings is higher for mandatory trips and the specification of the latent variable comfort allowed us to confirm the hypothesis that it increases as the level of comfort is lower. In the Madrid-Barcelona corridor, we also obtained a high WTP for reductions in delay time. Finally, we obtained the WTP for improved comfort in the plane (more space and legroom) demonstrating that the impact of comfort attributes on the perception of time is not negligible.

We have demonstrated that HST demand is inelastic to price, time and especially to headway. However, it is necessary to recognize that in the short-distance Madrid-Zaragoza corridor, the demand is more sensitive to travel time than to price or access-egress time. Regarding cross-elasticities of HST demand to changes in car price and time, it can be seen that policies that penalize the travel cost are more effective than pure congestion of highways. In the case of competition between HST and air transport in the Madrid-Barcelona corridor, we showed that HST demand is more sensitive to air travel cost and access-egress times.

We also analyzed demand response to different policy scenarios that consider variations in some level-of-service attributes. In the case of Madrid-Zaragoza, we obtained a low response to policies that only penalize car alternatives by increasing their travel costs. However, substantial gains for the market share of the HST were obtained when these policies are combined with reductions in HST travel time. In the Madrid-Barcelona corridor, demand for the new HST was more sensitive to those policies that penalize time attributes of the plane. The results of our analysis, together with the low rate of return of HST projects, cast some doubts on the potential competition that HSTs can exert in air markets that have been characterized by a high frequency of air services in the past. However, the HST could be a more competitive alternative in the short distance segments (Madrid-Zaragoza and Zaragoza-Barcelona) by trying to capture traffic from car and bus users.

Although demand response is a key element of cost-benefit analysis, other aspects such as the impacts of the new infrastructure on regional development and welfare should also be considered prior to the decision to build new transport infrastructures.

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Notes

[1] In this corridor conventional train was replaced by the new HST.

[2] By latent variable we mean an attribute which is probably considered by individuals but is not easy (or feasible) to measure in practice (Espino *et al.* 2006a).

[3] Expenditure rate is defined as *per capita* family income divided by available time, that is, total time per period (a week in this case) minus working hours.

[4] This is a standard software, developed by *Rand Europe* http://www.hpgholding.nl/ (the former *Hague Consulting Group* (HCG)), which was frequently used to conduct SP experiments at the time this data set was gathered. However, authors are aware that orthogonal data are not suited for the estimation of nested Logit Models and recognize that the state-of-the-art is now moving toward the use of D-optimal stated choice designs (See e.g. Bliemer and Rose 2009).

[5] Those where the individual chose the worst alternative.

[6] This specification corresponds to the second order Taylor expansion of the conditional indirect utility obtained from a Cobb-Douglas direct utility function.

[7] Different threshold values were tested in order to analyze whether the differences in the perception of access+egress time could be explained by the magnitude of this variable. We only found these differences significant for the Madrid-Barcelona corridor and the best fit was obtained when the threshold value was equal to one hour.

[8] This variable was only specified in the utility of the HST and plane. As the number of departures per day was very low in these alternatives (in comparison with bus with around ten departures per day) the specification of this variable in the bus alternative produced counterintuitive results, distorting the interpretation of the rest of the attributes.

[9] SVAT: Subjective value of access time; SVTT: Subjective value of travel time; SVWT: Subjective value of waiting time.