COMPETITIVENESS OF THE HIGH SPEED RAIL: LISBON-MADRID CORRIDOR ANALYSIS BASED ON DISCRETE CHOICE MODELS

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ABSTRACT
This paper has two main objectives: (1) to examine the potential of the high speed rail to compete against other transport modes currently operating between Lisbon and Madrid; and (2) to analyze the capacity of intermodal solutions incorporating the high speed rail to compete when included in air systems. Thus, more than evaluating the competition capacity of high speed rails in point-to-point trips, this research study assesses how attractive intermodal solutions in trips to medium and long haul destinations are.
The analysis is based on discrete choice models, calibrated with data collected through a web stated preference survey. Furthermore, scenarios are used to explore the results obtained by the models. The results obtained suggest that the high speed train will not only be able to compete with other modes in a point-to-point trip from Lisbon to Madrid, but also be part of an intermodal chain to destinations beyond. It was also concluded that within the Business segment, the medium haul market sets the limit of intermodal transport solutions' attractiveness. Within the Leisure segment, however, this limit might be extended up to the long haul market, depending on the pricing strategy. These conclusions are supported by the attractiveness of each transport mode.

Keywords: intermodality, competition, cooperation, air transport, high speed rail.

INTRODUCTION
According to André (2006, p.79), "in routes where the airplane allows a better transport, no prejudice against it is justified. On the contrary, the airplane's infrastructure flexibility, speed and efficiency in long routes, make this transport mode priceless." Strohl (1993, p.21) argues, however, that "there is an operating range where the rail transport constitutes a privileged option, as long as it offers adequate conditions in terms of speed, comfort and frequency. This distance range is between 100km to 600-800km, with a travelling time between one and four hours, but preferably with a maximum of three hours". The Lisbon-Madrid route (629 km by car) is within Strohl's distance range. So, in theory and assuming that Strohl is right, a high speed rail (HSR) alternative should have conditions to become a competitive option in transporting passengers.
In routes of about 600 km or 1-hour flight, the HSR and the air transport coexist in the same market as mutual substitutes. Because each mode is operated by a different operator, competition between them is inevitable (Givoni; Banisher, 2006). The French TGV and the Spanish AVE show that HSR can compete with other transport modes like air transport. The fact that the Eurostar had 80% market-share in trips between London and Paris/Brussels in 2011 serves as evidence of this (Eurostar, 2011). Apart from substitution, there is compatibility between the HSR and the air transport that can be regarded as complementary. This characteristic allows cooperation between these two transport modes, which may result in important benefits to both air and rail systems. For instance, better infrastructure capacity exploitation may be achieved through cooperation (EC, 1998).

Deregulation of international air transport had profound effects both on market structure and on operating patterns (Doganis, 2006). An important outcome of air transport deregulation was the emergence of hub and spoke systems centered on major airports where a single carrier is dominant (Rodrigue, Comtois, Slack, 2009). Although there are several definitions of hub and spoke systems, two fundamental features in these networks are acknowledged: spatial concentration and temporal concentration (Reynolds-Feighan, 2001; Burghouwt and Huys, 2003).
The HSR capacity to compete against the air transport in connections between airports proved that this transport mode is able to substitute some feeder flights within hub and spoke systems. Still, more than cooperation, the great opportunity is presented through the integration of rail services and air transport. Currently, the AIRail, a service operating in Frankfurt-Cologne and Frankfurt-Stuttgart, is the best example of intermodal substitution through air-rail integration. Lufthansa understood the benefits of this form of cooperation and stopped operating on these routes.
Based on the above, it seems that the HSR is able to alter competition dynamics within that link and also to other destinations as a result of intermodal integration, regarding cooperation between different transport modes. In this context, HSR services connecting airports appear to be suitable to substitute some air services, with positive effects to both rail and air systems.
The interaction between the HSR and the air transport has been the subject of much scholarly attention, though mostly from the competition standpoint. Compared to the amount of research on competition in point-to-point trips, research on the topics of complementarity, cooperation and integration between rail and air transport is still scarce. According to IATA (2004, p.40), "studies often deal with the passenger preferences between air and HST transport modes but not on the passenger preferences between direct connection and combined transport modes".
Against this backdrop, this paper has two main objectives: (1) to examine the potential of the HSR to compete against other transport modes currently operating between Lisbon and Madrid; and (2) to analyze the capacity of intermodal solutions incorporating the HSR to compete when included in air systems. Thus, more than evaluating the competition capacity of high speed rails in point-to-point trips, this research study assesses how attractive intermodal solutions in trips to medium and long haul destinations are.
The timeliness and importance of this study is undeniable, considering that the HSR introduction in the Lisbon-Madrid corridor, where a rail connection between the two capitals' main airports is expected, is currently under discussion. Hence, the study was conducted taking into account the expected characteristics and attributes of this rail service. Based on the service's characteristics offered by each transport mode, its attractiveness was analyzed. In order to accomplish this, it was necessary to understand how passengers value attributes when choosing a given transport mode.
It is important to note that this paper focuses on studying the interactions between transport modes; therefore, internal effects in each modal system and issues related to infrastructure capacity management were not considered.

METHODOLOGY

In order to achieve its objectives, this paper adopts a quantitative approach, using discrete choice models to assess the capacity of unimodal and intermodal solutions, incorporating the HSR, to compete when included in air systems.
The study begins with the literature review on intermodal competition and cooperation.
Furthermore, a case study was conducted, so as to evaluate the capacity of transport solutions to compete. As the title of this paper indicates, the Lisbon-Madrid corridor was selected. The competition capacity analysis was performed assessing the solutions' attractiveness from the passenger's point of view. It is considered that the competition and cooperation study between transport modes fits, in theory, discrete choice problems modeling, in which an individual needs to choose one element from a set of mutually exclusive alternatives – in this case, a transport mode in a

trip from Lisbon to the destinations Madrid, Stockholm and New York. The data needed to calibrate the models were collected through a stated preference web survey. The survey results were analyzed in order to verify their statistical relevance.

After calibrating the discrete choice models, it was necessary to decide what would be the inputs to be inserted in the models. To deal with uncertain future environment, prospective scenarios were used as a way to settle which inputs were more adequate. In each scenario a sensitivity analysis to the attribute "price" was performed to assess the attractiveness' limits of the transport solution and therefore its competing capacity.

LITERATURE REVIEW

Traditionally, air and rail services were not in competition. However, with the opening of the air market and the development of HSRs this situation changed (Givoni; Banister, 2006). Although the potential benefits of a more integrated network due to air and rail integration have been acknowledged, the HSR/air transport relation has been mainly seen from the competition point of view.

Intermodal competition between air transport and other transport modes has been approached by academics from two perspectives: *ex ante* (forecasts) and *ex post* (observation) (Dobruszkes, 2011). Forecasts concerns models used to predict the market's modal distribution. This is the approach adopted in this study. Other authors, such as the European Commission in COST 318 (1998), González-Savignat (2004); López-Pita and Robusté (2005); Steer Davies Gleave (2006); and Román, Espino and Martín (2007), have adopted this approach before.

According to Rodrigue, Comtois and Slack (2009), partial and total substitution of air transport by the HSR is possible in short and medium haul trips with a total travel time of up to three hours. In that case, the rail connection and air transport can be used complementarily, requiring schedule and tariffs coordination and physical integration of the infrastructures within the transport network. Cooperation arises due to the existence of a kind of compatibility for users that can be regarded as complementary. According to the European Commission (1998, p.59), "two transport modes will be regarded as complementary for the user when their successive utilization is either necessary or simply preferred to the utilization of a single transport mode for a journey between two cities".

The European Commission further considers that the contribution of HSR to a better utilization of the capacities of air and rail systems is twofold. First, the HSR generates competition where air capacities are congested, with a possible secondary effect on rail congestion. The main effect is to divert a part of the traffic, corresponding to the origin-destination link served by high speed train, from the congested airports. At the same time, it can absorb traffic from conventional tracks, releasing capacity for freight and suburban/interurban trains. Second, HSR enables connections between air and interurban rail services more convenient for travelers. The effect is to substitute feeder flights connecting with long-distance flights, by high-speed feeder trains, ensuring not only direct connections to airports but also compatible service schedules. The consequence is to increase the relative availability of airport slots for long distance flights.

IATA (2003), too, focused on intermodal cooperation, conducting a study that aimed to understand the agents' point of view (airlines, rail operators, airports and passengers) regarding the development and promotion of HSR services. EUROCONTROL (2004) analyzed the role of intermodal transport in future airports. Vespermann and Wald (2011) studied air transport intermodal integration state of the art, focusing on the reasons that motivate intermodal integration and its importance. They also tried to understand what could be the future developments in this field. More recently, Givoni and Banister (2006) examined the possibility of modal substitution in conditions of air and HSR integration. This research was conducted in a context of need for increasing Heathrow airport's capacity. Givoni and Banister assessed the benefits of intermodal integration as an alternative to the airport's expansion.

DISCRETE CHOICE MODELS

Looking back to research studies that aimed to predict market's modal share, Gonzalez-Savignat (2004) used probabilistic choice models to characterize passengers' preferences regarding trips between Madrid and Barcelona. Based on the data collected, it was possible to predict passenger's behavior, to assess the HSR ability to compete in this market and to simulate different policies related to service variables. In passengers' modal choice analysis, "discrete choice models are the most suitable for this purpose, as they guarantee consistency between the demand function and the consumer theory (McFadden, 1974)" (Gonzalez-Savignat, 2004, p.79). Román, Espino and Martín (2007) also analyzed the Madrid-Barcelona corridor, estimating disaggregated mode choice models using information provided by a revealed and stated preferences database.

The foregoing authors approached their research problems using discrete choice models. These statistical models are based on the Stochastic Utility Theory and try to reproduce people's decision-making conditions towards a finite set of alternatives. According to Train (2009), the statistical and economic properties of these models have already been profoundly studied. Discrete choice models, namely Logit and Nested Logit, were well succeeded when applied in Transportation, Energy, Housing and Marketing.

Although the Multinominal Logit (MNL) is the most widely used model due to the software availability and the easiness to implement the model and to interpret its output, its conditions are quite strict. However, when the Multinominal Logit's conditions are violated, other specifications can be used. Models like the Nested Logit (NL) allow for less restrictive conditions. The NL results from the partial relaxation of the MNL conditions. This relaxation occurs in the model's variance components, allowing some correlation between alternatives subsets. Like the MNL the NL is simple to use and as the benefits of being of closed-form solution (Hensher; Rose; Greene, 2005). In other words, it can be calculated using simple mathematical operations, not requiring complex analytical calculations. Other, more advanced, models exist, like the Multinomal Probit and the Mixed Logit. These models relax even more the MNL's initial assumptions. Though, these models are of open-form solutions requiring more complex analytical calculations to identify changes in the choice probabilities through varying levels of attributes and socio-demographic characteristics.

In what regards the types of choice data, two primary sources of choices emerged: revealed preferences and stated preferences (Hensher; Rose; Greene, 2005). "Both revealed preferences and stated preferences approaches have been widely used in the study of travelers' behavior to produce empirical models for predicting travel choices" (Hensher; Barnard; Truong (1988, p.45)).

Revealed preferences data refer to situations where the choice is actually made in real market situations. The term "revealed" is used because the passengers reveal their actual/real preferences. In contrast, stated preference data refer to situations where the choice is made by considering hypothetical situations. The term "stated" refers thus to the fact that passengers state what their choices would be in the hypothetical situations (Train, 2009). Stated preferences can be of two kinds. In the first kind, the individual is asked to indicate his preferences among a set of combination of attributes which define services of products, ordering or rating the alternatives. In the second kind, only one of the alternatives can be chosen. "Stated choice experiments are now the most popular form of Stated Preference method in transportation and are growing in popularity in other areas such as marketing, geography, regional science and tourism" (Hensher (1994, p.2)).

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CASE STUDY

The Lisbon-Madrid corridor

The present study is focused on the Lisbon-Madrid corridor, since, as mentioned before, there is the expectation that a HSR link will be implemented in the future. In fact, this project is identified as one of the priority axis in the Trans-European transport network.

The corridor under analysis is characterized by highly concentrated population centers usually separated by long distances. Although the car is the most common transport mode, with more than 50% of all trips, air transport also has an important market-share (28,4%). Today, the air transport market-share is supposed to be higher due to low cost carriers. The bus also has a meaningful position, having about 16% market-share. In contrast, the rail market-share is small – approximately 4%. Regarding travel motivations, around one third of the passengers state that their main motivation is Business and Education. Leisure figures as the main motivation, constitute more than 50% of the passengers' motivations.

Segmentation

Different passengers value the same attributes in a different way. This fact generates the need for segment markets. According to Boeing (2012), there are four main segments that should be considered by airlines. These segments are defined based on the passengers' motivation to travel (business/personal) and the flight's scope (short-haul/long-haul). Gillen, Morrison e Stewart (2003) identified six distinct markets for air travel: business and leisure travel; long-haul and short-haul; and international and domestic flights.

Based on this, two segmentation factors were considered: motivation to travel and flight's scope. First, concerning motivation to travel, leisure passengers were segmented from business passengers. Traditionally, airlines segment their customers into business and economy passenger in order to optimize product orientation (Teichert, Shehu and von Wartburg, 2008). Second, regarding the flight's scope, three destinations were considered: Madrid (short-haul), Stockholm (medium-haul) and New York (long-haul). These destinations were chosen because there are regular flights to these places departing from Lisbon.

Stated preference survey

In order to evaluate the competitiveness of transport solutions incorporating the HSR (unimodal and intermodal), a web survey was set up and advertised to collect stated preference (SP) data.

The survey was divided into two main parts. The first one aimed at obtaining the socio-demographic information necessary to characterize the sample surveyed. In the second one, SP experiments were presented to the respondents. Three experiments were presented for each segment. The data collection was performed using a convenience sampling technique.

In the SP experiments' construction, a fractional-factorial design was used with the attribute levels, ensuring null correlations among the attributes. This procedure was performed with the software SPSS®. The alternatives presented depended on the destination. For Madrid, only unimodal transport solutions were presented: car, bus, HSR, and air transport. For Stockholm and New York, intermodal and multimodal solutions were also taken into account, with the choice set including direct air transport, air transport with stopovers, an intermodal solution that combined the HSR until Madrid and direct air transport departing from Barajas to the final destination, and a multimodal solution that combined bus until Madrid and direct air transport.

The following attributes were considered in the survey: ticket price, total travel time, frequency, and comfort. An argument can be made that comfort is a subjective variable and thus difficult to measure. However, being an important source of utility, it should nevertheless be considered. In order to overcome the difficulties of measuring comfort, three attributes were considered in the study: seat pitch, noise level and hand luggage space. These last three attributes were obtained through a previous survey that asked the respondents which were the attributes that played the main role in the creation of an adequate comfort level.

Discrete choice models calibration

Owing to the segmentation adopted, six discrete choice models were calibrated based on the data collected. Two models were calibrated to each destination, one for the Leisure segment and another for the Business segment. The number of SP comparisons is different for each model, ranging from 373 and 1704. This difference is due to the fact that only the respondents that stated travelling regularly in Business answered the models from the Business segment. With respect to the motivation, 76% of the respondents revealed that their motivation to travel was Leisure, 7% Business, and 17% both. 71% of the respondents had gone to Madrid at least once during the current year. Regarding the respondents occupation, 48% were employed, 43% were students. 76% of the respondents had superior level qualifications. Concerning age, 64% of the sample is less than 31 years old, 34% is between 31 and 65 and only 2% is older than 65.

Every parameter of the models has the expected sign and the great majority is statistically significant to the null hypothesis rejection test. The models' validation criteria included the following items: 90% confidence level, adequate overall goodness of fit (pseudo-R^2 > 20%); more than 50% correctly predicted choices. The models' specifications can be viewed in the Appendix.

The NLOGIT® Version 4.0 module of the program LIMDEP® was used to estimate the discrete choice models. This software package allows for specifying the utility functions, using a maximum likelihood estimation of a discrete choice model, and performing several statistical tests on the results.

Table 1 – Calibration results. Model 1.1 – Madrid/Business

Parameter	Coefficient	*p-value*
Price – Air transport	-0.0156	0.0000
Total travel time – Air transport	-0.5818	0.0005
Seat pitch – Air transport	0.0174	0.0024
Price – HSR	-0.0261	0.0000
Total travel time - HST	-0.7066	0.0000
Frequency – HST	0.0438	0.0045
Seat pitch – HST	0.0154	0.0046
Constant – Car	-1.9336	0.0320
Price – Car	-0.0320	0.0000
Constant – Bus	-6.1869	0.0000
VTTS (Air transport)	37.3 €/h	
VTTS (HST)	27.1 €/h	
LL(4)	-350.196	
LL(10)	-266.665	
Pseudo - R^2	24%	
% of choices correctly predicted	64%	
Nº of comparisons	417	

HSR – High Speed Rail; VTTS – Value of Travel Time Savings

Table 2 - Calibration results. Model 1.2– Madrid/Leisure

Parameter	Coefficient	*p-value*
Price – Air transport	-0.0261	0.0000
Total travel time – Air transport	-0.2690	0.0047
Seat pitch – Air transport	0.0156	0.0000
Total travel time – Car	-0.3295	0.0006
Price – Car	-0.0235	0.0000
Noise level – Car	-0.3765	0.0425
Constant – HSR	2.5453	0.0000
Price – HSR	-0.0293	0.0000
Total travel time – HSR	-0.6953	0.0000
Noise level – HSR	-0.3931	0.0053
Seat pitch – HSR	0.0049	0.0893
Total travel time – Bus	-0.2265	0.0006
Price – Bus	-0.0361	0.0000
Noise level – Bus	-0.5223	0.0262
IV Parameter		
A	1.0000	
B	0.7457	0.0000
VTTS (Air transport)	10.3 €/h	
VTTS (Car)	14.0 €/h	
VTTS (HSR)	23.7 €/h	
LL(4)	-1743.040	
LL(15)	-1357.914	
Pseudo - R^2	22%	
% of choices correctly predicted	59 %	
Nº of comparisons	1796	

HSR – High Speed Rail; VTTS – Value of Travel Time Savings

Table 3 – Calibration results. Model 2.1 – Stockholm/Business

Parameter	Coefficient	*p-value*
Price – ATD	-0.0165	0.0000
Total travel time – ATD	-0.5542	0.0000
Price – IS	-0.0083	0.0000
Total Travel Time – IS	-0.5208	0.0000
Constant – ATS	-5.7349	0.0030
Total Travel Time – ATS	-0.2763	0.0257
Price – ATS	-0.0166	0.0020
Constant – MS	-2.9454	0.0311
Total Travel Time – MS	-0.3857	0.0000
Price – MS	-0.0146	0.0000
IV Parameter		
A	1.0000	
B	0.7177	0.0000
VTTS (ATD)	33.6 €/h	
VTTS (IS)	62.7 €/h	
VTTS (ATS)	16.6 €/h	
VTTS (MS)	26.6 €/h	
LL(0)	-385.092	
LL(11)	-247.504	
Pseudo - R^2	36%	
% of choices correctly predicted	66%	
Nº of comparisons	417	

ATD – Air Transport Direct; IS – Intermodal Solution; ATS – Air Transport with Stopovers; MS – Multimodal Solution; VTTS – Value of Travel Time Savings

Table 4 - Calibration results. Model 2.2 – Stockholm/Leisure

Parameter	Coefficient	*p-value*
Price – ATD	-0.0162	0.0000
Total Travel Time – ATD	-0.3128	0.0000
Noise level – ATD	-0.6149	0.0001
Constant – ATS	-2.4693	0.0004
Total Travel Time – ATS	-0.2605	0.0000
Price – ATS	-0.0148	0.0000
Noise level – ATS	-0.5234	0.0083
Seat pitch – ATS	0.0101	0.0044
Constant – IS	-1.4194	0.0108
Price – IS	-0.0119	0.0000
Noise level – IS	-0.6683	0.0000
Total Travel Time – IS	-0.3557	0.0000
Seat pitch – IS	0.0063	0.0395
Constant – MS	-4.8761	0.0001
Seat pitch – MS	0.0299	0.0212
Price – MS	-0.0162	0.0000
Total Travel Time – MS	-0.3031	0.0000
IV Parameter		
A	1.0000	
B	0.8683	0.0000
VTTS (ATD)	19.3 €/h	
VTTS (ATS)	17.6 €/h	
VTTS (IS)	29.9 €/h	
VTTS (MS)	18.7 €/h	
LL(4)	-1691.430	
LL(18)	-1151.842	
Pseudo - R^2	32%	
% of choices correctly predicted	62%	
Nº of comparisons	1704	

ATD – Air Transport Direct; IS – Intermodal Solution; ATS – Air Transport with Stopovers; MS – Multimodal Solution; VTTS – Value of Travel Time Savings

Table 5 - Calibration results. Model 3.1– New York/Business

Parameter	Coefficient	*p-value*
Price – ATD	-0.0075	0.0000
Total Travel Time – ATD	-0.2837	0.0000
Frequency – ATD	0.2054	0.0321
Constant – MS	-2.8499	0.0470
Total Travel Time – MS	-0.3906	0.0000
Price – MS	-0.0039	0.0004
Price – IS	-0.0099	0.0000
Total Travel Time – IS	-0.2541	0.0026
Total Travel Time – ATS	-0.2870	0.0000
Price – ATS	-0.0058	0.0000
VTTS (ATD)	37.8 €/h	
VTTS (MS)	100.2 €/h	
VTTS (IS)	25.7 €/h	
VTTS (ATS)	49.5 €/h	
LL(4)	-387.224	
LL(10)	-248.662	
Pseudo - R^2	36%	
% of choices correctly predicted	64%	
Nº of comparisons	373	

ATD – Air Transport Direct; IS – Intermodal Solution; ATS – Air Transport with Stopovers; MS – Multimodal Solution; VTTS – Value of Travel Time Savings

Table 6 - Calibration results. Model 3.2 – New York/Leisure

Parameter	Coefficient	*p-value*
Price – ATD	-0.0080	0.0000
Total Travel Time – ATD	-0.3499	0.0000
Seat Pitch – ATD	0.0099	0.0004
Noise level – ATD	-0.7939	0.0000
Constant – MS	-5.0957	0.0000
Total Travel Time – MS	-0.2625	0.0000
Price – MS	-0.0067	0.0000
Noise level – MS	-0.9399	0.0002
Frequency – MS	0.0972	0.0010
Constant – IS	-4.9950	0.0001
Price – IS	-0.0074	0.0000
Total Travel Time – IS	-0.2466	0.0000
Noise level – IS	-0.5644	0.0034
Seat pitch – IS	0.0175	0.0000
Constant – ATS	-2.0103	0.0012
Total Travel Time – ATS	-0.1863	0.0000
Price – ATS	-0.0074	0.0000
IV Parameter		
A	1.0000	
B	0.8335	0.0000
VTTS (ATD)	43.7 €/h	
VTTS (MS)	39.2 €/h	
VTTS (IS)	33.3 €/h	
VTTS (ATS)	25.2 €/h	
LL(4)	-1957.592	
LL(18)	-1321.370	
Pseudo - R^2	33%	
% of choices correctly predicted	59%	
Nº of comparisons	1746	

ATD – Air Transport Direct; IS – Intermodal Solution; ATS – Air Transport with Stopovers; MS – Multimodal Solution; VTTS – Value of Travel Time Savings

RESULTS

The choice probability of each alternative depends on the attributes' value, the models' inputs (Table 9). Thus, changes in these values are reflected in the final results. As a way to deal with an uncertain changing environment, scenarios were used to assess future changes in terms of modes' attractiveness. Scenarios from EUROCONTROL Long-Term Forecast: IFR Flight Movements 2010-2030 were used (Table 7). In these scenarios there are four variables capable of influencing the price of travel:

- Environmental regulation;
- Oil and fuel;
- Security;
- Operating costs.

Table 7 - Scenarios capable of influencing Price. Adapted from EUROCONTROL (2010)

	Scenario A	Scenario B	Scenario C	Scenario D
Environmental regulation	€37/tonne CO_2 in 2030	€90/tonne CO_2 in 2030	€60/tonne CO_2 in 2030	€60/tonne CO_2 in 2030
Oil and fuel	Steady increase, $130/barrel in 2030	Steady increase, $130/barrel in 2030	Production uncertainty, price volatility, $200/barrel in 2030	Peak in production in 2020, $220 in 2030
Security	Decreasing costs	No change	No change	Increasing
Operational costs	Decreasing	Decreasing	Decrease	Decrease

These four scenarios from EUROCONTROL generated eight scenarios due to the introduction of two variables capable of influencing total travel time, namely congestion and airport relocation (Table 8). The variable airport relocation is related to the intention of implementing a new airport in the Lisbon Metropolitan Area.

Further analysis identified small differences between the scenarios. As a result, a deeper analysis was performed, but only for the two extreme scenarios (A.1 and D.2). It was considered that the intermediary scenarios do not add value to the results.

Table 8 – Scenarios generated after the introduction of the variables Congestion and Airport Relocation

Travel time		Scenario A	Scenario B	Scenario C	Scenario D
Congestion	Increase. 15 min/departure delay	A.1	B.1	C.1	D.1
Congestion and airport relocation	Increase. 15 min + 15 min/departure delay	A.2	B.2	C.2	D.2

Table 9 - Inputs used in the models – Origin: Lisbon; Destination: Madrid / Stockholm / New York

Segment	Transport solution*	Price (€)*	Total travelling time*	Frequency*	Seat pitch (cm)*	Hand luggage space (high/low)*	Noise level (high/low)*
Business	ATD / ATD / ATD	120 / 325 / 800	3h03min / 6h15min / 10h35min	-	81/81/81	Low / Low / Low	-
	HSR / IS / IS	100 / 270 / 700	4h15min / 9h25min / 15h35min	-	90/90/90	High / High / High	-
	Car(1pax) / ATS / ATS	75 / 270 / 700	6h39min / 8h25min / 13h35min	-	90/90/90	High / Low / Low	-
	Bus / MS / MS	40 / 390 / 790	8h33min / 12h45min / 18h25min	-	75/75/75	Low / Low / Low	-
Leisure	ATD / ATD / ATD	120 / 325 / 800	3h03min / 6h15min / 10h35min	-	81/81/81	-	High / High / High
	HSR / IS / IS	100 / 270 / 700	4h15min / 9h25min / 15h35min	-	90/90/90	-	Low / Low / Low
	Car(3pax) / ATS / ATS	75 / 270 / 700	6h39min / 8h25min / 13h35min	-	90/90/90	-	Low / High / High
	Bus / MS / MS	40 / 390 / 790	8h33min / 12h45min / 18h25min	-	75/75/75	-	High / High / High

HSR – High Speed Rail; ATD – Air Transport Direct; IS – Intermodal Solution; ATS – Air Transport with Stopovers; MS – Multimodal Solution

*Remark: This table summarizes the inputs used in the models. Each cell includes three figures that refer to the destinations Madrid, Stockholm and New York, respectively.

After defining the models' inputs, the following results were obtained.

Lisbon-Madrid corridor

Based on the obtained results, it is possible to conclude that the HSR introduction in the Lisbon-Madrid corridor will enhance competition between transport modes, especially with the air transport. However, HSR attractiveness highly depends on the fares charged. Considerable differences were exhibited between the Leisure and Business segments. In the Leisure segment, assuming both the existence of competition with a conventional airline and a 100 Euros fare, the HSR shows a 30,4% choice probability. Nonetheless, results show that the high speed train will hardly be able to compete with low cost airlines. In what concerns the Business segment, high speed train's choice probability is lower than 23%. This solution is only competitive if it presents an average fare of about 75 Euros.

Taking into account other possible future scenarios, the results show that an increase in air congestion and fuel costs will contribute significantly to an increase in HSR attractiveness.

Medium haul

The destination Stockholm was considered a medium haul trip. An intermodal solution was included in the set of alternatives, combining HSR and air transport.

The obtained results show that, in the Business segment, an intermodal solution is more attractive than air transport with stopovers. However, the HSR is less competitive comparing to direct flights. Regarding the Leisure segment, more competition is observed as passengers in this segment have lower elasticity to travelling time. It can be seen that in Leisure, indirect air transport's (with stopovers) choice probability is higher than in Business. Considering the lower elasticity travelling time from passengers travelling in Leisure, the choice probabilities within the set of alternatives is more balanced.

Taking into account future scenarios, the HSR will increase its attractiveness in both segments, though this increase will be more significant in the Business segment.

Long haul

Preferences from passengers travelling to New York were studied in order to analyze competition and cooperation in long haul trips. An intermodal solution combining HSR and air transport was also considered within this destination's set of alternatives.

Results show that, in the Business segment, an intermodal solution with the characteristics assumed will hardly be able to compete with direct air transport. High intermodal attractiveness within this segment can only be found in scenarios where airline fares and travelling time markedly rise. On the contrary, in Leisure, the intermodal solution may indeed compete with the other transport modes.

Table 10 – Results obtained for a set of prices of transport solutions including the HSR

			Segment									
			Business					Leisure				
Madrid	HSR's price		50	75	100	125	150	50	75	100	125	150
	Business as usual	ATD	42%	56%	68%	76%	81%	18%	28%	38%	45%	50%
		HSR	52%	36%	22%	13%	7%	54%	47%	30%	18%	9%
		Car	5%	7%	8%	9%	10%	13%	17%	21%	24%	26%
		Bus	1%	1%	1%	2%	2%	5%	8%	11%	13%	15%
	A.1	ATD	21%	33%	47%	60%	70%	5%	8%	12%	17%	21%
		HSR	75%	61%	45%	30%	18%	79%	66%	50%	34%	20%
		Car	2%	4%	5%	7%	8%	11%	16%	23%	28%	33%
		Bus	1%	2%	3%	3%	4%	6%	10%	15%	21%	26%
	D.2	ATD	13%	23%	35%	50%	63%	2%	4%	8%	13%	19%
		HSR	85%	36%	61%	45%	30%	90%	83%	71%	57%	40%
		Car	0%	0%	1%	1%	1%	7%	11%	16%	23%	30%
		Bus	1%	2%	4%	5%	6%	1%	3%	5%	8%	11%
Stockholm	IS' price		250	325	400	475	550	250	325	400	475	550
	Business as usual	ATD	54%	63%	70%	74%	76%	42%	52%	57%	59%	61%
		IS	31%	19%	12%	7%	4%	31%	15%	7%	3%	1%
		ATS	15%	17%	19%	20%	21%	27%	33%	36%	38%	38%
		MS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	A.1	ATD	18%	28%	38%	48%	55%	17%	28%	38%	45%	49%
		IS	73%	59%	44%	30%	18%	68%	46%	26%	13%	6%
		ATS	9%	13%	18%	23%	26%	15%	26%	36%	42%	46%
		MS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	D.2	ATD	8%	13%	21%	30%	39%	7%	13	23%	32%	39%
		IS	87%	78%	66%	51%	36%	86%	71%	50%	29%	14%
		ATS	5%	9%	13%	19%	25%	8%	16	27%	39%	47%
		MS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
New York	IS' price		700	800	900	1000	1100	700	800	900	1000	1100
	Business as usual	ATD	66%	71%	72%	73%	73%	31%	35%	37%	39%	39%
		IS	10%	4%	2%	1%	0%	25%	15%	9%	5%	3%
		ATS	23%	25%	25%	25%	26%	44%	49%	53%	55%	57%
		MS	1%	1%	1%	1%	1%	1%	1%	1%	1%	2%
	A.1	ATD	22%	36%	47%	53%	56%	9%	14%	21%	28%	33%
		IS	62%	37%	18%	8%	3%	79%	67%	53%	37%	24%
		ATS	15%	25%	32%	37%	38%	11%	17%	25%	33%	40%
		MS	1%	2%	3%	3%	3%	1%	1%	1%	2%	3%
	D.2	ATD	7%	15%	27%	36%	44%	2%	4%	7%	12%	17%
		IS	85%	67%	43%	22%	9%	95%	90%	83%	73%	59%
		ATS	7%	16%	27%	37%	42%	3%	5%	9%	33%	40%
		MS	1%	2%	3%	4%	5%	0%	0%	1%	1%	2%

ATD – Air Transport Direct; IS – Intermodal Solution; ATS – Air Transport with Stopovers; MS – Multimodal Solution; VTTS – Value of Travel Time Savings

CONCLUSIONS

Regarding the destination Madrid, it can be seen that the HSR can be competitive against other transport modes that currently operate in the Lisbon-Madrid corridor. As to the destination Stockholm, which, in this study, represents a medium haul trip, results show that an intermodal transport solution is competitive, especially in the Business segment. Concerning New York, the destination chosen to represent a long haul trip, it is verified that the intermodal solution has low attractiveness, particularly in the Business segment. Nevertheless, in a scenario with higher air tariffs and with the increase of airport congestion, a substantial increase in the intermodal solution's choice probability could be witnessed, especially in the Leisure segment.

Given these results, the following conclusions can be drawn:

- HSR may be a competitive alternative to transport passengers in the Lisbon-Madrid corridor, especially in the Leisure segment;
- In medium haul trips, intermodal solutions integrating HSR and air transport show a substantial choice probability in both segments;
- In long haul trips, an intermodal solution integrating the HSR and the air transport shows a low attractiveness for the Business segment.
- A more balanced choice probability distribution is found in the Leisure segment for both medium and long haul markets.
- Future fare and travelling time increases in air transport, that result in an attractiveness decrease for this alternative, shall encourage choosing intermodal solutions.

Hence, it can be concluded that for the Business segment the medium haul market sets the limit for intermodal solutions' attractiveness. For the Leisure segment, however, this boundary may be extended to the long haul market, depending on the tariffs strategy.

The results of this study show also that the HSR may not only be a direct transport mode to Madrid, but as well be part of an intermodal transport chain to destinations beyond. All the conclusions drawn are supported by the choice probabilities obtained for each transport mode within the alternatives' set.

Despite the foregoing results, a remark is necessary. Looking back to discrete choice models that tried to predict modal distribution, significant differences can be observed. In the case of the Madrid-Barcelona corridor, two studies presented quite different results. The first predicted less than 35% market-share for the HSR. The second predicted a value between 53% and 63%. Recent data from Renfe (2011) show that HSR market-share compared to air transport is approximately 45% in this route. These differences may be caused either by limitations in the studies conducted or by market changes.

Study's limitations

"Essentially, all models are wrong, but some are useful" (Box, 1987). Since it is not possible to see reality completely reflected in a model, certain assumptions had to be made in this study. The models' limitations arose from these assumptions. First, a biased sample was obtained in the stated preference survey due to the sampling technique used. Second, the sample used to calibrate the Business models is approximately four times smaller than the Leisure sample. As a consequence, statistical representativeness was limited.

Third, price and time were treated as alternative-specific variables rather than generic. Although this is not outright wrong, doing so allowed for time and cost to vary by mode. The purpose was to account for possible differences between each user group/alternative. In the case of time, it allowed for the estimation of alternative-specific measures of VTTS. Other HSR have generally treated time and cost as generic constants.

Fourth, and last, the utility functions calibrated included attributes related to comfort that can be considered subjective. Even though comfort attributes can be important sources of utility, it must be noted that the addition of this kind of variables renders the results arguable.

Future developments

The models built have a static character. However, some of the alternatives' attributes (the price, in particular) are not static. This may limit the models' scope of use. Thus, in the future, these models should be integrated in a more extensive model that takes into account not only external and internal factors, but also the operators' strategy.

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