Transportation Research Part A 69 (2014) 461–475

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Does European high-speed rail affect the current level of air services? An EU-wide analysis

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ARTICLE INFO

Article history:
Received 6 February 2013
Received in revised form 10 July 2014
Accepted 15 September 2014

Keywords:
Air transport
High-speed rail
Intermodal competition
Europe
Censored regressions

ABSTRACT

This paper analyses whether the current provision of air services in Europe is impacted by high-speed rail (HSR). An ex-post analysis is carried out considering 161 routes EU-wide using transnational data. We use censored regressions with special attention paid to the presence of outliers in the sample and to the potential problem of non-normality of error terms. It is found that shorter HSR travel times involve less air services, with similar impact on both airline seats and flights. This impact quickly drops between 2.0- and 2.5-h HSR travel time. The impact of HSR frequencies is much more limited. Hubbing strategies led by the airlines have the opposite effect from HSR, as hubs involve more air services. Airline/HSR integration at the airport and cities being served by both central and peripheral stations have no significant impact. Metropolitan and national spatial patterns may help to better understand intermodal effects.

1. Introduction

Modern high-speed rail (HSR) has been expanding throughout Europe for more than three decades. Further developments are ongoing, and others may be later decided. In the meantime, some HSR routes have proven to significantly decrease airlines' market shares or volumes supplied (Albalate and Bel, 2012a,b; Givoni, 2006; Patterson and Perl, 1999; Vickerman, 1997). This makes HSR appealing for policymakers and researchers involved in climate change mitigation and thus in policies leading to less oil-dependant mobilities (Givoni, 2007). For example, the 2011 European Union's (EU) White Paper on transport states the following goals:

> "By 2050, complete a European high-speed rail network. Triple the length of the existing high-speed rail network by 2030 and maintain a dense railway network in all Member States. By 2050 the majority of medium-distance passenger transport should go by rail." (EC, 2011)

However, policy relies on very little empirical evidence for the impacts of HSR on air transport, a gap this paper aims to help fill by examining airline services in the presence of HSR services in Europe.

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http://dx.doi.org/10.1016/j.tra.2014.09.004
0965-8564/

Of course, the expansion of HSR in Europe and Asia, along with construction and planning in other countries such as Australia and the US, has led to an increase in scientific research on HSR and its intermodal impacts. However, as shown by Kroes (2000), quoted by Wardman et al. (2002), Capon et al. (2003) and Givoni and Dobruszkes (2013), research is mostly done on expected intermodal competition and considering demand (i.e. passengers) (see, for example, de Rus and Inglada, 1997; Hensher, 1997; and Román et al., 2007). Ex-ante analysis is naturally necessary to assess projects and to select which ones should be carried out first. However, there is clear evidence that traffic forecasts are often wrong (Flyvbjerg et al., 2005). To give only one example, a traffic forecast by the London & Continental Railways for the Cross-English Channel market in 1998 predicted 25 million HSR passengers in 2006 (Preston and Wall, 2008). In 2012, five years after completion of all high-speed line sections being operated, there were still only 9.9 million passengers. This suggests that the intermodal impacts of HSR should also be monitored once the services are operational. However, ex-post analysis based on observed competition is scarce by contrast with ex-ante analysis (Givoni and Dobruszkes, 2013).

Table 1 summarises ex-post evidence from research on the intermodal impacts induced by HSR. It is first found that most research focuses on a very limited range of routes, if not only one. Of course, considering only a few routes makes it possible to survey passengers and to consider properly some relevant variables (such as fares) that are otherwise very difficult to gather for a large set of routes. However, restricted route samples raise the issue of representativeness. Also, studies restricted to one given domestic market potentially hide national specificities as nothing says that, all other things being equal, the intermodal effects due to HSR would be similar anywhere.

As noted, much more attention is paid to the passengers than to the services (for example, the number of flights or seats offered). This is surprising, since data on services are becoming more available (Dobruszkes, 2012). But, above all, neglecting trends in services is problematic because ultimately, transport services are what generate environmental impacts.

Finally, while a lot of ex-ante works focused on HSR impacts use econometrics (see Wardman et al., 2002; Capon et al., 2003, for more details), this is clearly not the rule with regards to ex-post analyses. Most authors provide figures but do not implement econometric analyses to interpret them. Yet when such methods are used, they usually concern very limited sets of routes. We can quote only four ex-post works that cover a large range of routes. Two of them cover only one country, namely Japan or Germany (although international routes are included in the latter). Clever and Hansen (2008) analyse 82 airport-pairs and 1,260 HSR station-pairs in Japan. They notably find that airlines are more affected by HSR when access/egress times to HSR stations are either short or long.[1] Friederiszick et al. (2009) investigate 207 routes (130 international) serving Germany. On a subset of 84 domestic routes, they find that low-cost airlines (LCAs) entry resulted in a decrease in rail passengers of at least 7% in second class and 18% in first class. Two other papers do not focus specifically on HSR-induced intermodal effects, but nevertheless do consider HSR as a potential factor. Bilotkach et al. (2010) analyse how airline frequencies are impacted by distance, considering 887 airport-pairs serving the 10 largest European airports. Their models also include a variable indicating whether air services are competed by HSR. The authors expect more flights in the case of HSR, because frequency is seen as a major attribute of competition. However, because HSR is beyond the scope of their research, its presence is only rendered by a dummy variable, although it is known than HSR travel time is usually considered as fundamental for competitiveness (Givoni and Dobruszkes, 2013). Yet, they found mixed evidence of impact. Givoni and Rietveld (2009) investigate airlines' choice of aircraft size for 549 routes worldwide. They report that considering competition from HSR (as a dummy for less than 3 h of service) did not significantly affect aircraft size.

Finally, it is worth mentioning that the various papers investigating the relations between the provision or use of air services and various transport- and geo-economics attributes usually do not consider HSR (see, for example, Cattan, 1995; Jorge-Calderón, 1997; Dobruszkes et al., 2011). However, Jiménez and Betancor (2012) find an HSR effect on airline business but working on a small sample of routes.

In short, there is no analysis that focuses on the impact of HSR on other transport modes while considering appropriate transport-related factors and covering a large range of European routes, and using econometric methods. This paper aims at conducting such a global analysis for Europe. More precisely, this paper aims to analyse whether the existing EU-wide HSR services significantly affect the volume of air services. In contrast to previous works, our research (1) embraces all relevant routes throughout Europe, (2) is interested in the ex-post effect of HSR on air services, and (3) focuses on the supply rather than demand. In the remaining of the paper, Section 2 introduces the data used and the models built; Section 3 presents the results; and Section 4 the conclusions.

2. Research strategy

2.1. Data and variables

This research is an ex-post analysis of the current air services under the influence of HSR using censored regressions. First, we build a model describing the volume of air services, and then add several HSR-related variables. The analysis is at the route level, more specifically, at the city-pair level, thus merging airports belonging to the same metropolitan area according to functional urban areas' (FUAs) limits defined at the EU level (see below).[2] Airport pairs are relevant if one investigates the

[1] Shorter access or egress journeys are attractive by nature, but longer journeys by train provide the opportunity to work while travelling.

[2] For example, Paris includes Paris Charles de Gaulle (CDG) and Paris Orly but not Paris Beauvais-Tillé Airport, which is dedicated to the low-cost airlines and located out of the Paris FUA (more than 80 km by road). By contrast, Rome includes Fiumicino – Leonardo da Vinci Airport, which is used by traditional airlines, and Ciampino Airport, which is dedicated to the low-cost airlines since both airports belong to Rome's FUA.

Table 1
Published ex-post analyses of HSR-induced intermodal effects.

Sources	Focusing on (a)	Markets	Econo-metrics	Main results with regards to Air/Rail competition
Bonnafous (1987)	A	Paris-South-east (1984)	N	33% of HSR pax diverted from planes
Cascetta et al. (2011)	A	Rome-Naples (2005/7)	N	0.6% of HSR pax diverted from planes and bus
	C		Y	Higher frequency, discount fares and better access/egress facilities would help in transferring pax from cars to HSR
	D (demand)		N	−30% conv. train users −1% car users
	E		N	Travel time is the main factor of modal choice
EC (1998)	A, B	Hamburg-Frankfurt (1991/2), Madrid-Seville (1990/4), Paris-South-east (1980/90)	N	Most diverted passengers come from air, and HSR market share decreases with longer travel times
	D (supply and demand)	Madrid-Seville (1990/6)		Quick drop in airline passengers and market shares after the introduction of HSR
	E	Madrid-Seville (N.A.)		The main reasons for still flying are connections (53%) and speed (18%)
Suh et al. (2005)	A	8 city pairs from Seoul (2003/4)	N	17% of HSR pax diverted from planes
	B		N	Rail market share has increased
	D (supply and demand)		N	Airlines then express coaches were more affected by HSR than cars
Vickerman (1997)	A	Madrid-Seville (2002/4) Germany as a whole (N.A.)	N	32% of HSR passengers diverted from air and 25% from car Germany: 12% of HSR traffic would come from air and road
	D (demand)	Paris-Lyon (1980/4) Paris-Geneva (1980/4) Madrid-Seville (2002/4)	N	Air traffic halved 20% decrease in air traffic 60% decrease in air traffic
RSIS (2009)	B	4 city pairs from Seoul (2004/8)	N	HSR mainly affects air and car travel
Cheng (2010)	B, D (demand)	4 city pairs from Taipei (2005/8)	N	Air transport is the most affected transport mode
Campos and Gagnepain (2009)	C	Paris-Amsterdam (2005)	Y	A change of HSR fare has a limited impact on both traditional and low-cost airlines' market shares
Clever and Hansen (2008)	C	82 airport pairs and 1,260 HSR station pairs in Japan (1995)	Y	Access to/egress from HSR affects intermodal competition
Steer Davies Gleave (2006)	C	15 routes throughout Europe (of which 8 are real HSR services) (1999/2005)	Y	Travel time is the main factor of modal split
Zembri (2010)	C	6 domestic city pairs from Paris (2006/8)	N	HSR travel time has apparent impact on rail vs. air market shares. When flights survive the competition, they tend to serve Air France's hub at Paris CDG Airport
Pagliara et al. (2012)	C	Madrid-Barcelona (2003/10)	Y	Travel cost, smooth check-in and security controls at the airport, service frequency and parking capacity at the station all influence modal choice (travel time is not part of the analysis)
	D (demand)		N	The decrease in air traffic only happened when HSR travel time went down to less than three hours (HSL then fully opened)
Behrens and Pels (2012)	D	London-Paris (2003/9)	Y	Travel time and frequency are the main determinants of market shares. Higher frequencies can offset longer travel times
Friederiszick et al. (2009)	D (demand)	207 routes (130 international) serving Germany (2006/7)	Y	Drop in rail passengers following the entry of LCAs into the market; stronger effect on longer routes
Jiménez and Betancor (2012)	D (supply and demand)	9 city pairs from Madrid, of which 4 are served by HSR (1999/2009)	Y (on the current level of services)	Airlines reacted to HSR-induced competition by reducing their operations
Lee et al. (2012)	D (supply and demand)	Seoul-Busan and Seoul-Daegu (2003/11)	N	The lower HSR travel time, the higher the drop in airline passengers/services
Park and Ha (2006)	D (supply and demand)	Seoul-Daegu (2003/4)	N	Decrease in airline passenger/operations
Dobruszkes (2011)	D (supply)	Cologne-Munich, Paris-Brussels, Paris-Metz, Brussels-London, Paris-Marseilles (1991/2010)	N	The lower the HSR travel time, the higher the drop in airline passengers/services; considering airline seats or flights can affect the results

(*continued on next page*)

Table 1 (*continued*)

Sources	Focusing on (a)	Markets	Econo-metrics	Main results with regards to Air/Rail competition
Fu et al. (2012)	D (supply)	Guangzhou-Wuhan and Guangzhou-Changsha (2008/10)	N	Large decrease in airline seats
Coto-Millán et al. (2007) quoting a 1993 survey	E	Madrid-Seville (N.A.)	N	The main reasons for choosing HSR are speed/time (57%) and comfort (17%). The main reason for still flying is comfort (31%), while speed/time (42%) and comfort (35%) are quoted by car users
Chang and Lee (2008)	E	Seoul–Busan and Seoul–Mokpo (2003/5)	N	Fare and poor station accessibility are the main reasons stated for not using HSR services
Bilotkach et al. (2010)	Z (airline frequencies)	887 European airport pairs (2006/7)	Y	HSR services (dummy) marginally affect airlines' frequency choice for shorter routes (less than 475 km flown)
Givoni and Rietveld (2009)	Z (airlines' aircraft size)	549 routes worldwide (2003)	Y	Less-than-3-h HSR services (dummy) do not impact aircraft size
Kappes and Merkert (2013)	Z (barriers to entry into aviation markets)	Europe (2010)	N	Airlines' managers perceive HSR services as the second most effective barrier to entry into the market
Zhang et al. (2014)	Z (market power in airline industry)	China (2010/1, quarterly data)	Y	HSR is the main factor reducing market power in the domestic airline industry

(a). A: HSR passengers by mode of origin. B: Before/after modal shares. C: Current passenger modal shares. D: Trends in traffic (various transport modes) with regards to supply and/or demand. E. Survey on modal choice. Z: Other analyses including HSR among the explicative variables. N.A.: period not available.

strategies of airlines at service level, including, for example, travel fares and changes in multiple airport systems. It would nevertheless raise the issue of more weight given to those city-pairs served by more than one airport-pair. By contrast, city pairs are relevant if one focuses on the dynamics by transport mode, as this is the case here, since we are interested in how the total provision of air services between two cities is possibly affected by HSR.

All routes where direct HSR services compete with air services were considered, including those where airlines exited the market following intermodal competition. At least one leg of the HSR service must be operated at 250 kph or more, thus involving a high-speed line (HSL). For the Paris-Marseilles-Nice corridor with an HSL between Paris and Marseilles, for instance, we consider Paris-Marseilles and Paris-Nice as routes, because the passenger travels at more than 250 kph on part of the journey. In contrast, Marseilles-Nice is rejected, because there is no HSL between these two cities; thus, there is not high-speed service, since high-speed trains (HSTs) do not go faster than conventional trains. Some city-pairs where the dynamics of air services are clearly not linked with HSR are rejected as well,[3] leading us to consider 163 city-pairs. Since some variables are not available for two city-pairs, our final set of data contains 161 city-pairs Europe-wide. The two directions are considered once, in each case from the largest city to the smallest (for example, we considered London–Brussels rather than Brussels–London). Fig. 1 shows our sample, and makes the distinction between routes that are still operational and those that have been terminated (see below). Most routes are domestic and serve the four large European countries with large HSL networks (namely, France, Spain, Germany and Italy). Only 36 international city pairs meet our criteria.

We consider two dependent variables relating to the volume of regular air services supplied: the number of seats and the number of flights. For a given number of seats supplied, the airlines can use smaller or larger planes, thus offering higher or lower frequencies, respectively (Givoni and Rietveld, 2009; Bilotkach et al., 2010). Frequency-oriented supply can be part of a strategy to keep time-sensitive passengers, usually business passengers, prepared to pay high fares in order to save time.[4] Airlines facing HSR competition may thus decrease the number of seats supplied while maintaining or even increasing frequencies, which has important implications in terms of airport congestion and environmental impacts.

Following, Jorge-Calderón (1997) and Bilotkach et al. (2010), for example, our initial set of independent variables is a mix of geo-economic and transport-related factors introduced in Table 2. This set is also guided by the findings summarised in Table 1, which notably highlight the role of travel time, frequency, airline hubs and access to the station. Table 2 includes some variables that will be rejected at a later stage (see below). Geo-economic variables come from research commissioned by the French DATAR.[5] (LATTS et al., 2011) Updating previous works produced for ESPON (European Observation Network,

[3] For example, the Lille–Basel/Mulhouse EuroAirport route was terminated in 2003, four years before the launch of the Eastern French HSR. The reason is that Air Lib went bankrupt, and no other airline wanted to operate this low-density route. Another example is the Torino-Bologna route. HSLs opened in 2006, 2008 and 2009, and air services were sporadically operated in 2002 (by Air Vallee, a regional airline with a changing network strategy) and around 2008 (by Interstate Airlines, which went bankrupt in 2010).

[4] Button and Drexler (2005) found only weak and past evidence that increasing frequency helps US airlines gain higher market shares. However, they admit that this does not prevent airlines from supplying (too) high frequencies, believing that such an effect exists.

[5] Interdepartmental Delegation for Territorial Development and Regional Attractiveness.

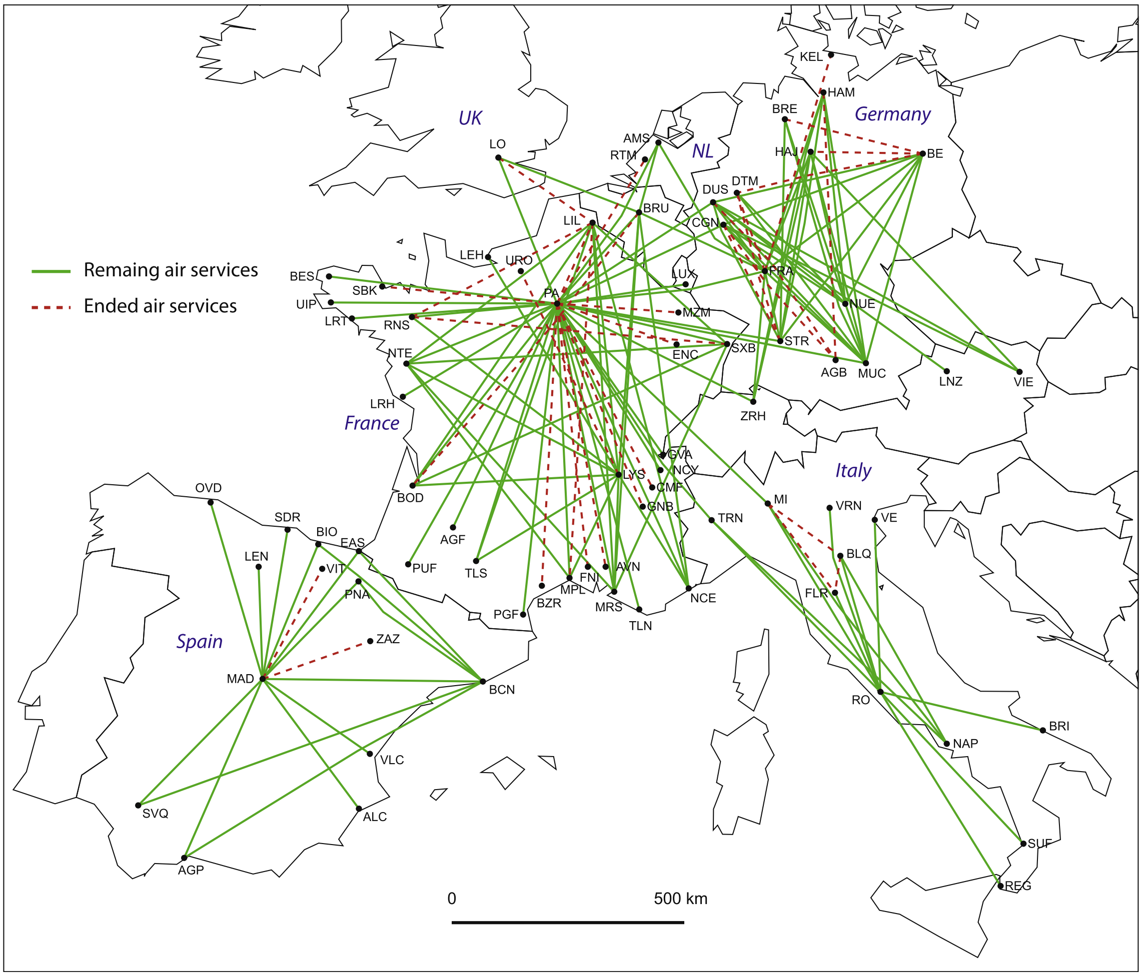

Fig. 1. The 161 city-pairs considered. Source: authors' elaboration.

Territorial Development and Cohesion), the research teams involved defined the limits of both morphological and functional urban areas for the whole EU, using a constant methodology and working from disaggregated data. The results offer the most up-to-date data on EU cities and one of the very rare opportunities to compare them on a transnational and homogenised basis that allows international comparisons. The size of the potential market is determined by the number of inhabitants within the functional urban areas (FUAs).[6] Because the same total may hide different configurations (e.g., a large city plus a small city or two middle-sized cities), PopFuaRatio gives the ratio between departure (larger) and arrival (smaller) cities. Because size is not everything and air services are expected to be used more by professionals working in advanced services (Liu et al., 2006) and in wealthier areas (Dargay and Clark, 2012), we also consider the share of GDP in some specific economic sectors (GDPserv) and GDP per capita (GDPcap). Then, we control for some spatial factors, namely aircraft distance (Distance and Distance2) and dummies for domestic services (with four countries being concerned). In the case of international routes, all domestic dummies equal zero.

Transport-related variables include airline hubs at both ends (HubDep and HubArr). Through spatial and temporal concentrations of flights that optimise passenger transfers between airplanes, hubs lead some airports to be significantly more serviced than required by the sole surrounding area (O'Kelly, 1998; Derudder et al., 2007). Furthermore, for those passengers who have to connect, it is usually easier to travel by airplane from or to the hub even in the case of an HSR on the same city-pair. Indeed, HSR services usually go from city centre to city centre, thus involving costly and time-consuming journeys between HSR stations and airports. To identify hubs, we start from analyses conducted by Derudder et al. (2007). Yet these data have to be updated given recent changes into hubs' patterns. We take into account the fact that Milan Malpensa has been significantly deserted by Alitalia (Beria et al., 2011), while Air France set up a regional hub at Lyons Airport.

[6] Alternatively, we considered using the number of inhabitants living in the morphological urban areas (MUAs) or FUAs' gross domestic products, but they are all highly correlated. We use FUAs' populations because intermediate results show that it offers even better results.

Table 2
Variables initially considered.

Label	Description	Source	Models					
			(1)	(2)	(3)	(4)	(5)	(6)
Dependant variables								
Seats*	No. of airline seats in January 2012	OAG	X		X		X	
Flights*	No. of flights in January 2012	OAG		X		X		X
Geo-economic variables								
PopFua*	No. of inhabitants in the functional urban areas [FUAs] (summation of the both end-points of the route)	LATTS et al. (2011)	X	X	X	X	X	X
PopFuaRatio*	Ratio of departure city to arrival city according to the No. of inhabitants in the respective FUAs	LATTS et al. (2011)	X	X	X	X	X	X
GDPserv*	Share of GDP in financial intermediation, real estate, renting and business activities (weighted average of the both end-points of the route)	LATTS et al. (2011)						
GDPcap*	GDP per capita at the FUA level (weighted average of the both end-points of the route)	LATTS et al. (2011)						
Distance*	Airline (great-circle) distance	OAG						
Distance2	Distance squared	OAG						
France	Domestic service within France (dummy)		X	X	X	X	X	X
Germany	Domestic service within Germany (dummy)		X	X	X	X	X	X
Italy	Domestic service within Italy (dummy)		X	X	X	X	X	X
Spain	Domestic service within Spain (dummy)		X	X	X	X	X	X
Transport-related variables								
HubDep	Airline hub at the departure city (dummy)	Authors from Derudder et al. (2007)	X	X	X	X	X	X
HubArr	Airline hub at the arrival city (dummy)	Authors from Derudder et al. (2007)	X	X	X	X	X	X
Lowcost*	Share of low-cost air services (in terms of seats supplied)	OAG	X	X	X	X	X	X
TIMEhsr*	Weekly average travel time by high-speed rail (in-vehicle travel time + boarding time)	Computed from web-based searches	X	X			X	X
FREQhsr*	Weekly HSR services	Computed from web-based searches			X	X	X	X
IntegDep	Airline/HSR integration at the departure city	Authors' knowledge	X	X	X	X	X	X
IntegArr	Airline/HSR integration at the arrival city	Authors' knowledge	X	X	X	X	X	X
DualDep	HSR services calling at both central and peripheral stations at the departure city	Authors' knowledge	X	X	X	X	X	X
DualArr	HSR services calling at both central and peripheral stations at the arrival city	Authors' knowledge	X	X	X	X	X	X

'Authors' means authors' own calculations or judgement.
* LN transformations are applied to obtain more linear relations between the dependent variable and the explanatory variables.

Fares are not considered, because yield management has made them highly variable according to travel date and day of purchase (Vasigh et al., 2008). For example, on the London–Paris route, the most expensive fare can be up to 12 times higher than the cheapest, depending on mode, service, cabin class and dates of purchase and travel; for the HSR the most expensive ticket could be almost seven times more than the cheapest. However, low-cost air services have been considered, as they may imply more air services than expected, because cheap air transport can induce new traffic, divert passengers from other routes, recapture market shares from HSR or limit the decrease in air services following the introduction of HSR (Friederiszick et al., 2009; Dobruszkes, 2011; Rothengatter, 2011). Thus, the Lowcost variable gives the share of low-cost seats among all airline seats.

Six variables describe HSR services. TIMEhsr relates to the average travel time, including boarding time when there are special procedures like custom and/or luggage inspections. FREQhsr gives the weekly number of HSR services. Both variables were systematically obtained from train companies' websites by simulating booking for all trains operated within one week. This very time-consuming task makes it possible to take into account the fact that travel time may vary from one service to others on the same route. In addition, when HSR serves both central and peripheral stations, frequency-weighted averages were computed.[7] We also consider HSR–airline integration (IntegDep and IntegArr) at the airport, as it may involve less air services than expected. Indeed, if HSR directly serves an airport and if airlines and rail companies cooperate, airlines can use HSR services as short-haul feeders replacing their flights (Givoni and Banister, 2006; Chiambaretto and Decker, 2012;

[7] For example, various French cities are served by HSR services calling either at an 'old' central station or at a new HSR station located on HSL (Paris, Valence, Avignon, Tours, etc.).

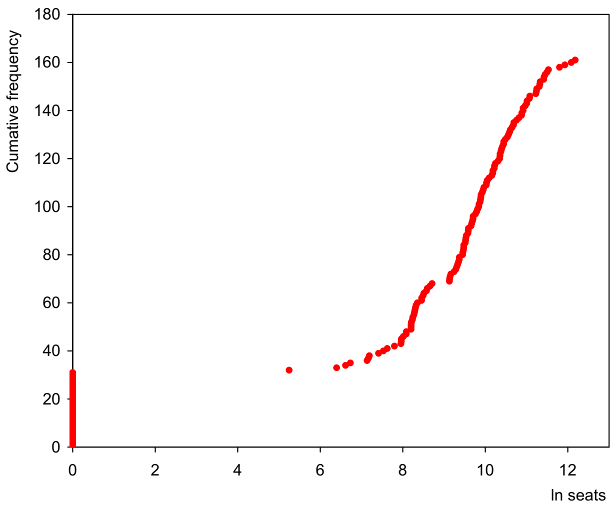

Fig. 2. Left-censored sample. Source: authors' elaboration.

Socorro and Viecens, 2013). Finally, we take into account the fact that HSR services may call at central and/or peripheral stations. Central stations are either inherited rail stations (like London St Pancras, Paris Gare du Nord, etc.) or new stations located on new rail links crossing a city (for example, the new underground part of Berlin Hauptbahnhof or Lille-Europe). Peripheral stations are mainly stations built on HSLs bypassing the city centre of middle-sized cities (like Avignon TGV in France) or skirting around large cities (like 'Aéroport Charles-de-Gaulle 2 TGV', 'Marne-la-Vallée – Chessy' and 'Massy TGV' stations around Paris). Within our set of routes, almost all cities are served by a central rail station and possibly also through a peripheral station. As a result, DualDep and DualArr are dummies highlighting cities served by HSR calling at both central and peripheral rail stations.

In the paper, parametric and semi-parametric models are used. Those models assume a linear relationship between the dependent and explanatory variables. Logarithm transformations are usually applied on quantitative variables to linearise the relation. The bivariate descriptive analysis of our database confirms the need to use logarithm transformation on quantitative variables. Moreover, this type of transformation allows us to use elasticities in the interpretations.

2.2. Methodology and models

The 161 routes considered contain two subsets of observations: 130 routes with remaining air services (thus $Y > 0$) and 31 routes abandoned by the airlines (thus $Y = 0$). In other words, our dependent variables are left-censored (Fig. 2). The ordinary least-squares (OLS) estimator is inappropriate on censored samples due to the double structure in the data. On the truncated sample, the OLS would supply biased parameter estimates due to a potential problem of sample selection (Heckman, 1979). In such cases, the best-known econometric model is the Tobit model proposed by Tobin (1958), which includes quantitative and qualitative structures:

$$ln(Seats_i) = \begin{cases} X_i\beta + u_i & \text{if} \quad X_i\beta + u_i > 0 \text{ for } i = 1, \ldots, n \\ 0 & \text{otherwise,} \end{cases}$$

where X is the matrix of design (n times p) containing all explanatory variables plus a constant, β (p times 1) is the vector of unknown regression parameters and u_i is normally distributed with mean zero and constant variance. This equation can also be written as $\ln(\text{Seats}_i) = \max\{0, X_i\,\beta + u_i\}$ for $i = 1,\ldots, n$.

The key aspect in this model is that exactly the same structure is used in the selection equation (routes with and without remaining air services) and in the interest equation linking the volume of air services to the set of explanatory variables. This assumption could be viewed as a restriction. The Heckman model is a suitable alternative in the case of more variables providing explanations for the selection equation (here, the 31 routes which no longer offer air services). For example, one obvious hypothesis is that abandoned airline routes are the ones with very competitive HSR travel times. Indeed, one knows that airlines left several short routes served by HSR linking cities in less than 90 min (for example, Milan-Bologna, Bologna-Florence, Paris-Lille and Paris-Metz). However, the terminated airline routes in question face HSR travel time ranging from 0.6 to 6.3 h, the median time being three hours. HSR travel time can thus certainly not be the sole cause of airlines leaving some routes. Another hypothesis is that abandoned airline routes used to be public service obligations (PSOs) subsidised by public authorities; when HSR is launched, public authorities could stop financing air services. For example, the Lyons–Montpellier PSO was abolished after the Mediterranean HSR service launched (Dobruszkes, 2007). However, only one-third of the 31 routes confirm this scenario. A third hypothesis is that ceased airline routes are those with originally low-density traffic. Indeed, airlines would not try hard to remain in small markets. However, some abandoned routes were

Table 3
Descriptive statistics.

	Routes with remaining air services (Y > 0)					Routes with ended air services ($Y = 0$)				
	Min	Max	Share*	Median	St. deviation	Min	Max	Share*	Median	St. deviation
Dependant variables										
Seats (monthly)	189	194,757	–	16,898	34,759	0	0	–	0	0
Flights (monthly)	1	1,204	–	162	215	0	0	–	0	0
Geo–economic variables										
PopFua (inhabitants)	1,424,859	24,895,892	–	5,116,048	4,451,016	1,492,916	14,243,890	–	5,710,437	4,448,831
PopFuaRatio	1.02	100.62	–	2.84	14.32	1.01	69.50	–	5.92	18.09
GDPserv (%)	23	44	–	34	6	27	44	–	34	6
GDPcap (thousand EUR)	19.8	44.0	–	34.0	5.7	21.0	39.0	–	34.0	5.8
Distance (km)	135	830	–	463	162	79	779	–	385	174
France	0	1	31%	0	0.46	0	1	42%	0	0.50
Germany	0	1	22%	0	0.42	0	1	32%	0	0.48
Italy	0	1	9%	0	0.29	0	1	10%	0	0.30
Spain	0	1	12%	0	0.33	0	1	6%	0	0.25
International routes**	0	1	25%	0	0.44	0	1	10%	0	0.30
Transport–related variables										
HubDep	0	1	63%	1	0.48	0	1	52%	1	0.51
HubArr	0	1	13%	0	0.34	0	0	0%	0	0.00
Lowcost (%)	0	100	–	0	19	0	0	–	0	0
TIMEhsr (hours)	1.21	9.89	–	4.29	1.74	0.62	6.27	–	3.01	1.50
FREQhsr (weekly)	5	309	–	42	58	6	309	–	58	60
IntegDep	0	1	41%	0	0.49	0	1	48%	0	0.51
IntegArr	0	1	17%	0	0.38	0	1	3%	0	0.18
DualDep	0	1	17%	0	0.38	0	1	26%	0	0.44
DualArr	0	1	6%	0	0.24	0	1	3%	0	0.18

* For dummies only.
** Given for information only.

not thin ones (e.g. Paris–Grenoble or Paris-Nimes), and, conversely, many low-density routes are still operated by airlines despite the introduction of HSR services (e.g. Lille–Toulouse or Madrid–León). It thus seems clear that the withdrawal of the airlines from 31 routes is not always due to HSR, so analysing this is beyond the scope of this paper. As we fail to find valid explanations for all the terminated air services, the Tobit model is applied instead of the Heckman model.

In the first step of the analysis, the regression parameters of the Tobit model are estimated by the maximum likelihood estimator (MLE) and the "sandwich" estimator of variance is derived to obtain the robust[8] standard error. The majority of applied papers stop the analysis at this level without checking the validity of underlying assumptions. Unfortunately, MLE estimates become inconsistent when the normality assumption is violated. Moreover, as with the LS estimator in multiple linear regression, the MLE estimator is extremely sensitive to the presence of outliers in the sample (Maronna et al., 2006). The presence of a small proportion of atypical observations could have a large influence on the estimates of the parameters. Two types of outliers can affect the result of the classical estimates: vertical outliers and leverage points. Vertical outliers are observations that are outlying in the dependent variable but are not outlying in the design space (i.e. the x-dimension). Bad leverage points, the most problematic outliers, are observations that are both outlying in the design space and located far away from the regression line. To be robust to the normality assumption and vertical outliers, Powell (1984) introduced the non-parametric Censored Least Absolute Deviations (CLAD) estimator. This estimator does not depend on the distribution of the error and is more robust to outliers. The CLAD estimator is defined implicitly as the solution of this minimization problem:

$$\hat{\beta}^{\text{CLAD}} = \underset{\beta}{\operatorname{argmin}} \sum_{i=1}^{n} |y_i - max\{0, X_i\beta\}|.$$

This estimator is consistent and asymptotically normal for a wide class of error distributions and is robust to heteroscedasticity and to vertical outliers (i.e. outliers in the y-dimension). Nevertheless, this estimator is not robust to bad leverage points (outliers in the space of explanatory variables). In this paper, the estimator proposed to circumvent this problem uses a two-step procedure. In the first step, we use a robust method to detect leverage points (outliers in the design space); in the second step, we apply the CLAD estimator to a clean sample, where zero weights are given to leverage points. The detection of outliers, in more than two dimensions, is challenging, because visual inspection of the complete database is impossible. The degree of outlyingness is traditionally measured by the Mahalanobis distance, defined as follows:

[8] Robust against a potential problem of heteroskedasticity.

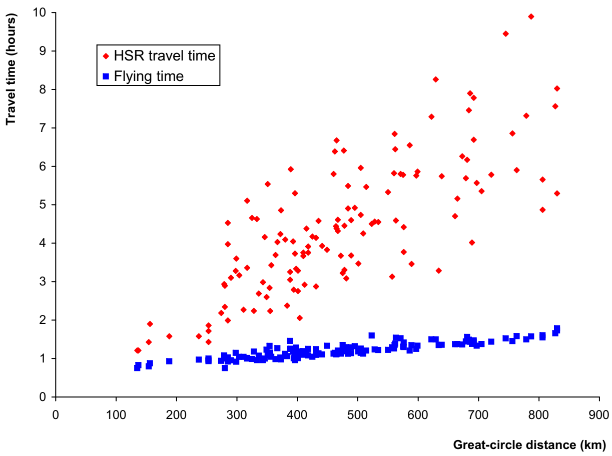

Fig. 3. Airline and HSR travel times within our sample. Routes not served by airlines anymore are not shown.

$$d_i = \sqrt{(X_i - \mu)\sum\nolimits^{-1}(X_i - \mu)'} \quad \text{for}\, i = 1, \ldots, n$$

where X_i is the row associated with individual i of the $(n \times q)$ matrix containing the quantitative explanatory variables, μ is the multivariate location vector and $\sum$ is the covariance matrix. In practice, however, μ and $\sum$ are unknown and must be estimated. Generally, classical estimators (empirical mean and covariances matrix) are used, but those estimators are not robust to the presence of outliers in the sample, leading to masking (i.e. failing to identify outliers) and swamping (i.e. mistaking clean observations for outliers). To guarantee the detection of real atypical observations, robust estimators of μ and $\sum$ are required. In this study, we use the well-known robust Minimum Covariance Determinant estimators introduced by Rousseeuw (1985; for implementation in Stata, see Dehon and Verardi, 2010). Using robust Mahalanobis distances in the design space and the associated cut-off,[9] we are able to detect leverage points. In the second step, we use the CLAD estimator on a clean sample where the leverage points have been previously removed. We call this two-step estimator 'weighted CLAD'.

In the next section, we compare two sets of parameter estimates: classical MLE estimates (hereafter referred as 'MLE') and weighted CLAD estimates applied to the sample where bad leverage points are removed (hereafter referred as 'weighted CLAD').

3. The impact of HSR on the current level air services

Table 3 gives the descriptive statistics for the set of variables described in Table 2, before logarithmic transformations and making the distinction between non-censored and censored subsets. As mentioned above, we could not find a reasonable explanation valid for all ceased air services. However, Table 3 shows that the remaining air services tend toward longer distances, higher HSR travel times and more airline hubs.

Distance and Distance2 are also rejected at an early stage, because while not being significant, they lead to models with many incoherent estimates. The main reason for distance not being significant is the large range of HSR average speeds. This is due to the fact that for many city pairs, HSRs ride on a mix of HSLs and conventional lines. In addition, many HSR routes do not follow a straight line because of intermediate cities to be served and obstacles (e.g., lakes and mountains) to skirt around. As a result, HSR travel time, which is a main driver of HSR attractiveness (see above) is poorly correlated with distance. Within our sample, this contrasts with aviation, where travel time remains relatively fixed around one hour (Fig. 3).

In addition, since GDPserv and GDPcap are not significant,[10] we exclude them to keep a better ratio in the model between the number of observations and of variables. Once the final models had been estimated, we verified that these excluded variables were not significant, and they were not. Finally, it appears that TimeHSR and FREQhsr (i.e. the two most important variables describing HSR services) are relatively well correlated ($r = -0.68$ when considering their logarithms, including the outliers). For the sake of simplicity in the interpretations, this leads us to first consider TimeHSR and FREQhsr separately and then together. Finally, six models are considered. The corresponding variables are shown in Table 2.

The estimates for Models 1 and 2 (i.e. HSR travel time impact on number of seats and flights, respectively) are summarised in Table 4.[11] First of all, the bias of selection (measured by the parameter sigma) is significantly different from zero,

[9] The squared Mahalanobis distances have asymptotically a chi-square distribution with q degree of freedom. Then, the 99th percentile of the chi-square distribution is used as a cut-off.

[10] As for GDP in advanced services, this may be due to uncertainties in the by-sector split of GDP and to the large diversity of jobs within advanced services, not all involving long-distance travel. As for per capita GDP, this may suggest that personal or household income would have been a better variable.

[11] The VIF (Variance Inflation Factor) values used to detect a problem of multicollinearity have been computed with a linear regression model, and the conclusion is that such potential problem is not present within our dataset. Even if some explanatory variables are correlated, the level of those correlations does not lead to instability caused by a problem of multicollinearity.

Table 4
Parameter estimates (Models 1 & 2).

Model	MLE	Weighted CLAD	MLE	Weighted CLAD
Model (see Table 2)	(1)	(1)	(2)	(2)
Dependent variable	ln Seats	ln Seats	ln Flights	ln Flights
ln PopFua	2.034***	1.274***	1.314***	0.774***
ln PopFuaRatio	−1.908***	−0.517***	−1.051***	−0.359**
France	0.576	0.463	0.610	0.620*
Germany	0.049	0.649	0.006	0.386
Italy	3.173**	1.264**	1.794***	1.090**
Spain	2.794**	0.816*	1.649**	0.963*
HubDep	2.840***	1.226***	1.623***	0.931*
HubArr	1.385*	0.770**	1.069**	1.087**
ln Lowcost	0.358**	0.274**	0.194**	0.150
ln TIMEhsr	**4.380******	**1.094******	**2.373******	**0.915******
IntegDep	0.157	−0.549	0.002	−0.296
IntegArr	1.478	0.493	0.859	0.282
DualDep	0.486	0.515	0.155	0.217
DualArr	0.860	0.081	0.327	0.052
Constant	−30.640***	−12.678***	−20.185***	−9.272***
Sigma	3.682***	N.A.	1.943***	N.A.
Observations	161	131	161	131
Censored observations	31	20	31	20
Pseudo R2	0.092	0.253	0.125	0.289

Significant at *** 99 percent, ** 95 percent or * 90 percent level of confidence.

meaning that censored models are required. Second, Table 4 shows there is a large gap between MLE and weighted-CLAD estimators. The significant variables are not exactly the same, and their values are quite different (although with the same signs when variables are significant). Given that weighted-CLAD models are more robust (see above), Table 4 demonstrates that simply using classical estimates would have led to invalid conclusions. In particular, the impact of HSR travel time on airline seats or flights would have been overestimated by a factor 4.0 or 2.6, respectively. Weighted CLAD models exclude 30 routes. As stated above, the exclusion is based on multi-dimensional inspection of atypical points.

Considering only weighted CLAD estimates, all significant variables have the expected sign (although no sign was expected for domestic services). The models are consistent with various authors who found that city size is an important factor predicting the provision of air services (Cattan, 1995; Discazeaux and Polèse, 2007; Dobruszkes et al., 2011). The estimates also show that the volume of air services is impacted by the ratio between (larger) departure and (smaller) arrival cities. More precisely, there are more services on a route linking, say, two cities of 1 million inhabitants than on a route linking a city of 1.8 million and a city of 0.2 million inhabitants.

As expected, airline hubs are significant, involving more air services on corresponding city-pairs. The share of low-cost airlines is associated with more airline seats, suggesting that cheap flights tend to induce more traffic (Graham and Shaw, 2008). However, within our sample, the LCA effect is limited and only occurs as far as airline seats are concerned. The fact that the number of flights would not be affected by LCA presence may be due to the latter's strategy giving priority to lower costs than to frequencies, thus involving a trend in higher seat-density planes (Dobruszkes, 2013). The limited effect may also be a consequence of some LCAs not being as cheap as they used to be, partially as a result of adopting a hybrid low-cost/full service model (Klophaus et al., 2012).

HSR travel time is found to have a strong significant impact on the provision of air services; that is, lower HSR travel times involve less air services. Such result was expected based on ex-post evidence already published (Givoni and Dobruszkes, 2013). However, to our knowledge, it has never been found through an EU-wide quantitative analysis covering over a hundred routes and making the distinction between the provision of airline seats and flights. This result thus confirms that within a free competition between modes (i.e. without regulation of the modal choice), HSR helps to restrict the provision of air services when travel time is not too high. The models also show that HSR travel time similarly impacts the number of airline seats and the number of flights. This contradicts the hypothesis that airlines set up frequency-oriented strategies to maintain their competitive position. With such strategies, we would expect TIMEhsr's estimate to be significantly higher for Model 1 than for Model 2.

The other HSR-related variables are not significant (nor are they within our other models). HSR–Air integration is not significant, arguably because there is a spatial overlap with the airline hub effect. Most airports directly served by HSR are also airline hubs (Amsterdam, Paris CDG, Frankfort and Lyons). In this context, it is not surprising that HSR–Air integration has little effect, because the range of routes involved is smaller. For example, in 2012, Paris CDG airport was linked to 234 other cities by air[12] compared to 73 by HSR, several of which with unattractive travel times. Figures for Amsterdam airport were 223 and 12, respectively.

[12] Of which 170 are served by Air France (which set the hub up) or its partners.

Table 5
Parameter estimates (Models 3 & 4).

Model Model (see Table 2) Dependent variable	MLE (3) ln Seats	Weighted CLAD (3) ln Seats	MLE (4) ln Flights	Weighted CLAD (4) ln Flights
ln PopFua	1.494*	1.200***	1.015**	0.958***
ln PopFuaRatio	−1.597***	−0.742***	−0.881***	−0.550**
France	0.238	0.153	0.422	0.412
Germany	−0.786	0.017	−0.461	0.118
Italy	1.091	0.889*	0.662	0.512
Spain	1.172	0.635	0.766	0.739
HubDep	2.488***	1.110***	1.428***	0.711***
HubArr	1.997**	1.220*	1.399***	0.938**
ln Lowcost	0.757***	0.331***	0.411***	0.123***
ln FREQhsr	**−0.491**	**−0.206***	**−0.256*****	**−0.117**
IntegDep	−0.918	−0.786	−0.580	−0.474
IntegArr	1.105	0.109	0.657	0.423
DualDep	−0.229	0.278	−0.235	0.042
DualArr	0.273	−0.200	0.005	−0.391
Constant	−13.803	−8.638*	−10.993*	−9.643***
Sigma	4.036***	N.A.	2.139	N.A.
Observations	161	139	161	139
Censored observations	31	24	31	24
Pseudo R2	0.060	0.203	0.084	0.223

Significant at *** 99 percent, ** 95 percent or * 90 percent level of confidence.

In addition, cities served by HSR services calling at both central and peripheral stations have no significant effect on airlines' seats and frequencies (Table 4). On the one hand, this could mean that HSR stations have catchment areas so large that their location does not really matter. On the other hand, this may mean that their location should be considered with regards to the precise departure and arrival points of people travelling by HSR or plane.[13] This means considering the spatial patterns of metropolitan areas. For example, French surveys show that upper social and occupational groups overuse HSR services.[14] Since European cities are segregated (Vandermotten et al., 1999; Cassiers and Kesteloot, 2012), the location of these groups within the metropolitan space may influence how far long-distance travellers are from HSR stations and airports. In other words, the socio-spatial pattern of cities may influence the respective attractiveness of HSR and airlines.

Finally, Italy and Spain (for both seats and flights) and France (for flights only) are significantly different from the international routes with a positive estimate. This means that additional country factor(s) lead to more air services when controlling for the aforementioned significant variables (cities' population, HSR travel time, etc.). However, the other models analysed (see below) show different results. This suggests that country dummies play their control role as expected but are not stable enough to make it possible to interpret them. It is worth mentioning that we tried similar models without any national dummy. The results (not showed here) then appear to be inconsistent. We also tried models replacing all national dummies with a single dummy for domestic routes (versus international ones) and computing the interaction with HSR variables. However, the results are thus not convincing due to the relatively small number of international routes and do not allow us to draw conclusions.

Let us turn to the impact of HSR frequency on air services (Table 5). There are 22 routes excluded, and the set of significant variables is similar to Models 1 and 2, except for the national dummies. Furthermore, HSR frequency only has a slightly significant and limited impact on the provision of airline seats, with the expected sign. A 10% increase in HSR frequency would result in only a 2% decrease in airline seats. Actually, HSR frequency should be regarded as giving rather similar information as HSR travel time since the former tends to decrease when the latter increases.

Table 6 then shows regression analysis results for Models 5 and 6, considering both HSR travel time and HSR frequency. Only six routes are now excluded, thus 155 observations are included. HSR frequency, which is well correlated with HSR travel time, does not have the expected sign –it is now positive. Moreover, its estimate is much smaller than that of HSR travel time. These two findings should be understood as evidence that HSR travel time has much more impact on air services than HSR frequency. This suggests that, all other things being equal, passengers would prefer fast services over frequent services. Higher frequency can only yield a small competitive advantage. However, controlled notably by HSR travel time, one could also interpret HSR frequency being positive as coherent if one considers that large airline markets are potentially large enough to let train companies schedule frequent HSR services. In addition, among national dummies, only Spain in Model 6 is significant here. This highlights how difficult it is to interpret such variables, but it is important to consider them as control variables.

[13] We also tested models with airport–HSR station distance as a proxy for catchment area similarity. The assumption was that shorter distances would mean similar catchment areas. However, this did not provide better results.

[14] For example, they represented 37% of the passengers in the Mediterranean HSR in 2003 and 46% in the Northern HSR in 2004/5, compared to 8% within France as a whole (RFF and SNCF, 2007).

Table 6
Parameter estimates (Models 5 & 6).

Model Model (see Table 2) Dependent variable	MLE (5) ln Seats	Weighted CLAD (5) ln Seats	MLE (6) ln Flights	Weighted CLAD (6) ln Flights
ln PopFua	1.312*	1.178**	0.914**	0.755***
ln PopFuaRatio	−1.711***	−0.818***	−0.942***	−0.554***
France	0.015	−0.252	0.301	0.222
Germany	−1.097	0.339	−0.628	−0.281
Italy	2.152*	0.885	1.231*	0.508
Spain	2.743**	0.864	1.623**	1.126***
HubDep	2.642***	1.399**	1.513***	1.018***
HubArr	1.186	0.615	0.959**	0.917
ln Lowcost	0.352**	0.276**	0.191**	0.147**
ln TIMEhsr	**5.926*****	**1.879*****	**3.228*****	**1.921*****
ln FREQhsr	**1.402*****	**0.332***	**0.775*****	**0.497****
IntegDep	0.613	−0.196	0.257	−0.013
IntegArr	1.533	0.700	0.890*	0.216
DualDep	0.268	0.434	0.034	0.158
DualArr	0.505	−0.132	0.131	−0.090
Constant	−26.473**	−13.043**	−17.870***	−11.854***
Sigma	3.597***	N.A.	1.894***	N.A.
Observations	161	155	161	155
Censored observations	31	30	31	30
Pseudo R2	0.100	0.230	0.136	0.253

Significant at *** 99 percent, ** 95 percent or * 90 percent level of confidence.

Table 7
Parameter estimates for Models 1 & 2 but TIMEhsr being replaced with a dummy related to incremental thresholds.

Model Model (see Table 2) HSR travel time Dependent variable	Weighted CLAD (1BIS) >2.0 h ln Seats	Weighted CLAD (1BIS) >2.5 h ln Seats	Weighted CLAD (1BIS) >3.0 h ln Seats	Weighted CLAD (2BIS) >2.0 h ln Flights	Weighted CLAD (2BIS) >2.5 h ln Flights	Weighted CLAD (2BIS) >3.0 h ln Flights
ln PopFua	1.087***	1.225**	0.980***	0.742***	0.759***	0.762***
ln PopFuaRatio	−1.125***	−0.849***	−0.793***	−0.611***	−0.604***	−0.611***
France	−0.511	0.066	−0.151	0.064	0.261	0.276
Germany	−0.040	0.185	0.192	−0.043	0.079	0.111
Italy	0.559	0.913	0.881	0.428	0.610	0.622
Spain	0.988	0.898	0.837	0.726	0.829	0.866*
HubDep	1.207***	1.092***	1.007***	0.775***	0.835***	0.888***
HubArr	0.482	0.920	0.966	0.716	0.896*	0.913*
ln Lowcost	0.272***	0.249***	0.291***	0.100***	0.117***	0.112**
TIMEhsr (dummy)	**6.181*****	**1.108*****	**0.774*****	**4.163*****	**0.673*****	**0.718*****
IntegDep	−0.410	−0.638	−0.398	−0.246	−0.378	−0.416
IntegArr	0.498	0.896	0.905	0.464	0.588	0.550
DualDep	0.537	0.439	0.313	0.207	0.244	0.238
DualArr	0.451	−0.291	−0.339	−0.254	−0.329	−0.304
Constant	−6.972	−9.578	−5.806	−6.520*	−6.963*	−7.026*
Observations	157	157	157	157	157	157
Censored observations	31	31	31	31	31	31
Pseudo R2	0.228	0.205	0.206	0.249	0.225	0.229

Significant at *** 99 percent, ** 95 percent or * 90 percent level of confidence.

A final point this paper assesses is whether the impact of HSR travel time on air services is really linear, as the use of the TIMEhsr variable in the model presupposes. In order to detect such an effect, we first considered a quadratic function (namely, squared HSR travel time), but it did not give significant results. We then transformed HSR travel time into a dummy variable according to 30-min incremental thresholds, ranging from one to four hours. Not all the results can be published here, but we found that the estimated impact of HSR travel time on air services decreases quickly between 2.0- and 2.5-h thresholds, which correspond approximately to a rail distance of 500 km (Table 7). Between 2.5- and 4.0-h thresholds, the estimates for the TIMEhsr dummy remain much more stable, highlighting the fact that there is a breakdown between 2.0 and 2.5 h and that the dummy clearly makes the distinction between two groups of routes, depending on the impact of HSR travel time on air services. Finally, it should be noticed that in contrast to our results in Table 4 (Models 1 and 2, thus with TIMEhsr as a continuous variable), the impact of TIMEhsr as a dummy on airline seats and flights apparently differs. Yet no conclusion should be drawn from this because the gap is not so large and because dummies are a reduction of the information using a discretisation process. This sheds important light on the threshold for competition between the modes, which usually is considered arbitrarily to be three or four hours (see e.g. EC, 1998; Chester and Ryerson, 2014). Here the evidence is based on a range of routes and is actually less than three hours.

4. Conclusions and research prospects

This paper analyses whether the provision of HSR services in Europe influences the provision of air services. An EU-wide, ex-post analysis is conducted, covering all routes where HSR and air services compete or used to compete, using transnational data to allow international comparisons. The methodology applied provides results that are more robust than the often-applied classical MLE estimates in the Tobit model. We found that air services are indeed affected by HSR travel time: there are more air services if HSR travel time is longer. However, this effect quickly decreases between 2.0 and 2.5 h of HSR travel time. We also found that HSR travel time has a similar impact on both airline seats and the number of flights of a similar magnitude. In our case, intermodal competition thus does not lead airlines following frequency-oriented strategies to maintain their competitive position. In contrast, HSR frequency is found to have only a weak impact on air services.

At the route level, hubbing strategies led by the airlines have the opposite effect from HSR, as hubs involve more air services. This raises the issue of whether airports should be served more by HSR, with the latter replacing short-haul flights to feed longer ones. On the one hand, this suggests that there is potential for additional mode substitution through either competition or integration if HSR served the airports. On the other hand, the success of such practice is subject to overcoming various market and technical obstacles including the range of airline connections offered, the geography of HSR routes versus airports locations, schedule optimisation, degree of commercial and technical integration, etc. (Givoni and Banister, 2006). Furthermore, at congested airports, the freed slots may be reused for other flights, potentially long-haul ones with larger environmental impact. Even without such rebound effect, the reduction in GHG emissions thanks to HSR substituting for air transport on short-haul routes is small compared with emissions from long-haul flights. For example, flying from Paris to Brussels represents 60 kg of CO_2-equivalent per passenger, but then connecting to Kinshasa involves 2,020 kg more.[15] Also, serving airports instead of city centres may mean higher car use for access and egress journeys; the latter may represent significant emissions of air pollutants (Givoni, 2007).

The transferability of our results to other markets is limited. Indeed, both the set of significant variables and the estimates themselves will be different for other markets. Furthermore, our methodology is not suitable to conduct ex-ante assessments, because our models' coefficients of determination (pseudo R^2) are weak. Nevertheless, the methodology used here can be used elsewhere and the conclusions derived from the above analysis can serve policy makers in other countries, especially where HSR is developing fast, but there is not enough experience to allow such ex-post analysis as we have done here. The most relevant case is undoubtedly China (Fu et al., 2012), although the nature of routes and competition between the modes is very different.

It would be desirable to improve the models used here by including additional variables. Fares are arguably an important point, but their temporal variation is so high that it is difficult to collect them. Considering the annual average based on tickets sold would be an option, but competition has made this kind of information very sensitive and thus unavailable. Variables relating to metropolitan spatial patterns could arguably enhance the analysis of intermodal competition (e.g. densities, relative location of business districts and edge cities, social classes' spatial patterns, HSR stations' and airports' catchment areas, etc.). National spatial patterns may also help to better understand intermodal impact (e.g., the potential impact of internal migration on domestic, long-distance travel).

Today, HSR is regarded as a means of reaching 'greener' mobilities. Our results suggest partial support for employing HSR in this way. However, two additional topics should be analysed before concluding that HSR can contribute in this respect. First, this paper analyses the impact of HSR on the current level of air services. The next step would be to analyse changes in air services when making comparisons before and after the inauguration of HSR services and when these change substantially (e.g. speed on the route is increased), that is to analyse the dynamic relations and influences between the modes. It is therefore important to re-emphasize that results and conclusions in the analysis above refer to a given, static situation. Second, after better understanding the reaction of airlines to HSR services (over time and across routes) there is a need to assess the overall potential for modal change from air to HSR, as infrastructure costs and traffic density are important to justify HSLs (de Rus and Nombela, 2007). Initial analysis suggests the potential is rather limited (Givoni et al., 2012), but this should be investigated in more depth.

Acknowledgements

This research is part of the DATE project, financed by the European Commission under a Marie Curie Intra-European Fellowship for Career Development. It reflects only the authors' views; the European Union is not liable for any use that may be made of the information contained therein. We also gratefully acknowledge research support from the IAP research network grant no. P7/06 of the Belgian Federal Government (Belgian Science Policy) and from the ARC contract funded by the Communauté Française de Belgique. We also wish to thank Didier Peeters (Brussels University, IGEAT) for his assistance with

[15] According to www.atmosfair.de.

data on European cities; Myoungshin Kim for her help with the RSIS report; and Tim Schwanen for his very useful comments and suggestions in the earlier stages of this paper. Finally, comments and suggestions received from other colleagues and at both ATRS and WCTR conferences are also much appreciated. Any remaining errors are our sole responsibility. Finally, our thanks to two anonymous referees for their valuable comments.

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