DOES EUROPEAN HIGH-SPEED RAIL AFFECT THE CURRENT LEVEL OF AIR SERVICES? AN EU-WIDE ANALYSIS

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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 covering a large sample of 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 normality assumption of error term. It is found that shorter HSR travel times involve less air services, with similar impact on both airline seats and flights. The impact of HSR frequencies is less clear, notably because of quasi-multicollinearity and of inverse proportion to HSR travel time. Airline/HSR integration at the airport has no significant impact. National dummies show Italian and French specificities that should be investigated. Metropolitan and national spatial patterns may also help to better understand intermodal effects.

Keywords: Air Transport, High-speed rail, Intermodal competition, Censored models, Europe.

1. INTRODUCTION

High-speed rail (HSR) was initially designed for various reasons away from the current environmental motives. Lack of capacity, declining passenger revenues in medium- and long-distance markets, commercial/market turn, a reputation for being outdated and new energy policy concerned with dependency to oil-exporting countries were the main initial drivers for improving trains' speed (Fourniau, 1989; Klein, 2001; Givoni, 2006; Takatsu, 2007). In France, HSR was jointly developed by the national railways —notably facing competition from air and automotive transport— and rolling-stock manufacturers (Powell, 1997). Symptomatically, the government decided to allow a new high-speed line to be built during an interdepartmental meeting on energy (Troin, 1995). Since then, some HSR routes have proven to significantly decrease airlines' market shares or volumes supplied (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 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, this new aim assigned to rail transport is not based on empirical evidence of the intermodal impacts driven by HSR. The intermodal effects of HSR remain partially unknown. On the one hand, as shown by Kroes (2000), quoted by Wardman et al. (2002), Capon et al. (2003) and Dobruszkes and Givoni (2012), research is mostly done on expected intermodal competition and considering demand (i.e. passengers). In contrast, ex-post analysis of the observed competition is scarce, and the supply dynamics (for example, the number flights or seats offered) is rarely investigated despite the fact that transport services are what generate environmental impacts. Furthermore, when ex-post assessments are performed, they usually concern a limited range of routes, generally the largest ones. For example, Behrens and Pels (2009) focus on the London-Paris route, Cascetta et al. (2011) on Rome-Naples, Campos and Gagnepain (2009) on three European routes, Dobruszkes (2011) on five European routes, Cheng (2010) on four routes from Taipei and Jiméneza and Betancor (2012) on nine Spanish routes (four of which are served by HSR).

Only a few papers perform ex-post analysis covering numerous routes. 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 (Dobruszkes and Givoni, 2012). 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 hours of service) did not lead to significant results. 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. Finally, Clever and Hansen (2008) analyse 82 airport-pairs and 1260 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]. In addition, 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-Calderon, 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.

Restricted route samples raise the issue of representativeness. Furthermore, 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. In this context, the aim of this paper is to analyse whether the existing EU-wide HSR services effectively affect the volume of air services. By contrast with previous works, our research (1) is spatially comprehensive, (2) is mainly interested in the effect of HSR on air services and (3) focuses on the supply rather the demand. The rest of the paper is as follows. Section 2 introduces the data used and the models built. Section 3 presents the results, followed by the conclusions.

2. RESEARCH STRATEGY

2.1. Data and variables

Our research is fundamentally an ex-post analysis of the current air services under the influence of HSR led through censored regressions. First, we build a model describing the volume of air services and then add several HSR-related variables. We work at the route level, more specifically, at the city-pair level, thus merging airports belonging to a same metropolitan area[2]. We considered all routes where direct HSR services compete with air services, 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 one (for example, we considered London-Brussels rather than Brussels-London). Figure 1 shows our sample, making the distinction between remaining and ended routes (see below). Most routes are

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[1] Longer access or egress journey by train allows making travel time useful.

[2] For example, Paris includes Paris Charles de Gaulle (CDG) and Paris Orly but not Paris Beauvais-Tillé airport dedicated to the low-cost airlines and located farther away (more than 80 km by road).

[3] For example, the Lille–Basel/Mulhouse EuroAirport route ended 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 changing network strategy) and around 2008 (by Interstate Airlines, which went bankrupt in 2010).

domestic and serve the four large European countries with large HSL extension (namely, France, Spain, Germany and Italy). Only 36 international city-pairs meet our criteria.

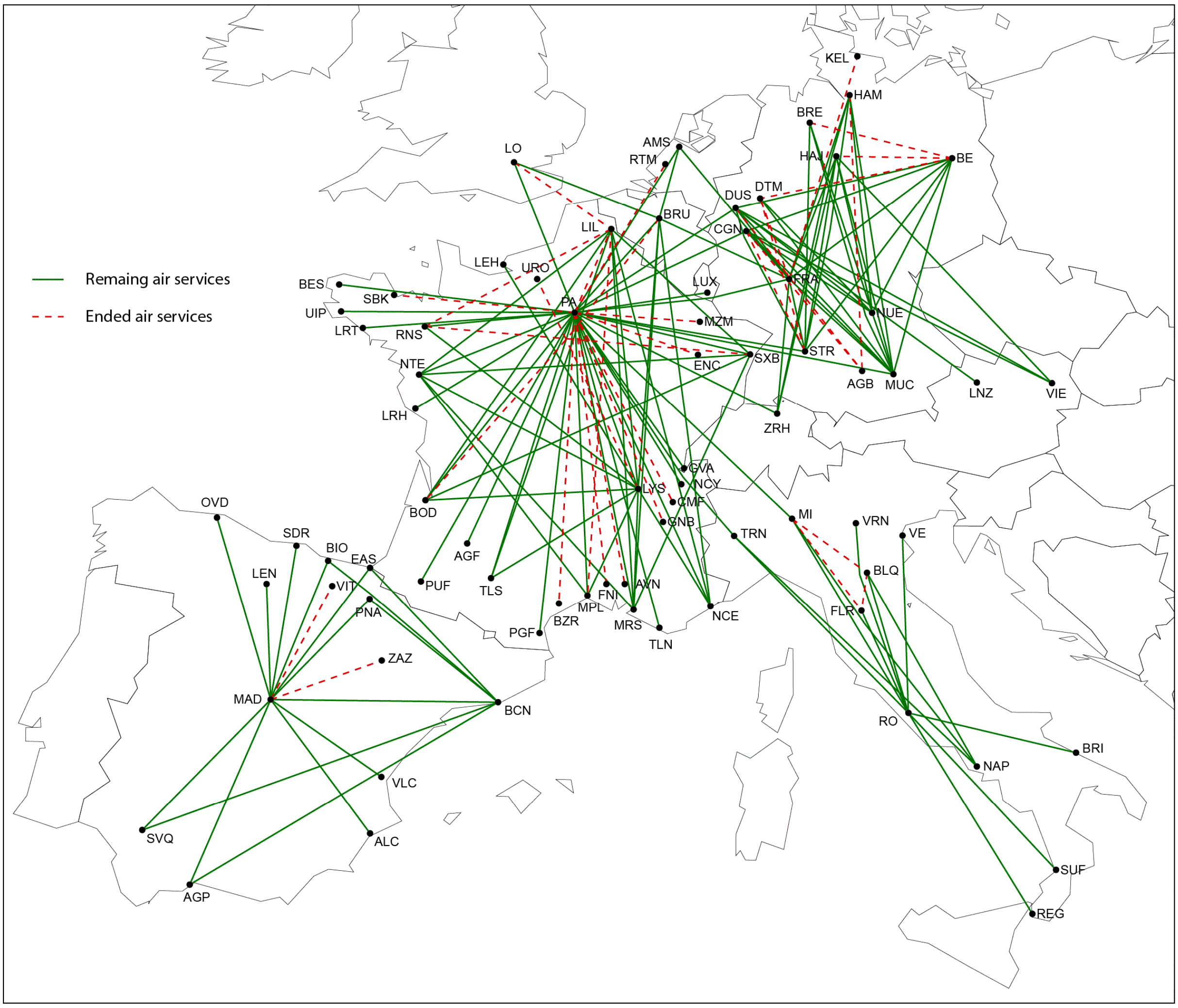

Figure 1 – The 161 city-pairs considered.

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.

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[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.

Table 1 – Variables initially considered.

Label	Description	Source
Dependant variable:		
Seats (Flights)*	No. of airline seats (or flights) in January 2012	OAG
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)
PopFuaRatio*	Ratio of departing city to arrival city according to the no. of inhabitants in the respective FUAs	LATTS et al. (2011)
PopMua*	No. of inhabitants in the morphological urban areas [MUAs] (summation of the both end-points of the route)	LATTS et al. (2011)
GDP*	Regional gross domestic product (summation of the both end-points of the route)	LATTS et al. (2011)
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 distance	OAG
Distance2	Distance squared	OAG
France	Control variable (dummy)	
Germany	Control variable (dummy)	
Italy	Control variable (dummy)	
Spain	Control variable (dummy)	
Transport-related variables:		
HubDep	Airline hub at the departure city (dummy)	Authors
HubArr	Airline hub at the arrival city (dummy)	Authors
Lowcost*	Share of low-cost air services (in terms of seats supplied)	OAG
TIMEhsr*	Weekly average travel time by high-speed rail (in-vehicle travel time + boarding time)	Authors
FREQhsr*	Weekly HSR services	Authors
IntegDep	Airline/HSR integration at the departure city	Authors
IntegArr	Airline/HSR integration at the arrival city	Authors
DistDep*	Distance between HSR station(s) and airport(s) at the departure city	Authors
DistArr*	Distance between HSR station(s) and airport(s) at the arrival city	Authors

'Authors' means authors' own calculations or knowledge.
* LN transformations are applied to linearize the relation between the dependent variable and the explanatory variables.

Following, for example, Jorge-Calderon (1997) and Bilotkach et al. (2010), our initial set of independent variables is a mix of geo-economic and transport-related factors (Table 1). Geo-economic variables come from research commissioned by the French DATAR[5] (LATTS et al., 2011) providing trans-national, homogenised data on European cities that allow international comparisons. The size of the potential market is determined by the number of inhabitants within both the functional (PopFua) and the morphological (PopMua) urban areas and through GDP. In all cases, data summate both end-points of the route. Because a 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 departing (larger) and arrival (smaller) cities. Because size is not everything and air services are expected to be more used by those professionals working in advanced services (Liu et al., 2006) and in wealthier areas (Dargay and Clark, 2012), we also considered the share of GDP in some specific economic sectors

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

(GDPSERV) and GDP per capita (GDPCAP). Then, we control for some spatial factors, namely the airline distance (DISTANCE and DISTANCE2) and dummies for domestic services (zero in the case of international route).

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 (Dobruszkes et al., 2011). 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.

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, airline fares range from 1 to 12 depending on mode, service, cabin class and dates of purchase and travel. The range is 1 to 6.6 for HSR. 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, LOWCOST 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. Thus, the fact that travel time may vary from one service to others on the same route is taken into account. In addition, when HSR serves both central and peripheral stations, frequency-weighted averages were computed[6]. 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). Finally, we compute the distance between HSR station(s) and airport(s) (DISTDEP and DISTARR) for each city[7]. These variables take into account the fact that access to stations or airports may strongly differ according to their relative location. Figure 2 shows different relative locations, suggesting they might serve different areas. It is expected that the longer DISTDEP or DISTARR are, the more the catchment areas will differ.

In this 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 linearize the relation. The bivariate descriptive analysis of our database confirms the necessity to use logarithm transformation on quantitative variables. Moreover this type of transformation allows to use elasticities in the interpretations.

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

[7] For multiple-airport cities, we computed an average distance weighted by the number of less than 800 km flights.

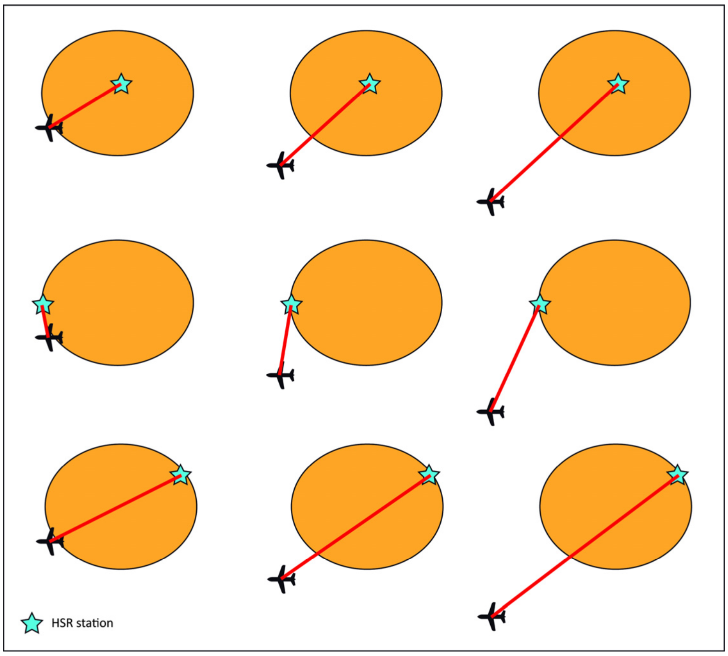

Figure 2 – HSR station–airport distances.

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 (Figure 3). The ordinary least-squares (OLS) estimator is inappropriate on censored samples due to the double structure in the data. On the truncated sample, the ordinary LS 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:

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

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 $\ln(Seats_i)=\max\{0, X_i\,\beta + u_i\}$ for i=1,…,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 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. Another 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 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). As we fail to find reasonable explanations for the ended air services, the Tobit model is applied instead of the Heckman model.

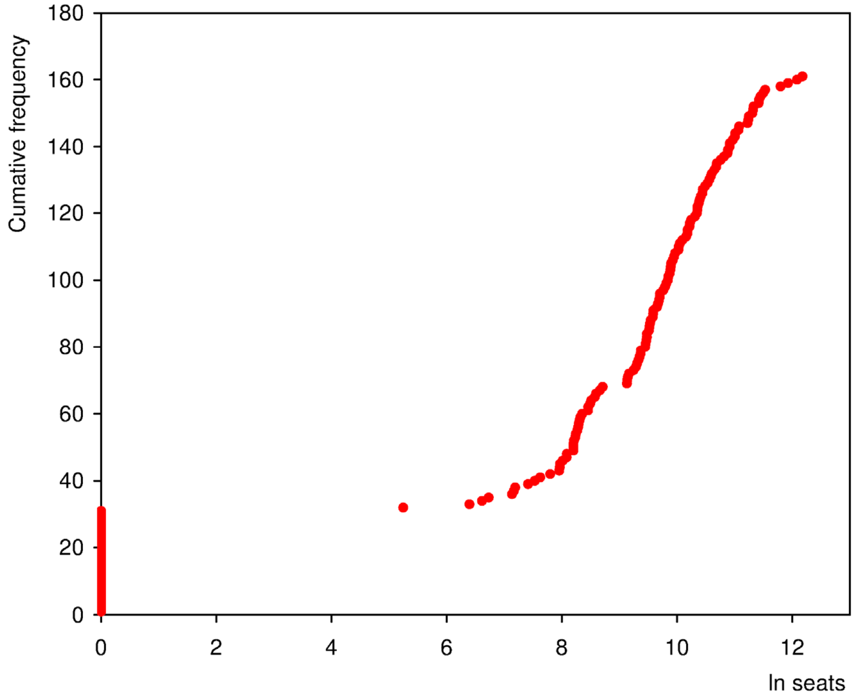

Figure 3 – Left-censored sample.

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 OLS 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 (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:

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[8] Robust against a potential problem of heteroskedasticity.

$$\beta^{CLAD} = \arg\min_{\beta} \sum_{i=1}^{n} \left| y_i - \max\{0, X_i\beta\} \right|.$$

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:

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

where X_i is the row associated with individual i of the (n × q) matrix containing the quantitative explanatory variables, μ is the multivariate location vector and ∑ is the covariance matrix. In practice, however, μ and ∑ 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 ∑ 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 2 gives the descriptive statistics for the set of variables described in Table 1, 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 2 shows that the remaining air services tend toward longer distances, higher HSR travel times and more airline hubs.

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

Table 2 – 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
PopMua (inhabitants)	859,645	17,771,981	-	3,176,950	3,630,729	668,746	10,615,883	-	4,467,100	3,660,738
GDP (million EUR)	33,102	994,270	-	168,760	183,958	37,362	550,226	-	165,299	185,226
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%	0.00	0.46	0	1	42%	0.00	0.50
Germany	0	1	22%	0.00	0.42	0	1	32%	0.00	0.48
Italy	0	1	9%	0.00	0.29	0	1	10%	0.00	0.30
Spain	0	1	12%	0.00	0.33	0	1	6%	0.00	0.25
Transport-related variables:										
HubDep	0	1	63%	1.00	0.48	0	1	52%	1.00	0.51
HubArr	0	1	13%	0.00	0.34	0	0	0%	0.00	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%	0.00	0.49	0	1	48%	0.00	0.51
IntegArr	0	1	17%	0.00	0.38	0	1	3%	0.00	0.18
DistDep	3.9	29.3	-	17.6	6.7	5.3	28.1	-	13.1	6.9
DistArr	2.1	29.3	-	8.6	5.7	4.2	35.6	-	8.4	7.0

* For dummies only.

Preliminary univariate and bivariate descriptive statistics show that POPFUA, POPMUA and GDP are highly correlated and redundant, thus interfering with the models. Because airports usually have rather large catchment areas (Lieshout, 2012; Maertens, 2012), only POPFUA is kept. DISTANCE and DISTANCE2 are also rejected at an early stage, because while not being significant, they lead to models with many incoherent estimates[10]. The more distant cities are, the less interactions they should have (all other things being equal), but the more air transport should be required. In addition, considering HSR travel time (TIMEHSR) and frequency (FREQHSR) together appears to lead to inconsistent results because of quasi-multicollinearity. Thus, the impact of HSR travel time (TIMEHSR) and frequency (FREQHSR) are analysed separately.

Finally, the specification of the models is as follows:

$$\begin{aligned}\mathbf{ln\ Seats} = {} & \max\{0,\ \beta 0 + \beta 1 \ln \text{PopFua} + \beta 2 \ln \text{PopFuaRatio} + \beta 3 \ln \text{GDPserv} + \beta 4 \ln \text{GDPcap} \\ & + \beta 5\ \text{France} + \beta 6\ \text{Germany} + \beta 6\ \text{Italy} + \beta 7\ \text{Spain} + \beta 8\ \text{HubDep} + \beta 9\ \text{HubArr} \\ & + \beta 10\ \text{IntegDep} + \beta 11\ \text{IntegArr} + \beta 12 \ln \text{Lowcost} + \beta 13\ \mathbf{ln\ TIMEhsr} + \beta 14 \ln \text{DistDep} \\ & + \beta 15 \ln \text{DistArr} + u\} \qquad \text{(Eq. 1)}\end{aligned}$$

$$\begin{aligned}\mathbf{ln\ Flights} = {} & \max\{0,\ \beta 0 + \beta 1 \ln \text{PopFua} + \beta 2 \ln \text{PopFuaRatio} + \beta 3 \ln \text{GDPserv} + \beta 4 \ln \text{GDPcap} \\ & + \beta 5\ \text{France} + \beta 6\ \text{Germany} + \beta 6\ \text{Italy} + \beta 7\ \text{Spain} + \beta 8\ \text{HubDep} + \beta 9\ \text{HubArr}\end{aligned}$$

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[10] Nevertheless, we checked whether these two variables were significant once the final models had been estimated, and they were not.

+ β10 IntegDep + β11 IntegArr + β12 ln Lowcost + β13 **ln TIMEhsr** + β14 ln DistDep
+ β15 ln DistArr + u} (Eq. 2)

ln Seats = max{0, β0 + β1 ln PopFua + β2 ln PopFuaRatio + β3 ln GDPserv + β4 ln GDPcap
+ β5 France + β6 Germany + β6 Italy + β7 Spain + β8 HubDep + β9 HubArr
+ β10 IntegDep + β11 IntegArr + β12 ln Lowcost + β13 **ln FREQhsr** + β14 ln DistDep
+ β15 ln DistArr + u} (Eq. 3)

ln Flights = max{0, β0 + β1 ln PopFua + β2 ln PopFuaRatio + β3 ln GDPserv + β4 ln GDPcap
+ β5 France + β6 Germany + β6 Italy + β7 Spain + β8 HubDep + β9 HubArr
+ β10 IntegDep + β11 IntegArr + β12 ln Lowcost + β13 **ln FREQhsr** + β14 ln DistDep
+ β15 ln DistArr + u} (Eq. 4)

Table 3 – Parameter estimates (Eqs. 1 & 2).

Model	MLE	Weighted CLAD	MLE	Weighted CLAD
Equation	(1)	(1)	(2)	(2)
Dependent variable	**ln Seats**	**ln Seats**	**ln Flights**	**ln Flights**
ln PopFua	2.824 ***	1.966 ***	1.666 ***	1.482 ***
ln PopFuaRatio	-2.659 ***	-1.387 ***	-1.461 ***	-1.067 ***
ln GDPserv	1.438	0.923	1.302	0.157
ln GDPcap	3.581	4.196	1.884	3.801
France	2.123 *	1.632	1.378 **	1.808 **
Germany	-0.132	-0.157	-0.109	-0.276
Italy	3.993 ***	2.325 **	2.269 ***	1.781 **
Spain	4.030 *	1.320	2.504 **	1.442
HubDep	2.722 **	1.139	1.505 ***	0.794
HubArr	1.560 **	0.522	1.105 ***	0.698
ln Lowcost	0.351 **	0.335 *	0.193 **	0.159
ln TIMEhsr	4.418 ***	1.120 ***	2.429 ***	1.105 **
IntegDep	-0.183	-0.905	-0.204	-0.636
IntegArr	1.654 *	0.252	0.927 *	0.373
ln DistDep	-0.871	-1.104	-0.429	-0.551
ln DistArr	-1.727 **	-0.655	-0.926 **	-0.521 *
Constant	-53.744 ***	-36.002 ***	-33.336 ***	-30.967 **
Sigma	3.585 ***	N.A.	1.885 ***	N.A.
Observations	161	140	161	140
Censored observations	31	29	31	29
Pseudo R2	0.101	0.222	0.138	0.243

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

The regression analysis results for Equations 1 and 2 (i.e. HSR travel time impact on number of seats and flights, respectively) are summarised in Table 3. First of all, the bias of selection (explained by the parameter sigma) is significantly different from zero, meaning that censored models are required. Second, Table 3 shows there is a large gap between Tobit and weighted-CLAD estimators. The significant variables are not exactly the same, and their values are quite different (although with the same signs). Given that weighted-CLAD models are more robust (see above), Table 3 demonstrates that 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 or 2, respectively. Weighted CLAD models exclude 21 routes. As stated above, the exclusion is based on multi-dimensional inspection of atypical points. However, several excluded routes correspond to non-competitive HSR travel time because of very long distances (e.g. 1,124 km for Barcelona-Malaga via the suburb of Madrid) and/or limited rides on HSLs (e.g. 778 km for Paris-Munich, 61% without HSL).

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) departing 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.

The share of GDP in advanced services is not significant. 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. Moreover, per capita GDP is not significant, which may suggest that personal or household income would have been a better variable.

In addition, the Italy dummy is significant (relative to international routes) with a positive estimate, as France dummy in Equation 2. This means that additional country factor(s) lead to more air services when controlling for the other significant variables (cities' population, HSR travel time, etc.). These additional factors may (for example, fares) or may not be transport-related. A potential factor for Italy is the deep regional divide, with numerous southern migrants living in the north (Bonifazi and Heins, 2000; Etzo, 2011). At the international level, there is strong evidence that the stock of migrants generates VFR (visits to friends and relatives) travel (Gheasi et al., 2011) and that VFR travel constitutes a large part of air travel (CAA, 2009). There is no apparent reason preventing similar effects within a domestic context if air travel is suitable. This should be investigated further with regard to the Italian case, but suggests that national spatial patterns may influence intermodal effects. As for France being significant only for Equation 2, this may be due to the high-frequency strategy led by Air France on some trunk domestic routes[11].

Airlines hubs are not significant. This is surprising given that hub-and-spokes networks often involve more seats or even flights per route than point-to-point networks (O'Kelly, 1998; Derudder et al., 2007). This may be due to the fact that outliers are excluded, as hubs are significant with the Tobit model. In contrast, the presence of low-cost airlines is associated with more airline seats, suggesting that cheap flights tend to induce more traffic (Graham and Shaw, 2008). However, the effect is limited and does not concern the number of flights.

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 (Dobruszkes and Givoni, 2012). However, to our knowledge, it has never been found through an EU-wide quantitative analysis covering a hundred routes. 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 excessive. The models also show that HSR travel time similarly impacts the number of airline seats and the number of flights. This contradicts the hypothesis

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[11] *La Navette* (The Shuttle) offers hourly services off-peak and up to four flights per hour on peaks.

that airlines set up frequency-oriented strategies to maintain their competitive position. With such strategies, we would expect TIMEHSR's estimate to be higher for Equation 1 than for Equation 2. This result is consistent with Bilotkach et al.'s (2010) mixed evidence, although they considered shorter routes (less than 550 km) and competition from HSR as dummy variables.

By contrast, 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 limited. 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.

Finally, distance between HSR stations and airports is only slightly significant for Equation 2, despite its large dispersion (Table 2). On the one hand, this could mean that HSR stations and airports 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 departing and arrival points of people travelling by plane or HSR. This means considering the spatial patterns of metropolitan areas. For example, French surveys show that upper social and occupational groups overuse HSR services[13]. 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, as illustrated by Figure 4. In other words, the socio-spatial pattern of cities may influence the respective attractiveness of HSR and airlines. Unfortunately, this potential factor is very difficult to turn into a variable. Indeed, socio-social patterns may follow very different forms, including concentric zones, sectors and multiple nuclei. In the end, it is possible that the distance between HSR stations and airports could take its significance only in relation with these socio-spatial patterns.

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

[13] 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).

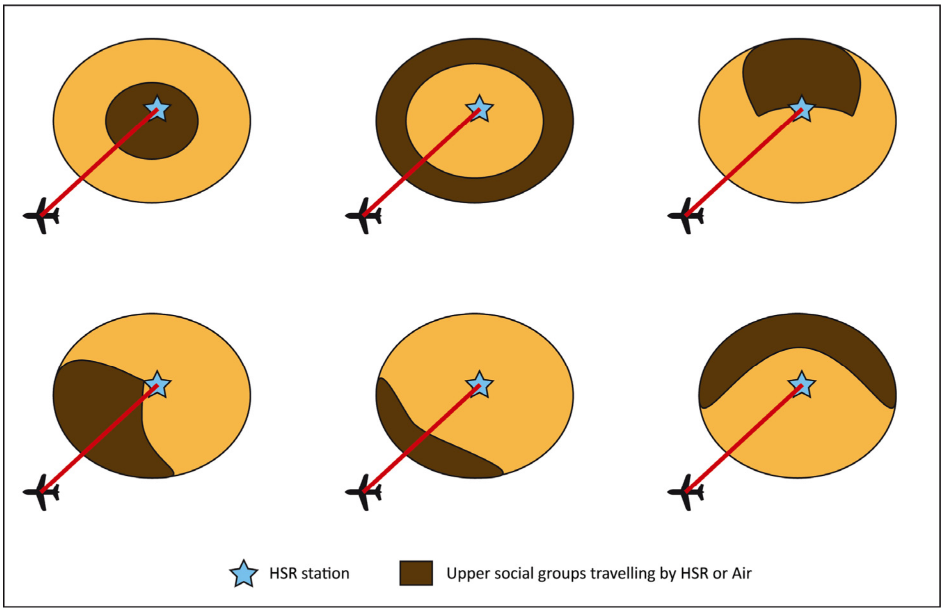

Figure 4 – Examples of socio-spatial patterns for one given HSR station–airport layout.

Let us turn to the impact of HSR frequency on air services. As previously discussed, this variable is not analysed jointly with HSR travel time because of quasi-multicollinearity. Among other things, HSR frequency gives similar information as HSR travel time (the former decreases when the latter increases). If HSR is competitive thanks to travel time, it can reach high market shares and induce new traffic, leading to higher frequencies. Considering HSR frequency without HSR travel time, Table 4 nevertheless shows no apparent impact. However, this does not mean that HSR frequency is not important. More likely, considering it as a proportional variable might not be a good option. This may be due to the fact that other factors influence passengers' modal choice before considering frequency or that frequency only indirectly plays a role, (for example, higher frequency makes same-day return journeys possible and offers more flexibility to time-sensitive passengers). Thus, FREQHSR becomes a dummy variable. Given breaks in its cumulative frequencies curb, we consider the following dummies:

- FREQHSR7=1 if FREQHSR >7, i.e. more than one HSR service per day
- FREQHSR 14=1 if FREQHSR >14, i.e. more than two HSR services per day
- FREQHSR 35=1 if FREQHSR >35, i.e. more than five HSR services per day
- FREQHSR 114=1 if FREQHSR >114, i.e. more than one HSR service per hour during 16 hours

Table 4 – Parameter estimates (Eqs. 3 & 4).

Model	MLE	Weighted CLAD	MLE	Weighted CLAD
Equation	(3)	(3)	(4)	(4)
Dependent variable	**ln Seats**	**ln Seats**	**ln Flights**	**ln Flights**
ln PopFua	2.403 **	1.183 **	1.445 ***	0.916 *
ln PopFuaRatio	-2.123 ***	-1.074 ***	-1.172 ***	-0.909 ***
ln GDPserv	-2.398	1.703	-0.787	0.632
ln GDPcap	4.798	4.604	2.560	4.762
France	1.694	1.410	1.152	1.878 *
Germany	-0.938	0.086	-0.544	-0.019
Italy	1.464	1.865	0.902	1.500
Spain	0.819	1.741	0.750	2.067
HubDep	2.894 **	1.031 *	1.602 **	0.562 **
HubArr	2.173 **	0.835	1.440 ***	0.827 *
ln Lowcost	0.792 ***	0.356 **	0.435 ***	0.209 *
ln FREQhsr	-0.525	-0.322	-0.298	-0.286
IntegDep	-1.478	-1.108 **	-0.921 *	-0.700 **
IntegArr	1.147	0.189	0.650	0.487
ln DistDep	-1.322	-0.607	-0.683	-0.012
ln DistArr	-1.465 *	-0.255	-0.785 *	-0.119
Constant	-29.058	-27.806 **	-19.957 **	27.168 **
Sigma	3.958 ***	N.A.	2.097 ***	N.A.
Observations	161	144	161	144
Censored observations	31	30	31	30
Pseudo R2	0.067	0.191	0.093	0.203

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

Results are shown in Table 5. Only FREQHSR114 is significant and displayed. This suggests that all other things being equal (and not considering HSR travel time), only high frequencies can cause HSR to decrease the provision of air services. In contrast with HSR travel time, the impact here is stronger on airline seats than on the number of flights. A 1% increase in HSR frequency involves a 0.94% decrease in airline seats but a 0.68% decrease in flights. However, this may be due to the fact that high-frequency HSR services are faster. The average HSR travel time is 2.3 hours for routes with more than 114 weekly HSR services, compared to 4.5 for the others. Moreover, the causality might be in the other direction: when airlines reduce their services for some reason, HSR can increase its frequency.

Finally, pseudo R^2 values in Table 5 are slightly lower than for the models considering HSR travel time (Table 3), suggesting that HSR travel time can better describe the impact of HSR on air services than HSR frequency.

Table 5 – Parameter estimates (Eqs. 3 & 4 with HSR frequency as dummies).

Model	Weighted CLAD		Weighted CLAD	
Equation	(3)		(4)	
Dependent variable	**ln Seats**		**ln Flights**	
ln PopFua	1.619	***	1.157	***
ln PopFuaRatio	-1.167	***	-0.791	***
ln GDPserv	0.188		0.206	
ln GDPcap	3.935		3.037	
France	1.279	*	1.472	*
Germany	-0.158		-0.169	
Italy	1.873	*	1.291	
Spain	1.498		1.285	
HubDep	0.653		0.807	**
HubArr	0.561		0.645	
ln Lowcost	0.357	***	0.240	***
FREQhsr114	-0.933	**	-0.679	**
IntegDep	-0.824	*	-0.716	*
IntegArr	0.674		0.391	
ln DistDep	-0.316		-0.544	
ln DistArr	-0.560		-0.235	
Constant	-27.692	***	-22.620	***
Observations	148		148	
Censored observations	28		28	
Pseudo R2	0.213		0.238	

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

4. CONCLUSIONS AND RESEARCH PROSPECTS

This paper analyses whether European HSR services impact the provision of air services. An EU-wide, ex-post analysis is conducted, covering a large sample of routes and using transnational data allowing international comparisons. The methods used provide results that are more robust than classical MLE estimates in the Tobit model. It was found that air services are indeed affected by HSR travel time: there are more air services if HSR travel time is longer. We also found that HSR travel time has a similar impact on both airline seats and the number of flights. In our sample, intermodal competition does not lead airlines following frequency-oriented strategies to maintain their competitive position. In contrast, HSR frequency is found to have only limited impact on air services. Furthermore, low-cost airlines competing with HSR services lead only to a slight increase in air services when controlling for other factors.

Our results are in line with the numerous studies that have highlighted the fact that HSR travel time is an important factor in the competition between HSR and airlines. However, there is a difference between the present research and previous ones: we focused on observed competition (and not forecast competition), on the provision of air services rather than on the number of passengers and on virtually all the city-pairs that are, or were, affected by rail/air competition and not only a few as in most other studies. Thus even if the results in terms of HSR travel time impact were expected, they had never been confirmed empirically in an ex-post and spatially comprehensive analysis. In addition, comparisons with the aforementioned authors who analysed large sets of routes are not really possible because of gaps in spaces and/or variables considered.

Of course, it might be possible to improve the models by including additional variables. Fares are probably an important point, but their temporal variation is so high that it is arguably difficult to gather them. Considering yearly 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 comprehension of intermodal competition (e.g. densities, number and relative location of HSR stations, airport, 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, as highlighted by the Italian case and the potential impact of its internal migration on domestic, long-distance travels.

Regardless, the analysis presented here should be considered as a step. Today, HSR is regarded as a means to reach 'greener' mobilities. Our results bring partial support for employing HSR in this way. However, two additional topics should be analysed before concluding that HSR is really helpful, environmentally-speaking. First, this paper analyses the impact of HSR on the current level of air services. A next step would be to analyse its impact on the change in HSR service, namely, a focus on before/after HSR provisions for air services. This involves gathering data relating to many different years and using appropriate methods to deal with the time issue. Second, one should then take into account the potential for modal change from air to HSR, as infrastructure costs and traffic density are important to justify HSLs (de Rus and Nombela, 2007). First attempts in this way suggest the potential are rather limited (Givoni et al., 2012), but this could be investigated in more depth as well.

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