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Competition and cooperation between high-speed rail and air transportation services in Europe

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ABSTRACT

New high-speed rail (HSR) lines may have an enormous influence on the provision of air services. The attention has been devoted to competition between both transportation modes but in some cases HSR services may also have an intermodal complementary role with air transportation. By taking a supply oriented empirical analysis, we study the impact of HSR on air service frequencies and seats offered by airlines in large European countries. We emphasize the distinction between routes with and without a hub airport as an endpoint and we also examine the influence of the location of the HSR station. We generally find direct competition between HSR and airlines, but we also provide some evidence that HSR can provide feeding services to long haul air services in hub airports, particularly in hub airports with HRS stations.

1. Introduction

High-speed rail (HSR) growth has led to major changes in the supply of interurban transportation in those countries that have extended their HSR networks and services. One of the main impacts has been the replacement of demand for other modes, most notably air transportation – HSR's main competitor, owing to the characteristics of the two services and their respective generalized costs. An extensive literature on the intermodal interaction of HSR and air services has developed, focused mainly on competition between the modes, while studies of their complementarities are much rarer. Our paper seeks to contribute to this literature, first, by providing relevant new evidence of the effects of HSR–air competition; and, second, by furthering our understanding of potential complementarities between the two services.

Demographics and mobility (including urban structures and economic and commercial patterns) along with supply features (including travel time, access to city centers, cost and frequencies) are all major determinants of the competitiveness of HSR (see González-Savignat, 2004; Dobruszkes, 2011; Albalate and Bel, 2012). The study of the fierce intermodal competition between air and HSR transportation is (as shown in the next section) an emerging area of research; however, little attention has been devoted to their intermodal complementarities. Exceptions include Givoni and Banister (2006), who highlight the potential integration of the two modes, with airlines using railway services as additional spokes in their network of services from a hub airport to complement and substitute for existing aircraft services. Similarly, Clewlow et al. (2012) suggest HSR might serve as a complementary mode to relieve congestion at airports by providing short-haul services in support of longer-haul airline services. They conclude that HSR lines appear to serve as successful feeders for international air traffic at Frankfurt Airport and at Paris-Charles de Gaulle (Paris-CDG). Grimme (2006) also illustrates cooperation by analyzing the case of AIRail, an integrated ticketing and baggage handling service offered by Deutsche Bahn (rail operator), Lufthansa (air carrier) and Fraport (airport). However, all in all, the scope for cooperation remains largely unexplored.

The intermodal complementarities of HSR and air transportation have been considered a primary transportation policy goal in France since 1995 and have recently been strengthened with the enactment of a national environment program, "Grenelle II". This 2010 program seeks – among other objectives – to promote HSR access and commuting to major airports. The policy framework facilitates the emergence of new cooperative experiences of code share, single ticketing and one-stop baggage check agreements between airlines and SNCF – the French railway operator (see Mell, 2013).

Here we undertake a supply-oriented analysis, as we empirically study the impact of HSR on air service frequencies and the number of seats offered by airlines in Europe. More specifically, we focus on the impact of HSR on national air routes in the four

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European countries with the longest HSR networks. In addition to examining the competitive role of HSR, we also seek to identify the potential for intermodal cooperation. In this regard, we provide new evidence of the disparate effects of HSR on air transportation, depending on an airport's characteristics.

In the next section we review the empirical literature on intermodal interaction between HSR and air transportation. We then present our empirical methodology and the main data used in our analysis, followed by our empirical results. Finally, we discuss our main findings and their policy implications.

2. Intermodal competition and cooperation between HSR and air transportation

The literature consistently shows that the competitiveness of HSR is highly dependent on route distance – seemingly more efficient on medium-distance routes than on short- or long-haul routes (Janic, 1993; Capon et al., 2003; IATA Air Transport Consultancy Services, 2003; GAO, 2009). However, given the heterogeneous speeds of high-speed services, route distance would appear simply to be an imperfect proxy of travel time, the definitive determinant of competitive advantage.

HSR undermines alternative modes because of its ability to capture a relatively large market share, with passengers being attracted away from airlines, primarily, over medium distances (see Román et al., 2007; Martín and Nombela, 2008).[1] In Japan (pioneering HSR since 1964) a rapid fall in airline transportation was noted after the extension of the HSR network. According to Taniguchi (1992), HSR was more competitive over distances of less than 438 miles because of higher frequency services, cheaper fares, the proximity to city centers and service reliability and safety. In fact, the market share of the *Shinkansen* is always greater than that of airlines on routes of less than 600 miles in Japan (Albalate and Bel, 2012). The distance between main cities, the city structure and the ability to exploit scale and density economies, which can be translated into a lower generalized cost of transportation, seem to account for the overwhelming superiority of Japanese HSR services.

Likewise, the European Commission (1996) has provided data on changes in modal shares following the introduction of HSR on some European routes, and has shown how air traffic suffered the most marked impact. On the Paris–Lyon route, for instance, the air traffic share fell from 31% to 7% between 1981 and 1984.[2] Klein (1997) evaluated the impact of the *TGV-Atlantique* on modal competition, finding that air travel recorded a sharp reduction in journeys between 90 and 180 min of duration, while it recovered competitiveness for distances beyond this time interval.

In the case of the Madrid–Seville route, the share of air traffic fell from 40% to 13% between 1991 and 1994 (European Commission, 1996; Park and Ha, 2006). More recently, in 2009, the Spanish *AVE* enjoyed 85% of the market share on the Madrid–Seville route, more than 70% on the Madrid–Malaga route, and around 50% on the Madrid–Barcelona line in 2009, in detriment, above all, to the airplane (Albalate and Bel, 2012). This superiority decreases with route distance given that its share becomes more modest on routes over 400 miles. Thus, the *AVE* only enjoys 30% of the market share of seats on the Barcelona–Seville route (though most of these seats are not used from point of origin to final destination – i.e., BCN-Seville, but rather to intermediate destinations between the two cities). This is attributable to the longer HSR journey time (twice that of the plane), the more expensive fare and by the limited frequency of the service. The continuous extension of the HSR network in Spain has allowed new studies to be made of the response of airlines. Jiménez and Betancor (2012), among others, report that new HSR connections have reduced the number of air transport operations by 17%.

In the case of Germany, Ellwanger and Wilckens (1993) identified an initial increase in rail market share of 11% following the introduction of HSR services between Frankfurt and Cologne, with air transportation suffering the most passenger losses. By contrast, Dobruszkes (2011) found that the flag carrier airline Lufthansa increased its services after the entry into service of the Cologne–Frankfurt line. However, it was later forced to reduce its flight frequencies with the inauguration of the HSR line between Cologne and Munich, despite this being a service that stops at several stations en route and the fact that the service is not high speed for the whole journey.

In Korea the two main airlines providing services between Seoul and the country's other main cities anticipated the arrival of HSR and drastically reduced the frequency of their flights in 2004. For example, between Seoul and Daegu the number of monthly air departures fell from 517 to 293 prior to the entry of HSR and 2 months after the entry they were down to just 183 (Suh et al., 2005). These figures are consistent with those of Park and Ha (2006). Similarly, in Taiwan, the market share held by air services between Taipei and Kaohsiung fell from 24% to 13% following the introduction of HSR services (see Cheng, 2010).

Intermodal competition not only effects market share, it is also responsible for reducing air fares. The Steer Davies Gleave report (2006) undertaken for the European Commission identifies sharp reductions in air fares attributable to competing HSR services, to the extent that they might fall below corresponding rail fares. Yang and Zhang (2012) also find that air fares decrease in rail speed when the marginal cost of HSR is not very high.

In spite of the competitive pressure exerted by HSR, the greater presence of low-cost carriers in the airline market provides the latter with more protection from the competition of HSR services. Indeed, Antes et al. (2004) report that the competitive pressure of low-cost carriers has obliged both air and rail transport to reconsider their pricing strategies. In Japan, for instance, the airline industry has effectively only been able to grow with the emergence of low-cost carriers following the liberalization of air transport (Albalate and Bel, 2012). Steer Davies Gleave (2006) acknowledges that competition between HSR and air transportation is not so straightforward when air services are operated by low-cost carriers. Similarly, Behrens and Pels (2012) show that although HSR is a competitor for both conventional and low-cost carriers, some conventional airlines have pulled out of the London–Paris passenger market.

The pressure of competition and its consequences seem to mitigate in the long run, especially once the market has adjusted to the entrance of the HSR competitor. Vickerman (1997) monitored the modal change provided by HSR in France and found that the increase in rail passengers was confined almost exclusively to the first years of HSR operations, becoming much more moderate thereafter. Similarly, Behrens and Pels (2012) consider that the evidence for the large market share gained by Eurostar on the London–Paris route, and the withdrawal of alternative air services, indicates that competition will certainly decline in the long run. These circumstances may boost the market power of HSR given that rail operators can increase their prices to maximize profits without losing a significant market share (Steer Davies Gleave, 2006).

[1] The absorption of what were frequent air passengers has been more significant than that of new, induced passenger traffic, which has been much lower than expected. For instance, 50% of the traffic on the Madrid–Seville route (de Rus and Inglada, 1997) and 20% on the Madrid–Barcelona route (Coto-Millán et al., 2007) were expected to be induced. In practice, new, induced traffic has amounted to 26% in the first case and 9% in the second (PWC, 2010). This is consistent with data elsewhere and as reported in Preston (2013).

[2] Bonnafous (1987) reports an even more pronounced fall from 48% to 17% on this route between 1980 and 1985.

Table 1
Air traffic and high-speed train lines in European countries – EU27 (data for 2010). *Source:* Eurostat and International Union of Railways.

Country	Domestic air traffic (passengers carried. In 000)	Length of high-speed train network (max. speed ⩾250 km/h)
Spain	38,227	1972
Italy	29,940	923
France	25,872	1896
Germany	24,164	1019
UK	20,980	113
Greece	6297	–
Sweden	6121	–
Portugal	3011	–
Denmark	2401	–
Finland	2250	–
Poland	942	–
Austria	762	–
Romania	746	–
Ireland	360	–
Czech Republic	206	–
Belgium	56	209
Slovakia	42	–
Estonia	25	–
Netherlands	3	120
Luxembourg	0.8	–
Latvia	0.3	–
Lithuania	0.2	–
Slovenia	0.1	–
Cyprus	0	–
Malta	0	–
Hungary	–	–

In some instances, the introduction of HSR services, as well reducing the market share of air transportation and impacting air fares, may result in the cancellation of air routes. This occurred in Japan, with the cancellation of the route between Tokyo and Nagoya.[3] In China, according to the managing director of the country's General Administration of Civil Aviation (CAAC), around 50% of flights over distances of less than 310 miles and about 20% of flights between 500 and 620 miles became unprofitable in 2009 as a result of competition from HSR services.[4] Two of the routes cancelled were Nanjing–Wuhan and Zhengzhou–Xi'an; however, these services were subsequently resumed when a decision was taken to reduce the speed of HSR services. Similarly, airlines in Taiwan responded to HSR competition by cancelling a number of services (for example, the Taipei–Taichung route flown by Mandarin Airlines) and by entering into cooperation agreements with other airlines so as to allow any passenger with a reservation to be able to use any of the airlines, thus cooperatively competing against HSR (see Albalate and Bel, 2012, for a review of these circumstances).

3. Empirical analysis: methodology and data

We conduct our empirical analysis on domestic route data for four countries in the European Union, namely, France, Germany, Italy and Spain. We have chosen these countries because of the size of their domestic air transport markets and because they present a sufficiently large number of air routes with and without competition from HSR services. In addition, they operate HSR networks that are large enough to compete with air transportation in their domestic markets (see Table 1). In fact, the HSR networks in these four countries alone accounted for 93% of the total European HSR network in 2010.

Data are available for a high proportion of domestic routes in each of the four countries. Given that our main interest is the analysis of competition and complementarities between air and HSR services, we exclude from our sample air routes that have an island as their endpoint. Likewise we also exclude routes that did not operate air services during most of the years of our period of analysis, which runs from 2002 to 2010 in the case of flight frequencies and from 2002 to 2009 in the case of the total number of seats available (in both instances the periods are determined by data availability).

The unit of observation is the route–year pair. We collected data for 180 routes (over 9 years for flight frequencies and 8 years for number of seats) and our final sample comprises 1396 observations for seats and 1572 for flight frequencies (with some missing values on routes with no air traffic in a specific year). The distribution of observations for each country is as follows: Spain (328 seats, 369 frequencies), France (224 seats, 255 frequencies), Italy (328 seats, 368 frequencies) and Germany (516 seats, 579 frequencies). We estimate the following equations for route k in time period t[5]:

$$\begin{aligned} Seats_{kt} = {} & \alpha + \beta_1 Population_{kt} + \beta_2 GDP_{kt} + \beta_3 Distance_k + \beta_4 D_k^{hub} \\ & + \beta_5 D_{kt}^{high\_speed\_train} + \beta_5 \mathrm{HHI}_{kt} + \beta_6 D_{kt}^{LCC} + \lambda' D_k^{country} \\ & + \mu' D_t^{year} + \varepsilon \end{aligned} \quad (1)$$

$$\begin{aligned} Frequencies_{kt} = {} & \alpha + \beta_1 Population_{kt} + \beta_2 GDP_k + \beta_3 Distance_k \\ & + \beta_4 D_k^{hub} + \beta_5 D_{kt}^{high\_speed\_train} + \beta_5 \mathrm{HHI}_{kt} + \beta_6 D_{kt}^{LCC} \\ & + \lambda' D_k^{country} + \mu' D_t^{year} + \varepsilon \end{aligned} \quad (2)$$

where the dependent variables are the total number of seats (*Seats*) and the total annual frequency (*Frequencies*) offered by airlines on

[3] Other routes abandoned after the introduction of HSR in Japan included those that connected Tokyo with Sendai, Niigata, Aichi and Iwate, all of which were below 350 miles in length (see Albalate and Bel, 2012).

[4] Li Jiaxiang's declarations made to Airline Leader, a publication for airline company executives (2011).

[5] We do not treat airline services in different directions on the same route as separate observations since this would overlook the fact that airline supply is identical, or nearly identical, in both directions of the route. Thus, we consider the link that originates at the largest airport. For example, on the route Madrid–Barcelona–Madrid, we consider the link Madrid–Barcelona but not the link Barcelona–Madrid.

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route i in year t. We consider the following exogenous explanatory variables in both equations:

Population: Weighted average of population in the regions of origin and destination for a given route.

GDP: Weighted average of gross domestic product per capita in the regions of origin and destination for a given route (weights are based on population).

Distance: Number of kilometers flown to link the endpoints of the route. Given that we expect a non-linear relationship between distance and the supply of flights, this variable is measured in logs.

D^{hub}*:* Dummy variable that takes a value of one for those routes on which at least one of the endpoints is a hub airport of a network airline.[6]

$D^{high\_speed\_train}$*:* Dummy variable that takes a value of one for those routes on which HSR services compete with airline flights. We only take into account direct services with no connections/transfers and where the entire line is a high-speed service (thus, routes with sections of conventional rail are excluded).

HHI: Competition at the route level, measured using the Herfindahl–Hirschman index, defined as the sum of the squares of the market shares of airlines operating the route in terms of flight frequencies.

D^{low_cost}*:* Dummy variable that takes a value of one on those routes on which low-cost airlines offer a service.

$D^{country}$, D^{year}*:* Country and year dummies, with 2002 being the year excluded and Germany the country excluded.

Airline frequency data were obtained from RDC aviation (Capstats.com). Data for population and GDP per capita at the NUTS 3 level (the statistical unit employed by Eurostat) were provided by Cambridge Econometrics (European Regional Database). Distance data were obtained from the Official Airlines Guide (OAG) and the WebFlyer website (http://www.webflyer.com).

The hub airports (i.e., those at which a network airline integrated in an international alliance exploits the connecting traffic) included in our analysis are Paris (Charles de Gaulle and Paris-Orly), Frankfurt, Munich, Madrid, Rome-Fiumicino and, until 2007 only, Milan-Malpensa. These airports are characterized by their size and the fact that a network airline operates a high percentage (usually over half) of all its flights out of them. Other large airports in the countries considered, including Barcelona, Dusseldorf and Milan-Malpensa, are not currently hub airports as most of their traffic is channeled by airlines operating point-to-point routes.

The *High Speed* variable applies to routes on which rail services operate at, at least, 250 km/h. We only take into account direct services with no connections/transfers and where the entire line is a high-speed service (thus, routes with sections of conventional rail are excluded). We obtained information about each line from the International Union of Railways' (UIC) HSR maps and information on direct services across Europe was collected from the search engines of *Voyages-sncf*, the commercial online ticket distributor of SNCF. This variable is constructed as a binary variable taking a value of 1 for HSR connections and 0 for routes not satisfying our requirements.

The population and GDP variables are demand shifters at the route level. Indeed, demand is expected to be higher on those routes that connect richer and more populous endpoints. The number of annual seats and frequencies should be higher on thicker routes. Thus, we expect the coefficients associated with population and GDP to be positive.

The hub airport variable is also a demand shifter at the route level. Demand at hub airports is higher than that generated by the local population alone because the hub airline exploits connecting traffic. Thus, we expect the coefficient associated with this variable to be positive.

In the case of the distance variable, demand for air services should be higher on longer routes as there is less competition with surface modes. Airlines may, otherwise, be required to offer high-frequency services on shorter routes in order to compete with other transportation modes. Note also that airlines may prefer to use smaller planes at higher frequencies on short-haul routes. Thus, we can expect a positive relationship between distance and the number of seats but the relationship between distance and frequencies is not so clear-cut.

We expect the coefficient associated with the concentration index to be negative because airlines not only compete in terms of prices but also in terms of flight frequencies. The presence of low-cost competitors on a route can reduce the price and spur demand but it can also reduce the profitability of that route and negatively affect rivals. Thus, the expected sign of this variable is ambiguous.

The main variable of interest in our analysis is the dummy variable for high-speed train services.[7] Competition from high-speed train services on given routes may have a substantial influence on the number of seats and flight frequencies offered by airlines on these routes.

Demand for air services is expected to be lower on those routes on which airlines compete with high-speed train services as travelers can choose another rapid option for making their trip. In the case of hub airports, the decrease in the demand for air services may be attributable to point-to-point traffic but also feeder traffic. This is particularly the case when the hub airport has its own high-speed train station, as is the case of Paris-CDG and Frankfurt.

However, airlines may still be required to maintain high-frequency services so as to be competitive with high-speed train services. Indeed, flight frequency is typically considered the main attribute of air services, as higher frequencies reduce expected schedule delay costs (i.e., the difference between the desired and actual times of departure).

Overall, therefore, we expect the coefficient associated with the dummy variable for high-speed train services in the seats equation to be negative, while the expected sign in the frequency equation is less clear.

Table 2 reports our descriptive statistics for the variables used in the empirical analysis. First, the country with the lowest number of observations is France, despite being the second largest country in our sample. Spain has the densest network of routes, while Italy has the least dense. The mean route distance is around 500–600 km for all countries except Germany at below 400 km. The proportion of routes with a hub airport as an endpoint is about 50% in all countries except France where the proportion is 65%. Finally, France is the country with the highest proportion of routes subject to competition from high-speed train services. Forty percent of air routes in France are subject to intermodal competition while these rates are lower than 10% in the other countries.

[6] It might be argued that the hub variable is potentially endogenous. The decision of an airline to build (or not build) a hub-and-spoke network centered on one airport would have been made much earlier than 2002 (the first year considered in our empirical analysis) for all the airports in our sample. The only possible exception is the de-hubbing strategy implemented by Alitalia in Milan-Malpensa in 2007. As such, we do not expect an endogeneity bias in our estimation.

[7] Our model does not provide a comprehensive explanation for changes to the supply of air services on the routes included in the sample, as this would require a large amount of micro-data at the route/city level (for instance, generalized price of the trip from airport/station to final destination and *vice versa*) that are not systematically available. Having said this, we believe our model provides a good, consistent specification that allows us to obtain robust results for the variables that are central to our analysis and research questions.

Table 2
Descriptive statistics of variables (values at the route level).

	Spain		France		Italy		Germany	
	Mean	Std. deviation	Mean	Std. deviation	Mean	Std. deviation	Mean	Std. deviation
Seats	296303.6	568156.7	254368.3	586350.4	237192.5	332312.6	238351.6	313891.3
Frequencies	2287.69	3300.99	1923.76	3613.43	1688.50	2088.95	1943.22	1973.75
Population	4375.42	1278.78	8085.34	4112.57	2944.14	766.69	1068.27	725.54
GDP	117.69	10.43	156.58	26.13	126.12	25.51	192.74	45.25
Distance	501.10	186.19	527.27	132.31	598.72	215.66	368.10	119.08
D^{hub}	0.46	0.49	0.65	0.47	0.48	0.50	0.42	0.49
$D^{high\_speed\_train}$	0.065	0.24	0.38	0.48	0.087	0.28	0.080	0.27
Number of observations	369		290		369		585	

Table 3
Descriptive statistics of largest airports in each country (data for 2010).

	Hub airport	National destinations with non-stop services	International destinations with non-stop services	Total frequencies (national + international)	Share dominant airline	High speed rail station at the airport
Madrid	YES	21	164	211,859	50% (Iberia)	NO
Barcelona	NO	22	133	130,394	22% (Vueling)	NO
Paris-CDG	YES	15	229	228,256	59% (Air France)	YES
Paris-ORY	YES	31	104	111,520	54% (Air France)	NO
Rome-FCO	YES	19	165	159,602	45% (Alitalia)	NO
Milan-MXP	YES/NO[a]	6	133	85,470	24% (Easyjet)	NO
Frankfurt	YES	14	244	218,664	63% (Lufthansa)	YES
Munich	YES	19	181	185,159	65% (Lufthansa)	NO

[a] Milan MPX cannot be considered a hub airport after Alitalia ceased offering connections and long distance flights in 2007.

Table 3 presents additional information for the largest airports in the four countries. Iberia is the dominant airline in Madrid, Lufthansa in Frankfurt and Munich, Alitalia in Rome-FCO and Air France in Paris-CDG and Paris-Orly. A low-cost airline is the dominant airline in Barcelona and Milan-MXP, the two large airports not considered as hubs in our analysis. One of the main points of interest are the data for Paris-CDG and Frankfurt airports, both of which have an on-site high-speed train station. Paris-CDG is the largest hub airport for Air France-KLM offering a highly extensive network of international destinations with non-stop flights. Compared to Paris-Orly, the number of domestic destinations with non-stop flights is surprisingly low out of Paris-CDG. The situation is similar in Germany where the main hub airport of Lufthansa, Frankfurt, offers flights to fewer national destinations than does Munich airport. In Spain, Madrid and Barcelona serve a similar number of national destinations, while Madrid has a denser network of international destinations. In Italy, Rome-Fiumicino has higher levels of connectivity than Milan-Malpensa whichever indicator of performance is used.

Our analysis relies fundamentally on routes with air traffic so we are unable to test whether feeder traffic from Frankfurt and, especially, from Paris-CDG is channeled by HSR but Table 3 provides some tentative evidence of this. There is, for example, evidence of combined services (high-speed rail + air transportation) being offered by Air France at Charles de Gaulle via the *TGV* station sited in the airport's terminal 2. These tickets are available for *TGV* users arriving at Paris-CDG airport and taking flights within the following 24 h or *vice versa*. Similarly, Lufthansa offers its AIRail services at Frankfurt Airport, which includes connecting HSR services to the cities of Cologne, Stuttgart and Dusseldorf, while Milan's Malpensa airport began to offer HSR services to Florence, Bologna, Roma and Naples in 2011 (however, they were terminated after a year due to a lack of passengers).

4. Results

Table 4 shows the results of the regressions using the random (route) effects estimator. A major advantage of such models is that they account for the route heterogeneity that is not captured by the explanatory variables in our equations. Standard errors are robust to heteroskedasticity.

Our results show that airlines subject to competition from HSR services reduce the number of seats they make available on that route compared to the response of airlines operating routes with similar features but not subject to HSR competition. Indeed, the coefficient associated with the dummy variable for high-speed train services is negative and statistically significant at the 10% level when the dependent variable is the number of seats offered on the route. However, while the coefficient associated with this variable remains negative, it is not statistically significant when the dependent variable is the flight frequency on the route. Thus, airlines appear to keep flight frequencies high when competing with HSR services even though demand for their services has fallen.

The population variable and the dummy variable for hub airports present the expected positive effects. However, the coefficient associated with the GDP variable is negative though not statistically significant.

The coefficient associated with the distance variable is positive and statistically significant in both regressions (number of seats and frequency). As expected, the number of seats offered by airlines on longer routes is higher due to their being more competitive than surface transportation modes. The positive effect of the distance variable in the frequency equation suggests that the increase in demand for air services on longer routes overrides the effect of competition from HSR and cars and the greater efficiency of larger planes that operate on longer routes. We would

Table 4
Results of equation estimates (GLS-Random effects model): direct competition between air and high-speed trains.

	Dependent variable: seats	Dependent variable: frequencies
Population	36.81***	0.20***
	(12.05)	(0.07)
GDP	−519.95	−1.32
	(625.08)	(3.67)
Distance	158686.1***	771.90**
	(50548.3)	(308.70)
D^{hub}	198539.4***	1079.13***
	(60336.39)	(332.03)
$D^{high\_speed\_train}$	−66255.2*	−358.32
	(38042.04)	(239.33)
HHI	−212069.7***	−1670.37***
	(63269.58)	(376.69)
D^{LCC}	4253.19	−25.51
	(18311.05)	(115.77)
Intercept	−574542.3*	−1835.33**
	(301030.6)	(1872.14)
D^{Spain}	−136850.3	−585.04
	(100,229)	(608.18)
D^{France}	−319595.6***	−1679.27**
	(84181.97)	(529.43)
D^{Italy}	−218,041***	−1356.2***
	(92175.35)	(577.04)
D^{2003}	13718.68	78.01
	(10687.84)	(68.39)
D^{2004}	19339.38	125.10
	(11837.37)	(77.02)
D^{2005}	4712.52	59.95
	(9692.41)	(61.73)
D^{2006}	26619.95	198.57
	(30,604)	(204.61)
D^{2007}	14674.1	142.71
	(15430.89)	(101.69)
D^{2008}	11909.89	72.53
	(15893.8)	(97.52)
D^{2009}	9444.322	5.19
	(13058.71)	(83.22)
D^{2010}	–	132.97*
		(80.70)
N	1396	1572
R^2	0.21	0.24
χ^2 (test joint significance)	97.70***	133.84***

Notes: Standard errors in parenthesis (robust to heteroskedasticity).
*** Significance at 1%.
** Significance at 5%.
* Significance at 10%.

expect our results for the distance variable to differ if our sample comprised intra-European and intercontinental flights, but the analysis we report is based solely on domestic flights.

The results also confirm the negative relationship between capacity and the concentration index, as the coefficient associated with this variable is negative and statistically significant for both regressions. The coefficient associated with the presence of low-cost carriers, however, is not statistically significant in either regression.

Based on these results, we conducted additional regressions for both equations with sub-samples that consider each country separately and then within each country we also distinguished between routes with hubs and no hubs as endpoints. In order to simplify the presentation of these results, Table 5 only shows the results of our main variable of interest, namely the dummy variable for high-speed train services.

In Spain we found that airlines reduced both the number of seats and the flight frequencies, while in Germany the number of seats was reduced but not frequencies on routes competing with high-speed train services. By contrast, no statistical significant effect of high-speed train services was found on the supply of air services in Italy and France.

When we distinguished between routes with and without a hub airport as an endpoint, we found that HSR services had a more markedly negative effect on routes with hub airports in Spain, France and Italy. Indeed, the coefficient associated with the dummy for HSR services is negative and statistically significant on Spanish routes with both hubs and no hubs as endpoints, but the magnitude of the coefficient is much higher in the case of routes with hubs. In France and Italy, the coefficient of this variable generally takes a negative sign in the regressions for routes with hubs and a positive sign in the regressions with no hubs as endpoints. In general, this variable does not present any statistically significant effects in the regressions for France and Italy. However, interestingly the coefficient of this variable presents a statistically significant negative sign in the regression of the seats equation that uses the sub-sample of routes that have Paris-Orly as an endpoint.

In the case of Germany, the coefficient associated with HSR services is negative and statistically significant in the regressions for routes with no hubs as endpoints both when considering seats and frequencies as the dependent variable. The same coefficient is also negative but not statistically significant in the regressions focusing on hub airports. Note that in this instance we do not have enough observations to draw a distinction between hub airports with and without an HSR station as we do in the case of France.

Overall, airlines operating out of Paris-Orly and Madrid are clearly affected by high-speed train services, where the losses from point-to-point traffic can be added to the lower profitability of connecting routes. It might be the case that these hub airports are losing flight frequencies in their connecting traffic due to competition from HSR services. By contrast, airlines operating out of Paris-CDG and Frankfurt are not affected by HSR services. Recall that these airports have on-site high-speed train stations so that competition from HSR services might be counterbalanced by higher numbers of connecting passengers reaching the respective airports by train. In Italy and France, HSR services do not seem to undermine the competitiveness of short-haul air routes on routes with no hubs. In these countries, the connectivity of cities not served by hub airports may in fact have been improved as travelers now have two fast alternatives offering high-frequency services for their journeys. In Spain, all air routes have been negatively affected by HSR services but it is Iberia's Madrid hub that appears to have been hit hardest by intermodal competition.

By contrast, cities not served by hub airports could have been more negatively affected in Germany by high-speed train services, while the Lufthansa hubs have not been notably affected by intermodal competition. A possible explanation for this result is that the design of the HSR network in Germany has focused more specifically on improving the connectivity of cities of different sizes and this may have had a detrimental effect on air services connecting these cities. In France, the HSR network has been designed so as to connect Paris with the rest of the country's cities so that the effect of these train services is mainly seen on routes to the Paris airport with an on-site high-speed train station. In Italy, the network seeks to connect the south and the north and as a result Rome-Fiumicino has perhaps suffered due to a fall in connecting traffic but this negative effect on air services has been modest.

5. Discussion

Our research has focused on the impact that the introduction of HSR services has on air traffic at the route level. In line with

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Table 5
Results of equation estimates for the variable $D^{high\_speed\_train}$ (GLS-Random effects model).

Country	Samples of routes	Dependent variable: seats	Dependent variable: frequencies
	All routes	−332748.4 (160,801) ***	−1852.22 (949.70) **
	N	328	369
	R^2	0.15	0.14
Spain	Hubs	−472018.4 (220949.6) **	−3355.96 (1111.95)***
	N	152	171
	R^2	0.09	0.08
	No hubs	−62184.42 (33628.13)*	−383.46 (126.35)***
	N	176	198
	R^2	0.53	0.35
	All routes	34218.79 (92102.26)	200.21 (553.11)
	N	224	255
	R^2	0.25	0.28
France	Hubs with HST station	−8592.62 (41130.74)	193.13 (217.08)
	N	46	52
	R^2	0.72	0.66
	Hubs with no HST station	−288655.1 (165877.4)*	−2060.13 (889.42)**
	N	97	112
	R^2	0.30	0.33
	No hubs	48155.71 (19901.9) **	245.48 (181.73)
	N	78	88
	R^2	0.48	0.49
	All routes	−21616.91 (30573.53)	−255.93 (342.64)
	N	328	368
	R^2	0.16	0.18
Italy	Hub airports	−41802.91 (43370.63)	−500.34 (488.73)
	N	161	178
	R^2	0.27	0.29
	No hub airports	6818.12 (14053.46)	133.51 (146.63)
	N	167	191
	R^2	0.42	0.45
	All routes	−83753.71 (42993.6)**	−224.50 (312.74)
	N	516	579
	R^2	0.49	0.58
Germany	Hub airports	−8300.54 (119465.7)	−37.54 (342.01)
	N	215	240
	R^2	0.40	0.43
	No hub airports	−114458.5 (37758.94)***	−1038.02 (256.31)***
	N	301	339
	R^2	0.62	0.71

Note: Standard errors in parenthesis (robust to heteroskedasticity) and clustered by route.
*** Significance at 1%.
** Significance at 5%.
* Significance at 10%.

previous studies examining the competition between HSR and air transportation, the empirical analysis reported here confirms that airlines subject to competition from HSR do reduce the number of seats they offer on a given route. However, we also show that the frequency of air services on these route do not suffer a significant reduction (with the exception of domestic flights in Spain). As such, airlines appear to adopt a strategy of maintaining high flight frequencies when in competition with HSR services even though demand for their services has fallen; and, in this way, their competitiveness is not further undermined. Our results indicate, therefore, that policy makers should expect a reduction in the number of seats offered by airlines following the entry of competing HSR services while flight frequencies are not expected to undergo significant reductions.

The reduction of air services at hub airports is generally greater than that at non-hub airports. In this respect Germany is an exception, its hub airports not showing a net decrease in air service supply. The reason for this might be that Germany's HSR network is less centralized on one city with a hub airport as tends to be the case in France and Spain.

Our results for hub airports show that the reduction in air services is greater at airports that do not have an on-site HSR station. As such, we provide indirect evidence that HSR links act as feeders to domestic air services at hub airports with on-site HSR stations (the case here of Paris-CDG and Frankfurt). Indeed, it might be the case that people in cities near the hub, and who previously had no air link with it, can now access it rapidly using an HSR connection. This complementary effect (i.e., increased demand from connecting passengers) may compensate in part for the fall in the number of passengers that air services might suffer from entering into direct competition with HSR. Needless to say, this final result may be conditioned by the current scarcity of data and further research needs to disentangle more clearly the differential effects of HSR services on hub airports.

Finally, we provide evidence that new induced traffic did not tend to increase additional demand of air services in these routes where air services were already offered before that HSR entered service. Actually, in those routes with travel time of between 2 and 3 h on HSR, remaining air services are frequently used for connections to long distance flights. Indeed, the effect of additional increases on air demand could happen for those routes where air traffic did not exist previously; for instance, Madrid-Ciudad Real and Madrid-Segovia in Spain. But volume of transit in these routes is a minimal fraction of the overall traffic in HSR networks (recall that large and medium cities enjoyed air services). And these small cities had (and still have) relatively short trips by road to large airports. In any case, our empirical analysis shows that the induced demand by HRS services could only have some effects in hub airports with a HSR station in their sites.

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Appendix A

A1. Summary of selected relevant empirical references on competition and cooperation between high-speed rail and air transportation.

Article	Country	Competition focus	Cooperation focus	Results
Behrens and Pels (2012)	United Kingdom	X		Conventional airlines were pulled out of the market between London–Paris with HSR introduction
Yang and Zhang (2012)	China	X		Reductions in air service fares due to introduction of HSR
Jiménez and Betancor (2012)	Spain	X		HSR openings have reduced the number of air transport operation in Spain
Albalate and Bel (2012)	Spain	X		HSR market share respect to air transportation decreases with distance. Its share becomes modest for routes beyond 400 miles
Dobruszkes (2011)	Germany	X	X	Lufthansa increased services after the entry into service of the Cologne-Frankfurt HSR but they were reduced with new openings of HSR lines
Cheng (2010)	Taiwan	X		Air services lost market share from with the introduction of HSR services
Román et al. (2010)	Spain	X		Lower deviation than expected from airlines to HSR in Madrid–Barcelona corridor
Martín and Nombela (2008)	Spain	X		Impacts of HSR vary by spatial location of routes but main sources of their passengers are attracted from air transportation
Román et al. (2007)	Spain	X		Negative impact of HSR introduction on Airline market share
Steer Davies Gleave (2006)	France, Germany, Italy, Spain, United Kingdom	X	X	Reductions in air service fares due to introduction of HSR. Competition between HSR and air transportation is less straightforward where air transportation is operated by low-cost carriers
Park and Ha (2006)	Korea	X		Limited impact of HSR introduction on Airline market share due to instability of HSR services after opening
Suh et al., 2005	Korea	X		Air transportation departures fell even before the introduction of HSR, and even further after openings
Antes et al. (2004)	Germany	X		Find that the competitive pressure of low cost carriers obligates both air and rail transport to reconsider their pricing strategy
Vickerman (1997)	France	X		Increase of train passengers took place almost entirely during the first years of HSR operation and then became much more moderate
Klein (1997)	France	X		Negative impact of HSR introduction on Airline market share that diminishes with distance
European Commission (1996)	France/Spain	X		Air transportation receives the most pronounced negative impact with the introduction of HSR
Ellwanger and Wilckens (1993)	Germany	X		Early identified an increase of rail market share of 11% with the introduction of HSR between Frankfurt and Cologne, being air transportation the main loser of passengers
Taniguchi (1992)	Japan	X		HSR was more competitive in less than 438 miles distance because of higher frequency of services, the cheaper fare, the proximity to city centers and service reliability and safety
Bonnafous (1987)	France	X		Pronounced decrease of air transport market share after high speed rail introduction

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