The impact of high-speed rail and low-cost carriers on European air passenger traffic

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Abstract

The expansion of high-speed passenger rail service is often argued as a potentially effective, lower-carbon substitute for intercity air travel. Previous studies on high-speed rail on air travel in Europe and Asia have primarily examined the impact of travel time and price on market share for a specific city pair (or a handful of city pairs). There has been little focus on the extent to which high-speed rail (HSR) has reduced total short-haul air travel demand (versus market share), or on the potential impacts of high-speed rail on system-wide air travel demand. This paper presents an empirical, econometric analysis of air travel demand in Europe, utilizing an expanded data set to explore: 1) the impact of rail travel times, population density, and market characteristics on air traffic; and 2) the impact of high-speed rail and low-cost-carriers on system-wide air traffic. Although improvements in rail travel times have resulted in reductions in short-haul air travel, variations in city and airport characteristics significantly influence the substitution between air and rail. This paper also finds that HSR substitution has resulted in a modest reduction in system-wide air travel demand, whereas the expansion of low-cost carriers has led to a significant increase in total European air traffic. As concerns about the climate impacts of transportation grow, these results have significant implications for future transport and energy policy.

Keywords: high-speed rail; high-speed train; air transport; low-cost carriers; climate

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1 Introduction

Broad analyses of human travel behavior suggest that general transportation volume is likely to increase and shift towards faster modes, including primarily aviation (Schafer & Victor 2000). Projections of global aviation demand estimate an average annual passenger growth rate of approximately five percent over the next two decades (Airbus 2009, Boeing 2009, ICAO 2010). These trends have significant energy and climate implications; a recent analysis of future global transportation and energy demand estimates the growth rate of aviation to be the largest among the transportation subsectors from 2000 to 2100 (IIASA 2012). Given aviation's growing share as a portion of transportation energy use, it may become increasingly difficult to meet future emission reduction targets of the transport sector.

Concerns about climate change have prompted the consideration of policies such as cap-and-trade to mitigate greenhouse gas (GHG) emissions of all sectors, including aviation. However, studies suggest that the potential for such policies to reduce aviation emissions may be limited; even under climate policy, aviation emissions are estimated to grow substantially in the future (Winchester et al. 2013). Although the air transportation sector has achieved significant efficiency improvements over time, there are limited opportunities for airlines to replace more CO_2-intensive energy sources with less CO_2-intensive energy sources.

High-speed rail (HSR) is often promoted as a lower-carbon alternative to aviation, particularly for short-haul, domestic travel. In recent years, policymakers in Europe and the United States have considered HSR infrastructure development as a possible strategy to reduce the climate impacts of the transportation sector (European Commission 2001, FRA 2009). There is some evidence from the European experience that HSR is, in fact, a competitive alternative to air transportation, particularly for short-haul, intercity markets. Furthermore, previous studies find that high-speed rail is more carbon-efficient, although more research is required to examine the long-range lifecycle impacts of both modes (Givoni 2007, Chester & Horvath 2010).

Previous studies of high-speed rail and aviation demand primarily examine market share between the two modes, and focus on only a handful of major corridors where high-speed rail development has occurred. Building on the existing literature, this paper explores the impact of high-speed rail on air travel demand by developing an expanded panel data set of European air traffic, high-speed rail travel times, regional demographics, and airport market characteristics. Utilizing random coefficient model specifications, the heterogeneity of European city and airport pairs is examined to determine how different city or airport characteristics influence the substitution between air and rail for intercity travel. In addition, we examine the impact of high-speed rail and low-cost carrier (LCC) service on broader, system-wide air travel demand by developing models of airport demand.

The remainder of this paper is organized as follows. Section 2 provides a brief overview of econometric models and functional forms often utilized to model aviation and high-speed rail demand, as well as key results from previous studies examining high-speed rail and aviation demand in Europe. Section 3 describes the data set utilized in this analysis. In Section 4, we present model structure and estimation results. Section 5 discusses the key findings from this analysis and potential policy implications.

2 Models of aviation and rail travel demand: A brief review

There is a significant body of rail demand modeling literature focused on examining *potential* demand where high-speed rail (HSR) infrastructure is being considered, as well as *realized* demand where HSR has successfully been constructed and provides service. In the past decade, numerous studies examined the substitution of high-speed rail for air transportation in Europe and Asia (López-Pita & Robuste-Anton 2005, Park & Ha 2006, Clever & Hansen 2008). The majority of these studies are focused on mode choice between two major cities, utilizing choice modeling methods to examine stated preference (SP) data, or revealed preference (RP) data.

Comparative case studies based on European high-speed rail development have also examined historical market share and general trends in air transportation and high-speed rail demand. Studies documenting air transportation and HSR in France, Spain, and Japan typically conclude that it is very difficult for air transportation to compete effectively with HSR in short-haul markets of 500 kilometers or less (GAO 2009). A multiple case study prepared for the European Commission documented eight intercity routes where air and high-speed rail are present (Steer Davies Gleave 2006). One the key conclusions of this report was that rail journey time (i.e. not distance) was the most significant factor impacting market share. Given that HSR speeds can vary substantially (from 200 kilometers per hour to 350 kilometers per hour), it can be concluded that the more precise and effective method is to incorporate travel time into demand models, rather than only using distance. A more recent supply-oriented case-based analysis also confirmed the importance of HSR travel time, while identifying the potential impact of market and regional characteristics (Dobruszkes 2011).

Although disaggregate mode choice models have come to dominate much of urban transportation demand analysis, basic linear regression-based econometric models are still heavily utilized in air travel demand research and forecasting practice. These econometric models are a dominant tool for examining origin-destination (O-D) demand, national and regional demand, and airport-level demand. Research on aviation demand at these levels is typically empirical, relying on cross-sectional, time-series data from publicly available or proprietary sources. Practitioners are likely to use historical data for a 12- to 20-year time period in order to estimate the parameters of a demand model (TRB 2002). These models are typically estimated using regression analysis, and are then utilized to predict future demand at the O-D, national, or regional level. The majority of econometric-based demand models in the aviation sector take on the following form shown in Eq. 1.

$$\ln(Demand) = \beta_0 + \beta_1 \ln(GDP) + \beta_2 \ln(Yield) + \beta_3 X + \epsilon \qquad (1)$$

where *Demand* is measured by passengers (or flights), *GDP* is some combination of the average gross domestic product at the origin and destination, and *Yield* reflects the average fares paid for air transportation service, X represents a number of additional parameters that are expected to influence demand, and ϵ is a random error term. The primary explanatory variables of most econometric-based demand models of air transportation are typically household income or GDP and yield (i.e., average airfares).

Recent research suggests that origin-destination level forecasts of air transportation can be significantly improved by considering local area information such as density, hub status of the airport, market power, and low-cost carrier presence (Bhadra 2003). In practice, these forecasts might also include dummy variables associated with significant events. For example, a recent study on the role of low-cost carrier entry examines how incumbents respond prior, during, and after the entry of Southwest Airlines, demonstrating that even the threat of entry has an impact on air transportation capacity and air traffic at the O-D level (Goolsbee & Syverson 2008). These studies and others suggest that incorporating airport-level characteristics (such as the presence of high-speed rail service) result in improved forecasts of air travel demand.

In this study, rail travel time data over a 15-year time frame was collected in order to improve econometric models of origin-destination air passenger traffic. In addition, we examine segmented airport-level demand data to explore the impact of high-speed rail on broader system-wide air traffic, as well as the influence of low-cost carriers on the system. This work builds on previous literature focused on rail and aviation market share by utilizing the traditional methods from aviation demand forecasting to demonstrate that rail journey time has a significant impact on air traffic reduction in short-haul aviation markets. By including a large number of short-haul air traffic routes in Europe, the relationship between regional variations (e.g., in household income, density, airport status) and the change in air traffic after the introduction of high-speed rail as a competitive alternative is examined.

3 Data

3.1 Overview of Data

The primary data utilized as our core predictor variables in this analysis are summarized in Table 1. All variables were gathered from publicly available data sources, including the statistical office of the European

Union (Eurostat), the Energy Information Administration, European rail operator timetables, airport annual reports, press releases, and low-cost carrier websites.

Table 1: Key variables and sources

Dimension	**Variable**	**Sources**
Aviation demand	Air traffic	Eurostat: Air transport, Passengers Carried; UK Civil Aviation Authority: UK Airport Statistics, Dom Air Pax Route Analysis, Scheduled Passengers)
Price/ fares	Jet fuel	EIA Annual Europe Brent Spot Price
GDP	GDP	Eurostat: GDP at current market prices by NUTS 3 regions
Population and density	Population and density	Eurostat (Regional Statistics, Regional Demographic Statistics, Population and area, Density)
Rail competition	Rail travel times	RENFE, SNCF, DB Bahn, National Rail, British Rail
Low-cost carrier presence	Low-cost carrier service	Airport publications, news articles, and press releases announcing low-cost carrier routes

Aviation demand. The primary metric for air traffic that is available through Eurostat is the total *Passengers carried* for an airport pair. This metric includes all passengers who travel between two airports, including those passengers who may be connecting to, or from, another flight. Outside of the United States, examining the true origin-destination traffic for a city pair is a complex exercise, often requiring access to expensive proprietary data maintained by airlines or industry specialists. True origin-destination traffic includes those passengers who board at the origin city and disembark and the destination city; it excludes those passengers who connect to or from another flight at either end of the trip.

For the purposes of this analysis, we examine the total passenger traffic between an O-D pair, including connecting passengers. This exercise is useful for the following reasons: 1) A preliminary study with easily accessible data can serve as a useful starting point for a more accurate and expensive analysis (Bonvino et al. 2009); 2) airport-rail connectivity can enable connecting passengers to travel by rail for the short-haul portion of their journey, and travel by air for the long-haul portion. The potential for cooperation between aviation and high-speed rail has been observed in previous literature (Grimme 2006, TRB 2010, Clewlow et al. 2012); thus it is useful to develop models that include connecting passengers when examining air and rail demand on short-haul routes.

Price/ fares. Origin-destination yield is the most precise metric one can utilize in econometric models of aviation demand. Given that airfares vary significantly depending on the class of ticket and time of purchase, aviation yield, or average operating revenue per passenger-mile, is often used as a metric for airfares. Similar to the challenge of obtaining true origin-destination air traffic data, origin-destination yield data (outside of the U.S.) is only available through proprietary industry sources.

The cost of jet fuel has grown as a share of airlines' operating expenses (ranging from 10 to 30 percent). Previous literature suggests that airlines pass a high portion of these fluctuating costs onto the consumer. In this study, we use jet fuel as a proxy for airfares and find that estimation results show similar price elasticities for jet fuel as for airfares.

Demographics. Regional GDP, population, and population density data were obtained through Eurostat's statistical databases for the origin and destination of each airport pair. For the O-D demand analyses, different combinations of origin and destination data were explored to determine which combination yielded the strongest explanatory power: separate origin and destination variables, a variable representing the geometric mean of the origin and destination data, and a variable representing the arithmetic mean of the origin destination data. In the final origin-destination model specifications, all three variables (GDP, population, and density) were found to yield the greatest explanatory power when incorporated as a geometric mean of the two regions. For the airport-level analyses, the GDP, population and density data for the region where the airport is located were utilized in the model development.

Rail competition. In order to determine rail journey times for the O-D pairs of interest, timetables for rail operators in Europe were accessed to gather the necessary travel time data. Historical timetables were accessed either by directly contacting the rail operator, or by searching through historical records. Rail data was gathered from RENFE (Spain), SNCF (France), DB Bahn (Germany), National Rail (UK), and British Rail (UK). Rail travel times decreased substantially for several corridors in Spain, France, and Germany over the time period of interest; however, rail travel times actually increased for some journeys in the UK when rail was first privatized, and then decreased after a change of contract to Virgin Trains in 1997. The rail journey time data was also utilized to determine the presence of high-speed rail service in the airport-level analyses, where "high-speed rail" is defined by the European Union standard of 200 kilometers per hour (124 mph) for upgraded track and 250 kilometers per hour (155 mph) or faster for new track.

Low-cost carrier presence. A data set was constructed to examine the potential impact of low-cost carrier impact on airport-level traffic. For each airport included in our analysis, the years when low-cost carriers offered service were determined by examining news articles, airport publications, and press releases of European low-cost carrier airlines announcing the opening of the new route. Low-cost carrier entry at an airport was often initiated by one of the older low-cost carrier airlines (Ryanair, Germanwings, Flybe, or XL Airways); service then often expanded as other carriers attempted to enter the airport.

3.2 Route, airport, and city selection

Origin-destination analysis. This paper examines all direct, short-haul air traffic O-D pairs in the four major European countries that generate the most air traffic: France, Germany, Spain, and the United Kingdom. The analysis includes all short-haul air traffic pairs in these countries where rail service is available; included are all routes where rail journeys can now be made in less than five hours and where air carriers provided service at some point in time between 1990 and 2010. There are numerous O-D pairs where we observe a significant decline in air traffic after the introduction of high-speed rail, as well as others where the reduction in air traffic was less substantial.

Airport and city pairs. In this analysis, airport pairs are examined, as well as city pairs. A city pair is defined as an origin city and destination city between which passengers might travel via air or rail. However, several major European cities are considered "multi-airport regions", where passengers can chose to travel through one of two (or more) airports. For example, passengers in London can choose to travel through one of five airports (Heathrow, Gatwick, London City, Luton, and Stansted) and passengers in Paris can travel through one of two airports (Charles de Gaulle and Orly). For our city pair analysis, the traffic from all airports serving an origin and destination are aggregated to determine the total traffic between the city pair. In the case of London and Paris, the traffic between all five London airports to both Paris airports is aggregated into one passenger traffic figure for each year.

Airport traffic analysis. This paper also includes an airport-level analysis of air traffic demand, in order to examine the impact of high-speed rail and low-cost carriers on airport utilization. For the airport-level analysis, our dependent variable is annual passengers on board (including both departures and arrivals). Our data selection includes all of the airports identified for the O-D air passenger traffic analyses (major airports in France, Germany, Spain, and the UK).

4 Model structure and estimation results

The goal of this analysis is to examine the extent to which improved rail travel times have impacted air traffic demand in Europe, the regional factors that influence variation of these air traffic trends, and the potential influence of low-cost carriers over the same time period. Four model formulations were developed to investigate these effects: 1) A city (or multi-airport region) model of origin-destination demand; 2) an airport-to-airport model of origin-destination demand; 3) a model of national air traffic demand originating at the airport; and 4) a model of intra-European Union (EU) demand originating at the airport. The latter two models aim to improve our understanding of the impact of high-speed rail, low-cost carriers, and other factors on airports, a common congestion bottleneck of air transportation systems around the world.

4.1 Impact of high-speed rail on O-D air traffic: city-pair analysis

To examine whether improved rail travel times have affected origin-destination (O-D) air traffic in Europe, a model specification was developed to estimate the effect of characteristics that are likely to impact air travel demand, as well as rail travel time. Eq. 2 defines the basic structure of the models utilized in the analyses in Sections 4.1 and 4.2.

$$\ln(OD\ Demand_{it}) = \beta_0 + \beta_1 \ln(Rail_{it}) + \beta_2\ \ln(X_{it}) + \mu_i + \epsilon_{it} \tag{2}$$

Eq. 2 is similar to the model specifications found in the literature and in practice described in Section 2, where the vector X represents the following parameters that are known to influence air traffic demand: GDP, population, density, and fuel price (as a proxy for airfares). The inclusion of *Rail* is added to the model to estimate the relationship between rail travel times (that change over the time period when improved rail service is introduced) and air travel demand.

Estimates were obtained using ordinary least squares (OLS) regression and a variance components model. A Breusch-Pagan test was used to determine the presence of heteroscedasticity in the classic linear regression (OLS) model for both the city and airport pair analyses (Breusch & Pagan 1979). The test statistics indicated that the OLS model specifications were inefficient; however, the estimates for the OLS and variance components model specifications yield similar results.

The variance components model specifications examined included a random effects estimator and a fixed effects estimator. In the random effects model specification, μ_i in Eq. 2 was assumed to be independent of X_{it} and $Rail_{it}$. That is, $E[\ \mu_i \mid X_{it},\ Rail_{it}] = 0$; the individual specific effect is uncorrelated with the independent variables. In the fixed effects model specification, it was assumed that μ_i is not independent of X_{it} and $Rail_{it}$. In order to test whether the random effects model provides consistent results, we performed a Hausman test (Hausman 1978). For both the city and airport pair analyses, we failed to reject the null hypothesis at a p=0.05 significant level that the coefficients estimated by the efficient random effects model are the same as the coefficients of the fixed-effects model; that is, we can assume that the random effects model is consistent.

Table 2 summarizes estimation results from alternative model specifications under the assumption that we have random individual differences.

Our alternative model specifications include first the key factors that are known to affect air travel demand (GDP and price), followed by additional factors that are typically utilized in econometric models

Table 2: Effect of improved rail travel times on O-D air traffic between cities

	(1)	(2)	(3)	(4)
ln(GDP)	0.297	2.280**	3.548**	5.192**
	(0.714)	(0.872)	(1.273)	(1.696)
ln(Fuel price)		-1.863***	-2.360**	-2.304*
		(0.476)	(0.714)	(0.906)
ln(Population)			1.961*	1.818
			(0.997)	(1.126)
ln(Density)			-0.427	-0.376
			(0.549)	(0.603)
ln(Rail time)				4.734***
				(0.834)
Constant	8.066	-5.472	-41.774*	-82.329***
	(7.389)	(8.111)	(19.187)	(24.589)
N	n=53, T=2-15, N=579	n=53, T=2-15, N=579	n=52, T=1-15, N=539	n=31, T=1-15, N=326
Adjusted R^2	0.163	0.185	0.181	0.296

Note: * significant at 0.05 level, ** significant at 0.01 level, *** significant at 0.001 level.

of air transportation (population and its density). The last model specification incorporates a rail time parameter to examine the effect of rail travel times on air traffic.

The elasticities of demand for air travel with respect to GDP and price are similar to previous studies on air travel demand elasticities. In the city pair model, jet fuel price elasticity of demand estimates for air traffic are between -1.863 and -2.304, close to the range of airfare price elasticities observed for intra-Europe short-haul air traffic (-1.23 to -1.96) (Kincaid & Trethaway 2007). Based on these preliminary results and further analyses in the remainder of this paper, jet fuel appears to serve as a reasonable proxy for airfares. GDP elasticity of demand estimates from the literature represent a much wider range (0.46 to 5.51) (Intervistas, 2007), which our estimates fall within.

The addition of rail travel time appears to add significant explanatory power to our model. The large positive value of the rail travel time coefficient suggests that as rail travel times are reduced, air traffic volumes are also reduced. Although these estimation results are likely influenced by significant air traffic reductions on corridors such as Frankfurt-Cologne, where air traffic was reduced to zero, the results do have implications for aviation planning at a broader system-wide level.

In the United States, population density tends to have a positive effect on air travel. It has been suggested that density can be viewed as representative of economic activities, and thus we would anticipate that it has a positive impact on origin-destination demand (Bhadra, 2009). An interesting observation from these model estimates is that the density coefficient is negative. The negative effect of density on air traffic reinforces previous findings that urban form may influence the substitution of rail for intercity air travel; that is, higher population density is more conducive to rail (including high-speed rail) travel for short-haul, intercity routes.

4.2 Impact of high-speed rail on O-D air traffic: airport-pair analysis

In this section, origin-destination air travel demand is examined from airport to airport, as opposed to the previous aggregation of multiple airports at the city level. The airport pair model presents an improved analysis for several reasons. First, GDP and population density can be observed at a more precise regional level in the Eurostat data; that is, the GDP and density data utilized in these models are associated with the specific urban regions where airports are located, as opposed to aggregated at the mega-city region. Second, we incorporate information about hub airports. As might be expected, the presence of a hub by a major airline is likely to have a positive effect on air travel demand. Airlines are more likely to increase frequency and reduce fares on routes serving airports where they have established a hub in order to maintain market share, thereby positively affecting air travel demand.

Table 3 summarizes estimation results from alternative model specifications under the assumption that we have random individual differences. The relationships between air travel demand and GDP, fuel price, population, density, and rail travel times are estimated with similar results as our previous analysis. Due to the improved resolution of data in this model specification (with demographic data at the intra-urban level versus mega-city level), we obtain more significant coefficient estimates for GDP and density. The relationship between air travel demand and population density is estimated to be between -2.479 and -2.511; that is, a 10% increase in density could lead to a 25% reduction in air traffic demand for short-haul origin-destination airport pairs. Although changes in density occur over long time scales, the result nevertheless provides some supporting evidence that high-speed rail may be more competitive against air travel in cities where there is more compact development.

Table 3: Effect of improved rail travel times on O-D air traffic between airport pairs

	(1)	(2)	(3)	(4)	(5)
ln(GDP)	0.280	3.394***	6.039***	5.857***	5.468***
	(1.420)	(0.831)	(1.061)	(1.060)	(1.181)
ln(Fuel price)		-2.287***	-3.412***	-3.312***	-2.913***
		(0.445)	(0.558)	(0.558)	(0.624)
ln(Population)			1.182	0.424	0.810
			(0.748)	(0.800)	(0.711)
ln(Density)			-2.484***	-2.511***	-2.479***
			(0.509)	(0.536)	(0.554)
Hub (origin)				2.491*	2.713**
				(1.013)	(0.951)
Hub (destination)				2.115	3.132^{+}
				(2.168)	(1.830)
ln(Rail time)					5.261***
					(0.857)
Constant	6.516	-17.229*	-38.367**	-26.818	-57.746***
	(5.966)	(7.506)	(13.654)	(14.483)	(14.473)
N	n=94, T=1-15, N=1124	n=94, T=1-15, N=1124	n=92, T=1-15, N=1083	n=92, T=1-15, N=1083	n=69, T=1-15, N=835
Adjusted R^2	0.073	0.094	0.113	0.119	0.172

Note: $^{+}$ significant at 0.10 level, * significant at 0.05 level, ** significant at 0.01 level, *** significant at 0.001 level.

4.3 Impact of high-speed rail on domestic airport traffic

In the following two sections, we present analyses of air travel demand at the airport level to explore the potential impact of improved rail service and introduction of low-cost carrier service on European airports. There are several motivations for forecasting air travel demand data, including primarily: 1) forecasting origin-destination traffic for airline and air traffic management planning purposes; and 2) forecasting airport-level traffic for airport capacity planning. The previous sections address the former; the remaining sections (4.3, 4.4, and 4.5) address the issue of airport capacity and examine the factors that influence demand at the airport level.

Utilizing airport-level passenger air traffic data, the following model specifications outlined in Eq. 3 and Eq. 4 were developed.

$$\ln(AirportDemand_{it}) = \beta_0 + \beta_1 \ \ln(Rail_{it}) + \beta_2 \ \ln(LCC_{it}) + \beta_3 \ \ln(X_{it}) + \epsilon_{it} \tag{3}$$

$$\ln(AirportDemand_{it}) = \beta_0 + \beta_1 \ \ln(Rail_{it}) + \beta_2 \ \ln(LCC_{it}) + \beta_3 \ \ln(X_{it}) + \mu_i + \epsilon_{it} \tag{4}$$

Both equations are similar to the previous model specification (Eq. 2), where vector X represents the following parameters that are known to influence air traffic demand: GDP, population, density, fuel price, and hub status. The categorical *Rail* parameter represents the presence of high-speed rail service. The categorical *LCC* parameter indicates whether or not low-cost carrier service is present at the airport.

Estimates were obtained using ordinary least squares (OLS) regression (Eq. 3) and a variance components model (Eq. 4). For this data set, a Breusch-Pagan test determined that the null hypothesis of homoscedasticity could not be rejected for our OLS model specification. Using a Hausman test, it was determined that the random effects model specification provides consistent results. Table 4 summarizes the estimation results for OLS and random effects model specifications of this data.

First, a model of national air traffic was developed, excluding all international traffic, in order to examine the relationship between air travel demand and the parameters of interest. In this airport-based analysis, the models estimate similar relationships between air travel demand and GDP, fuel price, population, and hub status. Jet fuel price elasticities are estimated at -2.203 and -2.202, and are significant.

As compared with the origin-destination analyses in Sections 4.1 and 4.2, the population density coefficient estimate is observed to be positive and significant, at 0.204 and 0.252. As mentioned previously, population density is often positively correlated with air travel demand. In this model, air traffic includes all national air traffic, including routes that were not included in the previous analysis focusing on short-haul travel.

Table 4: Effect of high-speed rail presence on national air traffic

	OLS	RE
ln(GDP)	0.220	0.047
	(0.163)	(0.282)
ln(Fuel price)	-0.203***	-0.202*
	(0.032)	(0.092)
ln(Population)	0.640***	0.721**
	(0.089)	(0.250)
ln(Density)	0.204***	0.252*
	(0.046)	(0.117)
Hub	0.897***	0.831$^+$
	(0.151)	(0.429)
High-speed rail	-0.487***	-0.119*
	(0.098)	(0.059)
Constant	2.431	2.409
	(2.136)	(4.694)
N	N=386	n=38, T=6-13 N=389
Adjusted R^2	0.395	0.386

Note: $^+$ significant at 0.10 level, * significant at 0.05 level, ** significant at 0.01 level, *** significant at 0.001 level.

As anticipated, the presence of high-speed rail in an airport market has a negative impact on national air traffic originating from (and arriving to) that airport. The coefficient estimate falls between -0.119 and -0.487.

4.4 Impact of high-speed rail and low-cost carriers on intra-EU airport traffic

Another key factor influencing airport traffic over the timeframe of this analysis is the growth of low-cost carrier (LCC) service in Europe. LCCs such as Ryanair, Germanwings, and easyJet expanded their services substantially from the 1990s to today, primarily focusing on intra-EU, mid-haul travel markets. The presence of low-cost carrier service is incorporated into a model specification to examine this impact on EU passenger traffic at the airport level. The estimation results are presented in Table 5.

The traditional factors that influence air traffic (GDP, fuel price, population, density, and hub status) are estimated with coefficients of the sign and magnitude that are expected. The presence of high-speed rail appears to negatively affect intra-EU air traffic at the airport level, though not as substantially or significantly as it does national air traffic. Given that many intra-EU destinations served by an airport are not likely located within a distance where high-speed rail would be competitive, this is a logical result.

The role of low-cost carrier presence at European airports has a significant positive impact on intra-EU

Table 5: Effect of low-cost carrier entry on intra-EU traffic

	OLS	RE
ln(GDP)	0.183	1.020***
	(0.136)	(0.136)
ln(Fuel price)	-0.172***	-0.019
	(0.033)	(0.017)
ln(Population)	0.574***	0.896***
	(0.084)	(0.249)
ln(Density)	0.337***	0.237*
	(0.043)	(0.107)
Hub	1.390***	0.930*
	(0.137)	(0.434)
High-speed rail	-0.186*	-0.009
	(0.093)	(0.049)
Low-cost carrier	0.893***	0.209***
	(0.105)	(0.045)
Constant	1.680	-11.092
	(1.865)	(3.826)
N	N=460	n=38, T=6-15 N=481
Adjusted R^2	0.576	0.613

Note: * significant at 0.05 level, ** significant at 0.01 level, *** significant at 0.001 level.

travel demand. Combined with the presence of LCCs at an airport, the primary drivers of intra-EU traffic appear to be GDP and population. Fuel price appears to play a less important role in these markets.

4.5 Implications for airport capacity planning

Our final analysis compares models of national, intra-EU, and total passenger traffic at the airport level. Using a random effects model specification we compare the impact of high-speed rail and low-cost carrier presence on airport-level traffic for all three cases. The estimation results are summarized in Table 6.

Population and population density appear to play a similar positive role in affecting air traffic at the airport level in all three analyses, though density appears to play a smaller role in driving national air traffic. Similarly, the hub status of an airport appears to have a greater impact on total air traffic, which is likely driven by airlines striving to maintain market share for international, long-haul flights that are typically more profitable.

Domestic air traffic appears to be the most sensitive to increasing jet fuel prices (as proxy for airfares), as compared with intra-EU or total traffic. One potential explanation is that as jet fuel prices increase (and thus airfares likely increase) in the domestic air travel market, passengers have greater flexibility in reducing their travel or switching to alternatives modes (e.g., auto, rail, or intercity bus).

Table 6: National, intra-EU, and total airport level traffic

	Domestic	Intra-EU	Total
ln(GDP)	0.064	1.020***	0.340
	(0.284)	(0.136)	(0.185)
ln(Fuel price)	-0.201*	-0.019	-0.075
	(0.093)	(0.017)	(0.067)
ln(Population)	0.724**	0.896***	0.786***
	(0.254)	(0.249)	(0.205)
ln(Density)	0.253*	0.237*	0.305***
	(0.119)	(0.107)	(0.092)
Hub	0.823	0.930*	1.223***
	(0.436)	(0.434)	(0.357)
High-speed rail	-0.123*	-0.009	-0.023
	(0.059)	(0.049)	(0.039)
Low-cost carrier	-0.054	0.209***	0.114**
	(0.058)	(0.045)	(0.038)
Constant	2.226	-11.092	-1.629
	(4.748)	(3.826)	(3.453)
N	n=38, T=6-13	n=38, T=6-15	n=38, T=6-13
	N=389	N=481	N=395
Adjusted R^2	0.386	0.613	0.599

Note: * significant at 0.05 level, ** significant at 0.01 level, *** significant at 0.001 level.

As we might expect, the presence of high-speed rail plays a greater role in reducing domestic air traffic, as compared to intra-EU or total airport traffic (e.g., where the coefficient estimates are small and not significant). It appears that as domestic traffic declines, capacity shifts are likely to take place, where short-haul flights are substituted at the airport level by medium- and long-haul flights.

5 Conclusions

In this study, an empirical econometric analysis was conducted to examine the impacts of high-speed rail and low-cost carriers on European passenger air traffic between 1990 and 2010, based on data from over 35 airports and 90 airport pairs. Consistent with previous studies of specific airport pairs, the improvement of rail travel times was found to be a significant factor in reducing short-haul air traffic in Europe. Furthermore, analysis of demand at the airport level revealed that the presence of high-speed rail contributed to lower domestic air passenger traffic.

Other factors that have influenced air travel demand in these markets include GDP, fuel price (as a proxy for airfares), hub status, and population density. Unlike previous origin-destination models of air travel demand, population density was found to have a negative impact on air travel demand in these models; that is, as population density increases, short-haul air travel declines when a rail option is present. This finding supports literature on urban form and travel, in which many studies suggest that rail may serve as a more competitive alternative in cities and regions where there is more compact development. Future work examining high-speed rail and air travel should carefully consider the role of land use and accessibility in shaping travel demand.

The second major issue that this paper highlights is the influence of low-cost carriers on air travel demand. While the introduction of high-speed rail has played a significant role reducing domestic air travel in Europe, over the same time period low-cost carriers have had a more significant influence increasing air travel, through primarily medium-haul, intra-EU flights. Considering both trends, the result has been a significant net gain in the total passenger-kilometers traveled in western Europe. There were significantly more medium-haul flights added to the system than short-haul flights removed. In considering policy options that aim to reduce climate impacts of the transportation sector, this work emphasizes the importance of considering broader, system-wide trends in addition to specific, regionally based analyses.

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