The effect of high-speed rail on air traffic volume at European airports

Master Thesis

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Abstract

The increasing focus of governments and the European Union on climate change and the decarbonisation of the transport sector has led to various high-speed rail developments in the past and many plans to induce passengers to switch from air transport to high-speed rail. Using panel data on air traffic from 30 European airports over the period 2004 – 2019 the effect of high-speed rail developments on airport traffic is analysed with a fixed effects estimator. The results of the econometric analysis suggest that connecting airports to the high-speed rail network leads to an overall increase in air traffic demand and supply, but that while a stronger complementary effect can be observed on long-distance flights, a reduction in demand and supply is found on short-haul, domestic flights. Meanwhile, a negative cross-elasticity of air traffic demand with regards to high-speed rail travel demand is found. These results suggest the existence of both complementary and substitution effects between high-speed rail and air traffic, resulting in unclear environmental effects. The co-existence of both effects has important implications for future policy decisions when the goal is to reduce greenhouse gas emissions and minimise the environmental damage caused by European passenger transport.

Keywords: high-speed rail, panel data, air transport, airports, intermodal competition

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List of abbreviations

EU	European Union
GHG	Greenhouse Gas
HSR	High-Speed Rail
LCC	Low-Cost Carrier
FE	Fixed Effects
NUTS	Nomenclature for Territorial Units for Statistics
RE	Random Effects

1. Introduction

The European Green Deal is a roadmap with goals, measures and strategies developed by the EU. The ambition of this roadmap is to make the EU economy carbon neutral by 2050 and significantly reduce greenhouse gas (GHG) emissions by 2030 (Pagand et al., 2020). Currently, the transport sector in the EU causes 25% of total emissions and is considered a sector with substantial potential for emission reduction (European Commission, 2020). To reduce transport-related emissions by 90% in 2050, radical changes are needed, and according to the EU, a greater focus should be put on the railway as a means of mass transportation.

The aviation sector has constantly grown over the past years and is expected to continue to do so in the future, leading to increasing levels of CO2 emissions far above those targeted by the EU (D'Alfonso et al., 2016). An additional issue is the fact that air transportation is difficult to decarbonize and so policymakers are increasingly interested in the idea to replace short- and medium-haul flights with high-speed rail (HSR). Railways are the mode of mass transportation with the lowest GHG emissions and therefore are at the core of the EU's policy for a carbon-neutral economy (Pagand et al., 2020). HSR causes GHG emissions of around 40 g per passenger-km excluding the effect of the construction of transport infrastructure, whereas those of air transportation are about 5 times higher, almost reaching 200 g per passenger-km (D'Alfonso et al., 2016). Baron et al. (2011) report the carbon emissions for various transport modes and include the emissions from the construction of transport infrastructure in their analysis. They conclude that including the construction phase leads to additional GHG emissions of 3.7 g to 8.9 g per passenger-km for HSR on top of the 40 g reported earlier, which still leaves HSR with substantially lower emission levels than air transportation. That means that significant investments will be made to improve the existing railway system. European cities will be better connected by new HSR lines that according to some authors can compete very well with air transport on distances between 300 km and 600 km (D'Alfonso et al., 2015). Some reports suggest that countries with HSR networks indeed have proportionally fewer short-haul flights, suggesting that investing in HSR can reduce the number of short-distance air traffic (Pagand et al., 2020).

Traditionally, high-speed rail and air transport have been viewed as competitors competing for the same travellers on short- to medium-haul flights. Several studies, however, have analysed the possibility of HSR and air transport being complements. For example, Socorro and Viecens (2013) analysed HSR and air travel theoretically, where their definition of passengers' generalised price included ticket prices, access and egress times, waiting times and in-vehicle time. They found that especially when HSR networks are directly connected to airports by on-site stations, HSR can have complementary effects on air transport. Clewlow et al. (2012) have examined the relation between HSR and air traffic in Germany and France. They observed that at Frankfurt airport, international air traffic increased over the period between 1999 and 2009, while a reduction in air traffic has been observed on a domestic level during the same period. They further found that on the route between Cologne and Frankfurt, all flight connections have been discontinued after the completion of the HSR link which supports the idea that HSR has replaced domestic feeder flights (ibid).

HSR is generally considered a more environmentally friendly mode of transport due to its lower marginal emissions than air transport, however, several studies have questioned the ability of HSR to lead to a real substantial reduction in GHG emissions. If HSR acts as a feeder service to international flights, these flights become more accessible which can lead to newly generated demand for long-distance air journeys which in turn leads to a net increase in GHG emissions from aviation (Zhang, 2019). It is therefore essential to further analyse the system-wide effects that HSR has on short-distance and long-distance air traffic.

While many previous studies have examined the substitution effects between air and rail or the success of HSR developments on specific routes, this study will analyse the effect of HSR on the number and type of air operations at an airport level. Although it might be the case that new HSR lines lead to a significant reduction of flights on the route they are operating, it is not clear whether airports of cities with HSR access experience a reduction in the total number of flights. The aim of this study is therefore to analyse the change in the number of total flights resulting from the connection of a city to the HSR network. Furthermore, changes in the mix of destinations will be analysed, distinguishing between short-haul routes that could be replaced by HSR and long-haul flights for which HSR may act as a complement.

Section 2 of the thesis will review existing literature about the HSR and air traffic markets, the interaction between them and the methods used in previous studies. In section 3, the methodology used for the empirical analysis is explained, while the results of the analysis are reported in section 4. Section 5 will discuss the findings before section 6 will conclude the thesis.

2. Literature review

This chapter provides an overview of the air travel and HSR markets in Europe (sections 2.1 and 2.2) and discusses the findings of existing literature regarding the effects of HSR on air travel. The chapter will discuss both substitutability and complementary effects between air travel and HSR, as well as the environmental impacts of both modes. Then, literature regarding the effects of HSR on airport traffic will be analysed and finally, the chapter concludes with a review of methods used in previous research papers.

2.1 The air transportation market in the EU

The deregulation and the creation of an EU single aviation market in 1992 have led to a reduction in costs, increased competition and consequently a reduction in airfares on intra-European flight routes (Directorate-General for Mobility and Transport, 2017). In addition, it has led to an enormous increase in intra-European routes served. For example, the number of EU destinations served by Dublin airport has increased from 36 in 1992 to 127 in 2016 (IAA, 2017). Abate and Christidis (2020) found that the liberalisation has led to an average fare reduction of 6% to 23% compared to before the introduction of the new policies. The increased choice and lower prices have led to a growing number of air passenger movements per year, with 1.9 billion passenger movements at airports in EU countries (including Switzerland, Iceland and Norway) in 2019 of which 19% were domestic and more than 50% were intra-European flights (European Commission. Directorate General for Mobility and Transport. et al., 2021). The growth in air traffic is driven mainly by the emergence of low-cost carriers that are also carrying out most flights in Central and Eastern Europe (ibid). The increase in air traffic has also led to more congestion at major airports, which is managed by a European airport slot allocation regulation (European Parliamant, 2022). The purpose of this regulation is to optimally allocate the available slots in a fair manner that ensures the competitiveness of the market (ibid).

Along with the growing air passenger volumes, growing concerns have been voiced regarding the environmental impact of the air transport market and GHG emissions caused by EU aviation have been predicted to grow further in the years to come (European Commission. Directorate General for Mobility and Transport. et al., 2021; D'Alfonso et al., 2016). This has led to a series of improvements such as the modernisation of air traffic management and aircraft and the development of new sustainable aviation fuels. However, compared to other transportation modes, air transportation remains difficult to decarbonize and therefore policymakers are increasingly interested in reducing the number of short- and medium-haul flights and substituting these flights with train journeys by improving rail connectivity (Pagand et al., 2020).

2.2 The HSR market in the EU

Since the 1970s, the rail travel volume has grown steadily within the EU and the success of the Japanese Shinkansen high-speed train has led to new developments in several European countries (UIC, 2022). The first HSR connection in Europe was introduced in 1981 by the French SNCF between Paris and Lyon and has consequently led to a significant reduction in air traffic on that route (Albalate et al., 2015; UIC, 2022). It is generally argued that HSR is leading to mode substitution and taking passengers away mainly from road and conventional rail, as well as air travel on short-distance routes (Albalate et al., 2015). A negative side effect of this might be the deterioration of the conventional rail networks, as has been observed in France for instance (Banister and Givoni, 2013).

The European train network contained approximately 9000 km of HSR lines at the end of 2017 with the majority of these lines being distributed over 4 countries; Spain, France, Italy and Germany (European Court of Auditors., 2018). This uneven distribution is the result of differences in investments made by the various member states of the EU and suggests that the benefits of HSR are felt differently between different countries (Banister and Givoni, 2013). For example, in France, a great number of fast rail connections between major cities exist, while major cities in other EU countries are not connected to the HSR network at all (ibid). Compared to countries that have not invested in HSR, there has not been a significant difference in overall rail travel growth rates, but rather there has been a significant shift from conventional rail toward HSR (ibid). At the same time, even within the countries with the largest HSR networks, there are substantial regional differences in accessibility to the network, with major economic and population centres benefiting from much better connections.

An important aspect of HSR network development is the connectivity to other travel modes, such as regional and local rail, as well as airports. Connecting HSR to airport stations rather than only to city-centre stations is argued to allow for the substitution of flights for train journeys and relieve the capacity constraints of some major airports (Banister and Givoni, 2013). As such, airport stations can become major train stations allowing for improved regional and international connectivity (ibid). This suggests that the accessibility in terms of stations served by HSR is crucial in fully taking advantage of its benefits. In France, the connectivity between HSR and air transport networks has been a policy goal since 1995, which has led to more seamless intermodal travel experiences such as single ticketing and baggage check-in agreements between the French railway operator and airlines (Albalate et al., 2015).

2.3 Air-to-rail substitution and competition

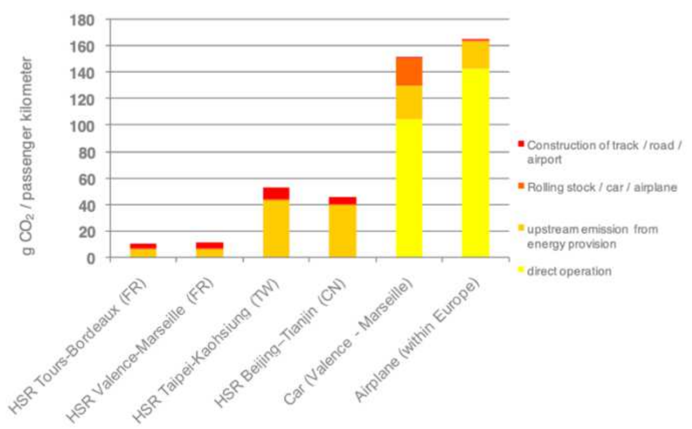
Whether investing in the expansion of the European HSR network will result in an environmental gain depends on the ability of HSR to attract demand from air transport. There is a wide body of existing literature examining the substitution effects between HSR and air transport both empirically and theoretically. The general agreement is that HSR acts as a good substitute on short-distance routes up to 500 km, but that limited substitution takes place on longer routes. In addition, HSR is expected to put pressure on the price levels of air tickets and is therefore expected to cause induced demand.

Givoni and Dobruszkes (2013) find that while a certain amount of substitution between HSR and air transport can be observed with 8% - 49% of HSR passengers having shifted from air transport, the majority of HSR demand is substituted away from conventional rail and a limited amount of passengers shifted away from coaches. Additionally, they find that induced demand makes up about 10-20% of total HSR demand, while Castillo-Manzano (2015) find that only 13.9% of HSR passengers in Spain were shifted away from air transport. Empirical studies suggest that substitution between HSR and air transport mainly takes place due to travel time savings, but that prices have a limited impact on substitution between both modes with estimated price cross-elasticities of between 0.06 and 0.28 and time cross-elasticities between 0.14 and 0.71 (Börjesson, 2014; Wardman et al., 2018; Clewlow et al., 2014; D'Alfonso et al., 2016; Givoni and Dobruszkes, 2013). On the other hand, a frequency cross-elasticity between -0.29 and -0.78 has been estimated, indicating that the frequency of services offered has a significant effect on the other mode (Behrens and Pels, 2012). The evidence is especially strong for domestic and short-haul flights, while the effect on longer routes has been found to be negligible, probably due to the inability of HSR to compete with air transport on such distances (Clewlow et al., 2014; Wardman et al., 2018). In a study on the substitutability and complementarity between HSR and air transport in Europe and East Asia, Zhang et al. (2018) conclude that substitution occurs mainly on short- and medium-haul flights up to 1000 km and that a significant complementary effect exists at primary hub airports that are connected to HSR with on-site stations. Their estimates suggest that the integration can lead to an increase in enplanements at hub airports of 6 – 8 million passengers per year in Central Europe (ibid).

Further, Clewlow et al. (2014) have found that the entry of low-cost carriers (LCC) has had a positive effect on intra-European air traffic, suggesting either a reduced substitution or strong induced demand by LCCs. Castillo-Manzano et al. (2015) and Dobruszkes (2011) confirm that the entry of LCCs has indeed negatively affected the ability of HSR to compete with air transport. Clewlow et al. (2014) and Castillo-Manzano (2015) also found evidence that HSR is especially performing well as a substitute for short- and medium-haul flights on routes between densely populated areas.

2.4 The environmental effects of HSR

HSR is considered to be much more environmentally friendly than air transport due to its lower marginal GHG emissions and is even considered the most sustainable mode of mass transportation, however, it still causes significant local air pollution and noise levels (D'Alfonso et al., 2016; Pagand et al., 2020). According to numbers reported in the Railway handbook 2012, air travel causes 5 times higher levels of CO2 per passenger-km than HSR with 200 g compared to 40 g (ibid). While these numbers do not consider emissions caused during the construction and maintenance phase of HSR, the total carbon footprint of HSR is not expected to be anywhere near that of air travel. Baron et al. (2011) found that including GHG emissions from the construction phase leads to an increase of between 3.7g and 8.9g of GHG per passenger-km for HSR. They also report much higher GHG emissions for air transport, with operations having the biggest impact on overall emissions (ibid).



(Baron et al., 2011)

While Dobruszkes (2011) has found that the introduction of HSR has led to a complete discontinuation of the flight route between Paris and Metz and significant flight reductions on the London-Paris and London-Brussels routes, this has not been observed for the Paris-Marseille route. The author did observe a significant drop in seats offered, but as airlines have chosen to opt for a high frequency and low-capacity strategy, no drop in flights offered has taken place (ibid). This suggests that even if substitution takes place, environmental gains strongly depend on airlines' strategic behaviour. This argument is backed up by Albalate et al. (2015) that found that airlines use smaller planes in response to reduced demand, but maintain flight frequencies to remain competitive. Similarly, D'Alfonso et al. (2015) find that the use of smaller aeroplanes by airlines can be counteractive to the goal of reducing GHG emissions, as they tend to have much higher per passenger-km emissions than larger planes. Regional aircraft that usually carry up to 100 passengers have average CO2 emissions per passenger-km that are almost 88% more than those of narrow-body or wide-body aircraft, carrying more passengers (Graver, 2013).

In their study, Socorro and Viecens (2013) find that at airports with capacity constraints, slots that are freed up through the substitution of short-haul flights are quickly filled up again with new flights to other destinations. This argument is supported by Givoni and Dobruszkes (2013) and means that any benefits in terms of a reduction in emissions or congestion are offset by new flight connections. This holds especially if short-haul flights are replaced by long-distance connections and it is more likely to occur the more capacity constrained an airport is (Socorro and Viecens, 2013). On the other hand, environmental gains might be achieved at airports that are not facing any capacity constraints as substituted flights are less likely replaced by new connections.

Avogadro et al. (2021) found that more than 3% of all intra-European flights could be replaced by train journeys without additional travel time, leading to a reduction of 1.2 million tons of GHG emissions. While this would result in a reduction of 2% in annual emissions caused by intra-European aviation, it is unclear what the net benefits would be after considering potential newly created routes. It is therefore essential to gain a better insight into what happens with freed-up airport capacity following the substitution of selected flight routes by HSR.

2.5 The effects of HSR on airports

While many studies have focused on the substitution between air and rail, Socorro and Viecens (2013) found in their theoretical study that these modes can be complements under certain conditions. This is especially the case when airports are directly connected to HSR by on-site stations as it enables the possibility of intermodal cooperation, where airlines and train operators can cooperate to provide connecting services to passengers (Avenali et al., 2018). Airports that are facing capacity constraints can substitute part of the feeder services with HSR and use freed-up slots for new, more profitable routes, which could lead to even more airport congestion (Terpstra and Lijesen, 2015; Avenali et al., 2018). Terpstra and Lijesen (2015) found that airports can also benefit from being connected to the HSR network as it will improve their accessibility and leads to an increased catchment area. Especially primary airports can benefit from this, attracting travellers that would have chosen to travel from a smaller regional airport in absence of a HSR connection to the larger airport (ibid). Major airports offer passengers better flight connections and so a positive effect of HSR on air traffic at primary airports could be expected, while a negative effect might exist for smaller regional airports (Zhang, 2019). On a similar note, Liu et al. (2019) find that it is especially hub airports that benefit from HSR, while non-hub airports tend to experience traffic reductions following the introduction of HSR.

Clewlow et al. (2012) analysed air traffic in Germany and found that after the Frankfurt airport has been connected to the HSR network by an on-site station, domestic air traffic has decreased by 3% per year between 1999 and 2009, while international air traffic has increased by 2% over the same period. Some feeder flight routes have been completely discontinued, such as the connection between Cologne and Frankfurt, suggesting that they have been replaced by the HSR connection (ibid). Socorro and Viecens (2013) studied the effect of complete air-rail integration at airports, meaning that passengers can book a single ticket for their combined air and rail journey without any additional costs or inconvenience. Their findings suggest that this type of full integration leads to fewer feeder flights to the airport which is, however, compensated by an increase in new flight routes at airports that were facing capacity constraints (ibid). Using dynamic regression analysis, Castillo-Manzano (2015) also find that HSR can act as a complement to air transport when providing direct connections to airports. Zhang et al. (2018) used a difference-in-difference approach to quantify substitution and complementary effects of HSR on air traffic in China and found that substitution occurs mainly on short- and medium-distance flights but that HSR encourages long-distance flights. They identify a significant complementary effect of HSR on air traffic at primary hub airports that are equipped with an on-site HSR station (ibid).

Albalate et al. (2015) use a random-effects estimator to examine the effect of HSR on airport traffic and found that hub airports that have on-site HSR stations do not experience any substantial air traffic reductions. Their findings do suggest, however, that airports in major cities that are not well connected to the HSR network see an overall reduction in air services (ibid). This emphasises the importance of the connectivity between HSR and airports and whether airport traffic increases or decreases are likely linked to how well the airport is accessible with HSR. Generally, there is some evidence that HSR can cause an increase in long-distance flights, that become more accessible to a larger group of potential travellers and would eliminate the environmental gains obtained through the reduction in short-haul feeder air traffic.

Zhang et al. (2019) also look into the air traffic distribution across different routes at airports that are facing capacity constraints, meaning that an overall increase in flight movements is not possible. They find that airports connected to the HSR network experience a change in the distribution of air traffic, away from shorter distances to more long-distance flights (ibid). This could even lead to more congestion at airports if airlines are increasingly using larger aircraft on new routes. The reason for this increase is that connecting airports to HSR networks increases their catchment area, makes them more easily accessible and therefore reduces the cost of travelling, hence leading to induced demand for long-distance travel (Liu et al., 2019).

2.6 Methods used in previous studies

Different methods have been employed in previous studies to measure the effect of HSR on air traffic at airports.

Zhang et al. (2018) make use of a difference-in-differences approach to estimate the causal effect of receiving access to HSR, using realised air traffic data to analyse the substitution and complementary effects between HSR and air transport. This econometric technique is commonly used to assess the implication of policy interventions and is based on dividing airports into a treatment group and a control group to quantify the treatment effect (ibid). The authors divide flights into broad distance groups and find that especially short-haul flights are substituted by HSR, while an increase in long-haul flights has been observed following the entry of HSR. In addition to the treatment, in this case, having access to the HSR network, other variables are likely to affect air traffic at airports.

Liu et al. (2019) explore the effects of HSR on airport-level traffic using a sample of Chinese and Japanese airports and find that as the accessibility of airports is increased by HSR, domestic travel decreases but they also identify a strong complementary effect on international flights. In addition to defining airports as treated if they have on-site stations, they also consider airports with convenient and fast connections to HSR stations to benefit from HSR connectivity. Liu et al. (2019) include a measure of centrality in their OLS regression analysis, measuring how well the airport city is connected within the HSR network as they argue that the effect of HSR does not depend solely on its introduction but on the importance of the airport city's station in the HSR network. They find that HSR leads to increases in long-haul air traffic mainly at hub airports that are well connected to the HSR network. However, if HSR provides good connections only to destinations far away, the effect is found to be negligible as HSR is not able to provide viable feeder services.

Clewlow et al. (2014) explore the effects of HSR and LCCs on system-wide air traffic using data from European airports. They find that HSR generally has led to a moderate decrease in air traffic in Europe, but that the emergence of LCCs has caused a substantial increase in flight movements. The authors use a logarithmic model including two categorical parameters indicating the presence of HSR and LCCs at the airport that are estimated using Ordinary Least Squares (OLS) regressions and a random-effects model.

Zhang et al. (2018) have included economic and demographic indicators such as GDP per capita, GDP from the services sector and population in the catchment area as control variables. The results of their study confirm a strong, significant positive effect of population and GDP per capita, on air traffic with the elasticity of airport passengers with regards to GDP per capita equal to 0.71 to 0.82. Liu et al. (2019) included control variables such as population size, GDP per capita, jet fuel prices and the presence of low-cost carrier operations (number of LCCs using the airport as their base), similar to the controls used by Clewlow et al. (2014). They further include the airport's hub status through an interaction term into the model to account for different effects between the hub and non-hub airports.

Castillo-Manzano (2015) use a dynamic linear regression model, which is an extension of the standard OLS linear regression that allows for coefficients to vary over time. They aim to measure the impact of HSR development on air transport in Spain, especially focusing on the Madrid-Barajas airport. This setup allows for the effect of HSR on air traffic to vary over time, reflecting major changes in the transportation sector such as the emergence of LCCs. Other explanatory variables included were population and the unemployment rate in the region of Madrid, as well as seasonal dummies capturing seasonal effects.

3. Methodology & data

3.1 Background

The goal of this study is to analyse the effect of HSR entry on air travel demand and supply at European airports. The previous sections have discussed the general characteristics of the air travel and HSR markets in Europe as well as the competition and cooperation between the two modes. This study aims to empirically analyse the effect of HSR entry on the volume and mix of air travel demand and supply at an airport level. The previous section has discussed multiple studies that have analysed the substitution between air transport and HSR and found that time savings are the main driver behind a potential substitution from air to HSR. Furthermore, it has been found that HSR can compete with air travel especially on short-distance routes of up to 600 km as the total travel time of HSR, including access and egress times, is likely to be shorter or equal to that of air travel on these routes. However, HSR has not been found to be able to compete with air travel on longer distances and some suggestive evidence for complementary effects has been found in some studies.

While previous studies agree that it is mainly time factors that affect HSR's ability to compete with air travel, there has been mixed evidence for the effect of prices. Given that detailed information on air and train fares is not openly available due to confidentiality the effect of prices cannot directly be measured, however, it could be instrumented using fuel prices as a proxy for airfares. Keeping in mind the goals of the EU to significantly reduce GHG emissions from transportation in the coming years, not only the effect of HSR on travel demand but also on supply should be considered. Albalate et al. (2015) and Dobruszkes (2011) have found that airlines may react strategically to reduced air travel demand by employing smaller aeroplanes but keeping up flight frequencies. However, most emissions reductions can be achieved by a reduction in the number of flights and so high-frequency and low-occupancy strategies might not lead to the expected reduction in environmental damage. Therefore, in this study, not only the effect of HSR on passenger demand but also flights supplied by airlines will be examined.

Finally, while many previous studies have focused on the effect of HSR on air traffic on specific routes on which they compete, this study will focus on broader, system-wide effects of HSR. Previous studies have concluded that HSR has led to a reduction in both air travel demand and supply on specific routes, however, overall environmental benefits remain unclear as it is not known whether discontinued flight routes will be replaced by new routes to other destinations by airlines. This study, therefore, aims at capturing the effect of HSR on airport operations. The hypothesis is that airports connected to the HSR network will see decreases in demand and supply of domestic and short-haul flights but might face simultaneous increases in supply on long-distance flight routes.

To test this hypothesis, a model will be constructed that measures the variation in airline flights offered, as well as passengers carried following a change in HSR services from an airport, using controls that are predicting air travel demand and supply.

3.2 Model & data description

The model used to test whether the introduction of HSR at an airport i has affected air traffic at time t is defined as follows:

$$(1)\quad \ln(AirVolume_{it}) = \beta_0 + \beta_1 \ln(GDP_{it}) + \beta_2 \ln(POP_{it}) + \beta_3 \ln(POP\_Density_{it}) + \beta_4 \ln(Fuel_t) + \beta_5 \ln\left(Tourist_{Arrivals_{it}}\right) + \beta_6 \ln\left(Hotel_{Nights_{it}}\right) + \beta_7 \ln\left(HSR_{PKM_{it}}\right) + \beta_8 \ln\left(HSR_{KM_{it}}\right) + \beta_9 D_{it}^{HSR} + \alpha_i + \delta_t + u_{it}$$

In the following section a detailed explanation of the variables will be presented. The unbalanced panel dataset has a cross-sectional spatial and a time-series dimension. In the dataset, each cross-sectional unit ***i*** represents a specific airport (***i*** = 1,…,30) and is observed over ***t*** time periods (***t*** = 1,…,192) which represents monthly observations over the period between 2004 up to and including 2019. Therefore, the dataset contains observations for ***I*** = 30 units over ***T*** = 192 time periods, resulting in a total of ***N*** = 5760 observations for each variable. There are some issues with the availability of data, especially for airports located in Ireland and the United Kingdom.

The selection of airports to include in this study was based on overall volume of air traffic movements in 2019, as well as whether HSR developments have been undertaken in the period analysed. The selected airports together accounted for 56% of all passengers carried within the EU plus Norway and Switzerland and 52% of all flights (Eurostat, 2022a). However, any airports located on smaller islands were removed from the dataset because they are not relevant to the analysis. This is because island airports are facing a different starting situation and are not able to be connected to the HSR network and thus are not comparable to the other set of airports. Airports located in the United Kingdom were excluded from the dataset although they could be connected to the European mainland HSR network by the channel tunnel. This is due to data unavailability for many control variables. Additionally, several major airports in Poland were removed from the list due to data unavailability for a large range of years between the observed period 2004 to 2019.

The variables $AirVolume_{it}$, GDP_{it}, POP_{it}, $POP\_Density_{it}$, $Tourist\_Arrivals_{it}$, $Hotel\_Nights_{it}$, HSR_PKM_{it}, HSR_KM_{it}, D_{it}^{LCC} *and* D_{it}^{HSR} vary both over time and across units, whereas the variable $Fuel_t$ only varies over time $\boldsymbol{t}$ but is constant across units $\boldsymbol{i}$.

Air traffic volume variables

The variable $\boldsymbol{AirVolume_{it}}$ is measured in the number of flights offered and the number of passengers carried at airport $\boldsymbol{i}$ during period (month-year) $\boldsymbol{t}$. The data was taken from the Eurostat database on transportation statistics which is provided by the statistical office of the EU (Eurostat, 2022b). This database provides detailed statistics on aviation within Europe for all major airports, as well as more detailed statistics on routes between airport pairs. Data for different airports in the same city region, such as Paris-CDG and Paris-Orly were not aggregated to analyse differences between airports, such as the presence of an on-site HSR station at one of the airports. There are great variations of air traffic between airports but also within airports over time, as next to seasonality effects there are effects of economic downturns that are reflected in air traffic volume. The models in this paper will use different measures for air traffic volume.

The Eurostat database contains information on the number of seats offered by airlines from and to a specific airport. However, given that environmental gains are determined by the number of flights rather than the number of seats, it has been decided to measure airline supply by the number of flights offered to and from an airport $\boldsymbol{i}$. Next, the number of passengers carried was also observed for each airport on a monthly basis, allowing for the analysis of actual passenger demand rather than airline supply.

Finally, while these aggregate numbers capture the total air traffic volume departing and arriving at a specific airport, further information on the type of flights is available in the database. Both measures can be specified into national versus international flights and passengers carried, allowing for the distinct effect of HSR on domestic and international air traffic. Further, a sub-division has been made between flights that take place within the EU and flights taken place outside of the EU. This distinction has been made to analyse different effects between short- and medium-haul flights taking place mostly within the EU and long-distance flights taking place mostly outside of the EU. In this definition, the EU has been defined as the EU-27 countries in addition to the UK, Switzerland, and Norway due to their geographical proximity to the EU-27 countries.

Control variables

The following variables have been included as they have been used in previous literature as factors explaining variation in air transport demand or supply. The aim of including these variables is to capture the variation in air traffic volume that is not caused by the presence of HSR but by variation in demographic or economic factors. While most of the variables have been measured in the NUTS-2 region where the airport is located, some variables were only available at the national level and will therefore be the same for all airports located in a specific country.

$\boldsymbol{GDP_{it}}$ measures the GDP at current market prices of the NUTS-2 region in which airport i is located in during a specific year t. The data is obtained from the Eurostat database (Eurostat, 2022c) and as monthly data is unavailable for this variable, yearly values will be used. The NUTS-2 statistical regions are used as they are considered in this study to be the catchment area of the airport. Where available, all demographic and economic variables are measured at the NUTS-2 level to account for regional differences within a country. GDP is included in the model as it indicates the overall level of business activities in the area close to the airport, higher GDP is expected to lead to higher travel demand from business travellers.

Further, $\boldsymbol{GDP\_capita_{it}}$ is measuring GDP per capita at current market prices within the NUTS-2 region of airport i at time t. While the overall GDP of the region indicates the overall level of business activities in a region, GDP per capita can be used as a measure of the purchasing power of residents living close to the airport. Higher GDP per capita is therefore expected to lead to a higher travel demand of residents.

$\boldsymbol{POP_{it}}$ measures the population in the NUTS-2 region that airport $\boldsymbol{i}$ is located in at time t. The values are obtained from the Eurostat database (Eurostat, 2022d) and measured on a yearly basis. A higher population closer to the airport is expected to lead to a higher air travel demand.

$\boldsymbol{POP\_Density_{it}}$ is collected from the Eurostat database (Eurostat, 2022d) as well and measures the population density in the region close to airport i at period t. A higher population density might lead to higher travel demand, but a higher population density might also make investments in the train network more attractive.

$\boldsymbol{Tourist\_Arrivals_{it}}$ measures the number of people arriving in the NUTS-2 area of airport i in period t for tourist reasons. Again, the data is obtained from the Eurostat database (Eurostat, 2022e) but is complemented with data from the Hungarian Central Statistical Office due to some data unavailability for Hungary in the Eurostat database (KSH, 2022a, 2022b). The number of tourist arrivals is an indicator of how popular a city or region is with tourists and thus acts as a proxy for tourism. The higher the number of tourist arrivals, the higher the number of travellers and therefore air traffic demand is likely correlated with this variable.

$\boldsymbol{Hotel\_Nights_{it}}$ is used as an alternative measure for tourism and business, the data is collected mainly from the Eurostat database (Eurostat, 2022e) but again complemented with data from the Hungarian Central Statistical Office (KSH, 2022a, 2022b).

$\boldsymbol{Fuel_t}$ measures the prices of kerosene or crude oil at time period t. The variable is included due to the unavailability of airfares, but a large part of fuel price increases is likely passed on to the customer by the airlines by increasing airfares (Clewlow et al., 2014). Higher fuel prices are therefore expected to lead to reduced air traffic. The data is obtained from multiple sources, monthly crude oil spot prices are obtained from Euromonitor (Euromonitor, 2022). Further, data on annual crude oil import prices are obtained from OECD for a selection of 16 EU countries (OECD, 2022). An annual indicator is created by averaging the prices across the selected countries to create an average annual price indicator for crude oil imports. For both, the data are measured in dollars per barrel. Finally, monthly kerosene jet fuel spot prices are obtained from the US Energy Information Administration, measured in dollars per gallon (EIA, 2022).

$\boldsymbol{HSR\_PKM_{it}}$ measures the number of HSR passenger-kilometers within the country that airport $\boldsymbol{i}$ is located in. Unfortunately, there is no more local data available, however, the number of passenger kilometres travelled in a year within a country are expected to reflect the size of the HSR market within the country. These numbers are obtained from the Statistical Handbook 2021 on EU transport figures published by the European Commission and the related datasets (European Commission. Directorate General for Mobility and Transport., 2021).

$\boldsymbol{HSR\_KM_{it}}$ measures the length of the existing HSR network in the country of airport $\boldsymbol{i}$ at time $\boldsymbol{t}$. This reflects the size of the HSR network within a country and is likely to affect air travel demand and supply negatively. These numbers are obtained from the Statistical Handbook 2021 on EU transport figures published by the European Commission and the related datasets (European Commission. Directorate General for Mobility and Transport., 2021).

$\boldsymbol{D_{it}^{HSR}}$ is a dummy variable that measures whether airport $\boldsymbol{i}$ was connected to the HSR network in time period $\boldsymbol{t}$. This dummy indicator is created with information obtained through local train operators, press releases and news articles. It is defined to be equal to 0 if airport $\boldsymbol{i}$ did not have access to the HSR network in period $\boldsymbol{t}$ and equal to 1 if airport $\boldsymbol{i}$ did have access to the HSR network in period $\boldsymbol{t}$. It is important to clearly define what the treatment of an airport entails as only a few airports have on-site HSR stations that offer seamless connections from HSR to the airport, but other airports do have HSR stations in their catchment area.

For this reason, three different HSR dummies are created. The first HSR dummy variable $\boldsymbol{D_{it}^{HSR\_1}}$ indicated whether an airport has direct access to the HSR network through an on-site station, the second dummy variable $\boldsymbol{D_{it}^{HSR\_2}}$ indicates whether an airport has convenient access to the HSR network. Having convenient access is defined as being connected to the nearest HSR station by public transport in less than 30 minutes. The last dummy variable $\boldsymbol{D_{it}^{HSR\_3}}$ is defined as having a HSR station in the airport's catchment area. Furthermore, HSR in this study is defined as trains operating at speeds higher than 200 km/h and must be connecting cities with each other. As such, for instance, the Gardermoen HSR line in Norway is not considered as it only covers a track of about 60km and does not connect Oslo to other major cities and thus does not provide the same benefits as other HSR lines in Europe.

Table 3.1. Key variables and data sources

Dimension	**Variable**	**Unit**	**Sources**
Air transport demand	Air Volume	Passengers / month	Eurostat: air transport, Flights offered
Air transport supply	Air Volume	Flights / month	Eurostat: air transport, Passengers carried
Economic controls	GDP GDP per capita	Million euros / year Euros per inhabitant / month	Eurostat: GDP at current market prices by NUTS 2 regions
	Tourist arrivals	Tourists arriving / year	Eurostat: Arrivals at tourist accommodation establishments by NUTS 2 regions, KSH: Tourist arrivals and tourism nights at commercial accommodation establishments by tourism region
	Hotel nights spent	Hotel nights / year	Eurostat: Nights spent at tourist accommodation establishments by NUTS 2 regions, KSH: Tourist arrivals and tourism nights at commercial accommodation establishments by tourism region
	Fuel	Dollars per barrel / month Dollars / gallon / month Dollars per barrel / year	Euromonitor: Crude Oil Spot Prices, EIA: US Gulf Coast Kerosene Type Jet Fuel Spot Price, OECD: Crude oil import prices
Demographic controls	Population	Inhabitants / year	Eurostat: Population by NUTS 2 region
	Population density	Persons per square metre / year	Eurostat: Population density by NUTS 2 region
HSR	HSR Passenger-km HSR km	Passenger-km / year Km / year	European Commission: Performance of high-seed rail passenger transport,

D_HSR	Binary	European Commission: Length of high-speed rail lines Press releases, Train operators' websites, News articles

3.3 Methodology

In this study, a difference-indifference approach similar to that applied by Zhang et al. (2018) and Wan et al. (2016) will be used to identify the effect of HSR entry on airport-level traffic. The key identification assumption underlying the difference-in-difference method is that both the treatment and control groups would have followed parallel trends over time if no treatment had taken place. Airports should therefore show common time trends in the periods before the treatment has taken place (Wan et al., 2016). This assumption ensures that both groups are comparable to each other over time and that any differences between both groups after the treatment are entirely caused by the treatment itself (Zhang et al., 2018). Applied to this study, this means that traffic at airports that are now connected to the HSR network should have followed similar time trends to that at airports without a HSR connection if it were not for the HSR access. This assumption ensures that access to HSR is the only factor influencing differences in air traffic and so the causal effect of HSR entry can be identified. If this assumption is violated and airports in both groups are fundamentally different from each other, this threatens the identification of the HSR effect. This is a common issue in evaluating policies using non-experimental data, with potential systematic differences between the treatment and control groups (Baum, 2013).

Receiving treatment in this study means being connected to the HSR network. This decision might not be fully random as it is likely that economic and demographic factors such as GDP and population density affect the likelihood of an airport receiving a HSR connection. For instance, in France, the expansion policy was to build new HSR lines only between crowded cities with high traffic demands, so that initially only the most populated cities of the country were connected by the new HSR network (Albalate and Bel, 2012). On the other hand, Germany's motive behind initial HSR developments was connecting industrial areas in the South to the seaports in the North, while Spain's goal was to promote the development of the economy in poorer regions of the country (ibid). However, this issue can be partially mitigated by including economic and demographic controls in the model as these same variables are likely to affect the demand for air travel and the decision to receive HSR access (Wan et al., 2016). One way to test for common time trends is to run a regression including only pre-treatment observations and including separate year dummy variables for both the group of airports that received treatment and the group that did not receive treatment (Wan et al., 2016). For the parallel trend assumption to hold, no significant difference between the year dummies of both groups should be observed.

The model will first be estimated using Ordinary Least Squares (OLS) and afterwards using an error component model, similar to the approach of Clewlow et al. (2014). The first pooled model that is estimated by OLS assumes that coefficients of variables are constant over time and between individual airports, as well as that the error term is uncorrelated with the dependent variable. This model does not consider the panel data structure and does not allow for fixed effects that reflect differences between airports that might be caused by unobserved variables. The error component model allows for airport-specific fixed effects, for instance, to account for inherent differences between airports that make them more or less attractive.

The error component model specifications include a random and a fixed-effects estimator and a Hausman-Wu test is conducted to determine whether a random or fixed effects approach should be preferred. The Hausman test is used to test whether the random effects estimator produces consistent results, thus if the coefficients estimated by the random effects estimator are equal to those estimated by the fixed effects estimator (Bell et al., 2019). If yes, then the random effects estimator is consistent and should be preferred as it is more efficient, however, if there are significant differences between the results of both approaches, this indicates that there might be omitted variable bias at the airport level and therefore the fixed-effect approach should be preferred. The results of the Breusch-Pagan and the Hausman-Wu test conducted suggest that both the pooled OLS and the random effects estimators lead to inconsistent results and therefore the fixed effects estimator is the preferred final model specification. The coefficient of the treatment variable D_{it}^{HSR} then captures the average treatment effect of HSR access on airport traffic (Wan et al., 2016).

First, the model will be estimated using total air traffic in terms of passengers carried and flights offered as dependent variables to measure the total effect of HSR on airport traffic. Next, the model is re-estimated using national, international, and extra-EU air traffic to get a better picture of how exactly HSR is affecting traffic at European airports. This allows for the identification of different effects of HSR, depending on the type of air traffic that is analysed and to analyse whether HSR leads to a change in the type of air traffic.

4. Results

This section presents the results obtained from the model estimations. It starts with a discussion of the overall data behaviour followed by the model estimations and a discussion of the estimated coefficients in relation to the hypotheses.

4.1 Data behaviour

Looking at the variables used to measure air traffic volume, there is more between variation than within variation. This means that there are greater differences in air traffic volume between the different airports in the sample than there is variation over time for a specific airport. This is caused by the fact that airports of various sizes were included in the sample. The mean number of total flights recorded per month is 16,929 with a minimum of 2,441 and a maximum of 47,806. The mean number of passengers carried per month is 1,899,174 with a minimum of 177,678 and a maximum of 7,469,755.

Table 4.1: Data overview

Variable	Mean	Minimum	Maximum
Total flights (per month)	16,929	2,441	47,806
Total passengers (per month)	1,899,174	177,678	7,469,755

The control variables *GDP*, *GDP per capita*, *Population*, *Population density*, *Tourist Arrivals* and *Hotel nights spent* all show relatively high between and within variation. However, there is more variation between the various airports included than there is variation over time. This reflects the fact that the sample includes airports located in areas that differ a lot from each other in terms of economic activity or demographic characteristics. As expected, there is no between variation for the variable capturing kerosene and fuel prices, *Fuel*. That is because European-wide price measures have been used, with the assumption that the same fuel prices apply to all airports in the sample at a given point in time. However, there is relatively large variation over time, reflecting the fluctuating fuel prices over the years.

Table 4.2 shows the correlation for a selection of variables. A relatively high correlation is found between total passengers and flights and GDP and GDP per capita. Furthermore, a moderate correlation is observed between the air traffic variables and tourist arrivals, hotel nights spent and population density. These correlations have the expected sign as it is expected that higher economic activity, higher population density and higher tourism activity lead to more flights and passengers carried.

Table 4.2: Correlations between selected variables

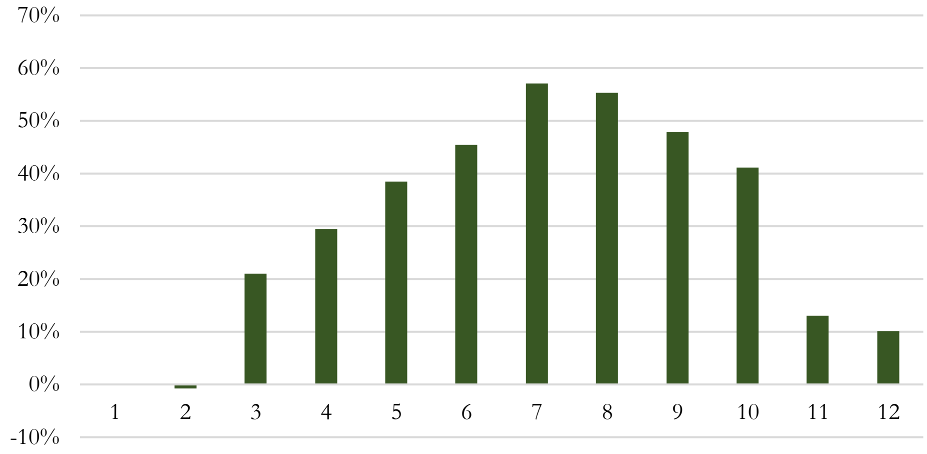
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) ln (Total Passengers)	1.000						
(2) ln (Total Flights)	0.963	1.000					
(3) ln (GDP)	0.572	0.506	1.000				
(4) ln (GDP per capita)	0.486	0.534	0.260	1.000			
(5) ln (Population Density)	0.302	0.348	-0.136	0.347	1.000		
(6) ln (Tourist Arrivals)	0.458	0.352	0.827	-0.083	-0.126	1.000	
(7) ln (Hotel Nights)	0.354	0.245	0.735	-0.184	-0.146	0.931	1.000

When looking at graphs of total air traffic in terms of passengers carried and flights offered, a clear seasonal pattern can be observed that is present at every airport in the sample. Regressing total passengers carried and total flights offered on month dummies also captures these seasonal effects as reported in Table 4.3 below. The month dummies indicate a strong seasonal effect with summer months diverting most from the base month January and January and February generally recording the lowest number of passengers carried. When regressing the natural logarithm of Total Passengers on the month dummies, the seasonal effect can be expressed in percentages. For instance, in July, which is the busiest month in terms of air traffic, there are generally 57% more passengers carried than in January. This suggests that it might be important to include month-fixed effects in the model to account for these seasonal trends in passenger demand and airline supply. Appendix 4.1 provides an overview of the seasonal trends in flights supplied.

Table 4.3: Seasonal effects

	Total Passengers		ln (Total Passengers)	
	Coeff.	p-value	Coeff.	p-value
Month: base 1	0		0	
2	-28,505	0.687	-0.007	0.886
3	276,792	0.000	0.191	0.000
4	388,870	0.000	0.258	0.000
5	520,615	0.000	0.326	0.000
6	604,585	0.000	0.375	0.000
7	782,709	0.000	0.452	0.000
8	760,239	0.000	0.440	0.000
9	643,544	0.000	0.391	0.000
10	561,873	0.000	0.345	0.000
11	169,622	0.024	0.122	0.016
12	135,188	0.072	0.096	0.057

Figure 4.1: Seasonal changes in passengers carried compared to January



To test the parallel trends assumption, a regression is run including only pre-treatment observations and separate year dummies for airports that will receive treatment and those that do not. For the parallel trends assumption to hold, the year dummies of both groups should not be significantly different from each other. For none of the year dummies, significant differences between both groups can be observed. Nevertheless, it is important to note that for later years the estimation might be unreliable as most airports in the treatment group have received treatment in the early years of the sample period.

4.2 Model estimation

After an initial data exploration, the pooled model is first estimated by OLS, which assumes that all coefficients are constant over time and equal for all airports and that the error term u_{it} is uncorrelated with the dependent variable, in this case, air traffic volume. In this estimation, the panel data structure is not considered because the estimated constant term is assumed to be equal for all airports.

Column (1) in Table 4.4 shows the results of a regression with *ln (Total Passengers)* on several control variables, Crude Oil, GDP per capita, Population, Population density and Tourist Arrivals as well as the HSR dummy indicating that an airport has convenient access to the HSR network. The economic and demographic controls have the expected sign and are statistically significant at the 1% level, except for the coefficient of *Crude Oil*, where the positive coefficient would indicate higher passenger volume following higher fuel prices, but the estimate is statistically insignificant. Furthermore, the coefficient of the HSR dummy indicates that having access to the HSR network leads to increased passenger volume. Column (2) in Table 4.4 reports the results of a regression which accounts for the strong seasonal trends in passenger volume using month-fixed effects. The main change compared to the earlier specification is the better model fit and the fact that the coefficient of *Crude Oil* has now the expected negative sign and is statistically significant at the 5% level.

Column (3) of Table 4.4 reports regression results with additional HSR-related controls added to the time fixed-effects specification. These include the number of passenger-km travelled in the country of the airport and the length of the HSR network in the country where the airport is located in. These variables are used as a proxy for the quality of the HSR network that the airport has access to, as having access to a relatively small HSR network is expected to have a different effect on air traffic volume than having access to a long and widely used HSR network. The estimation results show statistically significant negative coefficients for the additional HSR-related controls, while the coefficient of the HSR dummy has increased in size. Column (4) of Table 4.4 reports year-fixed effects that are added to account for factors varying between years but that are common to all airports in the sample. Including year fixed effects further increases the model fit and a joint test on the significance of the year fixed effects suggests that they should indeed be included. Therefore, estimation (4) is the preferred pooled OLS model, and the results suggest that the treatment effect of HSR entry is equal to 0.480 and significant at the 1% level. This suggests that airports that have been connected to the HSR network report (exp(0.480)-1*100) = 61.61% higher passenger levels than their counterparts that have no connection to the HSR network.

Table 4.4: Estimation results from OLS estimation for passengers carried

	(1) ln (Total Passengers)	(2) ln (Total Passengers)	(3) ln (Total Passengers)	(4) ln (Total Passengers)
Monthly dummies	no	yes	yes	yes
Yearly dummies	no	no	no	yes
ln (Crude Oil)	0.0192 (0.0198)	-0.0382** (0.0189)	-0.0469*** (0.0177)	0.0357 (0.0453)
ln (GDP per capita)	0.992*** (0.0168)	0.994*** (0.0151)	1.001*** (0.0138)	1.006*** (0.0142)
ln (Population)	0.224*** (0.0189)	0.223*** (0.0170)	0.327*** (0.0151)	0.321*** (0.0152)
ln (Population Density)	0.113*** (0.00626)	0.112*** (0.00597)	0.0589*** (0.00646)	0.0565*** (0.00654)
ln (Tourist Arrivals)	0.330*** (0.0182)	0.331*** (0.0166)	0.379*** (0.0141)	0.385*** (0.0146)
ln (HSR PKM)	-	-	-0.0191*** (0.00175)	-0.0190*** (0.00173)
ln (HSR Network)	-	-	-0.0247*** (0.00129)	-0.0250*** (0.00128)
D_HSR	0.341*** (0.0189)	0.343*** (0.0181)	0.473*** (0.0186)	0.480*** (0.0184)
Constant	-5.731*** (0.298)	-5.751*** (0.281)	-7.715*** (0.267)	-8.009*** (0.305)
Observations	5464	5464	5464	5464
R-squared	0.5707	0.6117	0.6569	0.6618

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The large size of the estimated treatment effect hints that there might be other factors playing a role in determining passenger volume. Possibly there are inherent factors that make an airport more or less attractive for passengers and therefore it will be useful to include airport-level fixed effects to account for these differences between the airports in the sample. An error component model can be used to estimate equation (1) by considering also airport-specific but time-constant effects and airport-constant but time-varying effects. Therefore, after the OLS estimation, the model is re-estimated using airport-specific fixed effects to account for possible fixed effects at the airport level. There are two approaches for this, the fixed effect approach (FE), and the random effects approach (RE). The difference between both is that the RE approach, unlike the FE approach, assumes that the individual fixed effects are random and uncorrelated with the other regressors included in the model.

First, the model is estimated using the FE approach with the results reported in Table 4.5 below. An F-test is used to test whether this FE model should be preferred over the standard OLS model. The F-test is based on the null hypothesis that all error terms u_{it} are equal to zero, versus the alternative hypothesis that individual fixed effects exist. This test statistic is automatically reported in Stata after running the FE model and with an F-score of 2364.88, the null hypothesis can be rejected. Therefore, the standard OLS estimation is biased, and the existence of fixed effects is assumed.

Not surprisingly, the results of the FE estimation vary significantly from those of the pooled OLS estimation, with the effect of HSR entry still being statistically significant at the 1% level but being reduced to 0.065 from 0.473. This suggests that the entry of HSR leads to a 6.72% increase in passenger volume compared to airports without HSR access and this estimate is much more realistic than that obtained with the pooled OLS estimation.

Table 4.5: OLS and FE Estimation results for passengers carried

ln (Total Passengers)	(1) OLS	(2) FE	(3) FE
Airport FE	no	yes	yes
Month FE	yes	yes	yes
Year FE	no	no	yes
ln (Crude Oil)	-0.0469*** (0.0177)	-0.0189*** (0.00501)	0.0369*** (0.0110)
ln (GDP per capita)	1.001*** (0.0138)	0.597*** (0.0344)	0.146*** (0.0341)
ln (Population)	0.327*** (0.0151)	0.466** (0.181)	-0.630*** (0.171)
ln (Population Density)	0.0589*** (0.00646)	0.349* (0.181)	0.325** (0.165)
ln (Tourist Arrivals)	0.379*** (0.0141)	0.507*** (0.0191)	0.168*** (0.0205)

ln (HSR PKM)	-0.0191*** (0.00175)	-0.0185*** (0.00429)	-0.0399*** (0.00410)
ln (HSR Network)	-0.0247*** (0.00129)	-0.00649*** (0.00212)	-0.0122*** (0.00195)
D_HSR	0.473*** (0.0186)	0.0626*** (0.0106)	0.0650*** (0.00960)
Constant	-7.715*** (0.267)	-9.442*** (1.751)	16.81*** (1.836)
Observations	5464	5464	5464
(Adjusted) R-squared	0.6569	0.7631	0.8104

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Then, the model is estimated using the RE and the simple Breusch-Pagan Lagrangian multiplier test is performed to test whether the RE model should be preferred over the pooled OLS model. The test statistic exceeds the 1% critical value and therefore the pooled OLS model can be rejected. Again, the results of the RE with and without year fixed effects are significantly different from those obtained with the pooled OLS model. The best RE estimate of the HSR treatment effect is 0.0625 and statistically significant at the 1% level. This suggests that airports with HSR access have seen an increase of 6.45% in passengers carried compared to those that have not received access to the HSR network.

Finally, a Hausman-Wu test is conducted to determine whether the FE or RE model should be preferred. If the stochastic structure of the airport fixed effects that are assumed by the RE model is correct, then this method should be preferred over the FE model. The null hypothesis of the Hausman-Wu test is that the airport-specific effects are independent of the other regressors in the model. Under this hypothesis both the FE and RE estimators are consistent, but the RE estimator is more efficient and should be preferred. Under the alternative hypothesis, however, only the FE estimator is consistent. The test statistic of the Hausman specification test exceeds the critical value of the chi-squared distribution at the 1% level and therefore the stochastic structure of the RE model is rejected, and the FE model should be used. Appendix 4.2 reports the detailed results of the RE approach and the Hausman-Wu test.

The preferred specification is therefore the following FE model:

$$(2)\ \ln(AirVolume_{it}) = \beta_0 + \beta_1 \ln(GDP_{it}) + \beta_2 \ln(POP_{it}) + \beta_3 \ln(POP\_Density_{it}) + \beta_4 \ln(Fuel_t) + \beta_5 \ln\left(Tourist_{Arrivals_{it}}\right) + \beta_6 \ln\left(Hotel_{Nights_{it}}\right) + \beta_7 \ln\left(HSR_{PKM_{it}}\right) + \beta_8 \ln\left(HSR_{KM_{it}}\right) + \beta_9 D_{it}^{HSR} + \alpha_i + \delta_t + u_{it}$$

The estimation of the model is repeated with total flights as the dependent variable to analyse the effect of HSR on air traffic supply rather than passenger demand as was done until this point. The results are reported in Table 4.6 below and suggest that the effect of HSR entry on flights offered is equal to 0.0583 and statistically significant at the 1% level. This means that airports that have received HSR access, see air traffic, in terms of flights offered, increase by (exp(0.0583)-1)*100 =6.00% compared to not having received HSR access. This suggests that HSR entry at an airport leads to a 6% increase in flights offered, thus of a similar size as the effect on demand. When using passengers carried as the dependent variable, the coefficient of the HSR dummy variable captures how passenger demand for flying changes after the introduction of HSR. In this case, when using flights offered as the dependent variable, the coefficient reflects the change in air traffic supply in terms of flights and thus the reaction of airlines facing the entry of HSR at the airport.

Another noticeable difference is the coefficient of ln(HSR PKM), capturing the cross-elasticity between flights offered and passenger-km travelled. When including airport FE, the estimate is equal to -0.0357, significant at the 1% level and more than twice as large as the OLS estimate. This means that as passenger-km travelled in the country of an airport increases by 1%, flights offered from the airport decrease on average by -0.0357%.

Table 4.6: OLS, FE and RE Estimation results for flights offered

ln (Total Flights)	(1) OLS	(2) FE
Airport FE	no	yes
Month FE	yes	yes
Year FE	yes	yes
ln (Crude Oil)	0.00978 (0.0413)	0.0102 (0.0103)
ln (GDP per capita)	1.017*** (0.0134)	0.208*** (0.0319)
ln (Population)	0.239*** (0.0138)	-0.505*** (0.160)
ln (Population Density)	0.0578*** (0.00612)	0.263* (0.154)
ln (Tourist Arrivals)	0.309*** (0.0137)	0.0988*** (0.0192)
ln (HSR PKM)	-0.0168*** (0.00157)	-0.0357*** (0.00383)
ln (HSR Network)	-0.0200*** (0.00115)	-0.00230 (0.00182)
D_HSR	0.413*** (0.0169)	0.0583*** (0.00896)
Constant	-9.943*** (0.285)	11.52*** (1.713)
Observations	5464	5464
R-squared	0.6337	0.5247

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.3 Effect of HSR on passenger- and flight-mix

After having found the preferred model specification, the various measures of air traffic volume can be used to get a better picture of the effect of HSR on the mix of passengers and flights at the airport level. Table 4.7 shows the coefficients for the HSR treatment dummy for equation (2) with air traffic volume equalling total, domestic, international, and extra-EU passengers. The results show that when only national passenger numbers are used as the dependent variable, the coefficient of the HSR dummy is equal to -1.01 and significant at the 1% level. This suggests a much stronger and negative effect of HSR on domestic passengers than on overall passenger levels. Using international passenger numbers results in insignificant estimates, while the coefficient of the HSR dummy variable is larger in size and significant at the 1% level when using extra-EU passengers as the dependent variable. The results suggest that HSR has the strongest positive effect on passengers to and from extra-EU destinations, that are generally travelling on long-haul flights, while a very strong negative effect can be observed on domestic passengers.

Table 4.7: Coefficients of D_HSR using FE estimation for air traffic demand

Dependent variable	Total Passengers	Domestic Passengers	International Passengers	Extra-EU Passengers
D_HSR	0.0650*** (0.00960)	-1.0104*** (0.13686)	0.0144 (0.01232)	0.0841** (0.035447)
HSR effect in %	6.72%	-63.59%	1.45%	8.77%

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Finally, the same analysis is repeated with the number of flights as the dependent variable to analyse the effect of HSR on the supply of air traffic at the airport level. The coefficients for the HSR dummy are reported in Table 4.8 shows the results for total, national, international, and extra-EU flights. Compared to the previous analysis, this helps to analyse the response of airlines rather than passengers following the introduction of HSR. The treatment effect on domestic flights is significantly negative as was already the case for domestic passengers, but it is much smaller in absolute size, suggesting that passenger demand changes stronger than airline supply following the entry of HSR. The treatment effect on international flights is statistically significant at the 5% level and equal to 0.026, suggesting a 2.6% increase in international flights following the entry of HSR, while that on extra-EU flights is negative with -0.16 and statistically significant at the 1% level, suggesting a 14.85% decrease in extra-EU flights. Especially the last estimate is noteworthy as it suggests that while passenger demand for extra-EU flights increases following HSR entry, the supply of extra-EU flights by airlines decreases.

Table 4.8: Coefficients of D_HSR using FE estimation for air traffic supply

Dependent variable	Total Flights	National Flights	International Flights	Extra-EU Flights
D_HSR	0.0583***	-0.3525***	0.0257**	-0.1608***

	(0.00896)	(0.09043)	(0.01067)	(0.02828)
HSR effect in %	6.00%	-29.71%	2.60%	-14,85%

Standard errors in parentheses
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

4.4 Sensitivity analysis

In this sub-section, the robustness of the results is checked by using different definitions of the HSR dummy variable. In the main analysis, the definition of the HSR dummy variable is that an airport has convenient access to the closest HSR station in period *t*, meaning that the HSR network can be reached by public transport from the airport in maximum 30 minutes. This variable is recorded in the dataset as D_HSR_2. The alternative definitions are that the airport has direct access to the HSR network through an on-site station, recorded under the variable D_HSR_1 and that the HSR network connects the catchment area of the airport, recorded as D_HSR_3.

Comparing the results for D_HSR_2 and D_HSR_3, the coefficients for the control variables are very similar in size and statistical significance. However, the treatment effect for D_HSR_3 is only half the size of that for D_HSR_2, which suggests that as HSR is less well connected to the airport its effect on air traffic demand becomes less strong. When using the D_HSR_1 dummy variable, which indicates an on-site HSR station, the treatment effect interestingly becomes negative indicating that HSR entry would lead to a decrease in passenger demand. A possible explanation for this could be that direct access to an on-site HSR station could lead to a larger substitution of feeder flights that is not compensated by an increase in long-haul air traffic demand. On the other hand, the sub-sample of airports that has on-site HSR access is relatively small with only 5 of the 30 airports having this type of connection. This can make the estimation less precise and the results less reliable.

Table 4.9: Dependent variable: Total Passengers

	D_HSR_1 FE	D_HSR_2 FE	D_HSR_3 FE
Airport FE	yes	yes	yes
Month FE	yes	yes	yes
Year FE	yes	yes	yes
ln (Crude Oil)	0.0370*** (0.0111)	0.0369*** (0.0110)	0.0368*** (0.0111)
ln (GDP per capita)	0.106*** (0.0341)	0.146*** (0.0341)	0.165*** (0.0355)
ln (Population)	-0.443** (0.173)	-0.630*** (0.171)	-0.630*** (0.172)
ln (Population Density)	0.209 (0.166)	0.325** (0.165)	0.373** (0.166)

ln (Tourist Arrivals)	0.187*** (0.0204)	0.168*** (0.0205)	0.176*** (0.0205)
ln (HSR PKM)	-0.0458*** (0.00421)	-0.0399*** (0.00410)	-0.0449*** (0.00412)
ln (HSR Network)	-0.00714*** (0.00199)	-0.0122*** (0.00195)	-0.0110*** (0.00194)
D_HSR	-0.0454*** (0.0140)	0.0650*** (0.00960)	0.0344*** (0.00738)
Constant	14.86*** (1.846)	16.81*** (1.836)	16.18*** (1.835)
Observations	5464	5464	5464
(Adjusted) R-squared	0.8092	0.8104	0.8096

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Using the same three HSR dummy variables with total flights as the dependent variable, again, the coefficients for the control variables are relatively robust and do not vary much between the different definitions of HSR access. The estimate of the treatment effect for having an on-site station (D_HSR_1) is statistically insignificant, again probably due to the small number of airports enjoying this type of HSR connection. When using the broader definition of HSR access, including airports that have HSR stations in their catchment area, the treatment effect is statistically significant ta the 5% level and equal to 0.014, and thus considerably smaller in size than with the definition chosen for the main analysis. On the other hand, the cross-elasticity between passenger-km and passengers carried is relatively consistent over all three specifications, indicating that the obtained result is rather robust.

Table 4.10: Dependent variable: Total flights

	D_HSR_1 FE	D_HSR_2 FE	D_HSR_3 FE
Airport FE	yes	Yes	yes
Month FE	yes	Yes	yes
Year FE	yes	Yes	yes
ln (Crude Oil)	0.0102 (0.0103)	0.0102 (0.0103)	0.0101 (0.0103)
ln (GDP per capita)	0.185*** (0.0318)	0.208*** (0.0319)	0.201*** (0.0332)
ln (Population)	-0.440*** (0.161)	-0.505*** (0.160)	-0.453*** (0.161)
ln (Population Density)	0.240 (0.155)	0.263* (0.154)	0.257* (0.155)
ln (Tourist Arrivals)	0.117*** (0.0191)	0.0988*** (0.0192)	0.112*** (0.0192)
ln (HSR PKM)	-0.0371*** (0.00393)	-0.0357*** (0.00383)	-0.0391*** (0.00385)

ln (HSR Network)	-0.000241 (0.00186)	-0.00230 (0.00182)	-0.000298 (0.00181)
D_HSR	0.0161 (0.0131)	0.0583*** (0.00896)	0.0136** (0.00690)
Constant	10.67*** (1.724)	11.52*** (1.713)	10.66*** (1.715)
Observations	5464	5464	5464
(Adjusted) R-squared	0.5211	0.5247	0.5213

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The results of the sensitivity analysis suggest that the definition of the HSR dummy variable plays an important role in the results obtained. Using the stricter definition of HSR access, only considering airports with on-site stations, leads to less significant results which are most likely because only a few airports fall in this category. Both other definitions lead to comparable results, yet when using the broader definition of airports that have HSR access within their catchment area, the treatment effect is considerably smaller in size. This suggests that the effect of HSR entry on air traffic at the airport level depends on how well the airport is connected to the HSR network. When evaluating the effect of HSR on air traffic, it is therefore important to consider the connectivity between the airport and the HSR network. Again, the cross-elasticity between passenger-km and flights offered is relatively consistent over all three specifications, indicating that the obtained result is robust to the various HSR dummy definitions.

5. Discussion

This section focuses on the interpretation of the estimated effects and their practical consequences. Furthermore, the limitations of this study will be elaborated and recommendations for future research will be formulated.

5.1 Interpretation of results

The analysis has focused on the effect of HSR on airport traffic both in terms of passengers and flights offered while controlling for several economic and demographic controls as well as airport and time-fixed effects. The impact on an airport of having convenient access to a HSR station has been captured by the coefficient of the D_HSR_2 dummy variable. When considering total passenger volume, the effect of HSR is equal to 0.065 and statistically significant at the 1% level. This means that passenger numbers at airports with convenient HSR access are (exp(0.065) -1) * 100 = 6.72% higher than at those without HSR access. This estimate is economically significant considering that the mean number of passengers observed in the sample was almost 1.9 million per month, indicating that HSR could lead to an increase in passengers of the magnitude of 127,000 per month. The estimate of the effect of HSR on the total number of flights is of a similar magnitude at 0.0583, translating into a 6% increase in flights for airports with HSR access. These findings suggest therefore that HSR has a complementary effect on European airports that is translated into both higher passenger numbers and more flights offered.

Having a closer look at the mix of passengers and flights, however, there seem to be two separate effects. The literature suggests that HSR can substitute flights, especially on shorter distances because on these, travel time savings can be achieved by HSR (Clewlow et al., 2014; Wardman et al., 2018). To analyse this effect, domestic flights and passengers have been used in the analysis as a proxy for short distances, while extra-EU flights and passengers have been used as a proxy for long distances. International and intra-EU flights have also been included in the analysis but delivered mostly insignificant results, which is likely since this measure includes short- as well as long-distance flights.

The effect of HSR on domestic airport traffic is negative with 63.59% fewer passengers and 29.71% fewer flights offered. While both estimates suggest a strong substitution effect between HSR and domestic flights, it is notable that the effect on passengers is more than double that on flights in size. This suggests that passenger numbers on domestic flights decrease much more strongly than the number of flights offered, which is indicative of airlines' strategic reactions to the entry of HSR at an airport. As suggested by previous studies, such as Albalate et al. (2015) and D'Alfonso et al. (2015), this could indicate that airlines are trying to maintain flight frequencies relatively high to remain competitive on these shorter distances but are using smaller planes to respond to the decreasing passenger demand. On the other hand, the effect on extra-EU airport traffic is more mixed, with an estimated 8.77% increase in passengers and a 14.88% decrease in flights offered, both statistically significant at the 5% level. The increase in extra-EU passengers is stronger than the increase in overall passengers, indicating that HSR has a stronger complementary effect on long-distance travel demand. However, the decrease in extra-EU flights is notable, which could indicate that airlines are increasingly making use of larger aircraft to meet the growing long-distance demand to carry more passengers per flight.

From this discussion, it can therefore be concluded that HSR seems to act as a substitute on domestic and possibly also short-distance flights and as a complement on longer-distance flights, especially in terms of passenger demand. This interpretation follows the findings of previous studies that have suggested that HSR is very well able to compete with air transportation on distances of up to 600 km, but that the increased connectivity of the airport can also lead to an increase in long-distance travel demand as more passengers can reach the airport and use its international network.

Another interesting point is the estimate of the cross-elasticity of air traffic with regards to HSR passenger-km travelled. The estimates of this cross-elasticity are between -0.0399 and -0.0458 for passengers carried and -0.0357 and -0.0391 for flights offered, all statistically significant at the 1% level. These estimates thus suggest a negative cross-elasticity, meaning that an increase of passenger-km travelled by HSR of 1% leads to a decrease in air traffic of around 0.03% to 0.05%. Contrary to the earlier reported complementary effect, this suggests that the substitution effect dominates the complementarity between the two modes. It is important to note, however, that the data on passenger-km travelled used is a national total and does not indicate passenger-km travelled from or to the airports in question. Therefore, it is difficult to draw clear conclusions from this estimate as more detailed data concerning the HSR passenger volume originating and ending at the airport city would be required. It does, however, indicate that the more passengers travel by HSR in a country the less they fly from the national airports, indicating that it is not merely being connected to the HSR network that affects airport traffic, but also the quality of the network is important.

The estimated effect of oil prices on airport passenger volume of 0.037 is significant at the 1% level and indicates a positive price elasticity if oil prices are used as a proxy for airfares. However, this seems implausible and does not match the negative price elasticities in the air transportation market that have been found in previous studies that are ranging between -0.11 and -5.77 (Behrens and Pels, 2012; Börjesson, 2014; Brons et al., 2002; Clewlow et al., 2014). This difference can also be caused by the fact that oil prices might not be a very good proxy for airfares in this setting and that other factors than only fuel prices are more determining of airfares and therefore the effect might not have been captured properly in the current analysis.

Finally, in the sensitivity analysis, two alternative definitions of the HSR dummy variable have been applied to compare the results. The strictest definition of having HSR access is that it requires airports to have an on-site train station that allows for direct switching between train and aeroplane. The results suggest that having such an on-site station leads to a negative effect on passenger volume, significant at the 1% level, while no significant effect could be found on flights offered. This would suggest that having an on-site HSR station allows for better substitution between flights and trains and would thus lead to an overall decrease in air transport demand, possibly due to passengers replacing their feeder flights to larger hub airports with train journeys. However, due to only 5 airports having such access, the treatment group, in this case, is small and the results might not be reliable and applicable to other airports.

Using a broader definition of HSR access, -that of having access to HSR within the airport's catchment area-, has led to different results on the effect of HSR on airport traffic. In this case, HSR is estimated to lead to a 3.5% increase in passengers, significant at the 1% level, and a 1.37% increase in flights, significant at the 5% level. This suggests that the complementary effect between HSR and air traffic that has been found earlier might decrease as it gets more difficult to access the airport from the HSR station. When the connection between the HSR station and the airport takes too much time, it is unlikely that passengers would see HSR as a feeder service to the airport to then continue with a long-distance flight.

Overall, the results suggest that if airports are relatively well connected to the HSR network, an increase in total passenger volume and flights offered can be observed. This increase especially stems from long-distance international flights and passengers, while a decrease in domestic air traffic is to be expected. Having an on-site HSR station could make the substitution between air and rail so easy that even an overall decrease in air traffic could be observed, while longer commuting times between HSR stations and airports could lead to a much more limited effect on airport traffic.

5.2 Limitations

This thesis made use of a FE estimator to estimate the impact of HSR on air traffic at European airports, using passenger and flight data obtained from the Eurostat Transport database and a dummy variable indicating the presence of HSR at specific airports.

One limitation of this approach is the way that the dummy indicator D_{it}^{HSR} has been defined. While three different definitions have been used in the sensitivity analysis to compare the results of these different approaches, these were all based on how well the HSR network was accessible from the airport. However, another factor seems to be important when estimating the impact of HSR on air traffic, namely the quantity and quality of the routes served from the airport by HSR. Likely, an airport that is connected through HSR to many different major cities in a fast and regular manner experiences different effects from this connection than an airport that is connected only to one other city by HSR. The measure used in this study does not consider these qualitative differences in HSR access. Therefore, an adjustment to the current study that could be made would be the development of a measure capturing the number and frequency of connections that are available by HSR from a specific airport, rather than just measuring whether or not the airport had HSR access at all.

Another limitation related to the data used in this study is the analysis of the different effects of HSR on short- versus long-distance flights. The available data in the Eurostat database allows for a distinction between domestic, international, intra- and extra-EU flights. Domestic flights are flights from an airport to another airport located in the same country, and intra-EU flights are defined as flights from an airport in the sample to a destination within the EU, the UK, Norway and Switzerland. Generally, it can be assumed that domestic flights are relatively short in distance and therefore this has been used as a proxy for short-distance flights. Given the small size of many European countries and the short distances between major European cities, however, international flights are not a useful proxy for long-distance flights, nor are intra-EU flights as both contain short- as well as long-distance flights. Therefore, only extra-EU flights can act as a proxy for long-distance flights in this study, leaving a large part of the data in the dataset unused for this estimation and making the results less reliable and less applicable to intra-European long-distance flights. An improvement to the current set-up would be therefore to obtain more detailed flight and passenger data for the selected airports and to divide air traffic more accurately into distance groups that allow to analyse the separate effects on short-, medium- and long-distance flights more accurately.

Further, the analysis in this study relies on the parallel trend assumption, meaning that both the control and the treatment groups are assumed to follow the same trend before treatment. However, is very much possible that this is not the case and that other underlying reasons explain differences in passenger and flight volume, other than the HSR access and the included control variables. A possible improvement could be the use of propensity score matching to ensure that airports from both groups are comparable to each other, even if there are still differences among them. Using this method, only airports in each group that can be matched with an airport from the other group will be included in the analysis.

In previous studies, authors have concluded that leisure and business travellers have different cross-elasticities with regards to price and time and that they hence react differently when facing the introduction of HSR on a route they would have flown (Behrens and Pels, 2012; Börjesson, 2014; Wardman et al., 2018). Especially with regards to travel time, business travellers seem to be more responsive and therefore the effect of HSR on airport traffic could be different for these two distinct groups of travellers. The current study has not been able to address this hypothesis due to detailed passenger segment data not being available from Eurostat.

5.3 Recommendations for future research

Based on the findings and limitations of the current study, some recommendations for future studies can be formulated.

First, a possible extension would be a study on whether having a HSR connection strengthens the position of a major hub airport relative to other regional airports in the region and what role capacity restrictions play in this setting. Likely, the impact of HSR at airports with and without capacity restrictions is different, especially in terms of the flights offered. Therefore, it would be useful to extend the current study to include an indicator for airports with and without capacity restrictions to analyse whether the effects of HSR on passenger and flight volumes indeed vary from each other.

Another factor that has not been considered in the current study is the type of airport and the size of the airport that is being considered. The interpretation of the findings is that passengers tend to replace their short-haul flights with HSR if possible or make use of HSR to access airports with larger international networks for their long-haul flights. For major international airports, the consequence is that there is likely to be a decline in domestic and short-haul air traffic, while the international and long-haul volume is more likely to increase, overall, possibly leading to an increase in total passenger numbers. For smaller regional airports, however, this theory is much less likely to hold. Such airports often only have a limited number of international connections and mostly offer air routes to larger hub airports, the routes that are most likely to be substituted by HSR. Therefore, another possible consequence of HSR developments is that the position of major airports is strengthened, while regional airports are likely to see a decline in overall activity.

Further, the current study finds varying results when passenger volume or flights offered are used as dependent variables, which suggests that as a response to HSR entry at the airport, airlines adapt their strategies. They tend to use smaller aeroplanes on short routes to maintain frequencies when facing a decrease in passenger demand, while the opposite is observed on long-haul routes, where the number of flights is reduced while the number of passengers carried increases. To further investigate this, it would be useful to analyse whether a change in aeroplanes used at airports can be observed. Such a study would focus on longer-term reactions from airlines and would enable researchers to get a better picture of the environmental effects of HSR on air traffic, given the differences in per passenger emissions of various classes of aircraft.

6. Conclusion

This study aimed to examine how traffic at European airports is influenced by the development of new high-speed rail lines that are connecting major cities. It contributes to the existing body of literature that examines inter-modal competition and cooperation between air travel and rail, with a focus on the environmental effects of new HSR developments. The study of these effects is important in the context of the new European Green Deal that aims to reduce European flight operations and reduce CO2 emissions by investing more heavily in new HSR developments throughout the continent. The research question of the thesis was: What is the effect of HSR on air traffic at European airports? Further, the aim was to identify whether the effect of HSR differs depending on the type of access airports have to the HSR network and on the type of flight operations considered, i.e., short- versus long-haul operations. First, existing literature findings were examined to determine what factors are generally considered to predict air traffic volume in terms of demand and supply, as well as what the substitution patterns were that have been discovered in the past between air and HSR. Then, a panel dataset was created using mostly statistics from the Eurostat database for a selection of 30 European airports.

Controlling for time and airport fixed effects suggests that the entry of HSR has indeed impacted air traffic volume at European airports and that different effects exist depending on the type of operation considered. The results are both highly statistically and economically significant with HSR leading to an estimated 6.72% increase in passenger demand and a 6.00% increase in air traffic supply. Furthermore, the results indicate that HSR leads to a reduction in short-haul air traffic demand and supply, but an increase in long-haul and total air traffic demand. The results show that demand is impacted much more strongly than supply in terms of flights, which reflects the strategic behaviour of airlines and the change in aircraft that are being used for various routes in response to a change in demand. Overall, the analysis suggests that HSR acts well as a substitute for short-haul feeder flights for larger hub airports but leads to an increase in demand for longer-distance air traffic. This is very likely the case because it increases the catchment area of major airports and makes it easier and cheaper for passengers to reach these airports and continue their long-haul journey by air. The analysis looking at different types of access, ranging from on-site stations to having HSR access in the same city as the airport has led to more mixed and less significant results, that do not provide a clear conclusion on whether on-site HSR stations lead to increased substitution of flights or increased demand for long-haul flights. The very limited number of airports with such access unfortunately does not allow for reliable analysis.

The findings of this thesis contribute to the existing literature on intermodal competition, which has until now mostly focused on the effect of HSR on air traffic at a route level rather than at the overall airport level. In the context of growing ambitions to reduce transport-related CO2 emissions, it is essential to analyse the effects of HSR not only on specific routes but on the overall level of air traffic departing and arriving at European airports. The results can therefore contribute to a better evaluation of new HSR developments when the goals are to reduce overall emissions and they raise the question of whether investing in new HSR infrastructure will be the way to achieve these goals, or whether additional forms of regulation are more effective.

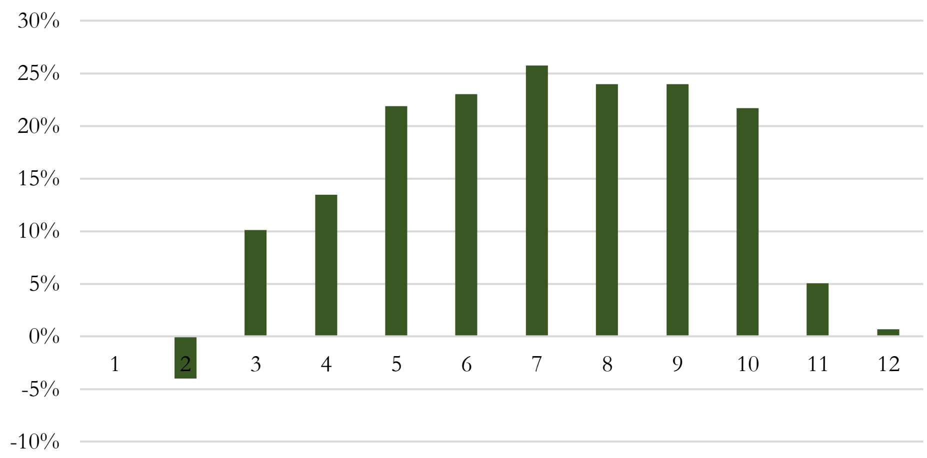
7. Appendices

Appendix 4.1

Table A4.1: Seasonal effects

	Total Flights		ln (Total Flights)	
	Coeff.	p-value	Coeff.	p-value
Month: base 1	0		0	
2	-632.459	0.286	-0.041	0.360
3	1374.092	0.029	0.096	0.033
4	1694.674	0.007	0.126	0.004
5	2943.078	0.000	0.198	0.000
6	2980.921	0.000	0.207	0.000
7	3447.512	0.000	0.229	0.000
8	3238.056	0.000	0.215	0.000
9	3154.471	0.000	0.215	0.000
10	2915.483	0.000	0.196	0.000
11	703.2	0.255	0.049	0.277
12	28.523	0.962	0.007	0.877

Figure A4.1: Seasonal changes in flights offered compared to January



Appendix 4.2

Table A4.2: OLS and RE Estimation results for passengers carried

ln (Total Passengers)	(1) OLS	(2) RE	(3) RE
Airport FE	no	yes	yes
Month FE	yes	yes	yes
Year FE	no	no	yes
ln (Crude Oil)	-0.0469*** (0.0177)	-0.0191*** (0.00496)	0.0370*** (0.0111)
ln (GDP per capita)	1.001*** (0.0138)	0.629*** (0.0330)	0.152*** (0.0336)
ln (Population)	0.327*** (0.0151)	0.461*** (0.0671)	-0.114* (0.0674)
ln (Population Density)	0.0589*** (0.00646)	0.273*** (0.0514)	0.00400 (0.0518)
ln (Tourist Arrivals)	0.379*** (0.0141)	0.504*** (0.0185)	0.201*** (0.0195)
ln (HSR PKM)	-0.0191*** (0.00175)	-0.0189*** (0.00419)	-0.0379*** (0.00403)
ln (HSR Network)	-0.0247*** (0.00129)	-0.00684*** (0.00209)	-0.0116*** (0.00193)
D_HSR	0.473*** (0.0186)	0.0664*** (0.0106)	0.0625*** (0.00962)
Constant	-7.715*** (0.267)	-9.177*** (0.833)	10.53*** (1.012)
Observations	5464	5464	5464
R-squared	0.6569	0.7631	0.8099

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A4.3: Hausman specification test

	Coeff.
Chi-square test value	83.63
P-value	0.0000

8. References

Abate, M., Christidis, P., 2020. The impact of air transport market liberalization: Evidence from EU's external aviation policy. Econ. Transp. 22, 100164. https://doi.org/10.1016/j.ecotra.2020.100164

Albalate, D., Bel, G., 2012. High-Speed Rail: Lessons for Policy Makers from Experiences Abroad. Public Adm. Rev. 72, 336–349. https://doi.org/10.1111/j.1540-6210.2011.02492.x

Albalate, D., Bel, G., Fageda, X., 2015. Competition and cooperation between high-speed rail and air transportation services in Europe. J. Transp. Geogr. 42, 166–174. https://doi.org/10.1016/j.jtrangeo.2014.07.003

Avenali, A., Bracaglia, V., D'Alfonso, T., Reverberi, P., 2018. Strategic formation and welfare effects of airline-high speed rail agreements. Transp. Res. Part B Methodol. 117, 393–411. https://doi.org/10.1016/j.trb.2018.09.002

Avogadro, N., Cattaneo, M., Paleari, S., Redondi, R., 2021. Replacing short-medium haul intra-European flights with high-speed rail: Impact on CO2 emissions and regional accessibility. Transp. Policy 114, 25–39. https://doi.org/10.1016/j.tranpol.2021.08.014

Banister, D., Givoni, M., 2013. High-Speed Rail in the EU27: Trends, Time, Accessibility and Principles. Built Environ. 1978- 39, 324–338.

Baron, T., Tuchschmid, M., Martinetti, G., Pépion, D., 2011. High Speed Rail and Sustainability. Background Report: Methodology and results of carbon footprint analysis. International Union of Railways (UIC), Paris.

Baum, C.F., 2013. Propensity Score Matching Regression Discontinuity Limited Dependent Variables.

Behrens, C., Pels, E., 2012. Intermodal competition in the London–Paris passenger market: High-Speed Rail and air transport. J. Urban Econ. 71, 278–288. https://doi.org/10.1016/j.jue.2011.12.005

Bell, A., Fairbrother, M., Jones, K., 2019. Fixed and random effects models: making an informed choice. Qual. Quant. 53, 1051–1074. https://doi.org/10.1007/s11135-018-0802-x

Börjesson, M., 2014. Forecasting demand for high speed rail. Transp. Res. Part Policy Pract. 70, 81–92. https://doi.org/10.1016/j.tra.2014.10.010

Brons, M., Pels, E., Nijkamp, P., Rietveld, P., 2002. Price elasticities of demand for passenger air travel: a meta-analysis. J. Air Transp. Manag. 8, 165–175. https://doi.org/10.1016/S0969-6997(01)00050-3

Castillo-Manzano, J.I., Pozo-Barajas, R., Trapero, J.R., 2015. Measuring the substitution effects between High Speed Rail and air transport in Spain. J. Transp. Geogr. 43, 59–65. https://doi.org/10.1016/j.jtrangeo.2015.01.008

Clewlow, R.R., Sussman, J.M., Balakrishnan, H., 2014. The impact of high-speed rail and low-cost carriers on European air passenger traffic. Transp. Policy 33, 136–143. https://doi.org/10.1016/j.tranpol.2014.01.015

Clewlow, R.R.L., Sussman, J.M., Balakrishnan, H., 2012. Interaction of High-Speed Rail and Aviation: Exploring Air–Rail Connectivity. Transp. Res. Rec. J. Transp. Res. Board 2266, 1–10. https://doi.org/10.3141/2266-01

D'Alfonso, T., Jiang, C., Bracaglia, V., 2016. Air transport and high-speed rail competition: Environmental implications and mitigation strategies. Transp. Res. Part Policy Pract. 92, 261–276. https://doi.org/10.1016/j.tra.2016.06.009

D'Alfonso, T., Jiang, C., Bracaglia, V., 2015. Would competition between air transport and high-speed rail benefit environment and social welfare? Transp. Res. Part B Methodol. 74, 118–137. https://doi.org/10.1016/j.trb.2015.01.007

Directorate-General for Mobility and Transport, 2017. EU Aviation: 25 years of reaching new heights [WWW Document]. URL https://transport.ec.europa.eu/transport-modes/air/eu-aviation-25-years-reaching-new-heights-0_en (accessed 5.11.22).

Dobruszkes, F., 2011. High-speed rail and air transport competition in Western Europe: A supply-oriented perspective. Transp. Policy S0967070X11000837. https://doi.org/10.1016/j.tranpol.2011.06.002

EIA, 2022. U.S. Gulf Coast Kerosene-Type Jet Fuel Spot Price FOB (Dollars per Gallon) [WWW Document]. URL https://www.eia.gov/dnav/pet/hist/eer_epjk_pf4_rgc_dpgD.htm (accessed 5.11.22).

Euromonitor, 2022. Statistics Redesign | Passport [WWW Document]. URL https://www-portal-euromonitor-com.vu-nl.idm.oclc.org/portal/statisticsevolution/index (accessed 5.11.22).

European Commission. Directorate General for Communication., 2020. The transport and mobility sector. Publications Office, LU.

European Commission. Directorate General for Mobility and Transport., 2021. EU transport in figures: statistical pocketbook 2021. Publications Office, LU.

European Commission. Directorate General for Mobility and Transport., EGIS., SEO., 2021. Study on the economic developments of the EU air transport market: final report. Publications Office, LU.

European Court of Auditors., 2018. A European high-speed rail network: not a reality but an ineffective patchwork. Special report No 19, 2018. Publications Office, LU.

European Parliamant, 2022. Carriage details | Legislative Train Schedule [WWW Document]. Eur. Parliam. URL https://www.europarl.europa.eu/legislative-train/theme-a-europe-fit-for-the-digital-age/file-allocation-of-slots-at-eu-airports-common-rules-recast (accessed 5.11.22).

Eurostat, 2022a. Statistics | Eurostat [WWW Document]. URL https://ec.europa.eu/eurostat/databrowser/view/AVIA_PAOA__custom_2818602/default/table?lang=en (accessed 5.30.22).

Eurostat, 2022b. Database - Transport - Eurostat [WWW Document]. URL https://ec.europa.eu/eurostat/web/transport/data/database (accessed 5.9.22).

Eurostat, 2022c. Statistics | Eurostat | Regional Economic Accounts [WWW Document]. URL https://ec.europa.eu/eurostat/databrowser/view/NAMA_10R_2GDP/default/table?lang=en&category=reg.reg_eco10.reg_eco10gdp (accessed 6.24.22).

Eurostat, 2022d. Statistics | Eurostat | Regioanl demoghrachic accounts [WWW Document]. URL https://ec.europa.eu/eurostat/databrowser/view/DEMO_R_D2JAN/default/table?lang=en&category=reg.reg_dem.reg_dempoar (accessed 6.24.22).

Eurostat, 2022e. Statistics | Eurostat | Regional Tourism Statistics [WWW Document]. URL https://ec.europa.eu/eurostat/databrowser/view/TOUR_OCC_ARN2/default/table?lang=en&category=reg.reg_tour.reg_tour_occ (accessed 6.24.22).

Givoni, M., Dobruszkes, F., 2013. A Review of Ex-Post Evidence for Mode Substitution and Induced Demand Following the Introduction of High-Speed Rail. Transp. Rev. 33, 720–742. https://doi.org/10.1080/01441647.2013.853707

Graver, B., 2013. CO2 emissions from commercial aviation: 2013, 2018, and 2019 36.

IAA, 2017. EU Aviation: 25 years of reaching new heights|Dublin Airport: Intra-EU routes from 36 in 1992 to 127 in 2016 [WWW Document]. URL https://www.iaa.ie/news/2017/06/29/eu-aviation-25-years-of-reaching-new-heights---dublin-airport-intra-eu-routes-from-36-in-1992-to-127-in-2016 (accessed 5.11.22).

KSH, 2022a. 27.1.1.18. Tourist arrivals and tourism nights at commercial accommodation establishments by domestic and international [WWW Document]. URL https://www.ksh.hu/stadat_files/tur/en/tur0017.html (accessed 5.11.22).

KSH, 2022b. 27.1.1.22. Tourist arrivals and tourism nights at commercial accommodation establishments by tourism region [WWW Document]. URL https://www.ksh.hu/stadat_files/tur/en/tur0021.html (accessed 5.11.22).

Liu, S., Wan, Y., Ha, H.-K., Yoshida, Y., Zhang, A., 2019. Impact of high-speed rail network development on airport traffic and traffic distribution: Evidence from China and Japan. Transp. Res. Part Policy Pract. 127, 115–135. https://doi.org/10.1016/j.tra.2019.07.015

OECD, 2022. Energy - Crude oil import prices - OECD Data [WWW Document]. theOECD. URL http://data.oecd.org/energy/crude-oil-import-prices.htm (accessed 5.11.22).

Pagand, I., Carr, C., Doppelbauer, J., 2020. Fostering Rail Through Green Deal. European Union - Agency for Railways.

Socorro, M.P., Viecens, M.F., 2013. The effects of airline and high speed train integration. Transp. Res. Part Policy Pract. 49, 160–177. https://doi.org/10.1016/j.tra.2013.01.014

Terpstra, I., Lijesen, M.G., 2015. The impact of high speed rail on airport competition. Tijdschr. Voor Econ. En Soc. Geogr. 106, 263–275. https://doi.org/10.1111/tesg.12103

UIC, 2022. High-Speed Rail History [WWW Document]. UIC - Int. Union Railw. URL https://uic.org/passenger/highspeed/article/high-speed-rail-history (accessed 5.11.22).

Wan, Y., Ha, H.-K., Yoshida, Y., Zhang, A., 2016. Airlines' reaction to high-speed rail entries: Empirical study of the Northeast Asian market. Transp. Res. Part Policy Pract. 94, 532–557. https://doi.org/10.1016/j.tra.2016.10.014

Wardman, M., Toner, J., Fearnley, N., Flügel, S., Killi, M., 2018. Review and meta-analysis of inter-modal cross-elasticity evidence. Transp. Res. Part Policy Pract. 118, 662–681. https://doi.org/10.1016/j.tra.2018.10.002

Zhang, A., 2019. Impacts of high-speed rail on airlines, airports and regional economies_ A survey of recent research. Transp. Policy 19.

Zhang, F., Graham, D.J., Wong, M.S.C., 2018. Quantifying the substitutability and complementarity between high-speed rail and air transport. Transp. Res. Part Policy Pract. 118, 191–215. https://doi.org/10.1016/j.tra.2018.08.004