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Transportation Research Procedia 86 (2025) 345–352

Transportation Research Procedia

www.elsevier.com/locate/procedia

26th Euro Working Group on Transportation Meeting (EWGT 2024)

The Impact of Reduced Railway Travel Time on Air Passenger Numbers: A Synthetic Control Group Approach

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Abstract

This paper studies the modal shift from air to rail transport using a synthetic control method. In 2017, the opening of a new high-speed rail line reduced travel time from six to four hours between Berlin and Munich. According to theoretical priors, travel time is a key factor in choosing a mode of transportation. Therefore, the reduction in rail travel time should encourage some passengers to switch from air to rail. The results indicate that the new high-speed rail line does not significantly affect the total number of air passengers between Berlin and Munich. However, the proportion of passengers using Low-Cost Carriers increased significantly.

Keywords: Modal shift; air transport; high speed rail; synthetic control

1. Introduction

In recent studies, it has been estimated that global air transportation contributes to approximately 3.5% of human-caused climate warming (Lee et al., 2021). Despite this relatively small percentage, air transport has emerged as one of the most rapidly increasing sources of greenhouse gas emissions (Pörtner et al., 2022). Without significant intervention, international air transport emissions are projected to triple by 2050 compared to levels in 2018, as reported by the International Civil Aviation Organization (ICAO, 2022).

For short- and medium-distance trips under 800 km high-speed rail (HSR) travel it is considered a viable alternative to both road and air travel (Givoni and Dobruszkes, 2013). According to research by (Dalla Chiara et al., 2017), high-speed trains consume less energy per seat-kilometer compared to aircraft, resulting in less carbon emissions and less climate warming. Modal shift from air travel to HSR can be influenced by various factors, including the frequency of daily departures, travel convenience, and ticket fares (Behrens and Pels, 2012; Kroes and Savelberg, 2019). However,

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10.1016/j.trpro.2025.04.044

several studies have highlighted the significance of travel duration as primary determinant (Zhang et al., 2019; Reiter et al., 2022). Therefore, reducing rail travel times should result in a shift from air to rail transport, thereby decreasing the climate impact of transportation.

In 2017, a new HSR line reduced travel time from six to four hours between Munich and Berlin at a cost of around 8.326 billion Euros. According to theoretical priors, this significant reduction in rail travel time could encourage some passengers to switch from air to rail transport. On the other hand, Burkhard Kieker, Managing Director of Visit Berlin pointed out in 2019: "Since the opening of the ICE high-speed line, we have had significantly more Bavarian tourists in the city. The ICE connection is therefore primarily a supplement to the existing air traffic, which generates more demand overall."[1]. Most notably, some empirical findings support this statement. For example, a significant positive impact of HSR on flight frequency has been observed on certain European routes (Bilotkach et al., 2010). Additionally, positive effects on airline seat capacity have been found on spoke-to-spoke routes in France, Spain, and Italy (Albalate et al., 2015). Wan et al. (2016) and Zhang et al. (2018) identified an increase in air passenger numbers due to the introduction of HSR on certain routes in China. This can occur if the shift from air to rail is mitigated by a decrease in airfares due to increased competition, and if the enhanced train service attracts new customers who would not have traveled previously. In specific cases, there may therefore be no shift from air to rail. This renders a case study highly valuable.

This paper studies the modal shift from air to rail transport after a significant reduction in rail travel time between Berlin and Munich, using a synthetic control group method. Synthetic control groups are particularly suitable for for comparative case studies (Abadie et al., 2010). The relevance of this case study on modal shift arises from the significant investments costs of this infrastructure project. My analysis focuses on comparing air passenger numbers on the Munich-Berlin city-pair before and after the new HSR line opening. Additionally, I will explore heterogeneity in the effects across Low Cost Carrier (LCC) and other carrier. Analyzing LCC is motivated by findings of Behrens and Pels (2012), showing that rail and LCC are particularly substitutable. This study utilizes the unique Sabre Market Intelligence dataset (Sabre-MI), which includes worldwide airline bookings on a monthly basis. Sabre is the primary provider of the global airline ticket distribution system utilized by airlines for sales processing. The panel structure of the dataset with monthly passenger numbers and average airfares allows the use of the synthetic control group method.

The findings of this paper suggest that the reduction in rail travel time between Berlin and Munich, has no impact on the overall air passenger numbers. However, the passenger numbers of LCC significantly increase by more than 128%, thereby increasing the share of LCC on overall passengers. The decline in the comparative advantage of air travel regarding travel time could be equalized by a reduction in airfares realized through the use of LCC.

The corresponding literature shows heterogeneity in the effect of HSR on air transport (Bilotkach et al., 2010; Albalate et al., 2015; Zhang et al., 2019). My paper contributes to this literature by providing the first causal empirical evidence on the specific impact of reduced rail travel time between Berlin and Munich on air passenger numbers, utilizing the synthetic control group method. The synthetic control group method allows for the identification of individual cases that deviate from the general trend, offering a more precise understanding of the causal relationship between high-speed rail and air transport demand. The findings of this study contribute to the understanding of how transportation infrastructure investments influence modal choice. By quantifying the magnitude of the effect and highlighting the trade-offs associated with transportation infrastructure investments, my study adds to the understanding of how policymakers can optimize transportation networks and promote sustainable travel options. For instance, when HSR investments are aimed at achieving significant emissions reductions, a thorough analysis is necessary to assess whether a cost of carbon calculation supports cost-effective emissions reduction. However, even if such cost-effectiveness is not realized, a new HSR route may still prove economically viable due to its broader regional economic importance.

[1] https://www.airliners.de/muc-ber-sehr-zuege-eurowings-fluege-analyse/50615

2. Data and background information about the Berlin-Munich HSR

2.1. Berlin-Munich HSR

The Berlin-Munich HSR line is part of the program ”Verkehrsprojekte Deutsche Einheit (VDE)”, with a total volume of over 45 billion euros, launched in 1991 to accelerate the integration of the eastern and western German federal states. Decades of division of the German Federal Republic and the German Democratic Republic had left considerable gaps in the transport infrastructure.

As part of the VDE, in December 2017 the HSR line Nuremberg - Ebensfeld - Erfurt (VDE No. 8.1) was put in operation. VDE No. 8.1 has as total value of 8.326 billion euros (Sachstandsbericht Verkehrsprojekte Deutsche Einheit (VDE) Stand Juli 2023)

The VDE 8.1 has a significant impact on travel time for the Berlin-Munich connection. With the timetable changes on December 10, the train is up to 2 hours faster than before (6 hours). Three times a day and in each direction, the trains travel the route from Berlin to Munich in 3 hours 55 minutes and every hour in around 4.5 hours (Pressemitteilung: Änderungen im Fernverkehrsfahrplan 2018). This result in an average daily HSR travel time of 4:22[2] hours. According to empirical data, a travel time of over 4 hours might be on the longer side for effectively competing with airlines (Kroes and Savelberg, 2019). The conditions of carriage of the only HSR provider in Germany, Deutsche Bahn, are uniform throughout Germany and do not allow, for example, any specific price competition on individual routes (Nr. 600 des Tarifverzeichnisses Personenverkehr (TfV 600)).

2.2. Data

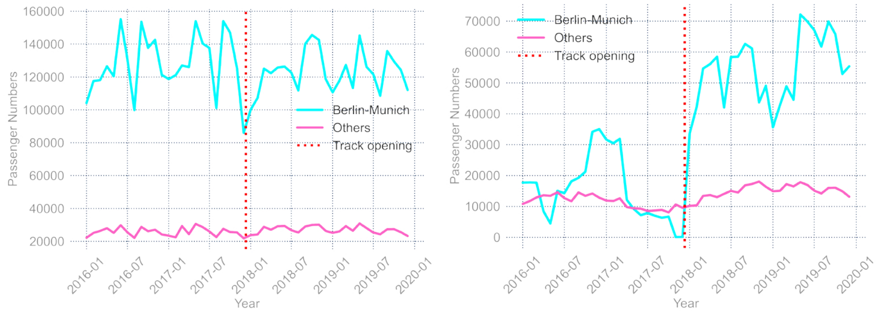
This paper uses panel data from Sabre Market Intelligence to study the impact of the reduced rail travel time on air passenger numbers. The dataset includes verified raw bookings collected from leading global distribution systems such as Sabre, Travelport, and Amadeus, and is compiled monthly. These systems serve as links between travel agents and airlines. The data comprises monthly aggregated connections within the air travel network, which may involve multiple flights, including connections between different airlines. For the analysis, I aggregate this data on a monthly city-pair level and generate a sub-sample for LCC whereas the main sample consists of all carrier. A city-pair consists of origin-destination passengers flying in both direction, e.g. from Berlin to Munich and from Munich to Berlin. I focus on the monthly number of air passengers and the average airfare at city-pair level between 2016 and December 2019 of German domestic flight. I truncate the dataset to city-pairs with more than 20,000 passengers per year to reduce idiosyncratic variation, resulting in 53 city-pairs. Figure 1a shows the development of passenger numbers of the full (Figure 1a) and LCC (Figure 1b) sample for the Berlin-Munich city-pair and the other German domestic city-pairs. According to Figure 1a, the Berlin-Munich city-pair is a major connection in Germany with more than 100,000 air passengers per month. The average passenger number of other domestic city-pairs in Germany is around 25,000 per month. In both cases, the development is rather constant over time, despite some seasonal fluctuation. As Figure 1b shows, there is a strong increase in LCC passenger numbers on the Berlin-Munich city-pair after the opening of the new HSR line, while there is only a small increase on other city-pairs. To evaluate the impact of the reduction in rail travel time, the central question is how passenger numbers would have evolved for the Berlin-Mich city-pair after December 2017 in the absence of the HSR. The synthetic control method provides a systematic way to estimate this counter-factual.

3. The Synthetic Control Method

This paper uses the synthetic control method, formalized by Abadie et al. (2010)), to estimate the effect of reduced rail travel time on air passenger numbers between Berlin and Munich. The synthetic control method is a statistical technique employed to assess the impact of an intervention in comparative case studies.

Using the synthetic control methodology, I analyse air passenger numbers for the Berlin-Munich city-pair alongside multiple untreated domestic city-pairs in Germany for comparison. A weighted selection of the untreated city-pairs

[2] (3*3,9+12*4,5=4:22)



(a) Full sample (b) LCC sample

Fig. 1: Passenger numbers over time

Notes: This figure illustrates the development of air passenger numbers over time for the Berlin-Munich city-pair and all other city-pairs within Germany, separated by full and LCC sample.

serves as a counterfactual estimate for the Berlin-Munich city-pair, termed as a synthetic control group. Weights are selected to minimize disparities in air passenger numbers between the synthetic control group and the Berlin-Munich city-pair before the HSR track opening. I estimate the weights using Lasso regression with cross-validation. I regress monthly passenger numbers of the Berlin-Munich city-pair on monthly passenger numbers and average airfares of all other German domestic city pairs, excluding connections originating or terminating in Berlin or Munich to address potential spillover effects.

By excluding city-pairs with less than 20,000 passengers per year, I only use city-pairs that resemble the treatment site, with outcomes influenced by the same structural process. This restriction reduces the risk of overfitting and potential bias from interpolation. Finally, treatment effect estimates are computed as the disparity between observed outcomes for the Berlin-Munich city-pair and its synthetic counterfactual after the new HSR line opening (Abadie et al., 2010).

Some studies imposes restrictions on the weights of the syntatic control group, ensuring they are non-negative and sum up to one. These constraints keep the synthetic control group within the range of other observations in the dataset, thereby preventing extrapolation, which can be advantageous. However, allowing negatively correlated city-pairs can aid in identifying underlying data generating processes, such as shift effects in the air transport network. Thus, I allow for negative weights.

One advantage of the synthetic control method compared to approaches like difference-in-differences is its ability to manage unobserved time-varying factors by generating a control group that closely resembles the treatment group in terms of characteristics correlated with the outcome's dynamics. The synthetic control method also reduces the potential subjectivity of choosing a single comparison site. Given the heterogeneity of German airports, the synthetic control group is particularly suitable for this paper. If the synthetic control is valid, it accounts for all time-constant and time-varying confounders. However, two primary exclusion restrictions need to be fulfilled. First, the intervention should not influence the outcome during the pre-treatment period due to anticipatory effects. Second, the intervention should not impact the outcomes of the control sites due to spillover effects. It might be possible that airlines adjust their flight schedules in anticipation of the HSR opening. However, as delays in the construction of such infrastructure projects are not uncommon and flight schedules are planned well in advance, this scenario rather unlikely. Furthermore, domestic flight in Germany are point-to-point connections, due to the relative small size of the country. Thus, spillover effects are rather unlikely. Similar to Abadie et al. (2010), I use placebo tests to assess the "statistical significance" of the estimated effect instead of regression-based inference.

4. Results

Figure 2 displays passenger numbers for the Berlin-Munich city-pair and its synthetic counterpart during the period 2016-2019 for the full sample (Figure 2a) and the LCC sample (Figure 2c). Passenger numbers in the synthetic Berlin-Munich control reproduce extremely well the trajectory of passenger numbers of the Berlin-Munich city-pair for the

(a) Full sample: Deviation

(b) Full sample: Effect size

(c) LCC sample: Deviation

(d) LCC sample: Effect size

Fig. 2: Effect size

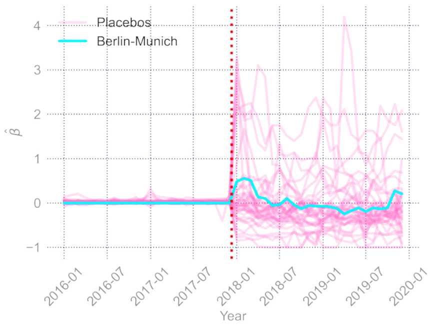
Notes: This figure illustrates the development of passenger numbers over time of the Berlin-Munich air transport connection and the corresponding syntactic control group. The red dotted line illustrates the track opening of the new Berlin-Munich HSR on 10.12.2017

entire period before the new HSR opening. This suggests that the synthetic Berlin-Munich control provides a sensible approximation to the passenger numbers that would have been traveled between Berlin and Munich between 2016 and 2019 in the absence of the new HSR line.

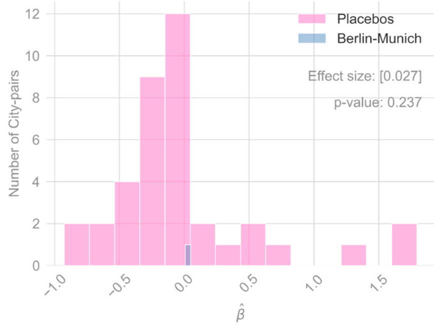
Table A.1 displays the weights of each control city-pair in the synthetic Berlin-Munich city-pair. The weights reported in Table A.1 indicate that passenger number trends of the Berlin-Munich city-pair prior to the HSR track-opening are reproduced by a heterogeneous combination of city pairs. The most important are Berlin-Cologne, Karlsruhe-Hamburg, Nuremberg-Dusseldorf, Nuremberg-Hamburg, Stuttgart-Berlin, Stuttgart-Dresden and Stuttgart-Dusseldorf.

The estimated effect of the HSR line opening between Munich and Berlin on air passenger numbers is the difference between air passenger numbers on the Berlin-Munich city-pair (Figure 2, turquoise line) and on its synthetic version after the opening of the new HSR line (Figure 2, pink line). Immediately after the HSR opening, the two lines began to diverge noticeably. While passenger numbers increase in case of LCC, overall passenger numbers increase at the beginning but then decline. Panel b and d of 2 plot the perceptual gaps in passenger numbers of the Berlin-Munich city pair and its synthetic counterpart. The average estimated effect for overall passenger numbers is 2.7%. In cased of LCC, air passenger numbers between 2018 and 2019 increased on average by almost 29,000 passengers or 128%. Due to the constant overall air passenger numbers, the share of LCC passenger numbers increased. Considering that ticket fares play a crucial role in determining transport mode preferences, it is reasonable to speculate that the decrease in rail travel time might be offset by a corresponding reduction in airfares facilitated by LCC. On the other hand, it was not possible for the HSR provider to offer connection specific discounts.

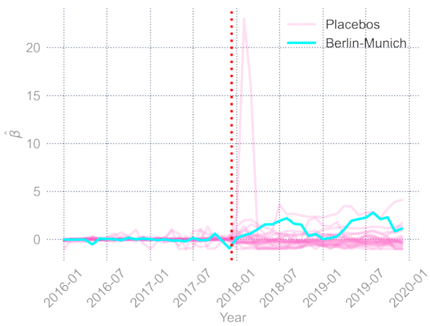
To assess the statistical significance of the estimates, I analyze whether they could be entirely due to chance. Specifically, I consider how frequently similar results would occur if a different city-pair were chosen for the study instead of Berlin-Munich. To address this, I employ placebo tests.



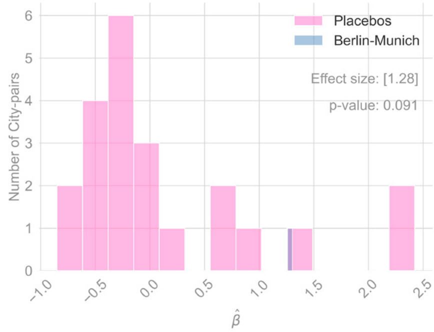
(a) Full sample: Placebo tests



(b) Full sample: Effect size and significance



(c) LCC sample: Placebo tests



(d) LCC sample: Effect size and significance

Fig. 3: Inference

Notes: This figure illustrates the significance of the effect size using placebo test. The red dotted line illustrates the track opening of the new Berlin-Munich HSR on 10.12.2017

Similar to Abadie et al. (2010), I conduct placebo studies by applying the synthetic control method to city-pairs that did not open a HSR line during the study period. If these placebo studies produce effect sizes of similar magnitude to the one estimated for Berlin-Munich, I interpret this as a lack of significant evidence for an effect of the HSR line opening on passenger numbers between Berlin and Munich. Conversely, if the placebo studies reveal that the effect size estimated for Berlin-Munich is unusually large compared to those for other city-pairs without an HSR line opening, I interpret this as evidence of a significant effect.

To assess the significance of my estimates, I iteratively apply the synthetic control method used for estimating the effect of the Berlin-Munich HSR line opening to each city-pair in the estimation sample. In each iteration, I reassign the date of the HSR track opening to one of the 52 control city-pairs and then compute the estimated effect for each placebo run. This iterative process yields a distribution of estimated effect sizes for the city-pairs where no intervention occurred.

Figure 3 displays the results for the placebo tests. The pink lines show the difference in passenger numbers between each city-pair in the estimation sample and its respective synthetic version for the full sample (Figure 3a) and the LCC sample (Figure 3c). The blue line denotes the effect size estimated for the Berlin-Munich city-pair. As this figure makes apparent, the estimated effect size in case of overall passengers of the Berlin-Munich city-pair is small relative to the distribution of the placebo effects for the other city-pairs in the estimation sample. However, in case of LCC the increase in passenger numbers is relatively large, compared to the placebo estimates. The distribution of the average effect size is plotted in Figure 3b for overall passengers and in Figure 3d for LCC passengers. In case of overall passengers, estimated effects are not significant. However, the number of LCC passengers increases significantly with a p-value of 0.091.

5. Conclusion

This paper studies the modal shift from air to rail transport using a synthetic control method. In 2017 a new high-speed rail line reduced travel time from six to four hours between Berlin and Munich. My analysis focuses on comparing air passenger numbers on the Munich-Berlin city-pair before and after the reduction in travel time. Additionally, I explore heterogeneity in the effects on passenger numbers across LCC and other carrier.

The findings of this paper suggest that the reduction in rail travel time between Berlin and Munich has no impact on the overall air passenger numbers. It must be taken into account, that a travel time of over 4 hours might be on the longer side for effectively competing with airlines. However, the passenger numbers of LCC significantly increased by more than 128%, thereby increasing the share LCC passengers. The decline in the relative advantage of air travel time may have been compensated for by a decrease in airfares facilitated by the utilization of LCC. On the other hand, it was not possible for the HSR provider to offer connection specific discounts.

For policy makers, this finding has important implications given the significant costs of rail infrastructure investments. While most of the literature shows that a reduction in rail travel time induces mode shifts from air to rail, the case study of this paper shows that it can differ in specific cases. Future research should focus on identifying the unique factors of the Berlin-Munich city-pair that prevent a substantial decrease in train travel time from prompting a shift in transportation modes.

Appendix A. Appendix

Weight	City-pair	Weight	City-pair
-0.030067	BERLIN-FRIEDRICHSHAFEN	0.112977	DRESDEN-HAMBURG
0.000000	BERLIN-KARLSRUHE/BADEN BADEN	-0.822115	DUSSELDORF-BERLIN
5.039901	COLOGNE-BERLIN	0.119424	DUSSELDORF-DRESDEN
0.355486	COLOGNE-DRESDEN	-0.583483	DUSSELDORF-HAMBURG
0.000000	COLOGNE-HAMBURG	-0.270984	DUSSELDORF-LEIPZIG/HALLE
1.007780	COLOGNE-LEIPZIG/HALLE	-0.000000	DUSSELDORF-MUNICH
0.000000	COLOGNE-MUNICH	0.008140	DUSSELDORF-NUREMBERG
0.334669	DRESDEN-DUSSELDORF	0.708164	DUSSELDORF-STUTTGART
0.548165	DUSSELDORF-WESTERLAND	0.023663	FRANKFURT-BERLIN
0.836149	FRANKFURT-BREMEN	-0.030251	FRANKFURT-DRESDEN
-1.483981	FRANKFURT-DUSSELDORF	0.135473	FRANKFURT-HAMBURG
-0.730209	FRANKFURT-HANOVER	0.000000	FRANKFURT-LEIPZIG/HALLE
0.733853	FRIEDRICHSHAFEN-HAMBURG	-0.000000	HAMBURG-DUSSELDORF
-2.107427	KARLSRUHE/BADEN BADEN-HAMBURG	1.363617	LEIPZIG/HALLE-DUSSELDORF
0.454725	LEIPZIG/HALLE-MUNICH	0.000000	MUENSTER-MUNICH
0.010504	MUNICH-BREMEN	-0.000000	MUNICH-DORTMUND
-0.000000	MUNICH-DRESDEN	1.391923	MUNICH-DUSSELDORF
0.302304	MUNICH-FRANKFURT	0.449475	MUNICH-HAMBURG
-0.275924	MUNICH-HANOVER	0.918234	MUNICH-PADERBORN
1.249147	MUNICH-WESTERLAND	0.000000	NIEDERRHEIN-MUNICH
0.258410	NUREMBERG-BERLIN	-1.997320	NUREMBERG-DUSSELDORF
-4.014839	NUREMBERG-HAMBURG	-0.738433	SAARBRUECKEN-BERLIN
-0.611918	SAARBRUECKEN-HAMBURG	-4.150700	STUTTGART-BERLIN
-0.181427	STUTTGART-BREMEN	4.841561	STUTTGART-DRESDEN
-2.632513	STUTTGART-DUSSELDORF	-0.000000	STUTTGART-HAMBURG
0.152825	STUTTGART-HANOVER	0.572230	STUTTGART-LEIPZIG/HALLE

Table A.1: Weights of synthetic control group

Notes: This table shows the weights of the synthetic control group

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