Universitat de Barcelona

Msc in Economics - Final Thesis

# Analysis of the inter-modal competition between high-speed rail and motorway: the Galician case

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# Abstract

High speed rail (HSR) had its beginning back in the sixties, its demand has been growing since nowadays and the capacity that has to attract new users from other means of transport plays a key role in it. The purpose of this study is to analyze the inter-modal competition between HSR and motorways by testing the impact of HSR on the average vehicle per day captured by traffic stations on motorways. The route of interest is mid-distance journeys, below 400km, where is said that HSR is more competitive against motorways. We employed the Synthetic Control Method (SCM) and we have focused on two different routes from the Galician transport infrastructure, which provides an appropriate setting for a quasi-experimental method. Results from the first analyzed route reveal a non-significant reduction in traffic after HSR was firstly introduced in the region. Conversely, results from the second analyzed route show an overall increase in traffic after HSR was launched four years later from its opening in the region.



**Key words**: Inter-modal competition, High-speed rail, Motorway, Middle-distance

# 1 Introduction

High speed rail (HSR) had its beginning back in the sixties, when Japan launched a 515 km line between Tokyo Central and Shin Osaka, operating at 210 km/h (*High Speed Rail History* - UIC). Nowadays, there are 56.000km of lines in operation worldwide and Europe accounts for 21% of these lines, that is, almost 12.000 km of lines (*ATLAS, High Speed Rail 2021* - UIC).

The reasons for such development in Europe have been several: to overcome limited capacity on critical links of the rail network, ameliorate accessibility to remote regions, increase travel amenities such as time-saving or commodity, and provide basic international links (Vickerman (1997)). However, there are new and current arguments aligned to future challenges. As pointed out by Dorien Rookmaker, member of the European Parliament, on the webinar *EU high-speed rial - The real green deal*, HSR contributes and addresses three of the main challenges of transport: emissions, fatalities and capacity storage. Moreover, HSR increases individual's activity space as at same time passengers can get to locations that are further away, improves access to high-order goods and services, provides flexibility on people's mobility, relieves pressure on congested road networks, allows better travel experience by reducing journey's time and ameliorating comfort or even provides socio-economic support to different regions (Cao and Zhu (2017), De Rus and Inglada (1997), Court European Auditors (2018)). On the other side, HSR is claimed by the European Commission to be part of the solution for an European Green Deal[1] so they nuanced it in the report *Fostering the railway sector through the European green deal*. In fact, one of the *Sustainable and Smart Mobility Strategy (2020)* milestones for a smart and sustainable future, released by the European Commission, is doubling high-speed rail traffic over the next 10 years (*Sustainable and Smart Mobility Strategy – putting European transport on track for the future*, Report from European Commission).

The potential capacity of HSR to attract new users is a strong argument to keep expanding the network. Román et al. (2007) mention this capacity in short and middle distance such as the Madrid-Zaragoza or Barcelona-Zaragoza routes, where HSR captures traffic from buses and cars. However, HSR is also able to capture passengers from long-distance routes, in this case at the expenses of long-distance conventional rail (Givoni and Dobruszkes (2013)). Literature provides forecasts and reviews where HSR increased its demand in a short period time between

[1] Set of policy and initiatives that target a zero net emissions by 2050.

1990 and 2010 (Martín and Nombela (2007), Campos and De Rus (2009)) that can be contrasted with current data: HSR passengers traffic in Europe increased from 15 billion passengers per kilometer (pkm) to 124 billion pkm in the period 1990-2016 (Court European Auditors (2018)). The most up-to-date data confirms this growing trend, according to *High-speed rail passenger traffic between 2010 and 2019* database from *Statista*, global HSR traffic increased from 245,1 billion pkm to 1029,4 billion pkm. The reasons behind this HSR demand increase are dissected by two factors. The first one known as the induced demand, which is the increase of demand due to the presence of a new transport that encourages people to take more trips, which is attributed to between 10% and 20% of the whole demand. The second one, which accounts for the remaining demand, is the role of HSR against other means of transport with its ability and capacity to be considered a substitute mode of transport (Givoni and Dobruszkes (2013)).

The capacity HSR has to compete against other means of transport has been widely analyzed against planes and conventional trains and to a lesser extent against cars and buses. The respective results mainly point in the same direction, HSR reduced and reduces passengers from other means of transport, although depends both on the mode of transport and the route analyzed. The ex-post evidence review made by Givoni and Dobruszkes (2013) with papers from 1970 to 2012 shows that passengers from rail, planes, cars and coaches have shifted to HSR, with planes accounting for the higher shares, rail being the second supplier followed by cars and finally coaches (on average 32.8%, 28%, 20.2% and 8.2% respectively). With respect to the specific case of air services where competitiveness against HSR is higher than with motorways (*reichert2015mode*), on the Madrid-Barcelona route, the reduction in air service passengers due to the introduction of HSR was found to be a maximum of 13% (Román et al. (2007)). On the Chinese routes with parallel HSR and air services, analyzed by Zhang et al. (2017), it was found a 7% drop in the demand on the air routes due to HSR presence and Li and Loo (2017) found that HSR shifts air transport passengers to HSR when the distance is shorter than 800Km. For some routes between 300-400km, where cars have been predominant, HSR introduction was predicted to attract a large group of individuals from highways (Martín and Nombela (2007), González-Savignat (2004)). Otsuka (2020) found a reduction in car users after HSR introduction in Japan and Nan and Li (2018) forecasted the same results in China modeling the passenger travel demand. Nevertheless, Borsati and Albalate (2020) found the opposite results in Italy; HSR expansion not reduced but even increased traffic in motorways.

This capacity that HSR has to attract travelers from other means of transport has to do with the competitiveness between modes of transport, although Campos and De Rus (2009) give special attention to the population density attribute to account for favorable demand growth rates in HSR market. If the population is not dense enough, the promising growth demand rates could easily vanish. Regarding the competition between HSR and air services, HSR is preferred for short-to medium-haul distances (Xia and Zhang (2016)). These results were also found with an empirical analysis by Albalate et al. (2015) who confirmed that airlines subject to HSR competition do reduce the number of offered seats. However, the competition between these two modes of transport has also induced integration strategies such as HSR acting as an airport passenger feeder or HSR taking advantage of major airports by having the opportunity to catch a bigger amount of potential passengers (Chen and Silva (2013)). In the case of motorway users, for distances between 150km and 1200km HSR has an increasing role in intercity travel (Chao et al. (2019)). For example, in routes from Madrid to Zaragoza and from Barcelona to Zaragoza, HSR was capturing traffic from cars and buses in 2007 (Román et al. (2007)). The reason for this shift, also found from Madrid to Barcelona route, is the property of HSR of being faster from door to door (Court European Auditors (2018)).

Considering the little literature related to the inter-modal competition between highways and HSR, its non-robust results and taking into account that such literature is mainly based on forecasts and ex-post analysis, this paper is going to provide an empirical and causal analysis of the inter-modal competition between HSR and motorways. To do so, we are going to study the inter-modal competition between HSR and motorways in the medium distance (between 0 km and 300 km according to Instituto Nacional de Estadística) using the Galician transport infrastructure by testing the hypothesis of whether the introduction of HSR in Galicia had a negative impact on the motorway infrastructure use during the 2007-2019 period. The paper will not only contribute to study the role of HSR on individual's transport habits but also provide empirical evidence of the capacity that HSR has to catch users from motorways. Moreover, it will provide arguments for the green mode of transport distinction that HSR has because for such affirmation a minimum inter-modal shift between other modes of transport is needed (Westin and Kågeson (2012)).

The reason to analyze the Galician case is that Galicia, on the one hand, had an isolated HSR infrastructure until 2021, launched in 2 different phases. The first one, inaugurated in 2011, connecting A Coruña with Santiago de Compostela and Santiago de Compostela with Ourense. The second one was inaugurated in 2015 and connected Santiago de Compostela with Vigo. This isolation plays in favor of the analysis, which is focused on middle-distance, as avoids having HSR users from long-distance trips that could bias results. The reason for working with medium distance is because it is in this type of route where highways are more competitive against HSR (Givoni (2006)). On the other hand, each of these routes has a parallel motorway with same origin, destination and similar distance inside the middle distance range. This overall setting allows us to work with quasi-experimental techniques to analyze the impact of HSR implementation on motorway use.

The methodology that is going to be applied is a Synthetic Control Method (SCM), firstly introduced by Abadie and Gardeazabal (2003). SCM is a quasi-experimental technique that builds a synthetic counterfactual for a treated unit that, compared to the real outcome of interest after a treatment, allows to estimate the causal impact of such treatment. The method is then complemented with a placebo test to assess the significance of the impact.

The remaining of this paper is organized as follows. In Section 2 we present the literature review. In Section 3 we disseminate the case study. In Section 4 we describe the used methodology and in Section 5 the used data. Section 6 presents the results of the study and finally, Section 7, we conclude and discuss results.

## 2 Literature review

HSR literature has focused on its impacts on different socio-economic variables and its intermodal competition against different means of transport.

Concerning the impact of HSR on socioeconomic variables, Cheng and Chen (2021) provide an extensive review of the impact of HSR in fields such as accessibility, environment, tourism, housing, the labor market and industry or economic performance. This review is characterized by a high degree of heterogeneity in the results and having non-robust conclusions. Positive and negative impacts are found in the mentioned fields and correspondent papers and this is due to the specificity of each analysis: different methodologies, different geographic units or different data types.

In regards to the intermodal competition between HSR and other means of transport, literature has focused on air services and the majority of results point in the same direction: HSR competes against air services and has reduced air transport market share (Jiménez and Betancor (2012), Behrens and Pels (2012), Albalate et al. (2015), Xia and Zhang (2016), Román et al. (2007)). Nonetheless, these results are dependent on different circumstances. The first aspect that plays a role in this intermodal competition is the route distance. Xia and Zhang (2016) and Román et al. (2007) through an analytical and a disaggregated demand model respectively, show that HSR is preferred in short and medium distances while air transport is preferred in long distance because it is more competitive. Another relevant factor is the trip purpose as Behrens and Pels (2012) studied in the London-Paris passenger market. Business and leisure passengers behave differently regarding frequency, total travel time and total distance route when traveling. Authors find that in the business segment, competition between low-fare air companies (e.g. EasyJet) and HSR is less fierce than the competition between non-low-fare air companies and HSR while in the leisure segment the competition that HSR faces is higher with low-fare companies.

The impacts that HSR can cause to air services are diverse; Xia and Zhang (2016) found that improving HSR travel time reduces airfares, Albalate et al. (2015) confirm through an empirical analysis with European data that even air services demand falls due to HSR competition, their flight frequencies are maintained to avoid further undermining competitiveness. Moreover, they show that HSR may only have effects in those hub airports which share HSR stations in their sites. In the specific case of Spain, Jiménez and Betancor (2012) conducted an empirical analysis which stated that, on average, the entry of HSR reduced air operations by 17% and the air transport share of the whole market reduced between 0.13 and 0.31 points. Again in Spain, Román et al. (2007) found that HSR would not reduce air service passengers by more than 13% and that the maximum market share of HSR would be 35%.

Focusing on the inter-modal competition of our interest, that is, between HSR and motorway, Givoni and Dobruszkes (2013) offered a meta-analysis of ex-post studies. On their work state that road transport is the third most important source of HSR passengers (behind conventional rail and air transport). They suggest that the share of road transport travel is affected but much less than those of the conventional train or air services. This shift depends largely on the facilities that individuals have to access HSR stations, which is linked to the size of the city and the location of the HSR station. The most relevant conclusion from the authors is that as itineraries distance increases (other things being equal), road transport loses market share in favor of HSR until at some point when it starts to lose it to air transport. This is in accordance with the conclusion from Givoni (2006) review, which highlights the relevance of route distance on the potential effect of HSR to substitute the car. Particularly they point to 300km routes as the maximum distance where HSR can have effects on the number of car users.

Some authors have worked with models to determine the power of HSR to capture passengers from road networks. In his paper, Otsuka (2020) analyze the Japanese case and found two main findings. The first one is that the presence of a modal shift from vehicles users to HSR can occur if the regional transport network reaches considerable improvements until reaching a threshold, which they do not define. The second one is that the introduction of the Linear Chuo Shinkansen (a Japanese HSR line) has reduced the energy consumption of the vehicle sector suggesting that car users are switching to HSR. In the Chinese case, Nan and Li (2018) built a highway passenger travel demand forecasting model that exhibits a decline of motorway users in part due to HSR infrastructure. However, this decline is claimed to be non-perpetual because of the imperfect competition scenarios that motorways have with other modes of transport, including HSR. González-Savignat (2004) highlights through a discrete choice logit model the relevance of fares for the inter-modal competition between HSR and highways. A 10% increase in the HSR fare in the long-distance market will, *ceteris paribus*, reduce the probability of choosing HSR for leisure alone travelers in 9.7% and 12% for leisure group travelers. In the short-distance market, the same fare increase would decrease the probability by 13 and 16% respectively, indicating an elastic demand for leisure travelers with respect to fares. Hence, a fare discount for group travel can have a significant impact on the users that switch from cars to HSR. The main conclusion from the paper relies on the importance that service supply conditions can have on the analyzed inter-modal competition.

Literature has also provided some empirical analysis regarding the intermodal competition between HSR and motorways. Coto-Millán et al. (2007) analyzing the Madrid-Barcelona corridor found a reduction of all modes of transports market share after the HSR launching. In the case of the car market share, it was reduced from 19.9% to 14.6%. Cascetta and Coppola (2015) provided empirical evidence from the Italian HSR market in the 2009-2013 period. In their work, they found that the modal share of HSR demand in the core area (that is where HSR network can be used), increased from 25.2% to 44.3% while the highway modal share experienced a reduction from 57.3% to 45.2%. Overall, long-distance highway traffic fell 10% in the whole country and 19% in the HSR core area. Lastly, there is a paper from Borsati and Albalate (2020), the only one using a quasi-experimental method to the authors knowledge, which analyzes whether the HSR expansion in Italy led to a modal shift from the motorway to HSR. Through a Difference-in-Difference methodology they reveal that neither the HSR opening (adjacent to motorways) nor the HSR market openness led to a modal shift from the motorway to HSR services. In fact, they find that HSR expansion had a smooth positive impact on motorway traffic probably; an increase of 10 percentage points of HSR length implies, on average, a 0.41% increase in total kilometers traveled by light vehicles. The reason behind is argued by, first, an increase in the total number of car journeys due to a positive impact of HSR on surrounding economic activities; second, to a negative impact on conventional rail services inducing an involuntary increase in car use.

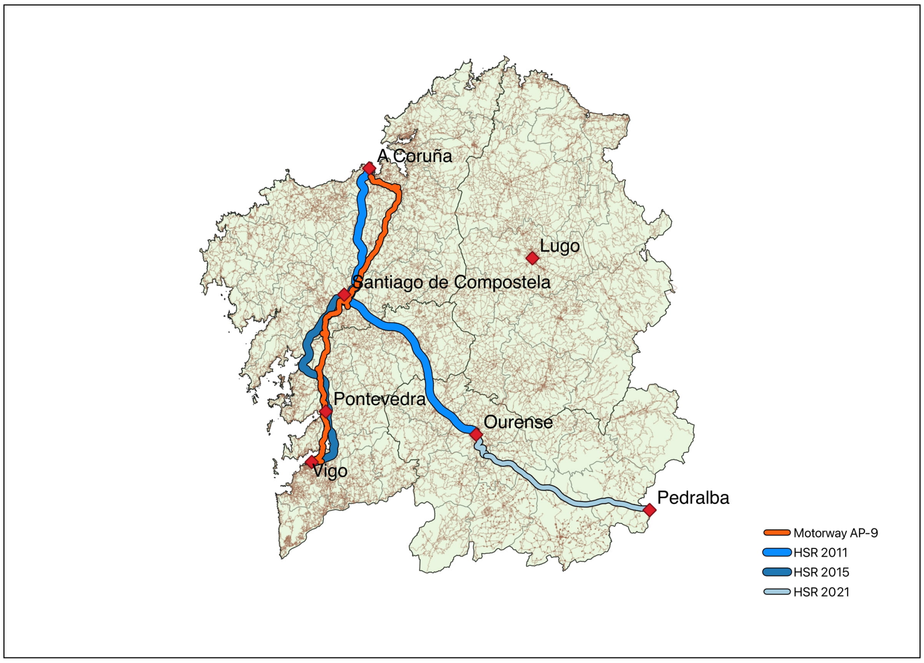
# 3 The Galician case

The geographical area of interest to analyze the inter-modal competition between motorway and HSR in the middle distance is Galicia. Galicia is the Northwestern region of Spain with a population of around 2.5 million inhabitants in 2021 and divided into 4 provinces; A Coruña, Pontevedra, Lugo and Ourense. The reason for choosing Galicia is because of its geographical transport infrastructure network, both at the level of highways and HSR as their combination.

The HSR network is built by Adif and works began in 2001. Was in 2011 when were inaugurated the first two lines, from Santiago de Compostela to A Coruña (L1) and form Santiago de

Compostela to Ourense. Then, in 2015 HSR was launched on the route Santiago de Compostela – Vigo (L2) and in 2021 on the route Ourense-Pedrabla, the line that allows connecting with Castilla y León, the rest of Spain. L1 and L2 are the routes of interest for this analysis because of data availability. L1 covers a distance of 61 km, each ticket costs 7.6€ (with AVE train) and the travel duration is 28 minutes. Regarding L2, its rail tracks have a length of 94 km, a cost of 7.7€ (Alvia train) per ticket and a duration of 55 minutes.

In regards to motorways, we are interested in AP-9, which offers the same route as L1 and L2. The motorway for L1 has a length of 73.5 km, the toll cost is 7.2€ (light cars) and the approximate duration is 50 minutes (in normal conditions) while for L2, the motorway has a distance of 89.1 km, a toll cost of 10.3€ (light cars) and the travel lasts 1h and 3 minutes (in normal conditions). In Table 1 we can find a summary of this data and Figure 1 provides a general overview of the framework.




*Own elaboration*

Figure 1: Map of Galicia with HSR lines and motorway of interest

| | Santiago de Compostela - A Coruña (L1) | Santiago de Compostela - Vigo (L2) |
|---|---|---|
| | **HSR** | |
| Lenght | 61 Km | 87 Km |
| Duration | 28 min. | 34 min. |
| Cost | 7.6€ (AVE) | 14.85€ (Alvia) or 17.7€ (Avant) |
| | **MOTORWAY** | |
| Lenght | 73.5 Km | 104 Km |
| Duration | 50 min. | 1h 11min. |
| Cost | 7.2€ | 6.15€ |

*Notes*: Data is from 02/03/2022

Table 1: Specific data summary

The Galician case offers a setting where both L1 and L2 reach the perfect conditions for our analysis because the only differences among the two involved types of infrastructures are their respective transport characteristics. Moreover, they are in the middle distance range and the fact that the HSR network was isolated from the rest of Spain until 2021 allows us to avoid having HSR users from long-distance trips that could bias results. Hence, this overall transport infrastructure sets an optimal framework to apply a quasi-experimental technique to assess the impact of HSR on motorway infrastructure use.

# 4 Methodology

Our hypothesis, whether the introduction of HSR in Galicia had a negative impact on the motorway infrastructure use is going to be contrasted with the SCM, firstly introduced by Abadie and Gardeazabal (2003). The impossibility to work with the Difference-in-Difference methodology due to the violation of the parallel trend assumption together with the fact that SCM better works under policies and socio-economic interventions that affect a small number of aggregate units, and especially when traditional regression methods are not suitable (Abadie et al. (2010)), we believe SCM is the most appropriate methodology to test our hypothesis.

SCM constructs a counterfactual of a treated unit and its outcome is compared with the outcome of the treated unit in the post-treatment period. Overall, the method needs a treated unit, an outcome of interest, which must be observed on pre and post treatment and a donor pool. The donor pool is a set of potential units that have a structural similarity to the treated unit in terms of the way that the outcome of interest emerges (these could include socioeconomic characteristics such as GDP, meteorological characteristics, etc.). The idea behind SCM is that the combination of the units from the pool constructs a counterfactual unit (known as the synthetic control unit) of the treated unit. To better construct the counterfactual, the methodology also makes use of covariates both from the treated unit and the donor pool that better allow explaining the outcome of interest. Then, the outcome of the synthetic control is compared to the outcome of the treated unit after treatment to assess the impact of the treatment. The way to construct the synthetic control is with a weighted average of the units from the donor pool and its respective covariates so that the weighted average outcome of interest in pre-treatment period resembles as close as possible to those of the treated unit. SCM quality relies on how similar the weighted synthetic outcome is compared to the outcome for the treated unit in the pre-treatment period and can be evaluated with the root mean squared prediction error (RMSPE[2]) in the pre-treatment period.

Such methodology makes it difficult to apply standard inference techniques to evaluate the statistical significance of results. This is why to test the relevance and significance of the results we make use of a placebo test. The idea of this placebo is to apply the SCM to every control unit from the donor pool and see whether the effect found in the treated unit is large relative to the false placebo effects (effects estimated on the donor units which have not been treated) (Abadie et al. (2010)). This placebo test allows to get the standardized p-values by comparing how unusual the observed effect on the treated unit is relative to the false placebo effects. If it is unusual, we can reject the null hypothesis of no effect. To measure the effect size across units (treated and all untreated) we make use of the RMSPE ratio (Abadie (2021)). The rationale behind is that if there is an effect, the RMSPE will be large in the post-treatment period. However, we normalize the post-RMSPE with the pre-RMSPE because the placebo effect may be large if their counterfactual is not well matched in the pre-treatment period. Hence, we use

[2]RMSPE is a metric that provides how similar is the synthetic counterfactual to the real values, which should be low on the pre-treatment period.

the ratio post-RMSPE/pre-RMSPE to get the inference and standardized p-values. Units with a higher RMSPE ratio are those experiencing a higher effect after the treatment.

In this paper, the outcome of interest is traffic on motorways, treated units will be eight different traffic stations: 2 from L1 and 6 from L2, the treatment (i.e. HSR launching) took place in 2011 (for L1) and 2015 (for L2) and the initial donor pool sample are 1.497 traffic stations from Spain. Donor pool units are from Spain because share a structural context with the treated units, which benefits the method as Abadie and Gardeazabal (2003) point. Moreover, to improve the accuracy of the methodology and interpretation of results we first, restrict those Spanish traffic stations located in motorways parallel to HSR lines; second, we selected those traffic stations with an annual traffic composition (e.g. similar proportion of bus, car, etc.) and traffic average that are maximum 2 standard deviations away with respect the same data from the treated units for the analyzed period.

# 5 Data description

The chosen period comprises a total of 13 years, starting in 2007 due to data availability and ending in 2019 in order to avoid the Covid-19 pandemic data, which can strongly bias results.

In regards to the outcome of interest, traffic on motorways, we use the average daily intensity of vehicles, that is the average number of vehicles per day. This data comes from Ministerio de Transportes, Movilidad, y Agenda Urbana and is reported by stations of traffic located alongside the motorways, which implies having several treated units (detailed in section 5?¿?¿?¿).

Concerning the other used variables, which allow to predict traffic, we work with tourism, unemployment, total population, GDP per capita, vehicle fleet, oil price and rain precipitation. To gather them we used four main databases. The first one is Instituto Nacional de Estadística (INE), where we obtained data for tourism, unemployment, total population and GDP per capita. For tourism, we use as a proxy the total amount of travelers involved in the hotel sector (not overnight stays) and contains data for national and foreign tourism. For unemployment, we work with the rate of unemployment. The second data base is Dirección General de Tráfico

(DGT) which is used to gather data for the vehicle fleet and its composition. The third one is Ministerio para la Transición Ecológica y el Reto Demográfico from Spanish government, which allowed to obtain oil prices (gasoline and diesel) in cts/l. Finally, from INE but also from Agencia Estatal de Meteorologia (AEMET) we could compile the annual precipitation in millimeters for each Spanish province.

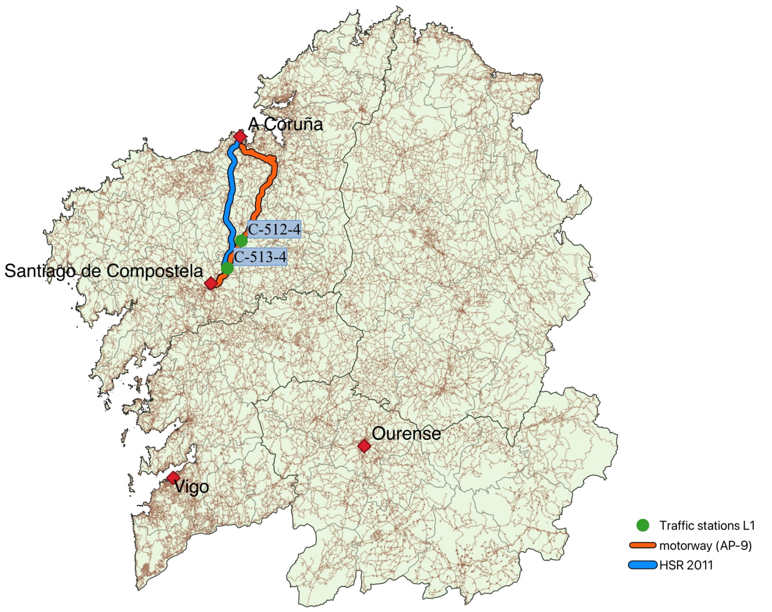
All these traffic predictor variables are compiled at a province level and yearly. We are aware that we might lack some crucial data such as HSR prices which have not been possible to gather because there is no available historic register or motorway tolls, which we were unable to collect.

As pointed out by Abadie et al. (2010) and bolstered by Ferman et al. (2020), including the outcome variable for the pre-treatment period as a predictor variable improves the SCM algorithm therefore we are also going to include it. Besides, including the outcome variable for the pre-treatment period allows not only to control for time-variant factors but also to better control for heterogeneous unobserved factors, which is not possible under other methodologies that look for causality.

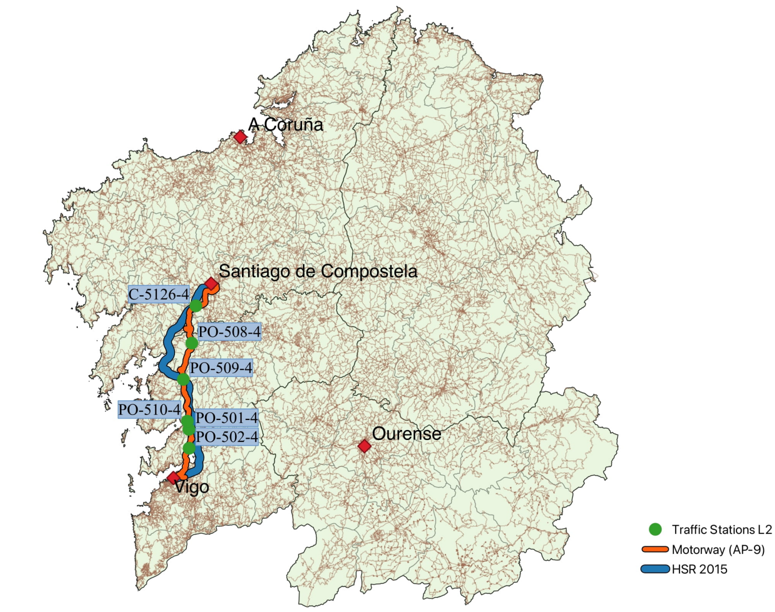
# 6 Results

Below we present the results from our analysis by dividing the section between results from L1 and results from L2 to have a better comprehension of our findings. In the case of route L1 we were able to analyze the hypothesis with two different traffic stations: C-512-4 and C-513-4, from now on C12 and C13 respectively (Panel 1), while in the case of route L2 we were able to work with a larger sample of six traffic stations: C-516-4, PO-508-4, PO-509-4, PO-510-4, PO-501-4 and PO-502-4 from now on C16, P8, P9, P10, P1 and P2 respectively (Panel 1).

In all cases we reduced the donor pool sample from the initial 1.497 donors to 250 donors. The reason for such reduction is because of limited computational capacity. We believe such a reduction has no impact on the quality of SCM as relevant and referent papers in the literature using the same methodology work with even fewer donors (Abadie and Gardeazabal (2003), Abadie et al. (2010), Grier and Maynard (2016), Munasib and Rickman (2015)). The manner to select the reduced sample was through a random process; for each traffic station we worked with a different random sample of 250 units from the original one[3].




Route L1




Route L2

*Own elaboration*

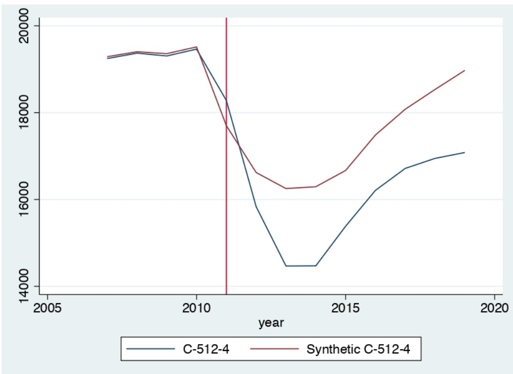
PANEL 1: Analyzed traffic stations

[3]To ensure the validity of working with random subsamples we performed a test with one traffic station per route. The test consisted of repeating the same analysis but working with different random subsamples. Results were satisfactory as with each subsample they were very similar, if not exact.

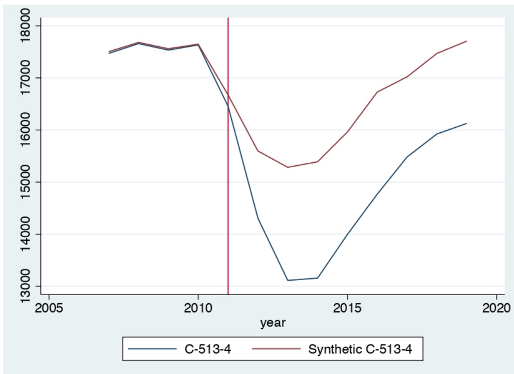
## 6.1 Route L1: Treated traffic stations in 2011

Before looking at the SCM results we show in Panel A1 in Appendix the traffic evolution for the analyzed traffic stations and the average traffic evolution of its respective pool. In both cases the average traffic from the pool follows a similar path to their respective treated traffic stations and serves as a first indicator to see the potential accuracy of the synthetic control to replicate the real traffic.

Following the intuition from the raw traffic evolution from Panel A1, Panel 2 illustrates the evolution of the synthetic and real traffic along the analyzed period per treated traffic station. Both synthetic counterfactuals can closely replicate the outcome of their respective treated traffic stations, which points to a high-quality synthetic control (RSMPE pre-treatment period is 1.38e-09 and 7.65e-09 for C12 and C13 respectively). In both cases, there is an almost perfect similarity between the synthetic and the real outcome in the pre-treatment period and after treatment appears, both traffic stations experience a reduction of traffic. Indeed the effect does not appear right at the time of treatment, however, it is clear that is around the treatment period when the synthetic and real outcomes start to diverge for both traffic stations.




Synthetic and real traffic in C12

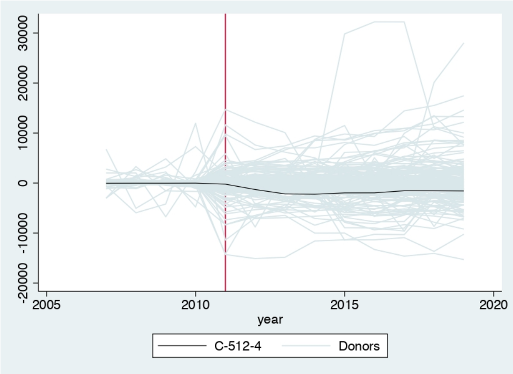


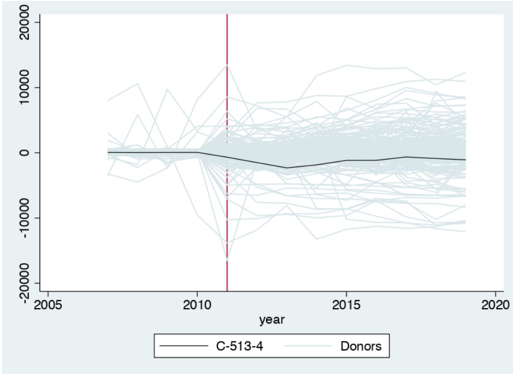

Synthetic and real traffic in C13

PANEL 2: Treated traffic stations and its synthetic counterfactual

The magnitude and direction of the treatment, that is, of the introduction of HSR can be better seen in Panel A2 from Appendix. With these figures we can appreciate the reduction in traffic after the treatment period. In the case of C12, traffic suffered a marked reduction between 2011 and 2013 when it reached 1784.085 average vehicles per day (avd) below the synthetic counterfactual. This difference of traffic represents a decrease of 11 percentage points respect its counterfactual in 2013. From 2013 to 2019 this reduction of traffic got stabilized with an average of 1572.401 avd below the synthetic counterfactual which represents a reduction of 8.7 percentage points (See Appendix Table A1 to see the treatment effect per year). In the case of C13, the impact of the treatment leads a similar path; traffic sharply dropped from 2011 to 2013 up to 2170.663 avd below its counterfactual (a difference of -14,2 percentage points). Between 2013 and 2019 traffic slightly increases and reaches an average traffic reduction with respect its counterfactual of 1901.760 avd, which represents a difference of 10,9 percentage points less (See Appendix Table A2 to see the treatment effect per year). Both traffic stations suffer a similar impact in terms of direction, magnitude and timing and the fact of not observing either asymmetric traffic flows or big differences between the two adjoining traffic stations gives veracity and accuracy to the methodology and results.

Although previous panels show an effect after treatment, the associated standardized p-values from the RMSPE ratio appear to don't reject the null hypothesis of no effect. In Panel 3 we have a visual representation of the placebo tests, that is, the effect found both in the treated unit and its respective donors. As we can appreciate, the effect found in the treated units is not the largest compared to the donors as it is not in the tails of the distribution. This indicates that even though a reduction of traffic appeared after HSR launching in the treated units, other traffic stations experienced such reduction without being treated, even experiencing larger traffic reductions. But we need to look at the RMSPE ratios to have an objective metric to assess the significance of the impact as they consider the accuracy of the synthetic counterfactual on the pre-treatment period. In Panel 4 we present all RMSPE ratios in order of magnitude and we can see how both treated units don't have the largest values. This means that the effect found on the treated units relative to the untreated is not large enough to confirm a significant impact from treatment. In fact, looking closely, any of the effect found in each post-treatment periods appears to be significant (See Appendix Panel A3 to see all the standardized p-values per period and treated traffic station). Consequently, although both analyzed traffic stations in route L1 experienced a reduction of traffic when HSR was first inaugurated in the region, placebo tests point to a non-significant reduction.

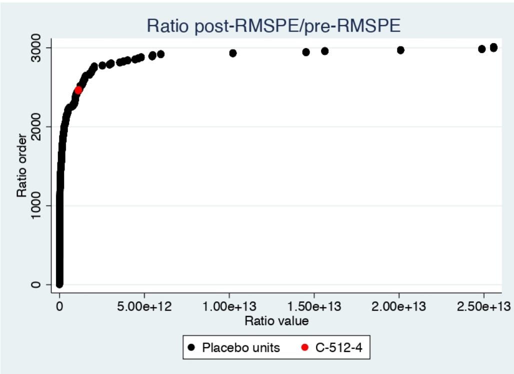


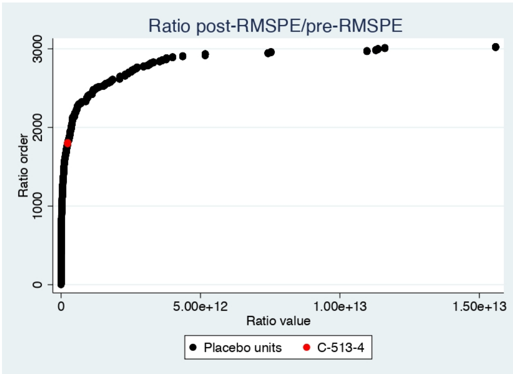




Placebo test for C12 Placebo test for C13

*Note*: The donor sample that allows to run the placebo test is 250 traffic stations

PANEL 3: Placebo test




RMSPE ratios for C12 and its donors RMSPE ratios for C13 and its donors

PANEL 4: RMSPE ratios

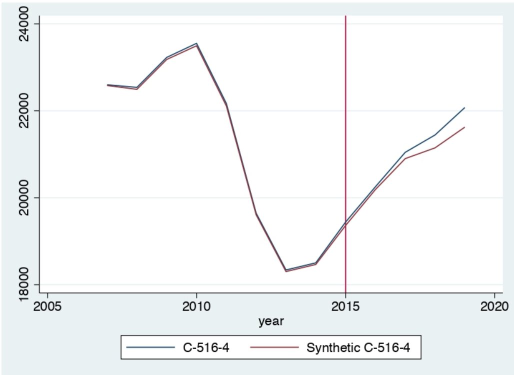
## 6.2 Route L2: Treated traffic stations in 2015

As we have done with the previous traffic stations, we present in Panel A4 in Appendix the traffic evolution of the treated traffic stations in L2 and their respective pool. The panel illustrates how the average traffic evolution of each pool has the same pattern as their respective treated units and therefore composing a reliable sample to construct a synthetic counterfactual. Results from SCM are shown in Panel 5 and in all cases the synthetic counterfactual can replicate the traffic from the treated units in the pre-treatement period, which can be contrasted with their pre-RMPSE: 2.003e-07 for C16, 4.972e-09 for P1, 2.837e-08 for P2, 5.391e-08 for P8, 7.382e-09 for P9 and 5.763e-08 for P10. Contrary to treated units in 2011, treatement effect in L2 had a smooth or large positive impact in traffic, depending on the traffic station.

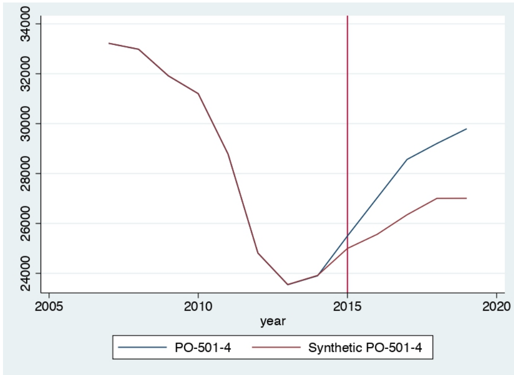
Traffic stations P1, P2 and P8 are the ones that experienced a notable increase in traffic after 2015. In all three cases, the divergence of traffic between the treated traffic stations and their counterfactual starts around the treatment period and keeps increasing until the last period, when reaches the maximum difference: 2786.926 avd, 3375.691 avd and 1398.314 avd for P1, P2 and P8 respectively. In percentage points, it represents a positive difference of traffic respect their counterfactuals of 10.32, 13.56 and 8.31 respectively. The average increase of traffic for the 2015-2019 period in percentage points is 6.92, 9.51 and 5.65 for P1, P2 and P8 respectively (see Appendix Table A3 to see the treatment effect per year and traffic station). In Panel A5 from appendix we can visually appreciate such increases.

Traffic stations C16, P9 and P10 show almost no traffic difference between them and their synthetic counterfactual during the post-treatment period. The maximum difference of traffic between C16 and its counterfactual is 450.374 avd in 2019, between P9 and its counterfactual 742.079 avd in 2017 and between P10 and its counterfactual 1462.195 avd in 2017 (see Appendix Table A3 to see the treatment effect per year and traffic station). In percentage points, the average increase of traffic for the analyzed period is 0.98 for C16, 2.97 for P9 and 1.33 for P10.

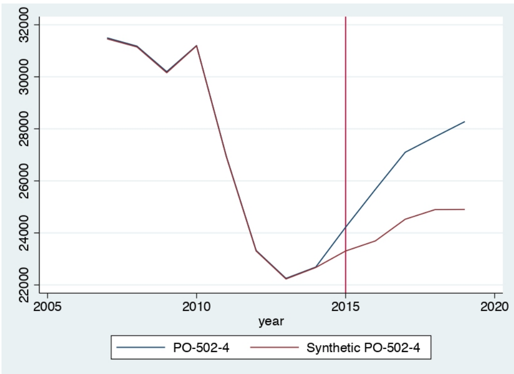
Regarding the significance of the impact, we have again to analyze it with the placebo test. Panel 6 provides an overview of the impact found on the treated units and their respective donor units and only in the case of P1 and P2 treated units appear close to the tails of the distribution of placebo estimates, which indicates a possible significant impact. However, only looking at the RMPSE ratios, which standardize the impacts to the pre-treatment period, we can confirm the presence of a significant impact. As figures in Panel 7 show, in no case, the relative impact on treated stations is the largest. However, considering that some stations show large values, we considered appropriate to analyze the standardized p-values per period to have a more detailed overview of the significance of the impact. Therefore, after closely looking at the standardized p-values by period, traffic stations P1, P2 and P9 have a maximum standardized p-value of 0.0248, 0.0673 and 0.064 respectively for the post-treatment period, shown in Table 2 (See in Appendix Panel A6 to see all the standardized p-values per period of the remaining treated stations). Hence, on these three traffic stations, we can confirm a significant increase in traffic after HSR was operational in L2. Among them, P9 is the one experiencing the lowest magnitude, about 1300.485 avd on average below what P1 and P2 experienced.



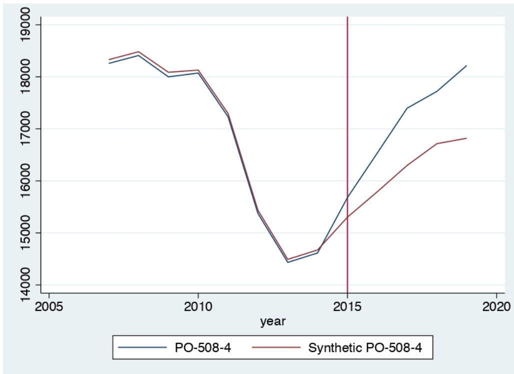

Synthetic and real traffic in C16



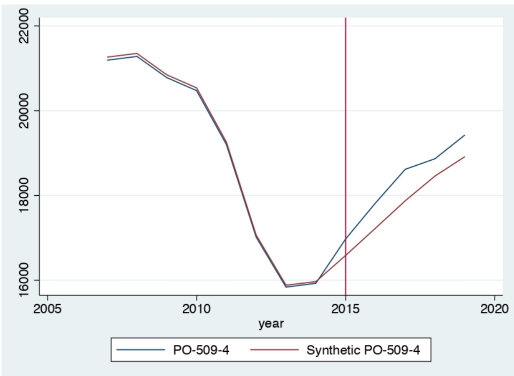

Synthetic and real traffic in P1



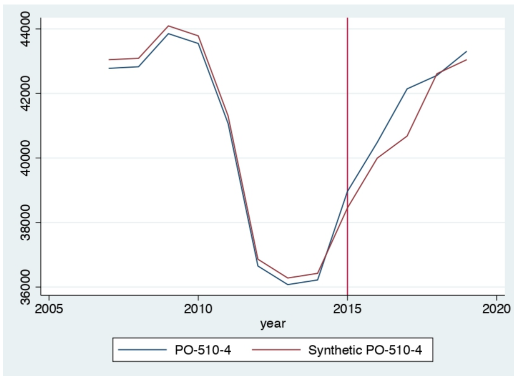

Synthetic and real traffic in P2




Synthetic and real traffic in P8




Synthetic and real traffic in P9



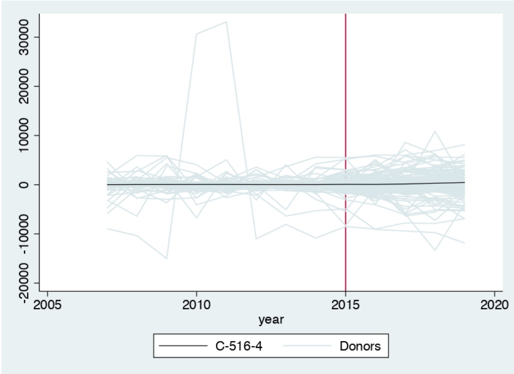

Synthetic and real traffic in P10

PANEL 5: Treated traffic stations and its synthetic counterfactual

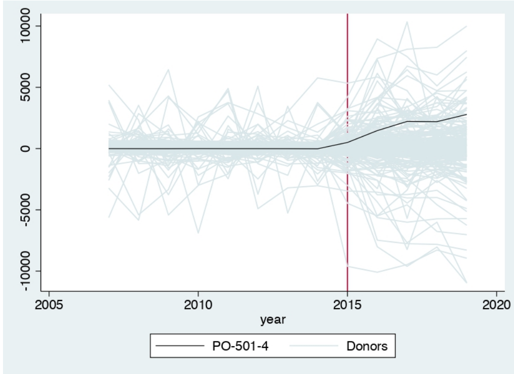
| Period | Estimates | | |
|---|---|---|---|
| | P1 | P2 | P9 |
| 2015 | 0,02480* | 0,06730* | 0,04450* |
| 2016 | 0,01492* | 0,06730* | 0,04950* |
| 2017 | 0,00490** | 0,04140* | 0,02470* |
| 2018 | 0,01490* | 0,05180* | 0,06435* |
| 2019 | 0,01490* | 0,05180* | 0,06435* |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

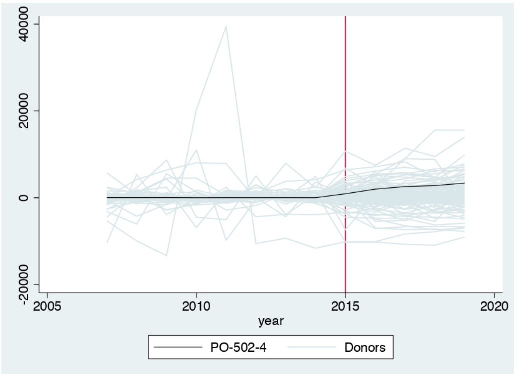
Table 2: Standardized p-values for traffic stations P1, P2 and P9



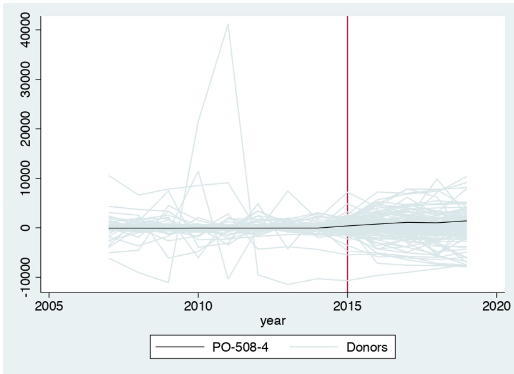

Placebo test for C16



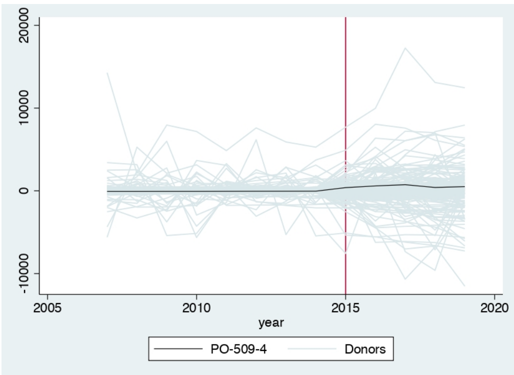

Placebo test for P1



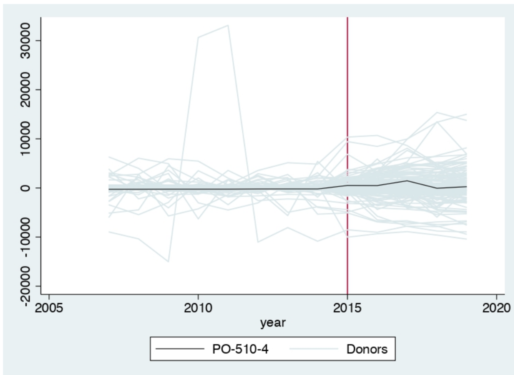

Placebo test for P2




Placebo test for P8



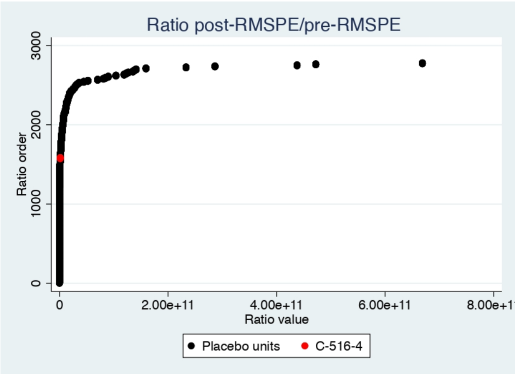

Placebo test for P9



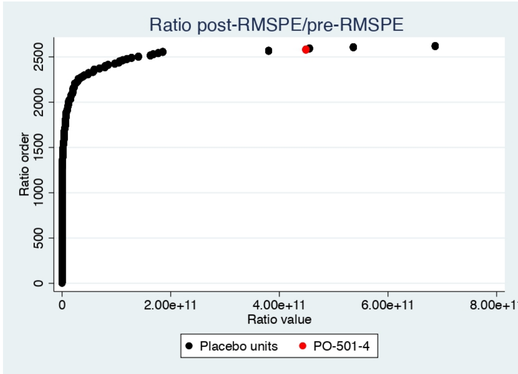

Placebo test for P10

*Note*: The donor sample that allows to run the placebo test is 250 traffic stations

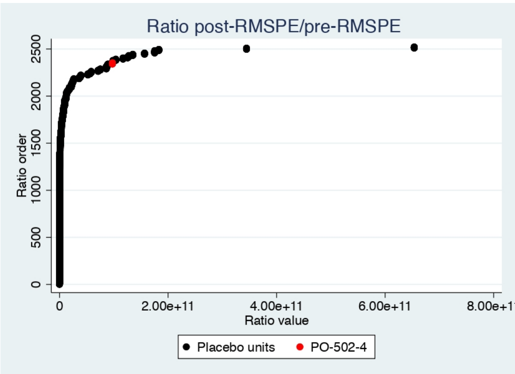
PANEL 6: Placebo test



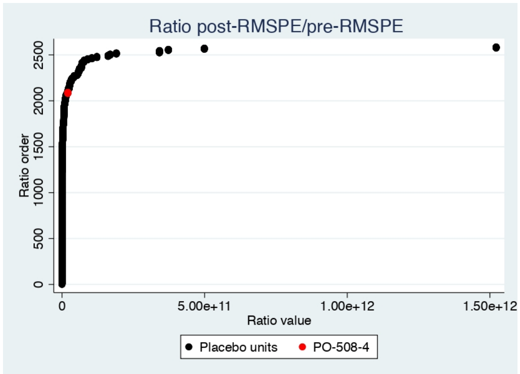

RMSPE ratios for C16 and its donors



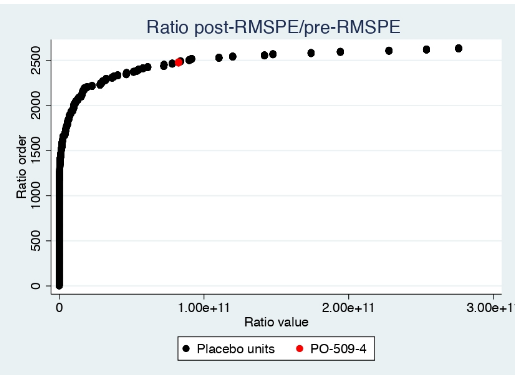

RMSPE ratios for P1 and its donors



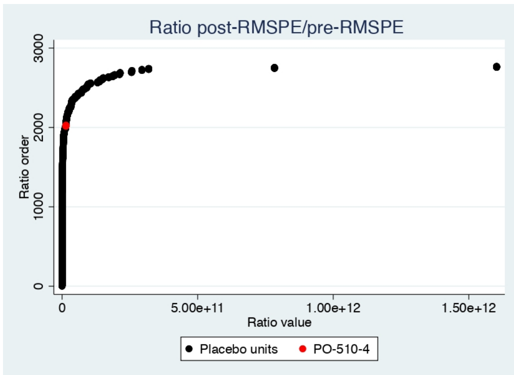

RMSPE ratios for P2 and its donors




RMSPE ratios for P8 and its donors




Placebo test for P9 and its donors




RMSPE ratios for P10 and its donors

PANEL 7: RMSPE ratios

# 7 Conclusion and discussion

This study has focused on the intermodal competition between HSR and motorways by testing the impact of HSR on the average vehicle per day captured by traffic stations on motorways. The analysis has focused on the Galician case, where we analyzed eight different traffic stations from two different routes; A Coruña – Santiago de Compostela (two traffic stations) and Santiago de Compostela – Vigo (six traffic stations). We used the quasi-experimental method of

Synthetic Control Method and the results obtained point to a decrease in traffic, although not significant, when HSR was firstly introduced in the region, and to an increase in traffic when HSR was introduced four years later.

In the case of the A Coruña – Santiago de Compostela route, when HSR was introduced in 2011 and became the first high-speed line of the region, traffic was reduced on average 1246.049 avd on the first traffic station (C12) and 1814.314 av on the second traffic station (C13) during the 2011-2019 period, which represents 8.7 fewer percentage points for C12 and 10.9 fewer percentage points for C13 respect to their counterfactuals. However, such reduction is non-significant in both traffic stations. The possible reason behind such a reduction is the inauguration of HSR in Galicia. Since citizens could for the first time travel with this mode of transport inside the region, it is reasonable to think that citizens started to use the new infrastructure. In favor of this explanation, we have a slight increase in traffic after 2 years of sharp decrease, which could be understood as the time that took citizens to have enough experience with the new mode of transport and evaluate it to decide whether was worth it to use it or not.

In the case of the Santiago de Compostela – Vigo route, HSR was introduced in 2015 and results show the opposite results to the previous route. From the six analyzed traffic stations, the treatment has a positive effect on traffic in all of them, although some with an almost insignificant increase. Of the analyzed traffic stations, half of them have a significant impact and their increase is: 1833.765 avd for P1, 2328.549 avd for P2 and 924.675 avd for P8, which can be translated into an increase of 6.92 percentage points for P1, an increase of 9.51 percentage points for P2 and an increase of 5.65 percentage points for P8 for the analyzed period. The possible explanation behind HSR impact on such route might be due to different factors. On the one hand, it might have to do with the previous experience of Galicia citizens with HSR along with a weakening of conventional train services (due to a possible reduction of investments in conventional rail), as suggested Borsati and Albalate (2020). A bad HSR experience together with a reduction of quality on conventional train services could motivate an increase in vehicle use. On the other hand, pointed out by the same authors, HSR expansion might had a positive impact on surrounding economic activities which could have increased the total number of car journeys.

The conclusion that we can draw from this analysis is that the introduction of HSR in Galicia for the first time reduced traffic, which could be associated with the enthusiasm from citizens to use the new mode of transport, however, this reduction was not significant. Four years after the launching of HSR in Galicia, the second line was introduced and it implied a positive impact in traffic on the analyzed traffic stations, with half of them constating a significant impact. Such an increase could be due to three main factors: the negative experience from users using HSR services in the previous years, the loss of quality from the conventional train due to more investments devoted to HSR and the economic impact that HSR brought to the region, leading to an increase of car use, as papers described on the literature point out. Nevertheless, not having a significant impact in all traffic stations does not allow us to strictly confirm that HSR causes an increase in traffic; those significant impacts might be casual.

It is also important to not extrapolate these results because we are analyzing the specific case of Galicia. Galicia is part of Spain and the introduction of HSR in the country did not have any economic or commerce criteria (Bel (2011)), contrary in countries where HSR had a negative impact on vehicles use. In fact, behind HSR development in Spain, there is a centralization plan around the capital city that did not consider mobility needs when was designed (Albalate and Bel (2012)). Hence, results could be conditioned by the reasons behind HSR implementation in Spain and are not extrapolated to other countries.

These results have to be taken with caution and cannot be generalized. In the first place because the direction of results is opposite depending on the route. Furthermore, having been able to work with more stations would have provided more robust results, as well as having been able to work with the route Santiago de Compostela-A Coruña. In the second place, the lack of decisive variables regarding the use of HSR, such as HSR ticket or toll prices could have underestimated real impacts. Thirdly, according to Givoni and Dobruszkes (2013), the impact of high speed train on itineraries made by car mainly depend on travel costs and travel time. Finally, the studied period comprises a few post-treatment years, especially for the Santiago de Compostela- Vigo route and could hide the impacts in the mid and long term.

# 8 Appendix

## 8.1 Tables

| | Treatment effect on C12 |
|---|---|
| 2011 | 579.264 |
| 2012 | -786.893 |
| 2013 | -1784.085 |
| 2014 | -1822.157 |
| 2015 | -1284.292 |
| 2016 | -1274.713 |
| 2017 | -1362.827 |
| 2018 | -1587.071 |
| 2019 | -1891.665 |

*Notes*: Unit is average vehicles per day

Table A1: Treatment effect on C12 per period after treatment

| | Treatment effect on C13 |
|---|---|
| 2011 | -216.005 |
| 2012 | -1289.644 |
| 2013 | -2170.663 |
| 2014 | -2231.917 |
| 2015 | -1965.477 |
| 2016 | -1958.617 |
| 2017 | -1538.356 |
| 2018 | -1545.527 |
| 2019 | -1579.1 |

*Notes*: Unit is average vehicles per day

Table A2: Treatment effect on C13 per period after treatment

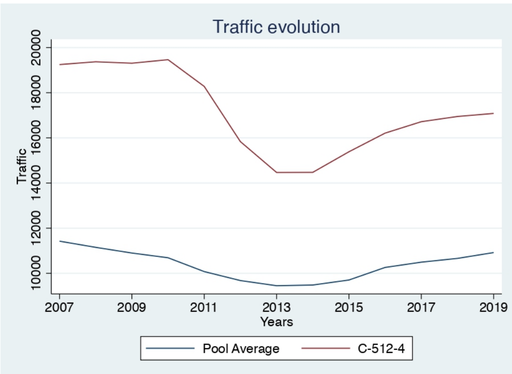
Treatment effect on L2 traffic stations

| | Station C16 | Station P1 | Station P2 | Station P8 | Station P9 | Station P10 |
|---|---|---|---|---|---|---|
| 2014 | 37.252 | -15.197 | 17.126 | -57.697 | -39.484 | -205.282 |
| 2015 | 78.538 | 498.946 | 913.615 | 376.054 | 387.723 | 512.503 |
| 2016 | 64.027 | 1.466.166 | 1.981.949 | 743.805 | 594.584 | 489.631 |
| 2017 | 144.235 | 2.217.986 | 2.573.436 | 1.099.929 | 742.079 | 1.462.195 |
| 2018 | 296.558 | 2.198.803 | 2.798.053 | 1.005.274 | 408.016 | -54.114 |
| 2019 | 450.374 | 2.786.926 | 3.375.691 | 1.398.314 | 510.923 | 260.711 |

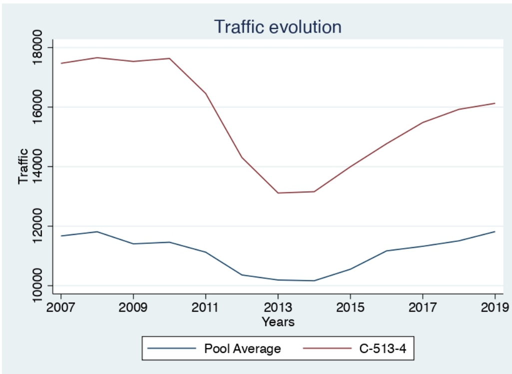
*Notes*: Unit is average vehicles per day

Table A3: Treatment effect on traffic stations located in route L2

## 8.2 Pannels

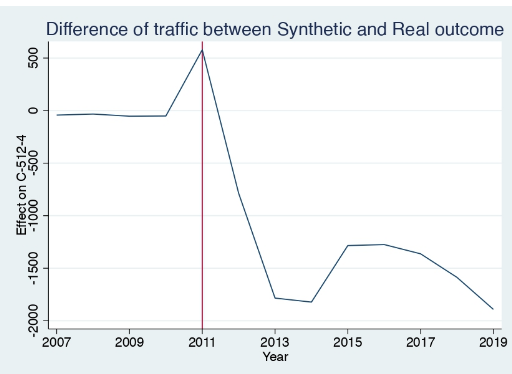



Traffic station C12

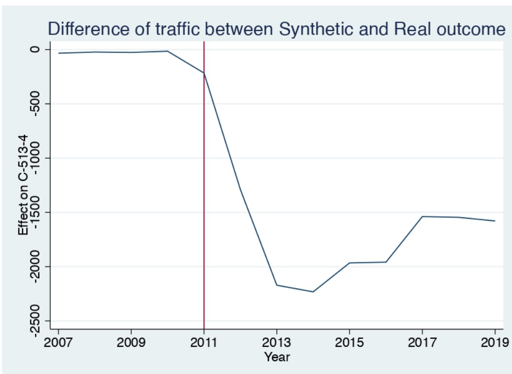



Traffic station C13

PANEL A1: Evolution of raw traffic

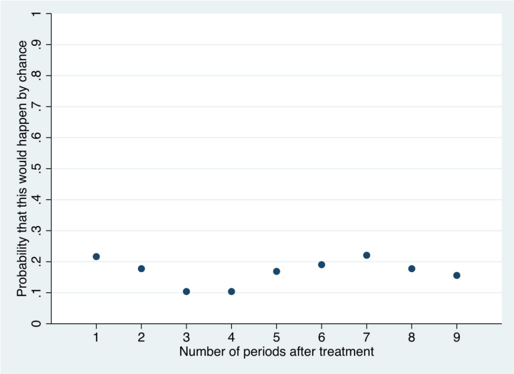



Treatment impact on C12

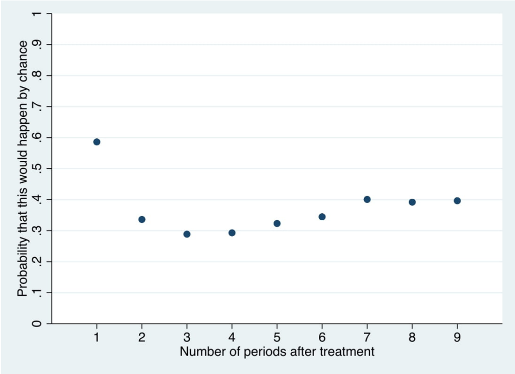



Treatment impact on C13

PANEL A2: Difference between real and synthetic traffic

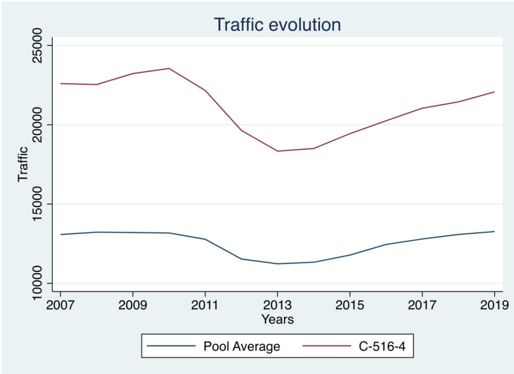



C12 standardized p-values

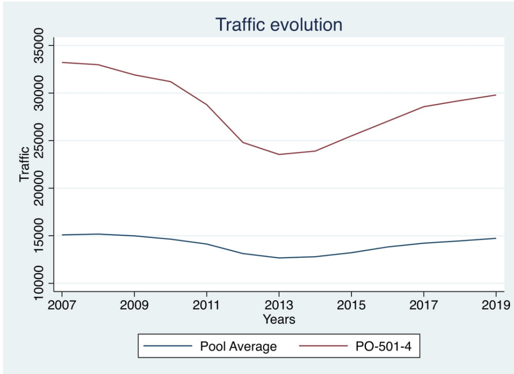



C13 standardized p-values

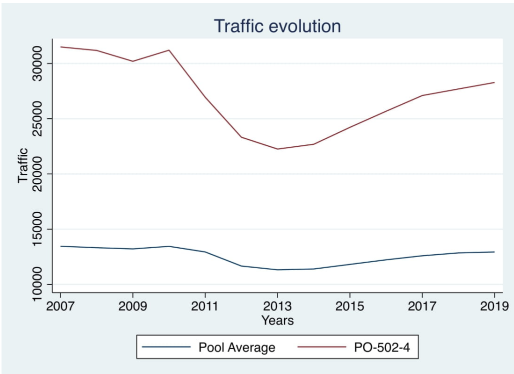
PANEL A3: Standardized p-values per year of traffic stations C12 and C13



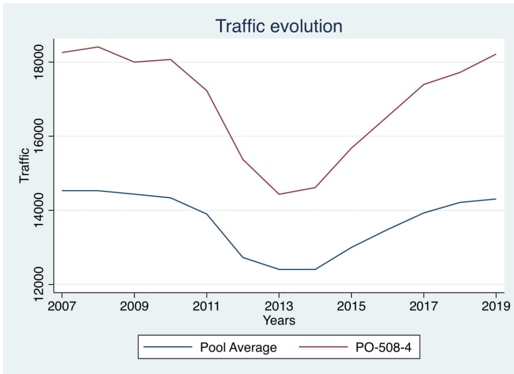

Traffic station C16



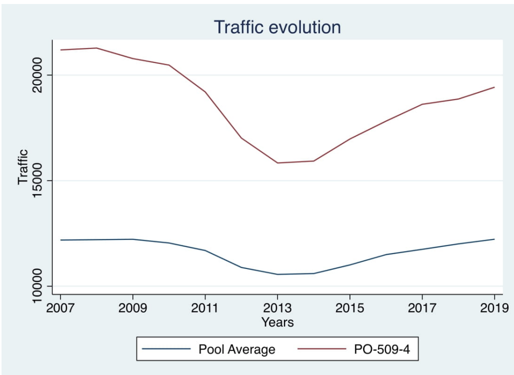

Traffic station P1



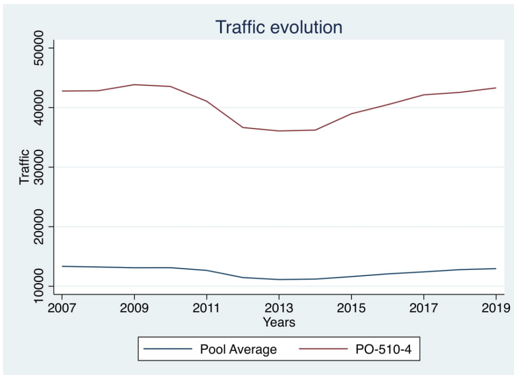

Traffic station P2




Traffic station P8

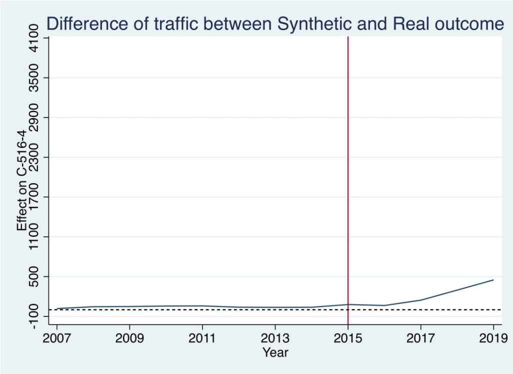



Traffic station P9

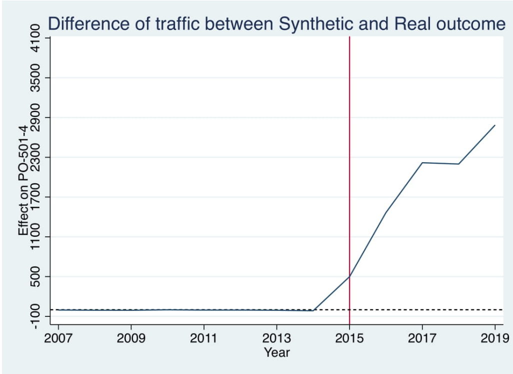



Traffic station P10

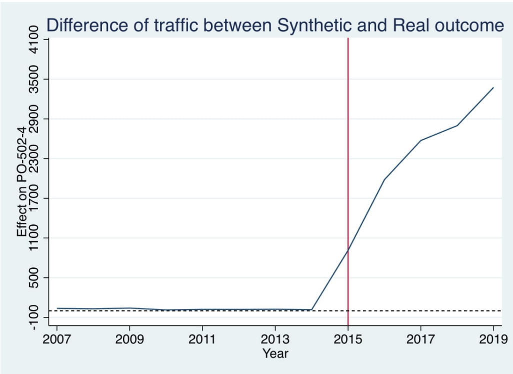
PANEL A4: Evolution of raw traffic



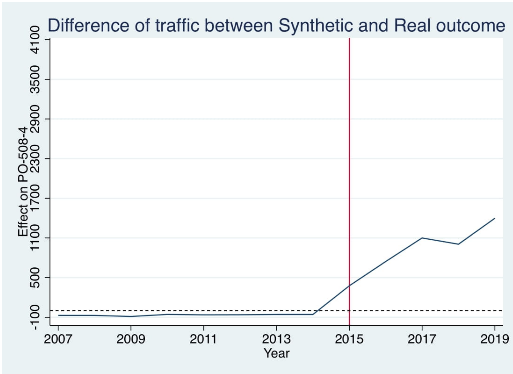

Treatment impact on C16



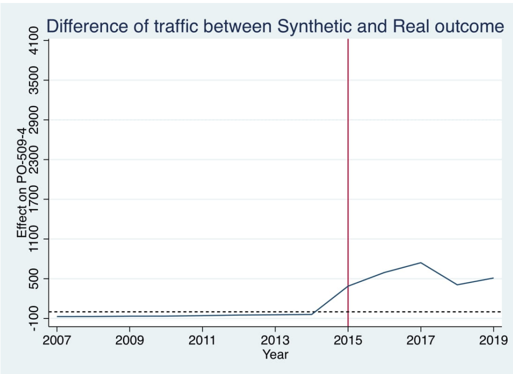

Treatment impact on P1



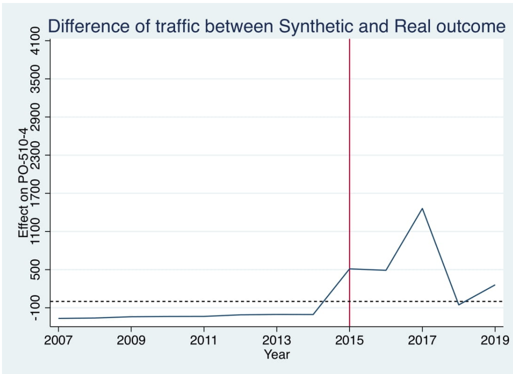

Treatment impact on P2




Treatment impact on P8

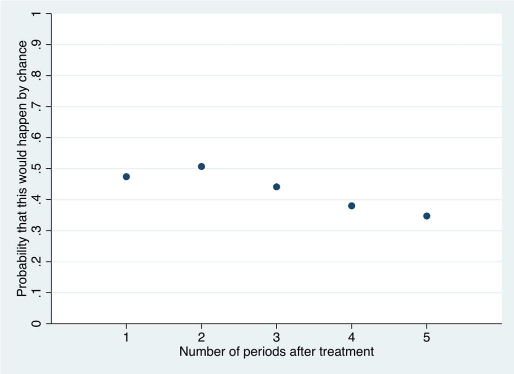



Treatment impact on P9

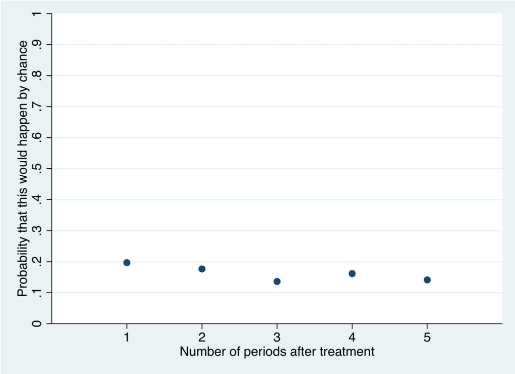



Treatment impact on P10

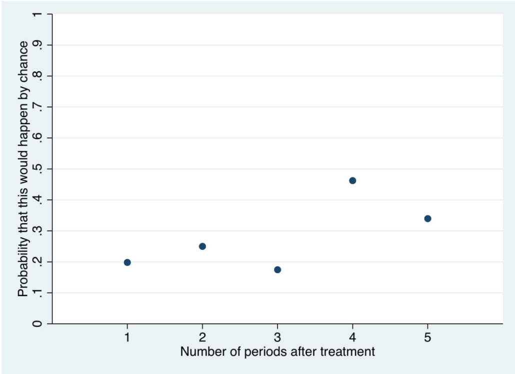
PANEL A5: Difference between real and synthetic traffic




C16 standardized p-values




P8 standardized p-values




P10 standardized p-values

PANEL A6: Standardized p-values per year of traffic stations C16, P8 and P10

## References

Abadie, A. (2021). Using synthetic controls: Feasibility, data requirements, and methodological aspects. *Journal of Economic Literature*, *59*(2), 391–425.

Abadie, A., Diamond, A., & Hainmueller, J. (2010). Synthetic control methods for comparative case studies: Estimating the effect of california's tobacco control program. *Journal of the American statistical Association*, *105*(490), 493–505.

Abadie, A., & Gardeazabal, J. (2003). The economic costs of conflict: A case study of the basque country. *American economic review*, *93*(1), 113–132.

Albalate, D., & Bel, G. (2012). *The economics and politics of high-speed rail: Lessons from experiences abroad*. Lexington Books.

Albalate, D., Bel, G., & Fageda, X. (2015). Competition and cooperation between high-speed rail and air transportation services in europe. *Journal of transport geography*, *42*, 166–174.

Behrens, C., & Pels, E. (2012). Intermodal competition in the london–paris passenger market: High-speed rail and air transport. *Journal of Urban Economics*, *71*(3), 278–288.

Bel, G., Bel. (2011). Infrastructure and nation building: The regulation and financing of network transportation infrastructures in spain (1720–2010). *Business History*, *53*(5), 688–705.

Borsati, M., & Albalate, D. (2020). On the modal shift from motorway to high-speed rail: Evidence from italy. *Transportation Research Part A: Policy and Practice*, *137*, 145–164.

Campos, J., & De Rus, G. (2009). Some stylized facts about high-speed rail: A review of hsr experiences around the world. *Transport policy*, *16*(1), 19–28.

Cao, J., & Zhu, P. (2017). High-speed rail.

Cascetta, E., & Coppola, P. (2015). New high-speed rail lines and market competition: Short-term effects on services and demand in italy. *Transportation Research Record*, *2475*(1), 8–15.

Chao, E., Vuchic, V. R., & Vashchukov, A. (2019). High-speed rail as a new mode of intercity passenger transportation.

Chen, G., & Silva, J. d. A. e. (2013). Regional impacts of high-speed rail: A review of methods and models. *Transportation Letters*, *5*(3), 131–143.

Cheng, J., & Chen, Z. (2021). Socioeconomic impact assessments of high-speed rail: A meta-analysis. *Transport Reviews*, 1–36.

Coto-Millán, P., Inglada, V., & Rey, B. (2007). Effects of network economies in high-speed rail: The spanish case. *The annals of regional science*, *41*(4), 911–925.

Court European Auditors. (2018). A european high-speed rail network: Not a reality but an ineffective patchwork.

De Rus, G., & Inglada, V. (1997). Cost-benefit analysis of the high-speed train in spain. *The annals of regional science*, *31*(2), 175–188.

Ferman, B., Pinto, C., & Possebom, V. (2020). Cherry picking with synthetic controls. *Journal of Policy Analysis and Management*, *39*(2), 510–532.

Givoni, M. (2006). Development and impact of the modern high-speed train: A review. *Transport reviews*, *26*(5), 593–611.

Givoni, M., & Dobruszkes, F. (2013). A review of ex-post evidence for mode substitution and induced demand following the introduction of high-speed rail. *Transport reviews*, *33*(6), 720–742.

González-Savignat, M. (2004). Will the high-speed train compete against the private vehicle? *Transport Reviews*, *24*(3), 293–316.

Grier, K., & Maynard, N. (2016). The economic consequences of hugo chavez: A synthetic control analysis. *Journal of Economic Behavior & Organization*, *125*, 1–21.

Jiménez, J. L., & Betancor, O. (2012). When trains go faster than planes: The strategic reaction of airlines in spain. *Transport Policy*, *23*, 34–41.

Li, L., & Loo, B. P. (2017). Railway development and air patronage in china, 1993–2012: Implications for low-carbon transport. *Journal of Regional Science*, *57*(3), 507–522.

Martín, J. C., & Nombela, G. (2007). Microeconomic impacts of investments in high speed trains in spain. *The Annals of Regional Science*, *41*(3), 715–733.

Munasib, A., & Rickman, D. S. (2015). Regional economic impacts of the shale gas and tight oil boom: A synthetic control analysis. *Regional Science and Urban Economics*, *50*, 1–17.

Nan, H., & Li, J.-t. (2018). Highway passenger travel demand forecasting incorporating relationships among travel modes. *Journal of Highway and Transportation Research and Development*, *12*(3), 90–96.

Otsuka, A. (2020). Assessment of the improvement in energy intensity by the new high-speed railway in japan. *Asia-Pacific Journal of Regional Science*, 1–16.

Román, C., Espino, R., & Martin, J. C. (2007). Competition of high-speed train with air transport: The case of madrid–barcelona. *Journal of Air Transport Management*, *13*(5), 277–284.

Vickerman, R. (1997). High-speed rail in europe: Experience and issues for future development. *The annals of regional science*, *31*(1), 21–38.

Westin, J., & Kågeson, P. (2012). Can high speed rail offset its embedded emissions? *Transportation Research Part D: Transport and Environment*, *17*(1), 1–7.

Xia, W., & Zhang, A. (2016). High-speed rail and air transport competition and cooperation: A vertical differentiation approach. *Transportation Research Part B: Methodological*, *94*, 456–481.

Zhang, Q., Yang, H., & Wang, Q. (2017). Impact of high-speed rail on china's big three airlines. *Transportation Research Part A: Policy and Practice*, *98*, 77–85.