APPLICATION NOTE

Evaluating the Causal Economic Impacts of Transport Investments: Evidence from the Madrid-Barcelona High Speed Rail Corridor. Supplementary Materials

Jose M. Carbo[a], Daniel. J. Graham[a], Anupriya[a], Daniel Casas[a] and Patricia C. Melo[b]

[a]Department of Civil Engineering, Imperial College London, London, SW7 2AZ, UK; [b]ISEG, University of Lisbon, Portugal

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1. Economic impacts of transportation

The economic impacts of transport have been investigated in numerous theoretical and empirical studies over many years [for reviews see 17, 19, 22]. The general consensus is that transport improvements can induce positive changes in the economy. The majority of work has considered the impacts of road and rail investments, where positive economic outcomes are thought to arise via the location of economic activity [19], the demand for skills [18], trade patterns [9, 10], urban growth and market access [4, 11], and via positive benefits from agglomeration economies [13, 21]. The spatial distribution of economic impacts from transportation has also been studied, with seemingly conflicting evidence from different empirical contexts [e.g. 5, 6, 8, 12, 14].

A small number of studies have specifically sought to evaluate the effect of HSR on economic performance [for a review see 7]. There are three studies of particular relevance to the work we conduct here as they have made explicit attempts to address causality. First, Lin [15] used a DID approach to quantify the effect of China's HSR on employment at the city level, and found a significant and positive effect of 7%. Second, Shao et al. [20] used a DID model to evaluate the effect of Chinese HSR on urban service industry agglomeration, and showed a positive effect on the cities located along HSR lines. Third, Ahlfeldt and Feddersen [2] used both DID and SCM to examine the effect of HSR on GDP in Germany and estimated an ATE of 8.5% on the GDP of the intermediate stops on the HSR line connecting Cologne and Frankfurt.

Although Spain has the largest HSR network in Europe, and the second largest in the world, the economic impacts of HSR have not yet been systemtically investigated. The two exitsing causal papers that have studied HSR in Spain have concentrated on impacts on tourism [3] and passenger movements Martí Henneberg [16]. To the best of our knowledge, our paper is the first to document causal evidence of economic impacts for this major HSR network. Our identification strategy, based on DID and SCM for incidental locations, is similar to the one used by Ahlfeldt and Feddersen [2], but we apply these approaches to a new dataset and analyse and compare the effects of HSR

CONTACT Daniel. J. Graham. Email: d.j.graham@imperial.ac.uk

on a number economic outcomes including numbers of firms, employment, GDP and labour productivity.

2. The Madrid-Barcelona high speed rail corridor

The Spanish HSR network was inaugurated on the 14th April 1992, connecting Madrid with Seville to coincide with the 1992 Universal Exposition of Seville. This first HSR network comprised 471 km of route. Since then, the network has expanded to a total of 3,240 kms, becoming the largest HSR network in Europe and second largest in the world after China. This vast infrastructure is shown in figure 1. The red line shows routes constructed by 2016, while the blue lines represent future planned routes. At the time of writing, Madrid is connected to Barcelona (2008), Valencia (2010), Alicante (2013), Leon (2015) and Zamora (2015). It is expected to be connected to Galicia by 2019, and to the Basque country by 2023.

In this paper we focus our analysis on the HSR line between Madrid-Barcelona, which is highlighted in figure 2. This corridor was implemented in phases as summarized in table 1. The link between Madrid and Lleida was inaugurated in late 2003, for speeds of up to 200 km/h, and increased to over 250km/h in late 2006 to coincide with the inauguration of the extension to Tarragona. This first stage provided HSR services to the provinces of Guadalajara, Zaragoza and Lleida. The connection between Zaragoza and Huesca opened in 2005, and the HSR corridor reached Barcelona on the 20th February 2008. The link was then extended to Girona in January 2014, which had previously been connected to Figueres and France. This was the last stage of the Madrid-Barcelona corridor, connecting Spain to France through HSR. In this paper we will focus on developments up to 2014, so we do not analyze the effect of the last extension of the line, the corridor between Barcelona and Girona.

The introduction of HSR between Madrid and Barcelona had a significant effect on the number of passengers. In figure 3 we show the evolution of train passenger numbers from Madrid in the treated provinces using 2000 as a reference year[1]. The data are obtained from the Observatorio del Ferrocarril en España. Figure 3 shows that the treated provinces experienced a large and positive shock in passenger numbers following implementation of HSR. Lleida and Zaragoza received the HSR service in late 2003, and the trend changed immediately afterwards, especially in Lleida. By 2006, passenger numbers in Lleida were 6 times higher than in 2000. Tarragona and Barcelona also experienced an impressive increase in passengers following the introduction of HSR (late 2006 and early 2008 respectively). By 2009, passenger numbers from Madrid were 6 times higher in Tarragona and 5 times higher in Barcelona than they were in the year 2000. This provides evidence of substantial changes in transportation patterns arising due to introduction of the HSR line.

[1]We do not include two of the treated provinces, Guadalajara and Huesca, since data is not available. The increase in numbers of passenger for those two provinces is believed to be negligible. Still, we keep those provinces in the DID specification, since there could be significant effects derived from the construction of the stations.

Province	HSR Implementation
Madrid	Late 2003, enhanced in late 2006
Guadalajara	Late 2003, enhanced in late 2006
Zaragoza	Late 2003, enhanced in late 2006
Lleida	Late 2003, enhanced in late 2006
Huesca	2005
Tarragona	Late 2006
Barcelona	Early 2008
Girona	Early 2013

Table 1.: Summary of HSR Madrid-Barcelona corridor implementation phases (Adapted from Adif, 2016)

Figure 1.: Representation of active and planned HSR networks in Spain in 2016 (Adif, 2016)

Figure 2.: Representation of Madrid-Barcelona corridor (Adif, 2016)

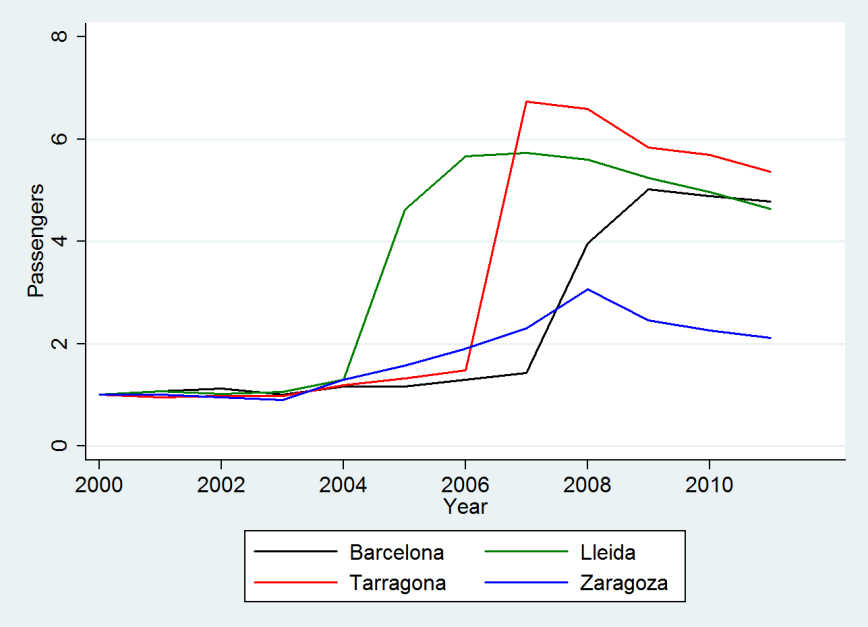

Figure 3.: Growth in number in passengers from Madrid

3. Supplementary analyses

Since the SCRs are trained to fit the behaviour of the treated provinces in the pre-treatment period, we expected a bigger gap between the treated province and its SCR after treatment. We found a considerable gap between Lleida and Tarragona and their synthetic analogues. But how significant are these differences? In order to answer this question, following Abadie et al. [1], we applied the SCM to all the control provinces available. This allows us to compare our analysis with a large number of placebo provinces. If the gaps in number of firms and labour productivity for Tarragona and Lleida are larger than the gaps for the placebo provinces, then this robustness check will provide significant evidence of the effect of HSR in Lleida and Tarragona. Figures 4 and 5 plot the difference in GVA per employee and number of firms between all provinces and their synthetic counterparts. Orange lines represents the difference between Lleida and Tarragona and their synthetic analogues. The gray lines represent the differences between each one of the available controls and their synthetic provinces. These differences are not exactly the same in the cases of Lleida and Tarragona for two reasons. First, Tarragona is excluded in the analysis of Lleida, and vice versa. Consequently, SCRs for control provinces that depend on Tarragona or Lleida would behave differently. Second, the treatment year for Lleida is 2003, and for Tarragona 2007. Therefore, the SCRs provide a slightly different fit.

Most of the SCRs provide an acceptable fit for GVA per employee and number of companies prior to 2003 (figure 4) and prior to 2007 (figure 5). Fits for Lleida and Tarragona are among the closest. After 2003 and 2007, the percentage difference between provinces and SCRs increase for all provinces. In the case of Lleida, figure 4, by 2008 the positive effect on GVA per employee is the largest, and in number of firms, the second largest. In the case of Tarragona (figure 5) by 2013 the positive effects on GVA per employee and in number of firms are among the three largest of all. We take this result as supportive of the robustness of our findings, especially in the case of Lleida.

(a) Percentage gap, GVA per employee (b) Percentage gap, number of companies

Figure 4.: Lleida vs placebo provinces

In table 2 we show the characteristics of synthetic Lleida and synthetic Tarragona when the variable of interest is GVA per employee. The controls have been averaged between 1995 and 2002 for Lleida, and between 1998 and 2006 for Tarragona. The results are very similar to those displayed in table 3 in the main paper.

(a) Percentage gap, GVA per employee (b) Percentage gap, number of companies

Figure 5.: Tarragona vs placebo provinces

	Lleida	Synth for Lleida	Tarragona	Synth for Tarragona	Rest of controls
Companies	28472	41179	47548	35027.4	33457
GVA per capita	32119.49	31753.17	43156.13	43073.62	35122.98
Investment	27.68%	25.66%	33.03%	26.87%	28.80%
Education	09.31	08.83	09.53	09.97	09.18
Agriculture	10.71%	10.34%	02.61%	03.51%	07.30%
Construction	10.76%	09.41%	10.62%	08.24%	08.81%
Industry	13.76%	11.75%	22.2%	25.95%	18.74%
Services	55.55%	57.08%	53.26%	57.4%	55.42%
Avg compensation	23105	22321	25897	26322	22036

Table 2.: GVA per employee

4. Spillover effects

As pointed out in the main paper, our data do not allow us to distinguish between relocation and net firm creation. What we can do, however, is compare the evolution of the number of firms in Lleida and Tarragona with that for adjacent provinces that did not receive the HSR service. Figure 6 below shows the Madrid-Barcelona corridor with the main stops. We highlight in orange both Lleida (HSR service since 2003) and Tarragona (HSR service since December 2006). In blue, we highlight the three adjacent provinces without an HSR service in the period 1999-2012: Castellon, Teruel and Girona. Figure 7 shows the evolution in the number of firms for both Lleida, Tarragona, and the three adjacent provinces. The number of firms has been normalized to the value for 1999.

The data indicate that there may have been a negative spillover effect in Girona, since immediately after 2003, the number of firms fell, and this could indicate a relocation effect to the treated provinces. Girona belongs to the same autonomous region as Lleida and Tarragona (Catalonia), and this may be relevant for the relocation of firms among these regions due to historical and institutional ties. However, we must stress again that we cannot conclude anything concrete on relocation with the available data, since it is simply impossible to know if the observed changes in figure 2 are due to relocation or firm creation.

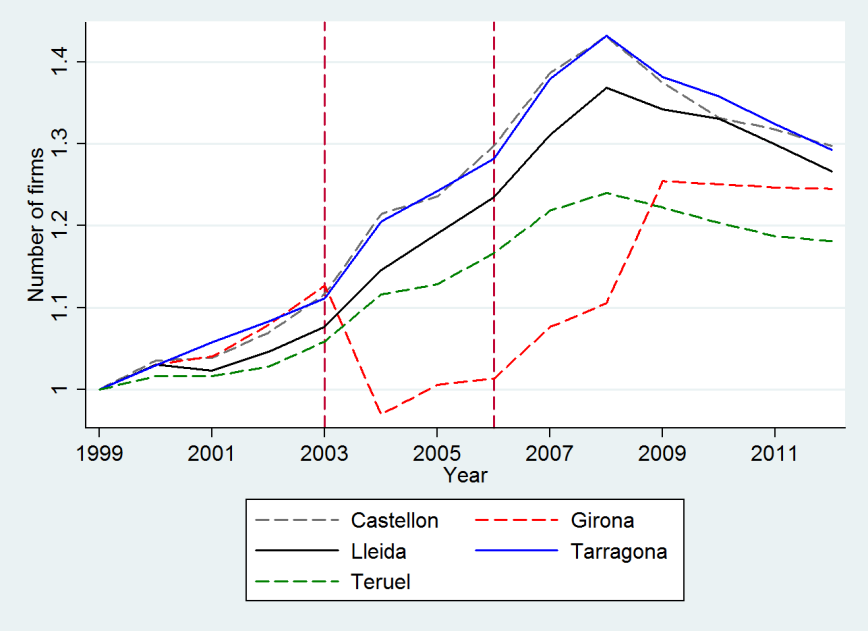

Figure 6.: Representation of Madrid-Barcelona corridor

5. Comparing the DID and SCM results

To compare the results of our DID and SCM analyses we have performed a DID with only Lleida and Tarragona as treated provinces. The results are shown in table 3 below. We find that the number of firms and GVA per employee are 3.5% and 4.4% higher in Lleida and Tarragona than in the controls. These estimates are greater than the ones

Figure 7.: Evolution of number of firms

we obtained when considering all the intermediate stops (2.8% and 2.1%).

In order to directly compare the results from SCM and the DID analyses, we have computed the average difference between Lleida and its synthetic region from 2003 to 2014, and between Tarragona and its synthetic region from 2007 to 2014. These differences are displayed in figures 1b, 2b, 3b and 4b of the main paper. The average difference between Lleida and Tarragona and their synthetic regions after treatment in the number of firms are 4.7% and 3.4% respectively. These two estimates are very similar to the result obtained with DID, 3.5%. On the other hand, the average difference between Lleida and Tarragona and their synthetic regions after treatment in GVA per employee are 7.5% and 2%. We must take into account that the difference between Lleida and its synthetic region is already 2.5% before treatment (e.g. 2002). Similarly, the difference between Tarragona and its synthetic region is -2.2% before treatment (e.g. 2006). If we adjust for these differences, the estimated average difference between Lleida and Tarragona and their synthetic regions in terms of GVA per employee are 5.1% and 4%. Again, these values are very similar to the estimate obtained using the DID method of 4.4%.

Table 3.: Summary of DID regression results for Lleida and Tarragona.

Variable	log (avg. GVA per employee)	log (no. of employees)	log (GVA)	log (no. of companies)
DID	0.0436***	-0.0065	-0.0035	0.0349***
	(0.0125)	(0.0169)	(0.0126)	(0.0120)
GDP share: service sector	-0.0703	-0.1352	-0.0738	-0.3907**
	(0.0831)	(0.1022)	(0.0896)	(0.1547)
GDP share: industry sector	0.3551***	-0.7632***	0.6829***	-0.1207
	(0.0838)	(0.1113)	(0.1489)	(0.1355)
GDP share: construction sector	-0.6869***	0.5601**	0.4207	-0.0028
	(0.2240)	(0.2405)	(0.2658)	(0.2051)
log(active population)	-0.1393***	0.3345***	0.1977***	0.4046***
	(0.0373)	(0.0441)	(0.0426)	(0.0361)
log(avg. years of education)	-0.0538	0.1619*	-0.0943	0.0933
	(0.0816)	(0.0959)	(0.0924)	(0.0761)
log(gross fixed captial formation)	-0.0386**	0.0341*	-0.0065	0.0594***
	(0.0152)	(0.0188)	(0.0180)	(0.0155)
log(avg. compensation per employee)	0.6737***	0.4332***	0.0359	0.1004
	(0.1317)	(0.1631)	(0.1383)	(0.2148)
Region dummies	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES
N	285	418	228	298
R square	0.9798	0.8887	0.9930	0.8950

1. Figures in brackets denote the standard errors associated with the estimates.
2. Significance: (***) 99 percent, (**) 95 percent, (*) 90 percent.

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