Regional infrastructure investment and efficiency

Anna Matas[a,c], Josep-Lluis Raymond[b,c] & Adriana Ruiz[a]

[a]Departament Economia Aplicada, Universitat Autònoma de Barcelona

[b]Departament d'Economia i Història Econòmica, Universitat Autònoma de Barcelona

[c]Institut d'Economia de Barcelona

Email: anna.matas@uab.cat josep.raymond@uab.cat adrianaruiz2005@gmail.com

This is a postprint version of the article: Regional infrastructure investment and efficiency, Regional Studies, vol.52, 1684-1694. https://doi.org/10.1080/00343404.2018.1445845

Abstract: Using Spanish data, this paper shows that improvements in the road network have a positive effect on private investment in capital assets, and this effect increases with the level of economic development of a geographical area. We use aggregate data at the provincial level between the years 1977–2008. Additionally, we propose a system of equations in order to approximate the long-run effects. We find statistical evidence of efficiency loss associated with the distributional aims of the infrastructure policy. More importantly, since the effects of infrastructure investment are permanent, in the long run, efficiency costs will be higher.

Keywords: Road infrastructure, Regional investment, Market potential

JEL: R4, R11, R1

INTRODUCTION

In recent decades, there has been much interest in quantifying the economic benefits of transport infrastructure on national, regional and municipality levels. Overall, the consensus seems to be that investment in infrastructure has a positive impact on economic development, yet the magnitude of this effect is still uncertain. The literature provides a wide interval of values that range from almost negligible effects to substantial positive effects. The disparity in the size of the impacts can be related to multiple causes, which include the definition of economic activity, the type of data and econometric strategy used, and also the type of infrastructure, the initial stock of the infrastructures and the characteristics of the area that benefits from the investment. In this regard, Melo et al (2013) carry out a meta-analysis focused on the effect of transport infrastructure on economic output, whereas Bom and Ligthart (2014) examine the impact of total public capital on productivity.

The objective of this paper is to contribute to the literature by providing evidence of the differential impact of an investment in road infrastructure with respect to the level of economic development of a region.

The impact of transport infrastructure on economic development can be analysed from different perspectives. The traditional approach considers that physical, human and public capital are complementary. In this way, infrastructure investment increases the stock of public capital and contributes to an increase in total output. From the New Economic Geography (NEG) perspective, an investment in infrastructure reduces travel costs and, hence, improves accessibility to input and output markets. As a consequence of broader markets, firms can take advantage of economies of scale, which in turn stimulate competition and result into higher productivity through a selection effect favouring the most productive firms. Furthermore, an area with better transport infrastructure increases its attractiveness as a location for new firms, which reinforces the concentration of economic activity and, consequently, the productivity gains derived from agglomeration economies (Graham, 2007; Combes and Gobillon, 2015).

Given the evidence concerning the positive effects of infrastructure on economic development, public investment has become a significant instrument of regional policy. On the one hand, investment in infrastructure raises the stock of public capital and, in this way, compensates for a lower endowment of private capital in less developed regions while, at the same time, increasing the attractiveness for new private investment in these regions. On the other hand, an improvement in infrastructure will reduce transport costs and accordingly improve accessibility to markets of less favoured regions. Nonetheless, the distributional aim of the regional policy may have a cost in terms of efficiency. As long as the economic benefits of an infrastructure investment are higher in more developed regions, investments based on distributional grounds will lead to a lower output increase for the whole economy.

Evaluating the efficiency costs of the Spanish infrastructure investment policy is a relevant issue, since the available evidence suggests that public investment has had an excessive distributional bias (see, de la Fuente, 2004; Castells and Solé-Ollé, 2005; Solé-Ollé, 2010). Nonetheless, Solé-Ollé (2010), analysing the time span between 1964 and 2010, shows that the intensity of the redistribution effect has not been constant and political variables, among others, also played a role. Castells et al (2006) estimate an efficiency cost of the spatial distribution of public investment between 2.4% and 4.8% of GDP, depending on the assumption about output elasticity with respect to capital stock. They conclude that, although the loss of efficiency derived from the spatial distribution of the public investment is relatively moderate, the results suggest that if the degree of redistribution observed in the eighties had remained constant over time, the efficiency loss would have been noticeable. In contrast, Albalate et al (2012) provide evidence that centralization objectives may have an influence on regional investment that extends beyond that of the efficiency-equity trade-off.

The work by de la Fuente (2004) and Castells et al (2006) approximates the relative return on public investment using the observed average product of infrastructure in each region under the hypothesis that the output elasticity with respect to the stock of capital is the same for all the regions. Our work contributes to this literature by estimating a different response of private investment to changes in the road connectivity of the Spanish provinces measured in travel time. When road connectivity increases, the response of private investment tends to be higher in more affluent provinces than in poorer provinces.

We analyse the economic benefits of an infrastructure investment through its effect on private investment in capital assets. Since private investment plays a key role in economic growth, we measure the impact on this variable as a way to approximate the potential for the economic growth of the different geographical areas.

Taking advantage of the rich dataset provided by the Fundación BBVA and the Valencian Institute of Economic Research (IVIE), we use aggregate data on private investment for 46 Spanish peninsular provinces (NUTS-3) across the period 1977–2008. Among the determinants of investment, we are interested in the effect of transport infrastructure. In this regard, we focus on road transport. We select road infrastructure first, because it is the main transport mode in Spain. According to official statistics, 91% of passenger transport and 84% of freight transport are by road. Secondly, the road network represents around 60% of total transport infrastructure capital stock. It is significant to note that our time span covers the period with the highest investment flows into the road network in

Spain. To give an example, the motorway network evolved from a rather short span of 1,753 kilometres in 1977 to one of the lengthiest in the European Union at 13,518 km in 2008.

As a second contribution of this paper, we propose a system of equations that approximates the long-run impact of an improvement of road transport on total output (GDP) by allowing for second-round effects. Specifically, we define a four-equation system that simulates the impact of a decrease in travel time through an improvement in accessibility and its corresponding increase in private investment, which, in turn, increases the capital stock of the province and, through the aggregate production function, increases output. By simulating the effect over a time span of 12 years, we approximate long-run effects.

The remainder of the paper is organised as follows. The second section discusses the related literature for Spain. The third section develops the conceptual framework of the research. The fourth presents the data with special emphasis on the changes in the road network. The fifth reports the econometric strategy and the estimation results. The following section analyses the long-term impact of road infrastructure on output and a final section concludes the work. Additionally, Appendix A presents complementary tables and figures, and Appendix B offers a robustness check in relation to the definition of market potential.

RELATED LITERATURE FOR SPAIN

We focus on research directly related to our work that uses Spanish data. First, we report evidence on the studies that analyse the effect of public infrastructure on private investment. Second, we review the research that uses aggregated panel data, similar to our study, to estimate the impact of infrastructure on output. Finally, because our research focuses on the road network, we also review those papers that employ microdata to analyse the effect of road accessibility on economic activity. A summary of all the papers reviewed can be found in Table A1 in the Appendix A.

The efforts of two institutions—Fundación BBVA and IVIE—have made available a rich set of data on provincial macroeconomic variables, as well as on the stock of public and private capital since the mid-60s. Their work has boosted extensive research on quantifying the effects of public capital, in particular of transport infrastructures, on the level of economic activity of Spanish regions (NUTS-2) and provinces (NUTS-3).

In this regard, the availability of data on private investment at the regional level has made it possible to study the role played by the endowments of different types of capital at the regional level on private investment. Escribá and Murgui (2008) study the location of manufacturing investment in the 17 Spanish regions between the years 1965–2000. Regional wages and the stock of human capital appear as the main determinants of the investment location. Likewise, transport infrastructure has a positive effect on regional investment. Moreover, this effect is more important on those regions with a long manufacturing tradition. Therefore, infrastructures would contribute to reinforcing agglomeration trends. In a later work, Escribá and Murgui (2009) estimate a manufacturing investment equation distinguishing among 12 branches of industrial activity for the 17 Spanish regions from 1980–2000. They confirm that regional transport infrastructure endowment and regional human capital have a positive impact on the investment rate in regional manufacturing companies. Finally, Escribá and Murgui (2011) also find a positive effect for the stock of public capital on infrastructure when they extend their research to include the non-manufacturing sectors of the economy.

Regarding the studies that analyse the impact of infrastructures on economic activity using panel data formed by the Spanish regions or provinces, de la Fuente (2010) and Boscá et al (2011) provide an extensive literature review[i]. The main conclusions that emerge from these studies can be summarised as follows: First, most of the studies report a positive and significant impact of infrastructure investment on output. In general, the magnitude of such an effect is higher than that estimated in other countries. Second, the estimated coefficients tend to gradually decrease as more recent temporal observations are added to the sample period. For instance, Mas et al. (1996) estimate an elasticity of 0.140 when the sample period is restricted to the years between 1964–1973, while it decreases to 0.077 when the sample period is extended to 1991. A possible explanation for this result is that elasticity tends to fall as the stock of infrastructure increases. Since the stock of public capital was smaller in Spain than in other countries until the mid-nineties, this hypothesis would also be consistent with the higher elasticities found for Spain. Third, the review points out a great disparity in the estimations of output elasticity with respect to the stock of public capital. In this regard, the evidence provided in Table A1 shows a range of variation for output elasticity between 0.02 and 0.25. Boscá et al (2011) suggest that elasticities increase when the measure of elasticity is restricted to productive infrastructure and when the productive capital of neighbouring regions is included (spillover effects). Conversely, lower values are obtained when the estimated equation controls for other relevant variables and for the economic cycle. These authors consider that a reasonable interval for the output elasticity with respect to public capital would lie between 0.05 and 0.10.

Additionally, output elasticity also varies for different types of infrastructures. As a general result, the highest effect is found for road transport (see Cantos et al, 2005 and Arbués et al, 2015). However, Fageda and González-Aregall (2017) find that the direct positive effects of motorways are compensated for by a negative effect of the same magnitude in other nearby regions.

Additionally, we have reviewed whether the existing literature distinguishes among the economic characteristics of the regions. In this regard, as far as we are aware, only de la Fuente and Doménech (2006) provide some empirical evidence. They conclude that the impact of infrastructure tends to be highest on the richest and more productive regions.

In the context of studies that evaluate the impact of the changes in the road network from a micro-perspective, Holl (2012) finds an output elasticity of manufacturing firms with respect to market potential around 0.045. Matas et al (2015), taking wages as a proxy for productivity and measuring accessibility according to effective density, estimate an elasticity around 0.06 with some evidence of a decreasing trend in elasticity over time. Martín-Barrosso el al (2015), compute firms' accessibility to workers and to commodities by integrating into the traditional definition of market potential the individual characteristics of both workers and firms. Their findings show a value of elasticity of firm productivity with respect to commodities of around 0.14, whereas the elasticity with respect to employment ranges between 0.024–0.059. Unlike previous research, Holl (2016) uses the distance between each firm and its nearest access to highways to measure the impact of motorways on firm-level productivity. After controlling for agglomeration effects, she finds an elasticity of firm productivity with respect to highway access to be in the range of 0.013–0.017.

CONCEPTUAL FRAMEWORK

We estimate an investment equation as a function of the determinants of local investment decisions. Therefore, our goal is not to explore the determinants of total investment, but rather, where investment flows tend to locate and why. In this regard, the location of investment can be analysed in the context of firm location,[ii] as Brown et al (2009) do.[iii] These authors analyse the factors influencing the investment flows in US manufacturing industries. They find a positive impact associated with the kilometres of interstate highway network after controlling for local agglomeration economies, market size, labour productivity, and fiscal policy.

The most common assumption in the literature regarding firm location is that firms choose locations that maximise their expected benefits. The profit of a firm in location *i* is as follows:

$$\pi_i = \pi_i(z_i)$$

where z_i is a vector of location characteristics. Those characteristics should approach location determinants. These can be grouped in the following way:

First, investment will be a function of factor supply conditions. In this regard, we consider two variables related to the labour market: human capital supply and labour costs. Several studies provide evidence of the increasingly important role of human capital when analysing location decisions (Combes et al, 2011). With respect to unit labour costs, there is empirical evidence that these costs have a negative impact on business location decisions (Coughlin and Segev, 2000).

A second group of determinants are provided by agglomeration economies derived from the spatial concentration of total economic activity (urbanization economies). In this respect, agglomeration economies have been extensively documented in the literature as one of the most important determinants of production location decisions (Ciccone and

Hall, 1996; Rosenthal and Strange, 2001). Consequently, agglomeration economies are expected to be a factor in attracting firms and investments to regions.[iv]

Additionally, it is common to include a measure of the economic diversification of a region. In our case, in preliminary estimations, we include the inverse of the Herfindahl index defined in terms of employment as a measure of the economic diversification of the region. However, this variable was not significant in any of our estimated equations nor did it have any noticeable effect on the remaining estimated coefficients. Moreover, since our dependent variable corresponds to the private investment by all sectors of the economy, the effect of the diversification is uncertain. Therefore, based on the above reasoning, we do not include this variable in the final estimations.

Finally, transport costs and accessibility are important determinants of location decisions. Combes et al (2008) maintain that the attraction of a location depends both on the relative size of its market and on the capacity and quality of its transport network to connect areas. A large number of empirical studies support the positive impact of transport infrastructure on location decisions. Restricting the evidence to the Spanish case, we may cite Holl (2004) and Alañón et al (2007).

In this research, we use a measure of market potential to approximate the improvements in the road network. As is known, market potential reflects both the agglomeration and the accessibility effects. Therefore, the estimated coefficient for this variable has to be interpreted accordingly.

Consequently, according to location theory and empirical evidence, the flow of investment in province *i* and period *t*, I_{it}, will depend on the stock of human capital (HC), the unit labour cost (ULC) and the market potential (MP). We also include provincial fixed effects and period fixed effects. Provincial fixed effects account for those nonobservable factors that do not vary over time but have an effect on investment location decisions, such as first nature forces like the geographic and climatic conditions of each province. By including time effects, we control for the common shocks, which have affected all provinces over time, thereby capturing factors such as the economic cycle or the monetary policy.

The corresponding equation is presented as:

$$I_{it} = f(HC_{it}, ULC_{it}, MP_{it}, \alpha_i, \gamma_t) \quad (1)$$

DATA

In order to analyse the effect of road infrastructure on investment decisions we use aggregated data at a provincial level (NUTS-3) between the years 1977–2008. Given that the focus is on road transport, the Canary Islands and Balearic Islands are excluded from the analysis. Additionally, we exclude the province of Guadalajara, since data on investment for that province was unreliable.[v] The final sample is composed of 46 provinces observed over a period of 32 years. While data on travel time are not available after 2008, after this year no major investment in the road network was made. Hence, our study covers most of the improvements in the motorway system.

Our dependent variable corresponds with the gross fixed capital formation in machinery and equipment defined according to the European system of accounts (ESA). Provincial data on investments are available from the Fundación BBVA-IVIE, which provides detailed information on investments by asset type and activity. On average, investment in machinery and equipment represents 25% of the total investment in fixed assets and includes transport equipment, ICT equipment and other machinery and equipment.[vi] We focus on private investment in all sectors of activity. Investment carried out by the public sector is excluded since it may be driven by criteria other than profit maximization.

Table 1 reports the summary of statistics for all the variables in the estimated equation. From 1977–2008, investment grew at a cumulative annual rate of 3.7%, following a clear cyclical pattern. So, while from 1977–1995 the annual rate of growth was 1.6%, it rose to 6.8% from 1995–2008. It is well known that over the latter period the Spanish economy faced a long period of intensive growth. Table A2 shows the amount of investment at the provincial level for the first and last years in the sample.

Regarding the determinants of private investment, the main variable of interest is road accessibility. We base the measure of accessibility on the concept of market potential, which is defined as follows:

$$market\ potential_i = \sum_j \frac{M_j}{C_{i,j}^{\alpha}} \quad (2)$$

where M_j reflects the economic mass of province j; $C_{i,j}$ is the travel costs between provinces i and j, and α is a distance decay parameter. This measurement corresponds to the sum of the economic mass in all provinces j, including the own area[vii]. In this way, we capture both the effect of external demand and the size of the own province (local demand).

Market potential offers two main advantages compared with alternative measures of accessibility to markets by road. On the one hand, improvements in the road network can be easily incorporated through changes in travel costs. On the other hand, since market potential is not bound by administrative limits, it explicitly takes into account spatial externalities across neighbouring provinces and, in so doing, reduces the potential for biased results in the econometric estimation (Combes et al, 2008). In this way, market potential can partially account for the potential existence of spillover effects when working with regional data.

Table 1. Descriptive statistics for the main variables in the study

	Mean	Std. Dev.	Minimum	Maximum
Private investment (thousands of €, 2008)				
1977	468,455	556,910	41,557	3,193,424
1995	624,903	898,877	63,837	4,984,175
2008	1,473,012	2,293,580	168,062	13,252,169
Market potential (according to GDP)				
1977	2,056,196	497,529	1,355,065	3,222,558
1995	3,439,084	787,766	2,186,018	5,449,670
2008	5,640,289	1,210,777	3,800,752	8,766,614
Average time between provinces (minutes)				
1980	335.3	156.2	30.6	737.6
1995	302.2	138.6	28.2	699.3
2008	283.7	128.0	27.6	641.3
Average years of schooling				
1977	6.4	0.6	5.5	7.7
1995	8.5	0.6	7.5	9.8
2008	9.8	0.6	8.4	11.1
Real Unit Labour Cost				
1977	0.58	0.07	0.44	0.76
1995	0.61	0.06	0.49	0.81
2008	0.57	0.06	0.45	0.76

Transport costs between provinces are approximated through actual travel time costs. The travel time matrix ($time_{ij}$) is constructed according to the minimum travel time route observed between provincial capitals, taking into account the type of road, distance and speed. Since changes in the road network over the span of two consecutive years are quite small, we divide the sample period into five-year intervals and construct the time matrices for the central year of each of them. Then, we compute the market potential for each year in the interval using the corresponding time matrix for the central year. For instance, 1980 time data is used to compute market potential for 1977–1982. Nonetheless, in order to account for the most recent changes in the road network, we make an exception for the last years in the sample. Thus, we calculate the time matrices for 2005 and 2007 and use these matrices to compute market potential for the periods 2003–2005 and 2006–2008, respectively. To compute travel times we use the ArcGIS network analyst for the national road network in Spain.

The distance-decay parameter reflects how the effect of market potential attenuates with distance from the source. In accordance with the results of some preliminary estimates, and in line with a large number of papers, including Graham (2007), Holl, (2012), and Combes et al (2011), we assume that this parameter is equal to one. That is, the effect of region j on the market potential of i is inversely proportional to the transport costs between them.

Market potential can increase either by a rise in the GDP or by an improvement in the road network that results in a decrease in travel time. In order to illustrate how investment in road infrastructure has affected market potential in Spain, Figure 1 shows the percentage change in travel time for each province between the years 1977–2008, computed as the sum of travel time from each province to the others. The time reduction ranges from 8.7% for the province with the lowest improvement to almost 20% for the province with the highest. The areas that have benefitted most from the road infrastructure plans are the provinces located in the north-west region, the southern region, Madrid and its adjacent provinces and the southern Mediterranean provinces. On the opposite side, we can find the northern Mediterranean provinces and to a lesser extent, the north of the country.

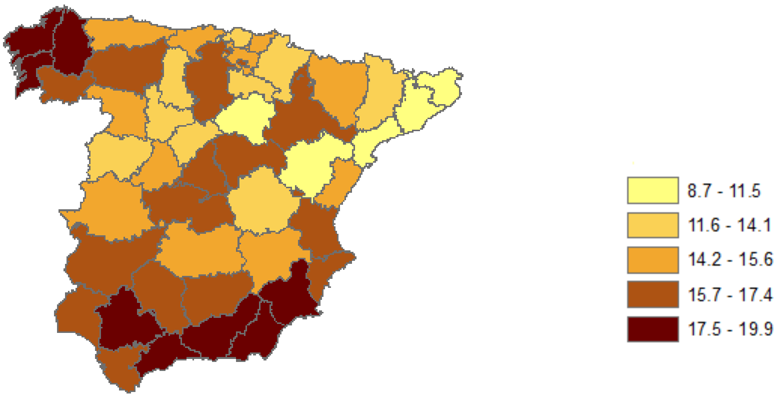

Figure 1. Percentage change in travel time (1977-2008)

It can be observed that the infrastructure investment policy favoured those provinces with lower levels of GDP per capita. Figure 2 plots the negative relationship between reduction in travel time and income per capita in 1980.

The territorial impacts of the road investment policy can be explained both by the location of the high-quality roads at the beginning of the period and by the criteria followed in subsequent investment programmes. In the late seventies, the high capacity network was limited to 1,800 kilometres of toll motorways mostly located along the northern Mediterranean coast and in the Basque Country in the north. From 1983 onwards, several road investment plans were implemented that transformed the Spanish motorway network into one of the highest quality networks in Europe. Essentially, the first investment plan consisted of upgrading to motorways the former two-lane radial network of roads connecting Madrid with other parts of Spain, except for those routes for which an alternative toll motorway existed. In later phases, investment decisions followed spatial cohesion arguments more than economic efficiency criteria. After 1993, investment was directed to the construction of motorways connecting the peripheral areas of Spain and it favoured sparsely populated regions with a low level of infrastructural stock.

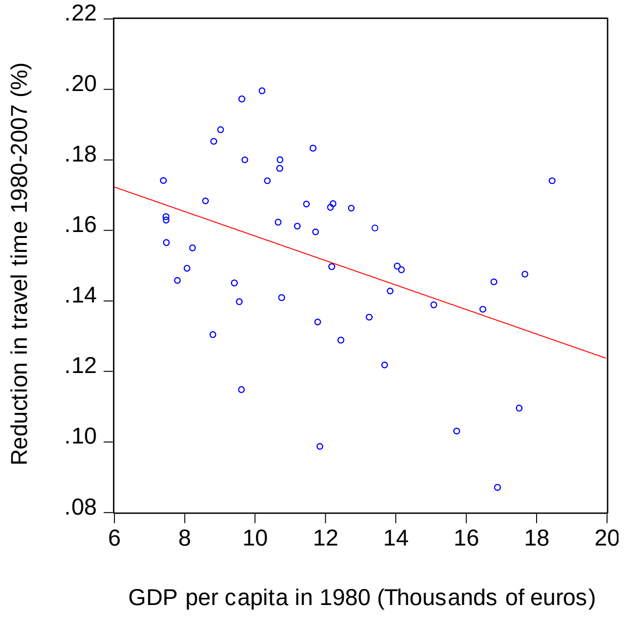

Figure 2. Reduction in travel time vs GDP per capita

The two other variables that are believed to affect investment are human capital and labour costs. Human capital is evaluated by considering the average years of schooling of the working-age population. The data comes from the IVIE database. A greater availability of human capital in a province is expected to have an investment-attracting effect. For the whole sample, the average years of schooling increased from 6.4 in 1977 to 9.8 in 2008, with a noticeable level of dispersion among provinces which was only slightly reduced over time.

Finally, in order to capture the average labour cost per unit of output produced in the province, we calculate the real unit labour costs (RULC). RULC is defined as the ratio between real labour costs per employee and apparent labour productivity (real GVA/employment), considering only the industry and services sectors. The data on labour costs, number of employees, real GVA and employment are obtained from the BBVA database. Since it is expected that high labour costs will deter investment, RULC should have a negative effect on production location decisions. The RULC slightly increased from 1977–1995, returning to its initial value in 2008. Nonetheless, the data show a high level of variability among provinces that remains approximately constant across time.

ECONOMETRIC STRATEGY AND ESTIMATION RESULTS

As previously stated, the aim of the study is to analyse whether the impact of improvements in transport infrastructure on economic activity tends to increase with the level of income of the geographical area that receives the investment. In order to test this hypothesis, we sort the 46 provinces according to the average value of the GDP per capita over the sample period (1977–2008). After that, we form homogeneous groups of provinces under the condition that the GDP per capita of the richest province in each group does not statistically differ from the poorest one using a significance level of 5%. In this way, we form six homogeneous groups of provinces as shown in Table A3 in Appendix A.

The estimated investment equation takes the following form:

$$linvest_{it} = \alpha + \sum_{k=1}^{6} \beta_{1k} lpot_{ikt} + \beta_2 lRULC_{it} + \beta_3 school_{it} + \gamma_i + \phi_t + \varepsilon_{it} \qquad (3)$$

where subscript *i* refers to the province, *k* refers to the group of provinces according to GDP per capita and *t* refers to the year. $linvest_{it}$ is the natural logarithm of the machinery and equipment investment. $lpot_{ikt}$ is the natural logarithm of the market potential. $lRULC_{it}$ is the natural logarithm of the RULC. $school_{it}$ is the average years of schooling. α is the constant term. γ_i and ϕ_t are the provincial fixed effects and the time effects, respectively. ε_{it} is the random disturbance term.

However, to estimate equation (3) we have to address two potential econometric concerns. First, a regression in levels between non-stationary variables may face a problem of “spurious regression.” Second, when estimating the impact of a variable on the level of economic activity, we have to be aware of a potential problem of reverse causation. If this is the case, the correlation between private investment and infrastructure improvement would simply reflect the fact that the public investment in infrastructure accrues to those regions with higher economic dynamism and higher potential growth and, hence, higher levels of private investment.

When working with time series, the econometric literature proves that when the variables are integrated and cointegrated, the ordinary least squares (OLS) estimator of the investment equation will be consistent. Specifically, it will provide consistent estimates of the long-run coefficients that affect integrated variables, even in the case of omission of the dynamic structure of the model or potential endogeneity problems provoked by reverse causation.

In our case, the plot of the series and the results of applying different panel unit root tests to the variables in levels and in first differences (Fig. A1 and Table A4 in the Appendix A), make it possible to conclude that all the variables in the equation, except the real unit labour costs, are integrated of order one. Additionally, from the application of the Kao residual cointegration test, it can be concluded that there is sufficient empirical evidence to reject the null hypothesis of no cointegration at the usual levels of significance (Table A5). Consequently, the OLS estimator of the investment equation will provide consistent estimates of the long-run elasticities for our main variable of interest: market potential.

Therefore, as a starting point we apply OLS to equation (3). The magnitude of the estimated coefficients for market potential suggests that the six groups of provinces could be reduced to three.[viii] We will refer to these groups as provinces with low, medium and high GDP per capita.

The first column in Table 2 shows the results of the estimated equation by OLS. All the coefficients have the expected sign and are statistically significant. It has to be mentioned that standard errors are clustered at the province level to take into account potential problems derived from autocorrelation and/or heteroscedasticity of the random disturbance terms.

Even though the OLS is consistent when applied to integrated and cointegrated relationships, the econometric literature (see, for instance, Kao and Chiang, 2000) shows that in finite samples the DOLS (dynamic ordinary least squares) estimator performs better than OLS. Essentially, the DOLS is a parametric method that tries to reduce the potential endogeneity bias by including the future and past values (leads and lags) of the differenced explanatory variables on the right side of a cointegrated equation. The underlying idea is that the inclusion of these variables in the equation makes it possible to soften the correlation between the explanatory variables and the random disturbances.

Alternatively, a standard way of dealing with endogeneity is to apply instrumental variables (IV). If the instruments fulfil the conditions, the method will also offer consistent estimates. The main difficulty of IV is finding the adequate instruments. In this estimation, we select as instruments the market potential calculated excluding the investment in machinery and equipment (that is, the dependent variable) from the definition of GDP.

Table 2 shows the estimation results according to OLS, IV, and DOLS. The first important result that emerges is that the coefficients of the market potential are very similar regardless of the estimation method used. This is particularly the case between OLS and DOLS and can be interpreted as a robustness check in terms of the estimation method.

Hence, we select DOLS as our preferred option. The highest difference is for the coefficient of unit labour costs, which, we recall, is the only non-integrated variable.

Table 2. Estimation results

Dependent variable: ln (investment)			
	OLS	IV	DOLS
ln (market potential Group I)	2.649	2.391	2.696
	(6.742)	(6.535)	(5.206)
ln (market potential Group II)	2.853	2.581	2.905
	(6.725)	(6.687)	(5.189)
ln (market potential Group III)	3.201	2.903	3.303
	(6.555)	(6.517)	(5.271)
ln (RULC)	-0.5378	-0.5507	-0.7495
	(2.300)	(2.443)	(2.045)
Years of schooling	0.1165	0.1225	0.1232
	(2.786)	(3.005)	(2.104)
Constant term	-36.104	-31.727	-37.930
	(4.978)	(4.797)	(4.096)
Time effects	yes	yes	yes
Provincial fixed effects	yes	yes	yes
R^2	0.9621	0.962	0.963
Standard error of regression	0.1909	0.1856	0.1884
Provinces (N)	46	46	46
Years (T)	32	32	32
Observations	1472	1472	1242

Notes: Standard errors are adjusted for clusters in provinces; cluster t-statistics in parentheses

The estimated equation confirms that, after controlling for provincial and time-fixed effects, the market potential has a positive and significant impact on private investment and the unit labour costs have a negative effect, whereas raising the average years of schooling contributes to attracting investment.

With respect to the main objective of our research, the results also confirm that the magnitude of the market potential impact increases with the level of provincial GDP per capita. The estimated coefficients range from 2.7 for those provinces classified as low-income, to 3.3 for those classified as high-income. Our work provides new evidence that infrastructure investment based on territorial distributional grounds will have a cost in terms of efficiency. Infrastructure investment in more developed regions will lead to higher private investment and, consequently, to higher economic growth.

In order to rule out the possibility that the relationship between private investment and market potential in terms of GDP is driven by the definition of the latter variable, we perform a set of robustness tests. First, we measure market potential using two alternative variables in the numerator: population and employment. In this way, we avoid the dependent variable entering the definition of the explanatory variable. Second, we substitute our measure of market potential with that developed by Alampi and Messina (2011). These authors propose a new index of accessibility defined as the difference between market potential using travel time and market potential using distance. The results, detailed in Appendix B, confirm that the estimated coefficients are robust with respect to the original ones when alternative measures of market potential are used.

Beyond the confirmation that there is a trade-off between efficiency and cohesion, it is necessary to provide some measurement of the efficiency costs. The estimated coefficients of our equation can be interpreted as the impact of an increase in market potential on private investment. However, when analysing these coefficients, it has to be considered that private investment is highly volatile and that there are substantial differences in its magnitude among provinces (see Table 1). Hence, an interpretation in terms of elasticities can be misleading.

We are interested in determining the long-run impact of an improvement in transport infrastructure on the income of the geographical area that benefits from the investment. To do so, we carry out a simulation exercise as described in the next section.

IMPROVEMENT IN ROAD INFRASTRUCTURE AND GDP GROWTH

To assess the long-run impact of transport infrastructures on GDP growth, we define a system of equations that simulates the final impact of a reduction in travel time on the GDP, including second-round effects. The system is composed of the following four equations:

$$pot_i = \sum_j \frac{GDP_j}{travel\ time_{ij}} \quad (4)$$

$$linvest_{it} = -37.93 + 2.696 * lpotI_{it} + 2.905 * lpotII_{it} + 3.303 * lpotIII_{it} - 0.7495 * lRULC + 0.1232 * school + \hat{\gamma}_i + \hat{\phi}_t \quad (5)$$

$$capital_{it} = (1 - 0.06) * capital_{it-1} + (invest_{it} + investconstr)_{it} \quad (6)$$

$$\ln(GDP_{it}) = 0.65 * \ln(employment_{it}) + 0.35 * \ln(capital_{it}) + \ln(A_{it}) \quad (7)$$

The first equation corresponds to the market potential equation as defined in (2). We simulate a decrease in travel time for all the links in the road network.

The second equation in the system corresponds to the estimated equation, and accounts for the impact of the increase in market potential in each group of provinces on private investment.

The third equation corresponds to the capital stock equation; it is defined according to the accounting identity of perpetual inventory. $Capital_{it}$ is the physical capital stock of province *i* in period *t*. The stock of capital in year *t* is equal to the stock in *t-1*, less depreciation plus total investment. According to the literature, we assume a depreciation rate of 0.06.[ix] Total investment is the sum of private investment, $invest_{it}$, plus investment in construction, $investconst_{it}$. The data on the stock of capital and investment are taken from the IVIE database.

The fourth equation is the aggregate production function for the economy. We assume a Cobb-Douglas production function. Under perfect competition and constant returns to scale, the coefficients of labour and capital should be equal to the shares of these factors in national income. Following de la Fuente (2010), the coefficient of labour should be between 0.6 and 0.7. We assume a coefficient of 0.65 and, consequently, the coefficient of capital is 0.35. The index of technical efficiency, A_{it}, is calculated as the difference.

This system of equations represents a simplification of a real economy. On the one hand, the underlying assumptions do not strictly hold in a real world. On the other hand, not all the interactions between the variables are modelled. For instance, we do not model the technical efficiency of the economy. Nonetheless, these simplifying assumptions do not alter the main aim of this simulation, which is to show that the impact of infrastructure improvements is greater when the feedback effects between the variables are taken into account.

The dynamic interactions work as follows: A reduction in travel time increases market potential, thus increasing private investment, which, in turn, leads to a larger capital stock and, consequently, to a growth in GDP. Higher GDP leads to a new increase in the market potential that further increases GDP through a series of second-round increments. Since the reduction in travel time in year t implies a higher level of investment in each of the subsequent years, it leads to a higher stock of capital and a higher GDP growth rate.

In order to compute the impact of a road investment, we simulate the GDP growth in two scenarios. In the baseline scenario, the starting values for the variables are equal to the actual values in 2008. According to the system of equations, the output growth in this scenario is due to the effect of investment on the stock of capital and consequently on the GDP. In the second scenario, the modified scenario, we assume a decrease of 10% in the travel time between all links in the network. This improvement in travel time leads to a higher level of investment and a higher level of GDP growth.

A first result that emerges from this simulation is the elasticity of output with respect to travel time; that is, the direct response of output to a decrease in travel time, or equivalently, an increase in market potential. The GDP elasticities for low-, medium- and high-income provinces are 0.022, 0.029 and 0.035, respectively. These values are on the lower bound of the review of output elasticities reported in the second section. Nonetheless, our main interest lies not in the absolute values, but in the differences between groups of provinces. In this regard, the output elasticity of the high-income provinces is almost 60% higher than that of the low-income ones.

More importantly, the computed elasticities do not take into account that the GDP growth translates into a higher market potential and, in turn, increases investment, capital stock and GDP. To include these effects, we forecast all the variables in the equations until 2020 and compare the rate of growth of GDP in the modified scenario with respect to that in the baseline scenario. The results show that a reduction of 10% in travel time will increase annual GDP growth by 0.16 additional percentage points for low-income provinces, and 0.20 and 0.26 for medium- and high-income provinces, respectively. In other words, according to our formulation, investment in infrastructure tends to boost economic growth through a rise in the private investment flow. As a consequence, in spite of the low value for elasticity, the accumulated impact over time can be substantial.

Likewise, the differences in the estimated impact of infrastructures among provinces also tend to be accentuated over time. Therefore, using infrastructure investment as a distributional policy can lead to considerable efficiency losses. Nevertheless, we want to point out that this conclusion does not rule out transport investment as an instrument of regional policy. In a recent paper, Cosci and Mirra (2017) conclude that road infrastructure investment failed to prevent a reduction in the north-south divide in Italy, possibly because investment in the south was not large enough to close the accessibility gap with the centre-north. What our work does is to highlight the possible costs of this policy.

CONCLUSIONS

This study estimates an investment equation for the Spanish provinces in order to provide evidence on the impact of improvements on the road infrastructure network. We use a panel data set formed by 46 provinces between the years 1977–2008. After testing that the variables are integrated of order one and cointegrated, we apply the DOLS estimator to soften the potential endogeneity problems.

The results show that road infrastructure has a positive effect on private investment in capital assets. Moreover, the magnitude of this effect varies with the level of economic development of the provinces. In this regard, the coefficient of the market potential variable estimated for high-income provinces in the preferred estimation is 1.23 times higher than the corresponding coefficient for low-income provinces. Additionally, for the first year, and before taking all the feedback effects into account, the elasticity of output with respect to travel time of the high-income provinces is almost 60% higher than that of low-income ones.

More importantly, when the permanent effects of an improvement in infrastructure are taken into account, we observe that a decrease of 10% in travel time will raise annual

GDP growth by 0.16 additional percentage points for low-income provinces, and 0.20 and 0.26 for medium- and high-income provinces, respectively.

As the effects of infrastructure improvements tend to be higher for the richest provinces than they are for the poorest, trying to achieve distributional targets through public infrastructure investment has a cost that must be considered in the design of public investment programmes.

In essence, our analysis neither ensures that any road investment will have a positive impact on private investment nor that the impact will always be higher in more developed provinces; rather, an infrastructure investment will lead to economic benefits only for those projects that effectively reduce transport costs to the markets, relieve pressure due to bottlenecks and/or connect strategic parts of the network. In general, the rich provinces more frequently fit these criteria, as captured by our estimations. But, in any case, a rigorous evaluation in terms of cost-benefit analysis is always needed as a first step to implementing a public investment project.

Acknowledgements: The authors would like to express their gratitude to J.Gutiérrez Puebla for providing the travel-time matrix used in the study. Thanks are due also to the anonymous referees for their valuable comments and suggestions.

This work was supported by the Ministerio de Economía y Competitividad under Grant ECO2014-52999-R and Departament d'Innovació, Universitats i Empresa, Generalitat de Catalunya under Grant 2014 SGR _ 1326

References

Alampi, D., & Messina, G. (2011). Time-is-money: i tempi di trasporto come strumento per misurare la dotazione di infrastrutture in Italia. In: *La infrastrutture in Italia: dotazione, programazione, realizzazione: Workshops and Conferences.* (137-174) Banca d'Italia, Eurosistema.

Alañón, A., Arauzo, J.M., & Myro, R. (2007). Accessibility, Agglomeration and Location. Aruzo, J.M. & Manjón, M. (eds), *Entrepreneurship, Industrial Location an Economic Growth*. Chentelham: Edward Elgar.

Albalate, D., Bel, G. & Fageda, X. (2012). Beyond efficiency-equity dilemma: Centralization as a determinant of government investment infrastructure. *Papers in Regional Science, 91,* 599-615. doi: 10.1111/j.1435-5957.2011.00414.x

Álvarez, A.; Orea, L., & Fernández, J. (2003). La productividad de las infraestructuras en España. Papeles de Economía Española, 95, 125-136.

Arauzo-Carod, J.M., Liviano-Solis, D., & Manjón-Antolín, M. (2010). Empirical studies in industrial location: An assessment of their methods and results. *Journal of Regional Science, 50*(3), 685-711. doi: 10.1111/j.1467-9787.2009.00625.x

Arbués, P., Baños, J., & Mayor, M. (2015). The spatial productivity of transportation infrastructure. *Transportation Research Part A: Policy and Practice*, *75*, 166-177. doi:10.1016/j.tra.2015.03.010

Argimon, I. and Gonzalez Páramo, J.M. (1997). Efectos de la inversión en infraestructures sobre la productividad y la renta de las CC.AA. In Perez Touriño (ed), Infraestructuras y desarrollo regional: Efectos económicos de la Autopista del Atlántico. Civitas, Madrid.

Bajo, O., C. Diaz & M. D. Montávez (2002). Optimal Endowments of Public Investment: An Empirical Analysis for the Spanish Regions- CentrA, Working Paper, E2002/14.

Bom, P.R., & Ligthart, J. E. (2014). What have we learned from three decades of research on the productivity of public capital? *Journal of Economic Surveys, 28*(5), 889–916. doi:10.1111/joes.12037

Boscá, J.E., Escribá, J., & Murgui, M. J. (2011). La efectividad de la inversión en infraestructuras públicas: Una panorámica para la economía española y sus regiones. *Investigaciones Regionales*, 20, 195-217.

Brown, J.P., Florax, R.J., & McNamara, K.T. (2009). Determinants of investment flows in US manufacturing. *The Review of Regional Studies*, *39*(3), 269-286.

Cantos, P., Gumbau-Albert, M., & Maudos, J. (2005). Transport infrastructures, spillover effects and regional growth: evidence of the Spanish case. *Transport Reviews*, *25*(1), 25-50. doi:10.1080/014416410001676852

Castells, A., & Solé-Ollé, A. (2005). The regional allocation of infrastructure investment: The role of equity, efficiency and political factors. *European Economic Review*, *49*, 1165-1205. doi:10.1016/j.euroecorev.2003.07.002

Castells, A., Montolio, D. & Solé-Ollé, A. (2006). Cuantificación de las necesidades de gastode las comunidades autónomas en infraestructuras. *Hacienda Pública Española*, 187, 23-54.

Ciccone, A., & Hall, R.E. (1996). Productivity and the density of economic activity. *American Economic Review*, 86, 54-70

Combes, P.P., & Gobillon, L. (2015). The Empirics of Agglomeration Economies. Duranton, Gilles, Henderson, Vernon, & Strange, William (Eds), *Handbook of Urban and Regional Economics Pages* (Vol. 5, pp. 247–348).

Combes, P.P., Lafourcade, M., Thisse, J.F., & Toutain, J.C. (2011). The rise and fall of spatial inequalities in France: A long-run perspective. *Explorations in Economic History*, *48*(2), 243-271. doi:10.1016/j.eeh.2010.12.004

Combes, P.P., Mayer, T., & Thisse, J.F. (2008). *Economic geography: the integration of regions and nations*. Princeton University Press.

Cosci, S., & Mirra, L. (2017) A spatial analysis of growth and convergence in Italian provinces: the role of road infrastructure. *Regional Studies*. doi: 10.1080/00343404.2017.1334117.

Coughlin, C.C., & Segev, E. (2000). Location determinants of new foreign-owned manufacturing plants. *Journal of regional Science*, *40*(2), 323-351. doi: 10.1111/0022-4146.00177

Dabán, T., & Lamo, A. (1999). Convergence and public investment allocation Spain 1980-1993. Dirección General de Análisis y Programación Presupuestaria, Ministerio de Economíay Hacienda, Working Paper, D-99001

De la Fuente, A. (2004). Second-best redistribution through public investment: a characterization, an empirical test and an application to the case of Spain. *Regional Science and Urban Economics, 34,* 489-503. doi:10.1016/j.regsciurbeco.2003.06.001

De la Fuente, A. (2010). *Infrastructures and productivity: an updated survey*. BBVA Research, Working Paper, 10/18.

De la Fuente, A., & Doménech, R. (2006). Capital humano, crecimiento y desigualdad en las regiones españolas. *Moneda y Crédito*, (222), 13-56.

Delgado, M. J., & Álvarez, I. (2000). Las infraestructuras productivas en España: Estimación del stock en unidades físicas y análisis de su impacto en la producción privada regional. Revista Asturiana de Economía, 19, 155-180

Escribá F.J. & M. J. Murgui (2007). El capital tecnológico como factor de producción en las regiones españolas 1980-2000. Investigaciones Regionales, 10. 33-52

Escribá, F.J. & Murgui, M.J. (2009). Government policy and industrial investment in Spanish regions. *Regional Science and Urban Economics*, *39*, 479-488. doi:10.1016/j.regsciurbeco.2009.02.005

Escribá, F.J., & Murgui, M.J. (2008). Factores de localización regional en las inversiones industriales. *Revista de Economía Aplicada*, *16*, 101-125.

Escribá, F.J., & Murgui, M.J. (2011). Determinantes de la inversión empresarial en las regiones españolas (1995-2007). *Moneda y Crédito*, (233), 45-73.

Fageda, X., & Gonzalez-Aregall, M. (2017). Do all transport modes impact on industrial employment? Empirical evidence from the Spanish regions. *Transport Policy*, *55*, 70-78. doi:10.1016/j.tranpol.2016.12.008

García-Fontes, W., & Serra, D. (1994). Capital Público, Infraestructuras y Crecimiento. Crecimiento y convergencia regional en España y Europa, vol. 2, Instituto de Análisis Económico, Barcelona, 451-478.

Goerlich, F., & Mas, M. (2001). Capitalización y Crecimiento. La evolución econòmica de las provincias españolas (1955-1998), vol 1. Fundación BBVA.

Gorostiaga, A. (1999). ¿Cómo afectan el capital público y el capital humano al crecimiento?:un análisis para las regiones españolas en el marco neoclásico. Investigaciones Económicas, 23, 95-114

Graham, D.J. (2007). Agglomeration, productivity and transport investment. *Journal of Transport Economics and Policy*, *41*(3), 317-343.

Holl, A. (2004). Manufacturing location and impacts of road transport infrastructure: empirical evidence from Spain. *Regional Science and Urban Economics*, *34*(3), 341-363. doi:10.1016/S0166-0462(03)00059-0

Holl, A. (2012). Market potential and firm-level productivity in Spain. *Journal of Economic Geography 12*(6), 1191–1215. doi:10.1093/jeg/lbr030

Holl, A. (2016). Highways and productivity in manufacturing firms. *Journal of Urban Economics*, *93*, 131-151. doi:10.1016/j.jue.2016.04.002

Kao, C. & Chiang, M.H. (2000). On the estimation and inference of a cointegrated Regression in panel data. In: *Nonstationary Panels, Panel Cointegration and Dynamic Panels, 15* (pp. 179–222). Elsevier Science Inc.

Martín-Barroso, D., Núñez-Serrano, J.A., & Velázquez, F.J. (2015). The effect of accessibility on productivity in Spanish manufacturing firms. *Journal of Regional Science*, *55*, 708-735. doi:10.1111/jors.12200

Mas, M., Maudos, J., Pérez, F., & Uriel, E. (1996). Infrastructures and productivity in the Spanish regions. *Regional Studies*, *30*, 641-649. doi:10.1080/00343409612331349938

Mas, M., Maudos, M., Pérez, F. & Uriel, E. (1994). Capital público y crecimiento regional espanyol. Moneda y Crédito, 198, 163-193.

Matas, A., Raymond J.L. & Roig J.L. (2015) Wages and Accessibility: The Impact of Transport Infrastructure, *Regional Studies*, 49(7), 1236-1254. doi:10.1080/00343404.2013.827336

Melo, P.C., Graham, D.J., & Brage-Ardao, R. (2013). The productivity of transport infrastructure investment: A meta-analysis of empirical evidence. *Regional Science and Urban Economics*, *43*(5), 695-706. doi:10.1016/j.regsciurbeco.2013.05.002

Nombela, G. (2005). Infraestructuras de transporte y productividad. Presupuesto y Gasto Público, 39, 191-215. Instituto de Estudios Fiscales (IEF). Madrid.

Rosenthal, S.S., & Strange, W.C. (2001). The determinants of agglomeration. *Journal of Urban Economics*, *50*(2), 191-229. doi:10.1006/juec.2001.2230

Solé-Oller, A. (2010). The determinants of the regional allocation of infrastructure investment in Spain. Bosch, N. Espasa, M. & Solé-Oller, A. (eds.) *The Political Economy of inter-regional fiscal flows*. Edward Elgar, Publishing Ltd.

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[i] We focus our attention on those studies that estimate a production function, the most usual approximation. Other studies use alternative methodologies (cost functions or VAR models).

[ii] Arauzo-Carod et al (2010) provide an extensive survey of the determinants of industrial location.

[iii] Alternatively, Escribá and Murgui (2008) follow an approximation based on the location of foreign investment. In any case, the set of selected determinants of investment is very similar to that in Brown et al (2009).

[iv] Nonetheless, after a certain threshold, diseconomies of agglomeration emerge and, hence, a higher concentration of activity may have a negative effect.

[v] The exclusion of that province does not modify the estimated coefficients.

[vi] The rest of investment in fixed assets corresponds to construction (69%) and intellectual property products (6.4%).

[vii] The average distance within a province has been calculated as the radius of a circle with a surface equal to the province's area.

[viii] The strategy followed to form the new groups is as follows: First, we estimate an equation in which Group 1 is taken as the reference category. Using a significance level of 5%, the null hypothesis that the coefficients of Group 2 and 1 were equal is rejected. Then a new Group I, which corresponds to the old Group 1, is formed. Taking Group 2 as the category of reference, the null hypothesis of equal coefficients for Groups 2, 3 and 4 is not rejected, whereas the null of equality between Groups 2 and 5 is rejected. So, a new Group II is formed, which includes the old Groups 2, 3 and 4. A similar strategy is followed to form the new Group III that includes the old Groups 5 and 6. Finally, using a joint test, the null hypothesis of equal coefficients for Groups 2, 3 and 4 and for Groups 5 and 6 is not rejected at the conventional significance level (in our case, the p-value was 0.5).

[ix] See, for example, De la Fuente and Doménech (2006).

Appendix A. Supplementary Tables

Table A1. Summary of the literature review for Spain

Authors	Dependent variable	Approach	Econometric specification	Period / spatial units	Elasticities
a. Investment function using aggregate regional data					
Escriba and Murgui (2008)	Manufacturing investment	Investment equation	OLS, different specifications	1964-2000 / NUTS2	Transport infrastructure: 0.204-0.282
Escriba and Murgui (2009)	12 branches of industrial activity	Euler Investment equation	SYS/GMM	1980-2000 / NUTS2	Not reported
Escriba and Murgui (2011)	13 branches of industrial and service sectors	Euler Investment equation	SYS/GMM	1995-2007 / NUTS2	Not reported
b. Production function using aggregate regional data					
Mas, Maudos, Pérez and Uriel (1994)	Private output	Production function	Levels and FE	1980-1989 / NUTS2	Productive public capital: 0.191 Productive public capital with spillovers: 0.214
Garcia-Fontes and Serra (1994)	Gross added value	Production function	Levels and FE Differences	1980-1988 / NUTS2	Productive public capital: 0.06 Productive public capital: 0.27 (sig. 1%)
Mas, Maudos, Pérez and Uriel (1996)	Private output	Production function	Levels and FE	1964-1991 / NUTS2	Productive public capital: 0.077 Productive public capital with spillovers: 0.141
Argimón and González-Páramo (1997)	Total output	Production function	Levels and FE	1964-1991 / NUTS2	Basic public capital plus other transport infrastructure: 0.09
Dabán and Lamo (1999)	Private output	Production function	GMM, with IV	1980-1993 / NUTS2	Productive public capital: 0.10
Gorostiaga (1999)	Gross added value	Convergence equation	FE, with IV	1969-1991 / NUTS2	Productive public capital: 0.03 (n.s.)
Delgado and Álvarez (2000)	Private output	Production function	Levels and FE Differences (OLS, IV)	1985-1995 / NUTS2	Synthetic physical indicator of infrastructure: between 0.10 and 0.25
Goerlich and Mas (2001)	Private output	Production function	Levels and FE	1965-1996 / NUTS3	Productive public capital: 0.02

Bajo, Díaz and Montávez (2002)	Total output	Production function	Levels and FE; GMM	1965-1995 / NUTS2	Productive public capital More productive regions: 0.054 Less productive regions: 0.048 (sig. 10%)
Álvarez, Orea and Fernández (2003)	Gross added value	Production function	Levels and FE, Period effects and CRTS assumed in some equations	1980-1995/ NUTS2	Productive public capital: 0.01-0.11-0.22 Synthetic physical indicator: 0.11-0.20-0.21
Cantos, Gumbau-Albert and Maudos (2005)	Private output	Production function	Levels and FE, with IV	1965-1995 / NUTS2	Transport infrastructure capital: 0.042 / with spillovers: 0.146 Road capital: 0.088 / with spillovers: 0.231 Ports: n.s. / with spillovers: 0.162 Airports: 0.0076 / with spillovers: n.s. Railways: n.s. / with spillovers: 0.108
Nombela (2005)	Gross added value	Production function	Levels and FE	1980-2000 / NUTS2, NUTS3	Transport infrastructure capital: NUTS2: 0.16 / NUTS3: 0.17
De la Fuente and Doménech (2006)	Gross added value	Production function	Differences, FE, period effects; allows for technological gap	1965-1995 / NUTS2	Productive public capital: 0.057
Escribá and Murgui (2007)	Gross added value	Production function	FE; controls for human and technological capital	1980-2000 / NUTS2	Productive public capital: between 0.079 and 0.107
Arbués, Baños and Matías (2015)	Gross added value	Production function	Spatial Durbin Model; IV/GMM (contiguity 150 kms)	1986-2006 / NUTS3	Direct / Indirect / total effects Road capital: 0.045/0.055/0.099 Rail capital: n.s / n.s / n.s. Air capital: n.s / n.s / n.s. Port capital: -0.036 / n.s. / n.s.
Fageda and González-Aregall (2017)	Industrial employment	Employment equation	Spatial Durbin Model; ML with bias correction fixed effects (contiguity 150 kms)	1995-2008 / NUTS3	Direct / Indirect / total effects Physical indicator of: Motorways: 0.225/-0.225/n.s. Rail: n.s / n.s / n.s. Airport: n.s / n.s / n.s. Port: 0.292/n.s./0.242
c. Economic impacts of road network using microdata					
Holl (2012)	Value added manufacturing firms	Production function	GMM	1991-2005 Firm data	Market potential: between 0.041 and 0.074

Matas, Raymond and Roig (2012)	Wages	Wage equation	OLS with IV	1995, 2002, 2006 Individual data	Market potential: 0.06
Martín Barroso, Nuñez-Serrano and Velázquez (2015)	Value added manufacturing firms	Production function / TFP	OLS / 2SLS	1999-2009 Firm data	Accessibility to commodities: 0.010-0.023 Accessibility to employment: 0.194-0.198
Holl (2016)	Value added manufacturing firms	Production function / TFP	OLS / 2SLS	1997-2007 Firm data	Distance to highway: -0.013-0.017

Notes: Productive public capital includes roads, water infrastructures, ports and urban structures. FE (fixed effects), RE (Random effects); IV (instrumental variables); GMM (Generalized Method of Moments); n.s. (not significant)

Table A2. Investment in machinery and equipment (thousands of €, 2008)

Provinces	1977	2008
Alacant	572,472	1,894,977
Álava	347,363	470,348
Albacete	153,586	598,441
Almería	150,032	654,397
Asturias	1,015,170	2,098,450
Ávila	60,724	168,062
Badajoz	232,768	890,124
Barcelona	3,193,424	9,687,898
Bizkaia	993,796	1,963,265
Burgos	222,127	837,180
Cáceres	424,782	293,014
Cádiz	425,902	1,252,967
Cantabria	450,849	740,547
Castelló	388,651	988,534
Ciudad Real	351,752	960,963
Córdoba	292,423	896,744
A Coruña	714,636	1,949,701
Cuenca	87,639	335,408
Girona	411,866	1,090,324
Granada	213,775	788,943
Guipuzcoa	794,742	1,359,074
Huelva	506,046	846,728
Huesca	202,121	429,449
Jaén	263,479	608,332
La Rioja	161,397	495,232
León	378,436	691,031
Lleida	292,418	718,418
Lugo	193,248	512,381
Madrid	2,271,865	13,300,000
Málaga	343,686	1,467,922
Murcia	493,230	1,859,665
Navarra	479,412	1,649,804
Ourense	181,627	480,933
Palencia	104,348	317,798
Pontevedra	429,065	1,367,815
Salamanca	159,312	598,184
Segovia	69,717	258,424
Sevilla	551,485	2,314,210
Soria	41,557	168,342
Tarragona	623,346	1,501,778
Teruel	160,750	582,012
Toledo	239,923	1,009,616
Valencia	1,099,807	3,556,015
Valladolid	267,066	1,076,948
Zamora	80,711	170,586
Zaragoza	456,401	1,905,388

Table A3. Provinces grouped according their GDP per capita

Group	Province	GDPpc	Variance	t-statistic
G1	Badajoz	11352.72	575.104	
	Jaén	11571.70	600.222	0.263
	Córdoba	12290.49	579.867	1.124
	Albacete	12376.80	609.784	1.217
	Cáceres	12428.60	695.036	1.164
	Ourense	12622.78	705.760	1.282
	Granada	12768.16	520.314	1.614
	Lugo	13111.42	648.783	2.115
G2	Zamora	13134.02	707.753	
	Ávila	13399.43	754.800	0.257
	Cuenca	13402.85	418.514	0.311
	Cádiz	13758.92	700.536	0.766
	Pontevedra	14086.95	633.421	1.009
	Ciudad Real	14185.78	669.707	1.141
	Málaga	14538.93	650.121	1.505
	Toledo	14590.98	529.182	1.738
	Huelva	14599.43	581.779	1.863
	Sevilla	14728.20	453.049	2.162
	Almería	15026.23	783.963	2.090
G3	Murcia	15048.97	828.874	
	Salamanca	15301.44	639.381	0.241
	Alacant	15684.90	431.564	0.824
	Coruña	15786.23	758.744	0.845
	Segovia	16301.00	763.290	1.163
	León	16439.13	732.659	1.314
	Palencia	16697.71	761.106	1.561
G4	Soria	16842.40	978.992	
	Teruel	17323.79	791.350	0.382
	Asturias	17434.34	550.910	0.614
	Valencia	17792.75	756.472	1.016
	Huesca	17876.97	647.950	1.039
	Castelló	18306.22	898.535	1.321
	Cantabría	18500.53	724.671	1.436
	Burgos	18859.96	824.976	1.837
G5	Valladolid	18883.02	813.357	
	La Rioja	19454.22	999.045	0.443
	Lleida	19658.35	808.089	0.603
	Zaragoza	20406.72	935.334	1.233
G6	Barcelona	22318.59	909.304	
	Guipuzcua	22671.99	907.881	0.275
	Navarra	23007.81	1042.394	0.499
	Tarragona	23085.30	742.429	0.599
	Bizkaia	24179.35	1070.371	1.428
	Girona	24189.32	932.007	1.318
	Álava	24646.03	992.169	1.710
	Madrid	25596.30	1001.622	2.325

Table A4 Unit root test for the variables in levels

Null Hypothesis: Unit root		
	ADF-Fisher Chi-square	ADF - Choi Z-stat
ln (investment)	30.682 (1.00)	5.957 (1.00)
ln (market potential)	6.962 (1.00)	10.915 (1.00)
ln (RULC)	93.603 (0.43)	0.303 (0.619)
Years of schooling	15.634 (1.00)	8.234 (1.00)

Notes: p-values in parenthesis; exogenous variables: individual effects; number of observations: 1434; cross-sections: 46

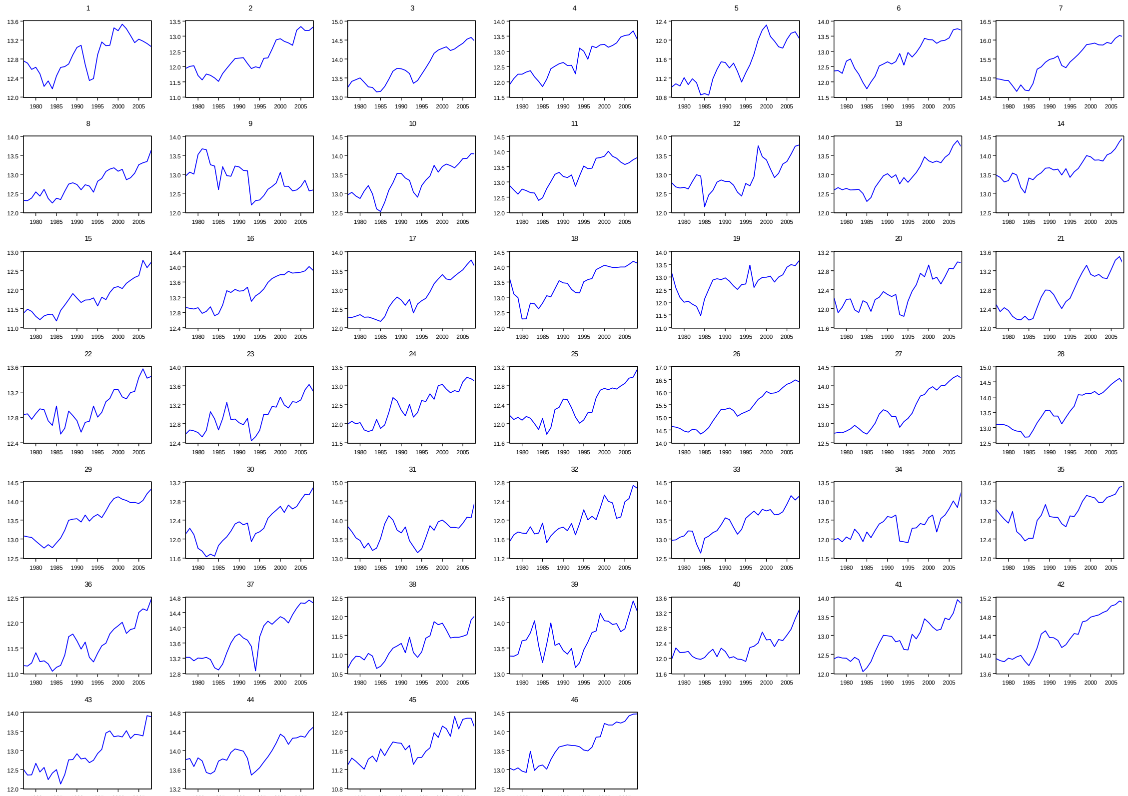
Table A5 Kao Residual Cointegration test

Series: ln(investment), ln(potential1), ln(potential2), ln(potential3), ln(RULC), years of schooling, fixed temporal effects		
Null Hypothesis: No cointegration		
	t-statistic	p-value
ADF	-7.222	0.0000
Residual Variance	0.0233	
HAC variance	0.0132	

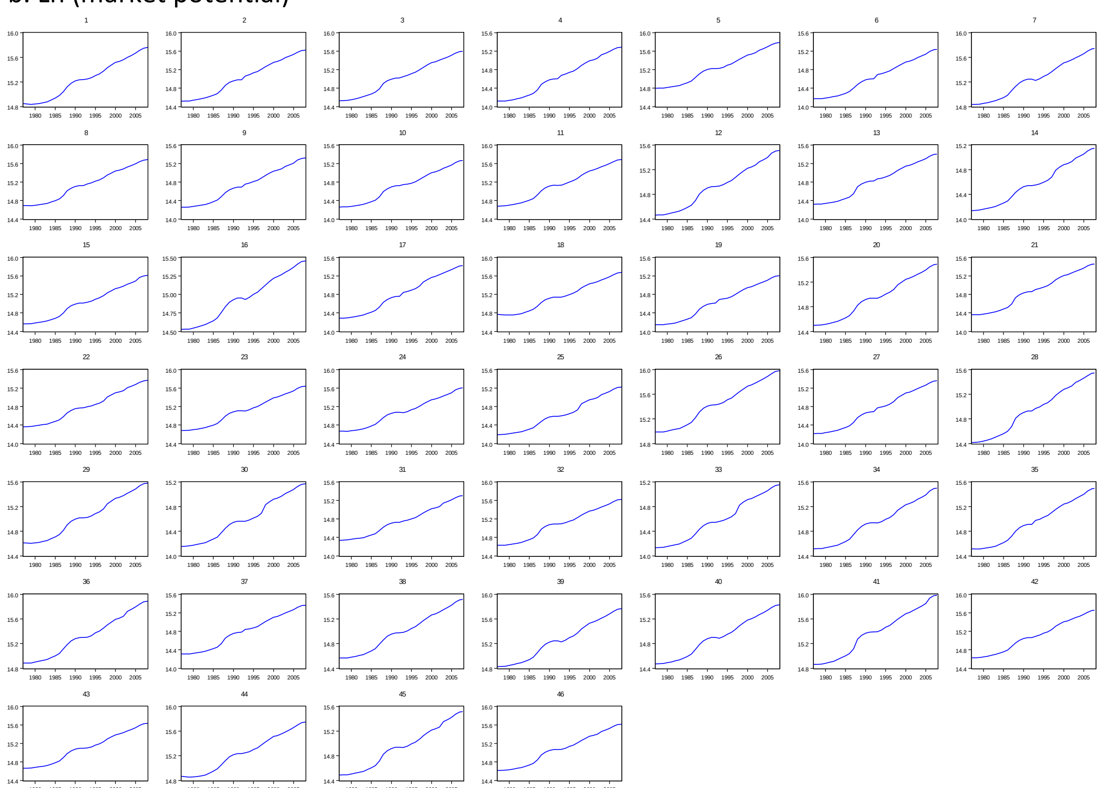
Notes: sample: 1977-2008; cross-sections: 46

Fig. A1: Annual value for the variables in the equation by province

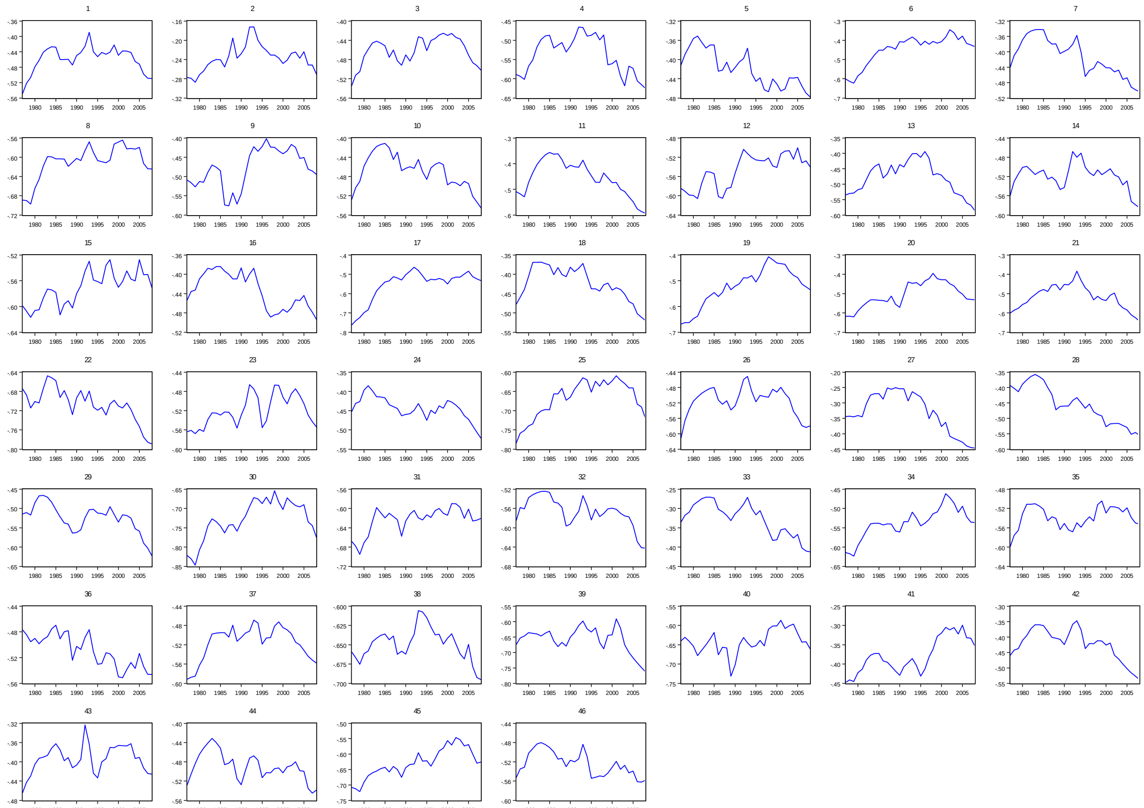
a. Ln (private investment)



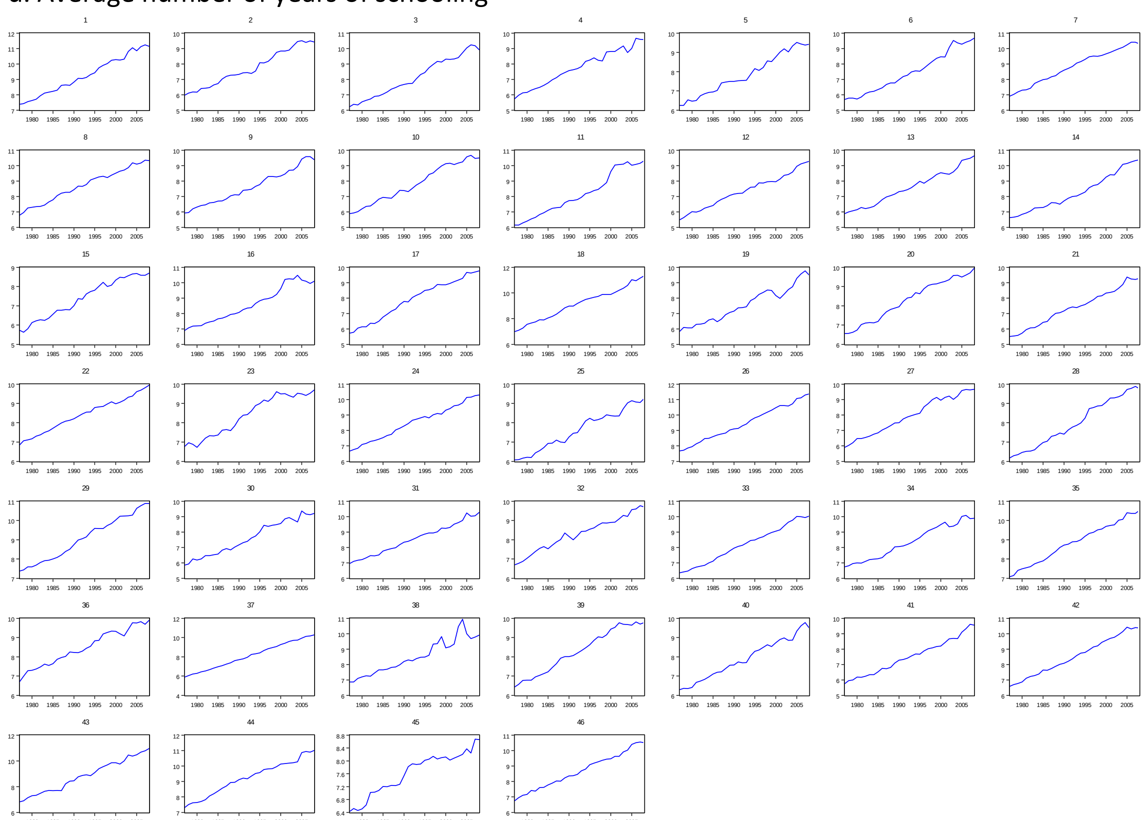
b. Ln (market potential)



c. Ln (Real Unit Labour Costs)



d. Average number of years of schooling



Appendix B: Robustness checks

We perform a set of robustness checks aimed at ruling out that the relationship between private investment and accessibility—measured as market potential in terms of GDP— is driven by the definition of the latter variable. Firstly, we measure market potential using two alternative variables in the numerator: population and employment. In this way, we avoid the dependent variable entering the definition of the explanatory variable. Secondly, we substitute our measure of market potential with that developed by Alampi and Messina (2011) [1]. These authors propose a new index of accessibility defined as the difference between market potential using travel time and market potential using distance. The underlying idea is that the accessibility of an area depends on the geographical distance to the relevant markets. However, road investment can improve such accessibility by reducing travel time. The index is defined as follows:

$$I_i^T = A_i^T - A_i$$

where A_i^T corresponds to the market potential defined in terms of travel time costs and A_i corresponds to the market potential defined in terms of Euclidean distance.

Table A.6 presents the investment equation estimated using the three previous definitions of market potential. All equations are estimated applying DOLS.

Looking at the results, we can confirm that the estimated coefficients appear fairly robust with respect to the original ones. Thus, defining market potential in terms of either employment or population presents the same pattern of coefficients as when using GDP. This is particularly true for employment, whereas in the case of population, the range of variation of the estimated coefficients for the three groups of provinces is slightly larger. The rest of the coefficients in the equation remain stable. Furthermore, the degree of adjustment of the equations is almost identical for the different definitions of market potential.

Regarding the equation estimated using Alampi and Messina's index, again we observe the same pattern of influence of market potential on investment. In this case, however, the difference between low and high income is larger. In our view, this analysis provides additional evidence that road transport costs have a significant effect on the macroeconomic variables.

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[1] Alampi, D., & Messina, G. (2011). Time-is-money: i tempi di trasporto come strumento per misurare la dotazione di infrastrutture in Italia. In: *La infrastrutture in Italia: dotazione, programazione, realizzazione: Workshops and Conferences.* (137-174) Banca d'Italia, Eurosistema.

Table B1. Estimated equations with different definitions of market potential

Dependent variable: ln (investment)			
	Eq(1)	Eq(2)	Eq(3)
ln (market potential Group I)	2.350	2.345	1.379
	(3.846)	(3.865)	(1.573)
ln (market potential Group II)	2.790	2.568	1.917
	(5.119)	(4.660)	(2.765)
ln (market potential Group III)	4.254	3.020	4.105
	(4.677)	(4.111)	(3.442)
ln (RULC)	-0.8513	-0.8157	-0.9796
	(2.375)	(2.288)	(2.458)
Years of schooling	0.1066	0.1313	0.161
	(1.817)	(2.244)	(2.48)
Constant term	-40.420	-22.680	9.480
	(3.676)	(2.786)	(14.98)
Time effects	Yes	Yes	Yes
Provincial fixed effects	Yes	Yes	Yes
R^2	0.963	0.963	0.961
Standard error of regression	0.1884	0.1878	0.1941
Provinces (N)	46	46	46
Years (T)	32	32	32
Observations	1242	1242	1242

Notes: Eq(1) market potential refers to population; Eq(2) market potential refers to employment; Eq(3) market potential corresponds to Alampi and Messina's index. Standard errors are adjusted for clusters in provinces; cluster t-statistics in parentheses