INTEGRATING NETWORK ANALYSIS AND INTERREGIONAL TRADE TO STUDY THE SPATIAL IMPACT OF TRANSPORT INFRASTRUCTURE USING PRODUCTION FUNCTIONS

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Abstract

The production function approach is used to analyze the role of transport infrastructure on GDP. Different regression techniques are employed to estimate its impact on production and in combination with other inputs, particularly employment and private capital stock. One problem with the traditional approach is that it incorporates as explanatory variable the public capital stock of transport infrastructure as a whole, i.e., the existing gross capital stock as calculated by statistical offices, which does not take into account the real use that economic agents make of the available transport networks (network effects). To overcome this drawback we introduce a new concept of transport infrastructure capital stock reflecting the real benefit obtained by the regions when accessing markets by using their own infrastructure (internal stock), as well as those of neighboring and non-neighboring regions (imported stock). While the former contributes directly to the production of a region, the latter can be associated to a spillover effect from importing transport infrastructure when exporting goods. Both, the internal and imported infrastructure stocks are calculated by network analysis performed in a GIS, which enables us to account exclusively for the public capital stock actually used in trading flows. Production functions incorporating the internal and imported capital stocks are estimated using panel data econometric techniques . The magnitude and significance of these variables on regional as well as provincial GDP is determined and discussed for the Spanish case and the 1980-2007 period.

KEYWORDS: Transport spillovers; Market access; Network analysis; GIS (Geographic Information Systems); Production function; Panel Data Econometrics.
JEL CODES: E22, H54, R49

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1. Introduction

When analyzing the impacts of transport infrastructure it is critical to take into account spillovers effects, understood as the benefits obtained by a region when using the infrastructures existing in other regions for trading (Pereira and Roca-Sagalés, 2003). Transport infrastructure not only brings benefits to the region where they are built, but they also provide services to citizens and companies located in other regions. Their benefits therefore transcend the borders of the regions where they are located. One of the most common methods existing in the literature for analyzing and quantifying regional spillovers of the public capital in transport infrastructure is the use of production functions, where private capital and employment are brought in as inputs of production, enhanced with the incorporation of public capital stock devoted to transport infrastructure as a third factor.

Some of these studies (García-Milá and McGuire, 1992; Cantos et al., 2005; Delgado and Álvarez, 2007) evaluate the importance of spillovers differentiating by levels of territorial disaggregation, and obtain values for the elasticity of the public capital that are lower as territorial units get smaller, i.e., elasticities at the provincial (NUTS 3) level are smaller than those at the regional (NUTS 2) level, and these, in turn, are smaller than those at the national (NUTS 1) level. These results has been attributed to the fact that the positive effect of the infrastructure extends to a much wider sphere than the one in which they are located, thus demonstrating the presence of spillover effects. In fact, investing in infrastructures in a particular region may generate positive or negative externalities in neighbouring regions, but these externalities do not show up when estimating production functions on a large national or regional scale.

Following this thread, other studies qualify these results and quantify the spillovers generated by incorporating not only the public capital stock existing within a region, but also the public capital stock of neighbouring and non-neighbouring regions, and justified by the principle that regional production do not only benefit from its own infrastructure but also from the infrastructure of all regions (Mas et al., 1994; Holtz-Eakin and Schwartz, 1995; Pereira and Roca-Sagalés, 2003; Crescenzi and Rodríguez-Pose, 2008). These methodologies thus follow a criterion of proximity and consider that the positive external effects will be more intense in the nearest regions (Cantos et al., 2005). The influence of the spillover effect on regional production levels can be very important. As an example, Pereira and Roca-Sagalés (2003) conclude that the effects of the spillovers and that of the internal infrastructure stock make a similar contribution to regional productivity in the Spanish case. Other authors such as Boarnet (1998) and Crescenzi and Rodríguez-Pose (2008) find positive effects in regions where the infrastructures are located, but also negative spillovers in the neighbouring regions which compete for factors of production.

One of the main criticisms levelled at the aggregate methods of measuring spillovers is that the same importance is attributed to the whole infrastructure situated in the neighbouring regions, regardless of their role in commercial relations, for which they are precisely relevant. The infrastructures in neighbouring regions will contribute differently depending on the location of the economic activities and the actual use that is made of these infrastructures. Cantos et al. (2005) improve this methodology by weighting the public capital stock by the value of the interregional trade flows, and based on the references in the economic growth literature which relate the spillover effects to the commercial relations existing between them. There are advantages to attributing greater weight to the infrastructures in the regions with which more commercial ties are established, but it continues to be an aggregate method which offers little information as to the real functioning of the transport networks in inter-regional economic relationships.

Spillovers depend on the characteristics of the transport infrastructures. For example, whether they are high or low capacity is an obvious determinant of their importance. But one relevant characteristic that has not been tackled by the existing literature is their particular geographical location, since it affects the intensity of the spillovers generated. For example, an infrastructure localized in the interior of a region will have as primary function that of connecting regional economic hubs, and its impact will be located above all in the interior of the region. However, the neighbouring regions may also benefit from this infrastructure if they use it in their commercial relations with that region but also as pass-through corridors to reach farther regions. In the case of a border road connecting two regions across a boundary, the spillover effect will be more extensive due to the importance of this type of infrastructure in promoting inter-regional relations. In contrast, some infrastructures in the neighbouring regions may be infrequently used due to their geographic orientation. If the infrastructure runs with an east-west orientation, the impact will be greater to the east and west of this infrastructure, but negligible in regions located on the north and south of the border. Previous studies consider all the capital stock in transport infrastructures in the neighbouring regions, regardless of whether that stock is used or not in commercial relations. Some infrastructures are of both regional and inter-regional importance (*e.g.*, high capacity roads), and are therefore used in multiple commercial relations and generate significant spillover effects, whereas others are only used for local relations and generate fewer spillovers and more internal benefits (*e.g.*, local roads).

As anticipated, it is also a well-established fact that high capacity infrastructures have a much greater weight in commercial relations than local roads. Considering the greater contribution of high capacity roads to commercial flows, some studies have opted to include only this kind of stock in their models (Crescenzi and Rodriguez-Pose, 2008). But this procedure may undervalue spillovers from transport infrastructures, particularly in regions that are less well-endowed with high capacity roads. Another drawback of this method lies in the concept of proximity itself, as by selecting only the adjacent regions the infrastructures from other more distant regions may be overlooked while the infrastructures in neighbouring regions may be overvalued. But if in order to overcome this limitation the infrastructure stock in neighbouring regions (adjacent or not) is weighted according to inter-regional commercial flows, then this also ignores the already mentioned fact that many infrastructures in nearby regions (and particularly in neighbouring regions) are used to conduct business with third regions, and this business is not taken into account in the weighting. In summary, previous studies failed to correctly consider the network properties of transport infrastructures.

To overcome these drawbacks, recently spatial spillovers of transport infrastructure have been measured and monetized using Geographic Information Systems, GIS, and accessibility indicators (Gutiérrez et al., 2010; Condeço-Melhorado et al., 2011; and Gutiérrez et al., 2011). This research, based on the hypothetical extraction method, provides insights into the benefits that a region receives from the infrastructure of another region. This methodology is useful for assessing spillover effects of transport plans and projects. However, from point of view of the this study it has three major drawbacks: first, it is only useful for the analysis of spillovers produced by future investments (not existing infrastructure); second, since it deals with future infrastructure, it considers hypothetical accessibility (market potential) and not real access to the markets (actual commercial flows); and third, spillovers are calculated in terms of investment, not in terms of production.

In this study we combine network analysis and econometric techniques to evaluate the impact of transport infrastructure on productivity, taking into account the direct effects of a region's own transport infrastructure capital stock, and the spillover effects that it receives from using other region's stock. Network analyses, present in GIS allow the representation of the behaviour of the transport networks and can thus reveal where and with what intensity the spillover effects occur. On the other hand, taking commercial flows into account we can represent the functional relationships between economic centres by attributing a greater weight to the relations established with the main hubs.

Focusing on Spain and for the 1980-2007 period where relevant investment decisions aimed at improving the road capacity network were taken, this study endeavours to provide an in-depth look at the relationship between the road network capital stock in the Spanish regions and provinces and their economic activity, introducing spillover effects in the analysis. With this proposal we have developed a new database, based on the access to the markets.[1] This database introduces what we term *used* capital stock, differentiating between the *internal* road network capital stock, which corresponds to the capital used within a region to carry out the

[1] Many authors study the contribution of transport infrastructures to improve the access to the markets. See, for example, Combes and Lafourcade (2005), Spiekermann and Neubauer (2002), Martín et al. (2004) and Zofío et al. (2011).

distribution (trade) of its domestic production, and the *imported* capital defined as the capital used from the rest of regions in order to export production. In the production function regressions we associate the spillover effect to this last concept of capital.

Accordingly, this study introduces a new concept of transport infrastructure capital stock reflecting the real benefit obtained by a region when using its own infrastructure, as well as regions, when accessing markets. While the former contributes directly to the production of a region, the latter can be associated to a spillover effect from importing transport infrastructure when exporting goods. Both, the internal and imported infrastructure stocks are calculated by network analysis performed in a GIS, which enables us to account exclusively for the public capital stock really used in trading activities. The stock that is actually used corresponds to those specific itineraries consistent with a minimizing—least—cost behavior on the part of firms, and therefore comprises the specific arcs used for exporting production. The value of each arc is distributed among all the regions using the relative value of the trade flows as weights.

The paper is structured as follows. In the next section we briefly summarize the standard regression techniques based on production functions that allow determining the effect that both own and other region's capital stock have on production activity. In section 3 we introduce the concepts and calculations necessary to come up with the aggregates of the used, internal and imported capital stocks. The difference between the capital stock with which a region is endowed at that finally used yields a balance of capital stock. The balance will be negative if the stock exported to other regions is less than that imported. In this section we briefly analyzed what regions benefit from the existing capital stock by exhibiting a positive balance and therefore use the stock of other regions to a larger extent than other regions use the stock they are endowed with. Since we calculate these new capital stock aggregates at the regional (NUTS 2) and provincial (NUTS 3) level, in section 4 we perform regression analyses at both levels to determine the direct and spillover effects of transport infrastructure on production. We estimate the spillover effects using the standard approach—including own capital stock and those of neighboring regions, as well as the novel approach that relies on the new aggregates of capital stock. This allows us to discuss the robustness and compatibility of both sets of results. In the last section we present the main conclusions along with relevant implications from the perspective of infrastructure policy.

2. Measuring the spillover effects of infrastructure with production functions

The final goal of this study is to determine the effects of transport infrastructure on regional production by embedding our new stock variables within the existing regional production functions models, and therefore measure the magnitude of the spillovers between regions and compare these results with the ones obtained by the traditional approach. Particularly, this analysis is developed introducing the internal and imported used capital stocks—defined and calculated as presented in the next section—within the production function methodology.

The departure point is the estimation of the following production function using panel of data for *N* observations along *T* periods:

$$Y_{it} = f(X_{it};\beta)e^{v_{it}}, \quad i = 1,...,N, \; t = 1,...,T, \tag{1}$$

where Y_{it} is the production of the *i*-th country, region, province,…, in period *t*; X_{it} is a (1 x *k*) vector of explanatory variables, β is a (*k* x 1) vector of parameters to be estimated, and v_{it} is the error term.

According to the standard literature, the basic model used in this study begins with the production function in which production (Y_{it}) is related to the amount of labor (L_{it}), private capital (K_{it}), plus the additional set of input factors incorporating the public capital stock in road infrastructure (KP_{it}):

$$Y_{it} = f(L_{it}, K_{it};\beta)g\left(KP_{it};\gamma\right)e^{v_{it}} \,. \tag{2}$$

We assume that the production function (2) is well-behaved satisfying the desirable neoclassical properties or regularity conditions: $f_L > 0$, $f_{L,L} < 0$, $f_K > 0$, $f_{K,K} < 0$, $g_{KP} > 0$, and $g_{KP,KP} > 0$. In the model, *KP* is assumed to be complementary to labor and capital. If markets are competitive and production factors mobile, each factor will be paid its marginal revenue product, given a certain amount of *KP*, whose choice is considered to be external to the firms located in a given area: $\partial Y/\partial L = f_L(L,K)g(KP)$ and $\partial Y/\partial K = f_K(L,K)g(KP)$.

The empirical analysis relies on the log-linear Cobb-Douglas aggregate production function, in which the capital stock is a separate input. Consequently, the functional form to be estimated corresponds to :

$$\log Y_{it} = \alpha + \beta_L \log L_{it} + \beta_K \log K_{it} + \gamma_{KP} \log KP_{it} + v_{it} \,. \tag{3}$$

Most studies use the production function approach**¡Error! No se encuentra el origen de la referencia.** to estimate the elasticity of inputs. Under the assumptions made above the coefficient γ equals to elasticity measure of the public capital stock in road infrastructure *KP* [2]. Using this structure, we incorporate the new concept of used capital stock to determine its contribution to regional production, thereby enabling us to differentiate between the internally used capital stock ($INTKP_{it}$) capturing direct effects, and the imported capital stock from other regions ($IMPKP_{it}$) to which we associate the spillover effects. In order to do so, we extend the production function (3) so as to include these new definitions as regressors:

$$Y_{it} = f\left(L_{it}, K_{it}, \beta\right) g\left(INTKP_{it}, IMPKP_{it}; \gamma\right) e^{v_{it}} \quad (4)$$

Again, the empirical model to be estimated is based on the log-linear Cobb-Douglas aggregate production function.

$$\log Y_{it} = \alpha + \beta_L \log L_{it} + \beta_L \log K_{it} + \gamma_{INT} \log INTKP_{it} + \gamma_{IMP} IMPKP_{it} + v_{it} \quad (5)$$

As anticipated, the sign and magnitude of the parameter allows us to determine the presence of spillover effects. One of the reasons for considering that investing in transport infrastructure in a particular area has a positive effect on the economic activity of other regions is based on its network nature. As a result, some of the benefits derived from the investment are extended outside the territorial limits of the region in which it is located. Nevertheless, in recent years several studies have confirmed the existence of negative spillover effects (Boarnet, 1998; Kelejian and Robinson, 1997; Holtz-Eakin and Schwartz, 1995). This type of effect arises under the assumption of factor price equalization with no trade and transportation frictions impairing the mobility of production inputs. This would be the case of private capital seeking for locations with higher returns, as those where transport infrastructure endowments are larger and therefore, given their complementarity, facilitate the location of private capital investments, which in turn could be detrimental to the region of origin.

3. Calculating the imported, exported, internal, and used capital infrastructure stocks

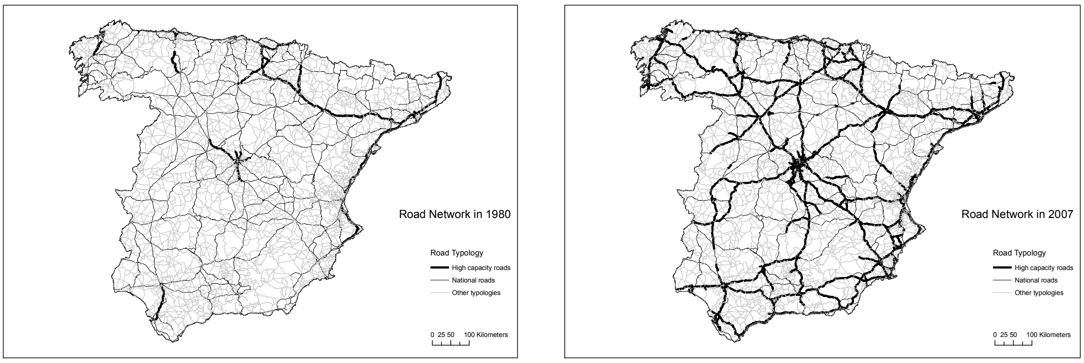
3.1 Data for network analysis

In this study we analyze the impact of road endowments in Spain for the period between 1980 till 2007, when a major development of the Spanish road network system has taken place. Several road networks are used to represent the situation in years 1980, 1985, 1990, 2000, 2005

[2] Some studies have used a translog specification, which differs from the Cobb-Douglas function in that it does not imply various restrictions on the production structure; e.g. the inputs elasticities of substitution are, by definition, equal to one in the Cobb-Douglas function.

and 2007. The networks are in digital format, having a cartographic representation and an associated table with several attributes characterizing each arc of the network (see subsections 3.2 and 3.3). Figure 1 shows the Spanish road network in years 1980 and 2007. In the first year there were few motorways, only 1,630 km of tolled highways and 335 km of free highways (Table 1). These were mainly located in the east part of the country, linking Barcelona with the Basque Country and Valencia. During this 27 years period there was a large increase of high capacity roads (77% for toll highways and 2,753% for free highways). In the first years this increase was part of an upgrading investment program from conventional 2x1 roads to high capacity 2x2 roads, with the latter ones occupying the lanes of the former in one direction. This is why conventional roads have decreased their length during the analyzed period.

Figure 1 – Road Network in years 1980 (left) and 2007 (right)



Source: own elaboration

Table 1 – Road network lengths by type of roads. Comparison between 1980 and 2007

Road type, *r*	Description	Distance km.		
		1980	2007	Δ%
1	Toll highways	1,630	2,883	76.9
2	Free highways	335	9,557	2,752.8
3	National roads	21,456	16,373	-23.7
4	1st order regional	11,704	10,715	-8.5
5	Secondary roads	47,930	47,321	-1.3
	All roads	83,055	86,849	4.6

Source: own elaboration

3.2. Valuating the capital stock of infrastructure at the arc level

The GIS road networks used in this study constitute a very detailed representation of the existing infrastructure differentiating by different types of roads, *r*. The full spectrum from high capacity roads to secondary roads (including main urban roads) is completely covered. The networks include all toll and free highways (2x2/3 lanes), national roads (2x1 lanes), as well as other roads belonging to regional governments (2x1lanes) and local municipalities (urban roads). We note that some of these roads are hardly used as itineraries between locations for freight road transportation, i.e., in our model assuming a cost minimizing behavior of the transport firms through optimal itineraries, these roads are not used for trading. However, they contribute to local economic activity (e.g., inputs mobility) and therefore their value represents an input contributing to (mostly local) economic activity. For this reason, in our analysis we consider them as internal capital stock within a region or province.

Each road in the digital network is divided in arcs, generally denoted by $a_k^{t,r}$, where the superscripts refers to the specific time period and type of road , respectively, and the subscript to its particular location. When calculating the value of a particular arc, the departure point is the aggregate public capital stock corresponding to the road network (gross public capital stock) at a regional level, elaborated by the IVIE in collaboration with the BBVA Foundation (Mas et al., 2010) and denoted by KP_G^t, where the subscript $G = \{R, P\}$ refers to a specific region or province. The methodology used by these authors to calculate the gross capital stock in Spain, including all the private and public stocks (also used in our empirical applications), follows the perpetual inventory method according to the guidelines set out by the OECD (2001), so it satisfies all the necessary prerequisites to be included in their related statistics, including its productivity database, Pilat and Schreyer (2004).

However, the existing aggregate of gross public capital stock in road infrastructure corresponds to the aggregate regional level and does not differentiate between high-capacity roads ($KP_R^{t,h}$)—comprising road types r = 1, 2 in Table 1—and other roads ($KP_R^{t,o}$)—r = 3, 4 and 5, which is a necessary distinction to finally distribute their values to the existing arcs. Using investment data, Álvarez and Delgado (2012) distributed the total stock between both sets of roads: $KP_R^t = KP_R^{t,h} + KP_R^{t,o}$, and further disaggregated them to a provincial (NUTS 3) level: $KP_P^t = KP_P^{t,h} + KP_P^{t,o}$. In order to adapt this information to our road network we disaggregate it according to our classification of types of roads (Table 1). This way, the stock devoted to high capacity roads is disaggregated into the stock of tolled highways and the stock of free highways. While the stock corresponding to other roads is disaggregated into the stock of national, first order, and, finally, secondary roads. The distribution of these stocks among the different kind of roads is done according to the relative values of the different types of roads r in the physical network, which are obtained by multiplying their total length in kilometers $Km_P^{t,r}$, by their relative unit (cost) prices per kilometer—*i.e.*, all prices are normalized (n) using as reference the price of free highways (r = 2): $p_n^{t,r} = p^{t,r} / p^{t,2}$, with $p_n^{t,2}$ = 1.[3] We can illustrate the step by step process as follows. From the existing gross capital stock of high capacity roads at the provincial level, $KP_P^{t,h}$ we recover the stock corresponding to toll and free highways , r = 1, 2, in the following way:

$$KP_P^{t,r} = KP_P^{t,H} \frac{Km_P^{t,r} p_n^{t,r}}{\sum_{r=1}^{2} Km_P^{t,r} p_n^{t,r}}. \tag{6}$$

The same process is followed to distribute the stock of other roads among national, first order and secondary roads (also relying on the price of free highways as normalizer). This completely exhausts the distribution of our initial gross public capital stock of road network at a provincial level and, consequently, at the regional and national levels. Once we have the total gross public capital stock distributed by each road type, we can obtain the price per km for each road type and each province consistent with the capital stock aggregate.

$$\hat{p}_P^{t,r} = KP_P^{t,r} / Km_P^{t,r}, \tag{7}$$

Finally the stock (value) of each arc is obtained by multiplying the length of each arc in province P: $Km_P^{a_k^{t,r}}$, by its corresponding price:

$$V_P^{a_k^t} = Km_P^{a_k^{t,r}} \hat{p}_P^{t,r}.. \tag{8}$$

Within the GIS, each arc and its corresponding value are associated to a specific Spanish region (NUTS 2) and province (NUTS 3).

3.3. The determination of the optimal itineraries: the generalized transport costs

As anticipated, not all the available capital stock is really used in commercial relations involving freight road transportation, but only a significant proportion makes up the optimal itineraries. Particularly in value, rather than distance, since it is the most expensive high capacity roads those normally used for transportation services. From an economic perspective firms exhibit an optimizing behavior by which they minimize the transport cost from an origin to a destination by choosing the least cost itinerary. Following Combes and Lafourcade (2005), we calculate these optimal itineraries within the GIS using the shortest path algorithm of

[3] Relative prices per type of roads are obtained from a study published by the *Ministerio de Fomento*, MFOM (2000).

Dijkstra (1959). In most research papers, these minimal paths are calculated among centroids of regions and provinces. However this may mask differences within each region or province, since centroids tend to be more accessible than the average (particularly if they correspond to the capital). To avoid this problem while considering internal relationships, each region and province is divided into several transport zones. In sum, the Spanish territory is divided into z = 1,…, 678 transport zones, as a result of aggregating almost 8,000 municipalities (Figure 2).

Figure 2 - Transport zones

Source: own elaboration

The road network contains information about the economic costs of using any arc for transportation purposes. These economic costs are related to the distance and travel time variables. Each arc of the network $a_k^{r,t}$, has primary physical attributes in period t such as distance, d_a^t, road type, r_a^t, and slope (steepness), g_a^t. From the latter two the arc speed can be determined, s_a^t (accounting for the actual speed—e.g. in case of congestion or very steep roads— given the road type: r), and from there we can determine the time it takes to cover it, t_a^t = d_a^t / s_a^t. As a result the physical characteristics of an arc are finally summarized by its associated distance and time variables: d_a^t and t_a^t.

The economic distance unit costs in time t, denoted by e_k^t, i.e., Euro per kilometer, include the following variables, k = 1, …, 5: (i) Fuel costs, which are associated with each arc given its road type r_a^t, gradient g_a^t and speed s_a^t : $fuel_i^t$. Fuel costs are computed multiplying the fuel price (Euro per liter) by the fuel consumption of its particular arc; (ii) Toll costs, $toll_i^t$, that result of multiplying the unit cost (Euro cents/km.) by the length of the arc d_a^t (r = 1 corresponds, once again, to a toll highway); (iii) Accommodation and allowance costs, *accom&allow*^{t}; (iv) Tire costs, *tire*^{t}, and, (v) Vehicle maintenance and repairing operating costs, *rep&mant*^{t}. Taking into account these operating costs, the total distance cost corresponding to an itinerary I_{ij}^t is:

$$DistC_{ij}^t = \sum_{a \in I_{ij}^t} \left(\sum_k e_k^t \right) d_a^t = \sum_{a \in I_{ij}^t} \left(fuel_{i,a(r,t)}^t + toll_{i,a(r=1,t)}^t + accom\,\&\,allow^t + tire^t + rep\&mant^t \right) d_a^t \tag{9}$$

Likewise, the economic unit costs associated to time, denoted by e_l^t, i.e., Euro per hour, include the following l = 1,…,6 variables: (i) Labor cost associated with gross salaries, lab_i^t, including social security payments; (ii) Financial costs associated to the amortization, *amort*^{t}, and (iii) financing of the truck, fin_i^t, assuming that it remains operative only for a certain number of hours/year (according to its technical characteristics and other institutional issues, for example, driving and resting times); (iv) Insurance costs, *ins*^{t}; (v) taxes, tax_i^t (including central, regional—state, provincial—county, and municipal—city— government taxes), and, finally (vi) indirect costs, ind_i^t, associated to other administration overhead (offices and other technical equipment), operating expenses (administrative employment) and commercial costs (outsourcing activities and marketing).

Given the driving time for an arc: $t_a^t = d_a^t / s_a^t$, the time economic costs in period t, and the existing road infrastructure in t, the overall cost associated to travel the whole length of an itinerary is:

$$\begin{aligned} TimeC_{ij}^t &= \left(\sum_l e_l^t \right) \left(\sum_{a \in \mathrm{I}_{ij}^t} t_a^t \right) = \left(\sum_l e_l^t \right) \left(\sum_{a \in I_{ij}^t} \frac{d_a^t}{s_a^t} \right) = \\ &= \left(lab_i^t + amort^t + fin^t + ins^t + tax_i^t + ind_i^t \right) \left(\sum_{a \in \mathrm{I}_{ij}^t} \frac{d_a^t}{s_a^t} \right). \end{aligned} \tag{10}$$

Given our z = 1,…, i, j, k,….N transportation zones, the calculation of minimum generalized transport cost between the origin i and destination j corresponds to the solution of the following problem that finds the least cost itinerary I_{ij}^{t*} among the set of likely itinerary joining origin i with destination j, I_{ij}^t : [4]

[4] See Zofío et al. (2011) for further details about the methodology in the calculation of the generalized transport costs in the Spanish case.

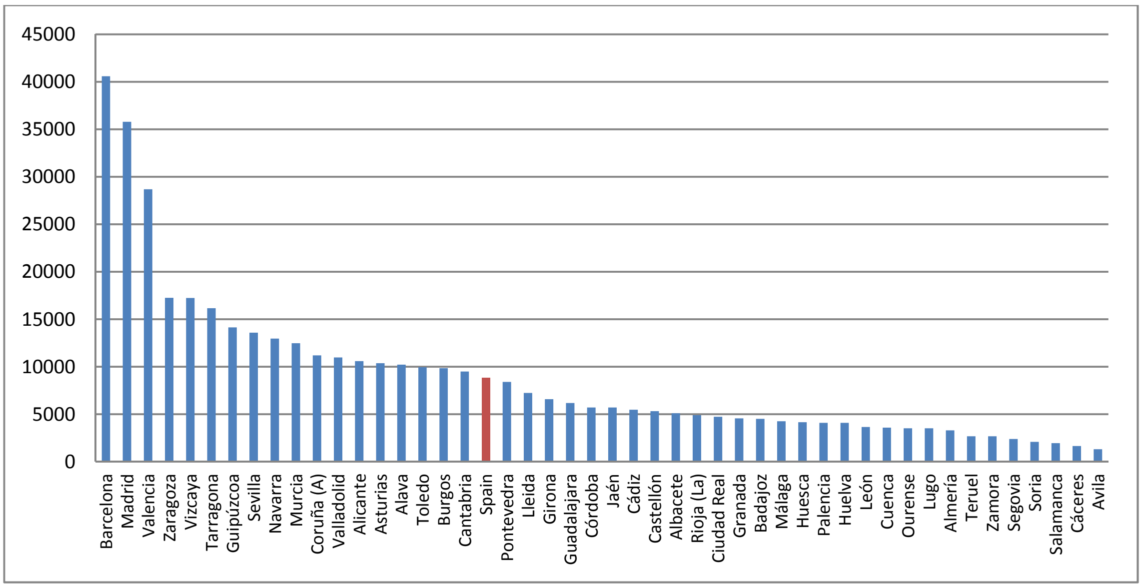
$$GTC_{ij}^{t} = \min_{I_{ij}^{t} \in \mathbf{I}_{ij}^{t}} \left(DistC_{ij}^{t} + TimeC_{ij}^{t} \right) = \\ = \sum_{a \in I_{ij}^{t}} \left(\sum_{k} e_{k}^{t} \right) d_{a}^{t} + \left(\sum_{l} e_{l}^{t} \right) \left(\sum_{a \in \mathbf{I}_{ij}^{t}} t_{a}^{t} \right) = \left(\sum_{l} e_{l}^{t} \right) \left(\sum_{a \in I_{ij}^{t}} \frac{d_{a}^{t}}{s_{a}^{t}} \right), \tag{11}$$

where the optimal distance and time variables solving (11) correspond to $d_{ij}^{t*} = \sum_{a^* \in \mathbf{I}_{ij}^{t*}} d_{a*}^{t}$ and $t_{ij}^{t*} = \sum_{a^* \in \mathbf{I}_{ij}^{t*}} t_{a*}^{t}$.

3.4. Calculating the used capital stock: Imported, exported and internal.

The aggregate of capital stock in transport infrastructure should reflect the real use in terms of trade flows made by each zone both from its own roads and those existing in other locations. The process of calculating the capital stock relays on the information on commercial flows in Euros between Spanish provinces (NUTS 3), which are obtained from the C-intereg database (see Llano et al., 2008 and Llano et al., 2010), and referred to 16 economic sectors whose goods are shipped by road. Barcelona, Madrid and Valencia are the most important provinces in terms of exports, with trade flows much higher than the national mean (red bar). This information was desegregated by transport zones, according to the population of each zone.

Figure 3 - Total exports by provinces, 2005 (million Euros).

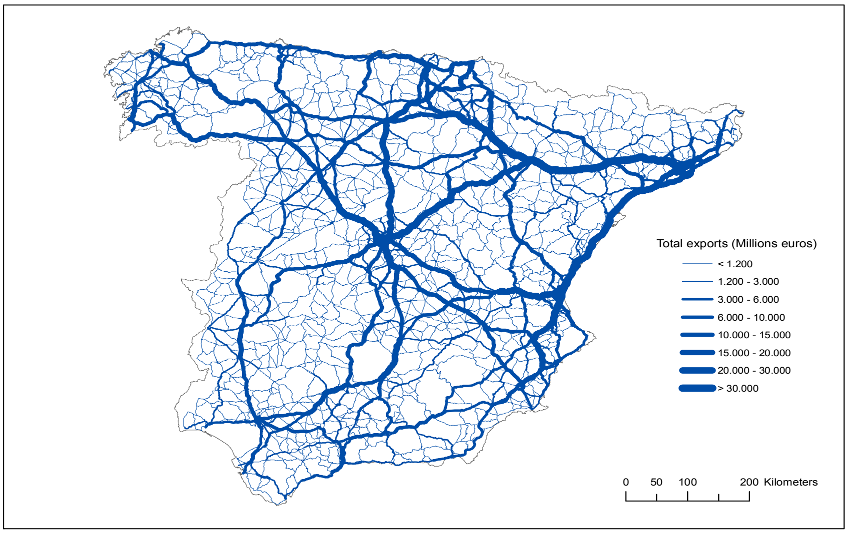


Source: C-intereg database

With these interprovincial trade flows it is possible to determine to what extent each region makes use of the capital stock corresponding to the optimal itineraries. The procedure takes four steps: The first step is to associate in the GIS database the exports from zone i to zone j, denoted by X_{ij} to its optimal itinerary I_{ij}^{t*}, and particularly, to each one of its arcs—dropping the road type superscript r to avoid notational clutter: $a_k^{t*} \in I_{ij}^{t*} : X_{ij}^{a_k^{t*}}$.[5] The total value of the trade flows is therefore allocated as many times as arcs comprise the optimal itinerary. The second step is to add all the export flows crossing a specific arc a_k^{t*}: $X^{a_k^{t*}} = \sum_{i=1}^{N} \sum_{j=1}^{N} X_{ij}^{a_k^{t*}}$, where the double summatory reflects that the arc may belong to numerous optimal itineraries both from the origin and destination perspectives. Figure 4 shows the result obtained by means of this calculation, which has been performed for all years in our study, showing that some arcs of the high capacity network concentrate high values in terms of exports. The third step calculates the relative importance that an optimal arc a_k^{t*} has for each origin according to its relative trade flows. For this purpose we calculate the weight that the trade flows originating in origin i with any destination j (including itself) have on the total flows crossing a_k^{t*}:

$$w_i^{a_k^{t*}} = \frac{\sum_{j=1}^{N} X_{ij}^{a_k^{t*}}}{X^{a^{t,*}}} = \frac{\sum_{j=1}^{N} X_{ij}^{a_k^{t*}}}{\sum_{i=1}^{N} \sum_{j=1}^{N} X_{ij}^{a_k^{t*}}}. \tag{12}$$

Figure 4 - Total exports crossing each optimal arc of the network, 2005



Source: own elaboration

For the last step we recall the methodology presented in section 3.2. For the particular case of a country C, and depending on the availability of economic statistics (capital stocks and trade flows) and infrastructure data (road networks), one may calculate the different capital stocks

[5] The flows of exports are maintained fixed in year 2005, in order to isolate the pure effect of public stock variation

associated to trade flows for different levels of aggregation. For example, one may consider alternative administrative divisions of the territory, i.e., taking as reference the set of regions (NUTS 2), $C = \{R_1, \ldots, R_M\}$, or provinces (NUTS 3), $C = \{P_1, \ldots, P_N\}$—as we do in our analysis. Once a given level of geographical aggregation has been settled, the last step consists in the distribution of the monetary value of the stock corresponding to each optimal arc located in a given province P, $V_P^{a_k^{t*}}$—as presented in eq. (8) but for effectively used arcs, to every i location using it, and proportionally to the relative amount of its exports:

$$KP_i^{a_k^{t*}} = w_i^{a_k^{t*}} V_P^{a_k^{t*}} , \tag{13}$$

Regarding the specific arc a_k^{t*}, this value represents the *imported* capital stock of location i from location k situated in province P, and therefore, the *exported* capital stock from k to i. Consequently, for $i = k$, with both locations belonging to the same province, (13) corresponds to the *internal* capital stock. Aggregating $KP_i^{a_k^{t*}}$ across all the i exporting zones situated in province P_p and using all the k arcs situated in the same province P_q, we can calculate the imported capital stock of province P_p from province P_q as follows: This exact same value represents the exports of capital stocks from all locations belonging to P_q to the importing location in P_p, which we denote by $EXPKP_{P_q}^{t,P_p} = IMPKP_{P_p}^{t,P_q}$. For a given province we can define its overall net balance between the imported and exported stocks as

$$BKP_{P_p}^{t} = \sum_{q=1}^{N-1} IMPKP_{P_p}^{t,P_q} - \sum_{q=1}^{N-1} EXPKP_{P_p}^{t,P_q} . \tag{14}$$

If $BKP_{P_p}^{t} > 0$ province P_p makes use of the capital situated in other provinces to a larger extent that other regions make use of its; and therefore, it is expected that it will profit from positive spillovers as it is a net user of the capital stock within a country. If $BKP_{P_p}^{t} < 0$ is negative, the opposite takes place and the province is a net exporter that does not profit from other region's stock as much as those regions profit from its stock. This would be the case of provinces situating along important corridors but whose economic activity (exports) is relatively low, and therefore become a transit province.

Finally, the internal capital stock corresponds to the aggregate value of all the arcs located in province P_p, used by all i exporting locations also situated in province P_p , plus all the arcs located in that province that do not belong to any optimal itinerary, but that nevertheless contribute to local economic activities (*e.g.*, local traffic for distribution of goods and mobility of productive factors), and therefore to overall production (as remarked at the beginning of section 3.2):

$$INTKP_{P_p}^{t,P_p} = \sum_{i \in P_p} \sum_{k \in P_p} KP_i^{a_k^{t*}} + \sum_{k \in P_p} KP_{P_p}^{a_k^t} = \sum_{i \in P_p} \sum_{k \in P_p} w_i^{a_k^{t*}} V_{P_p}^{a_k^{t*}} + \sum_{k \in P_p} V_{P_p}^{a_k^t}. \quad (15)$$

This last expression implies $i = k$ in (13), and therefore all the arcs used by all the i exporting locations and whose value we are distributing belong to the same province. We now define the capital stock *used* by province P_P as the sum between the internal and imported capital stocks:

$$UKP_{P_p}^{t,P_p} = INTKP_{P_p}^{t,P_p} + IMPKP_{P_p}^{t,P_q}. \quad (16)$$

Given our construction of the different aggregates of capital stocks: imported, exported, internal and used, the capital stock balance aggregate BKP_{P_p} can be expressed also as the difference between the capital stock used by a province and the gross public capital stock existing in it; i.e., $BKP_{P_p}^t = UKP_{P_p}^{t,P_p} - KP_{P_p}^t$, whose interpretation allows us to determine how the road investments efforts made by the different government levels (national, regional, provincial and municipal) translate into the real use of that network once trade flows are taken into account, and the cohesion implications it brings with it as presented in the following subsections.

Lastly, we remark that this process takes 2005 as the base year, whose values regarding both the relative prices of the different roads $p_n^{t,r}$ **¡Error! No se encuentra el origen de la referencia.** and the commercial flows used to distribute the values of the arcs, $w_i^{a_k^{t*}}$, are taken as reference when calculating the capital stocks in all years. Therefore, in these years it is the magnitude of the capital stock and the road networks what are successively updated, which in turn implies calculating their associated optimal itineraries and the arcs comprising them (with their corresponding attributes including distance—length—and travel time).

3.5. The allocation of the used public capital stock.

Using this methodology we calculate the capital stock matrices at a provincial and, by aggregation, regional level. At the highest possible level of disaggregation, the matrix of used transport infrastructure capital stock presented in Table 2. In this matrix the diagonal cells show the internal stock used by each province from its own roads: $INTKP_{P_p}^{t,P_p}$, while rows correspond to the capital exported to other provinces: $EXPKP_{P_q}^{t,P_p}$, and columns correspond to the imported stock: $IMPKP_{P_p}^{P_q}$. A high proportion of the gross public capital stock in a location remains in the province itself (60.14% on average for all Spanish provinces) and the remaining stock is exported to other provinces (39.86%). As expected, a relevant part of what is exported goes to the neighboring provinces (52.22%), which are the ones using the roads more intensively in their trade flows—but note that the remaining 50% corresponds to other non-adjacent provinces, a stock that is not taken into account in the existing literature. In accordance to the methodology introduced in the previous section, the sum of rows represents the total gross public capital stock endowment for each province: $KP_{P_p}^{t}$. On the other hand, the sum of columns represents the used public capital stock, $UKP_{P_p}^{t,P_p}$, i.e., the provinces own retained public capital stock plus the amount imported from other locations. Consistent with the export figures, provinces import more stock from their adjacent regions, because this neighboring infrastructure is crucial in channeling their exports.

Table 2 summarizes the most important figures of the matrix presented in Table 2. The first column represents the gross public capital stock of each province (sum of rows) which is distributed among the different capital stock aggregates. The internal amount of stock used by the provinces from their own roads is presented in the second column, while the two following columns show the imported and exported stocks, which can be interpreted as *outgoing* and *incoming* spillovers. The fifth column represents the total used stock (sum of columns of table 3) and the last column yields the balance between the used and the existing gross public capital stocks, which, by construction, also corresponds to the difference between the imported and exported capital stocks. Looking at the balance one notices that for some regions it is positive, indicating that the used stock is greater than the own-endowed gross public capital stock, while for other regions it is negative.

Table 1 - Used public capital stock matrix, 2007 (Thousand Euros)

	ALMERÍA	CÁDIZ	CÓRDOBA	GRANADA	HUELVA	JAÉN	MÁLAGA	SEVILLA	HUESCA	TERUEL	ZARAGOZA	ASTURIAS	CANTABRIA	ÁVILA	BURGOS	N47
ALMERÍA	1,187,515	13,257.0	30,043.2	173,223.5	13,568.8	80,703.5	53,284.1	46,780.6	757.9	2,861.8	4,335.4	0.0	0.0	125.1	1,883.1	...
CÁDIZ	23,189.0	1,829,977	13,755.7	20,911.3	19,840.5	5,634.1	193,570.2	149,874.3	196.9	85.9	7,193.9	5,700.6	1,861.3	493.3	3,996.9	...
CÓRDOBA	4,618.0	71,219.8	1,101,298	19,390.3	53,392.1	73,556.8	97,844.3	158,560.2	750.9	789.6	23,081.0	7,369.8	1,673.8	578.9	4,736.1	...
GRANADA	147,189.9	82,686.0	45,680.4	1,104,152	55,800.4	165,684.4	145,100.3	158,495.7	2,912.1	141.6	9,810.5	2,116.3	3,061.7	1,436.7	2,760.9	...
HUELVA	2,822.8	12,782.3	7,691.3	2,165.2	1,458,126	3,102.9	1,551.9	133,002.9	7.8	0.0	4,179.6	3,258.3	986.9	70.9	506.0	...
JAÉN	71,410.5	61,967.5	89,584.8	100,449.3	47,392.4	1,039,794	41,785.9	95,006.0	4,956.0	2,616.4	33,075.3	5,060.6	7,339.3	2,332.5	15,868.6	...
MÁLAGA	92,726.8	267,886.2	75,600.6	132,019.9	43,677.9	82,835.1	1,819,681	324,424.0	470.0	286.3	11,535.9	2,082.3	1,093.7	15.9	10,177.0	...
SEVILLA	17,451.6	179,586.4	103,252.7	40,975.7	306,764.5	34,160.9	94,842.0	2,009,237	982.0	137.3	18,772.2	15,391.8	4,403.8	659.7	5,163.6	...
HUESCA	657.0	1,372.9	4,555.6	19.6	376.5	0.0	1,362.5	6,136.5	1,165,351	23,461.6	240,860.0	863.8	3,444.9	3.8	1,546.2	...
TERUEL	3,613.2	333.1	935.4	69.0	1,335.5	820.6	113.8	966.4	9,162.9	479,170	172,256.6	7,761.5	24,476.9	60.2	21,255.7	...
ZARAGOZA	3,912.5	6,979.5	2,085.4	136.2	2,127.3	3,367.2	2,253.5	5,464.3	47,676.2	40,529.7	1,547,129	7,802.9	16,201.4	309.9	18,073.6	...
ASTURIAS	13,290.3	238.0	3,939.2	1,209.4	12,138.7	3,827.7	13,855.9	14,392.7	19,605.9	1,428.5	24,746.5	4,101,922	131,139.4	1,633.3	42,924.2	...
CANTABRIA	706.4	2,460.6	348.0	1,112.0	334.5	521.3	3,302.2	1,768.3	24,256.7	931.2	38,430.5	429,740.3	1,541,206	8,083.0	64,032.1	...
ÁVILA	1,717.6	268.5	3,422.5	649.1	139.5	6,827.5	1,253.9	2,488.4	67.1	13.8	530.0	22,685.4	2,703.8	717,608	584.0	...
BURGOS	1,202.4	22,203.1	4,999.6	1,756.1	1,648.2	1,666.3	2,713.7	12,355.9	4,112.6	495.2	18,314.6	24,234.7	73,262.1	1,421.0	1,156,478	...
LEÓN	4,231.6	10,823.4	7,270.2	973.1	4,172.1	2,666.6	3,758.6	7,525.5	4,716.6	557.2	41,854.5	362,891.0	19,417.2	1,613.1	45,459.8	...
PALENCIA	17.9	5,261.9	179.2	73.1	1,960.0	637.6	197.3	10,914.3	3,254.4	550.2	18,581.4	39,269.6	74,459.5	5,819.7	60,888.9	...
SALAMANCA	292.3	34,619.3	2,573.4	55.9	12,598.1	2,157.6	1,457.8	44,125.4	720.8	7.8	3,552.3	31,204.0	7,185.5	11,421.0	3,171.4	...
SEGOVIA	963.5	7,233.1	3,622.3	2,394.9	10.4	2,330.6	1,485.8	3,082.5	302.8	199.5	9,363.5	6,772.8	16,126.1	7,528.4	30,862.3	...
SORIA	0.8	7,918.7	981.6	84.1	1,026.9	932.7	693.2	3,954.2	4,127.8	3,648.1	59,074.0	3,171.7	4,077.1	331.9	24,774.5	...
VALLADOLID	3,045.9	11,705.9	5,061.9	1,497.9	5,514.8	10,854.0	2,171.0	31,208.5	2,298.1	3,461.3	19,962.4	40,951.7	21,203.8	8,694.6	23,375.8	...
ZAMORA	1,543.8	8,915.1	5,250.1	1,112.8	1,597.0	10,854.3	955.4	8,200.3	2,773.3	973.8	11,771.4	12,551.8	2,125.1	3,803.3	14,261.3	...
ALBACETE	8,163.9	4,881.2	9,754.4	3,070.3	8,604.3	26,705.0	6,522.5	15,523.4	1,350.6	1,537.5	6,586.0	16,432.8	15,973.0	175.9	9,004.1	...
CIUDAD REAL	25,665.0	40,364.9	64,621.4	22,673.3	18,973.6	60,018.2	20,782.8	38,431.5	2,640.0	1,435.0	30,468.9	5,453.0	4,847.6	1,794.3	14,860.0	...
CUENCA	5,618.3	4,809.6	7,236.6	295.3	6,062.1	1,951.6	326.9	8,003.2	832.4	16,268.4	6,137.5	7,382.3	26,552.8	387.4	15,026.5	...
GUADALAJARA	33.2	11,057.9	3,920.5	506.0	3,456.5	2,463.0	2,004.9	7,034.6	5,467.2	6,643.6	84,871.4	2,080.9	2,403.9	234.2	4,684.7	...
TOLEDO	13,143.3	14,501.4	24,496.3	11,809.0	8,556.7	29,782.4	11,446.6	25,607.1	1,825.4	1,064.2	24,382.6	6,123.9	4,990.3	13,319.4	8,744.4	...
BARCELONA	7,634.5	6,381.8	14,199.9	9,579.2	9,881.9	7,404.7	1,617.2	12,324.4	33,714.2	4,149.4	113,723.9	21,488.0	39,289.0	1,070.4	34,059.1	...
GERONA	0.0	205.9	2,965.4	1,522.0	271.0	1,787.8	0.0	2,582.3	3,468.6	256.3	4,819.5	2,569.4	2,532.9	172.6	809.6	...
LÉRIDA	92.1	1,348.2	3,531.4	53.0	870.3	4.3	1,323.3	5,592.8	98,945.6	44,237.4	67,108.4	5,600.2	18,100.8	92.6	8,349.8	...
TARRAGONA	4,291.2	3,178.5	4,262.4	2,400.5	3,705.0	1,628.7	1,702.1	5,130.7	31,560.5	8,693.8	19,841.2	1,494.4	4,963.4	33.3	4,858.2	...
ALICANTE	27,613.1	11,223.2	1,659.6	9,903.9	5,261.0	2,898.6	7,889.9	11,289.9	3,823.0	1,851.6	18,779.2	7,908.6	9,473.6	0.8	3,393.9	...
CASTELLÓN	2,787.0	1,863.5	1,348.6	1,535.9	1,073.2	297.7	5,922.1	1,688.4	39,628.0	81,611.5	47,736.8	7,266.8	9,810.7	87.7	8,608.6	...
VALENCIA	24,226.0	26,433.9	34,047.7	16,286.7	33,658.1	14,832.4	18,772.2	38,410.3	9,450.7	27,098.8	83,648.0	16,854.4	19,084.7	962.1	16,125.6	...
BADAJOZ	751.5	41,200.6	37,843.2	5,017.9	52,288.3	4,395.9	2,890.0	150,846.6	143.8	646.0	13,431.4	23,546.3	7,792.5	1,653.4	4,785.1	...
CÁCERES	0.0	44,332.3	6,488.8	1.4	51,819.6	384.1	3,109.9	142,858.4	422.4	1,198.4	21,508.1	21,068.5	14,627.0	2,606.1	9,231.2	...
A CORUÑA	147.2	1,343.5	4,473.9	200.4	669.9	3,597.9	1,005.7	1,791.9	299.4	639.6	18,966.1	75,430.2	5,862.0	660.8	19,759.0	...
LUGO	1,186.9	1,805.8	5,115.6	464.4	1,059.4	1,311.1	649.7	1,832.3	634.8	109.0	13,716.4	138,689.5	10,961.7	30.5	12,291.3	...
ORENSE	1,110.2	2,248.0	3,245.3	1,353.1	620.1	18,388.4	1,223.9	7,395.7	395.9	3,042.7	23,963.1	6,186.0	325.7	4,003.2	40,366.7	...
N47	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Source: Own elaboration

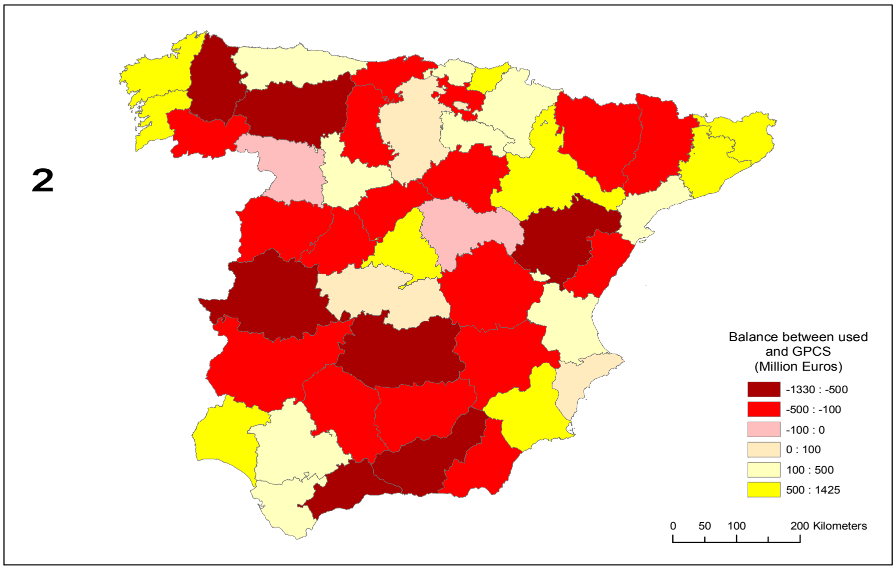
Table 2 - Capital stock aggregates, 2007 (Thousand Euros)

Provinces	Gross public capital stock (sum of rows): KP_P^t (a) = (b)+(d)	Internal stock: $INTKP_{P_p}^{t,P_p}$ (b)	Imported stock: $IMPKP_{P_p}^{t,P_q}$ (c)	Exported stock: $EXPKP_{P_q}^{t,P_p}$ (d)	Used stock (sum of columns): $UKP_{P_q}^{t,P_p}$ (e) = (b)+(c)	Balance between the used and gross public capital stock: $BKP_{P_p}^t$ (e)-(a) = (c)-(d)
ALMERÍA	2,044,676	1,187,515	651,620	857,161	1,839,135	-205,541
CÁDIZ	2,439,186	1,829,977	1,106,446	609,209	2,936,423	497,237
CÓRDOBA	2,079,579	1,101,298	702,042	978,281	1,803,340	-276,239
GRANADA	2,682,582	1,104,152	664,423	1,578,430	1,768,575	-914,007
HUELVA	1,737,763	1,458,126	823,659	279,637	2,281,785	544,022
JAÉN	2,273,310	1,039,794	748,910	1,233,517	1,788,704	-484,606
MÁLAGA	3,330,748	1,819,681	807,899	1,511,066	2,627,581	-703,167
SEVILLA	3,374,761	2,009,237	1,769,884	1,365,523	3,779,121	404,361
HUESCA	1,824,345	1,165,351	405,585	658,994	1,570,935	-253,409
TERUEL	1,394,213	479,170	294,707	915,043	773,877	-620,336
ZARAGOZA	2,646,924	1,547,129	1,641,421	1,099,795	3,188,550	541,626
ASTURIAS	5,502,245	4,101,922	1,680,782	1,400,323	5,782,704	280,459
CANTABRIA	2,974,882	1,541,206	1,263,081	1,433,676	2,804,287	-170,595
ÁVILA	1,012,528	717,608	135,480	294,920	853,087	-159,441
BURGOS	2,039,181	1,156,478	910,373	882,703	2,066,851	27,670
LEÓN	3,157,955	1,430,319	398,552	1,727,636	1,828,871	-1,329,084
PALENCIA	1,017,701	385,481	366,064	632,220	751,545	-266,156
SALAMANCA	1,443,690	961,487	187,782	482,203	1,149,269	-294,421
SEGOVIA	1,217,938	840,897	168,692	377,041	1,009,589	-208,349
SORIA	825,348	405,243	164,192	420,105	569,436	-255,913
VALLADOLID	1,511,089	721,191	912,550	789,898	1,633,741	122,652
ZAMORA	1,384,835	751,112	618,014	633,723	1,369,126	-15,709
ALBACETE	1,427,345	601,743	414,025	825,602	1,015,768	-411,577
CIUDAD REAL	1,727,338	713,777	468,145	1,013,561	1,181,923	-545,416
CUENCA	1,853,609	1,135,575	273,493	718,035	1,409,068	-444,542
GUADALAJARA	1,239,104	576,536	573,835	662,569	1,150,370	-88,734
TOLEDO	2,575,628	1,624,890	1,003,215	950,738	2,628,106	52,477
BARCELONA	8,896,108	6,753,727	3,427,325	2,142,381	10,181,052	1,284,944
GERONA	2,425,211	2,196,259	1,053,138	228,952	3,249,397	824,186
LÉRIDA	2,546,549	1,477,996	670,418	1,068,552	2,148,414	-398,135
TARRAGONA	2,836,643	2,066,977	1,080,011	769,666	3,146,988	310,345
ALICANTE	3,291,563	2,212,761	1,129,607	1,078,801	3,342,369	50,806
CASTELLÓN	2,274,152	1,621,079	399,970	653,073	2,021,049	-253,103
VALENCIA	5,409,396	3,497,692	2,344,469	1,911,704	5,842,161	432,765
BADAJOZ	2,394,056	1,554,145	569,208	839,911	2,123,354	-270,703
CÁCERES	1,914,307	650,233	198,848	1,264,073	849,081	-1,065,226
A CORUÑA	3,535,549	2,842,506	2,118,257	693,043	4,960,763	1,425,215
LUGO	2,397,761	1,362,265	514,860	1,035,495	1,877,126	-520,635
ORENSE	1,660,894	904,311	324,610	756,583	1,228,921	-431,973
PONTEVEDRA	3,182,722	2,573,275	1,286,498	609,447	3,859,773	677,051
MADRID	9,089,801	6,495,994	3,573,256	2,593,808	10,069,249	979,448
MURCIA	2,534,838	1,752,626	1,434,253	782,212	3,186,879	652,041
NAVARRA	2,595,655	1,921,241	1,072,690	674,414	2,993,930	398,275
ÁLAVA	1,698,888	537,582	847,702	1,161,307	1,385,284	-313,605
GUIPÚZCOA	2,777,430	1,889,749	1,696,762	887,681	3,586,511	809,081
VIZCAYA	3,558,397	2,174,804	1,808,856	1,383,593	3,983,660	425,263
LA RIOJA	1,531,058	1,118,916	572,840	412,142	1,691,756	160,697

Source: Own elaboration

We observe in Figure 5 that provinces with positive balances are those using their own roads as well as those situated in all other Spanish provinces when developing their commercial relations. As a result, two types of provinces exhibit a positive balance: (i) on one hand those situated in the periphery and, therefore are less likely to export their own stock as they do not conform corridors for the flow of goods, and (ii) wealthy provinces that exhibit large exports both in absolute and relative terms, and therefore use (import) the stock in all surrounding regions and main corridors so as to reach all potential markets. This is the case of Madrid representing and interesting case in itself, since it allows us to portrait these two (counterbalancing) forces simultaneously. By locating in the center of the Iberian Peninsula, Madrid is a key corridor in all commercial flows, a situation that induces capital stock exports, but Madrid has grown also into an economic hub with a large share of the Spanish export flows, resulting in capital stock imports. In fact, Madrid is the province with the highest GDP in Spain, thereby accounting for the second largest share in the overall Spanish export flows after Barcelona (Figure 3). Since the capital stock balance amounts a positive value of €979.4 million Euros, we conclude that the relative road freight exports of Madrid (within itself and other provinces) outweigh the use that other provinces make of its endowed capital stock; a situation that is not observed in almost all its adjacent regions: Avila, Segovia, Guadalajara and Cuenca whose balance is negative precisely because of the pressure (formally the weight defined in eq. (12)) that Madrid exerts over their stocks and the fact its neighbors are relatively poor provinces and therefore present relative low export flows (the only exception is Toledo that presents a small surplus of €52.5 million euros). We conclude that a positive balance between the imported and exported stocks is more likely to be observed depending on the following characteristics related to geographical location and relative export activity. The more peripheral and export active (richer) is a province, the higher the likelihood that it will exhibit a positive balance. On the contrary, the more centrally located (crossroads effect) and less export activity presents a province, the lower the likelihood of a positive balance.

Figure 5 - Balance between the used and gross public capital stocks, 2007.



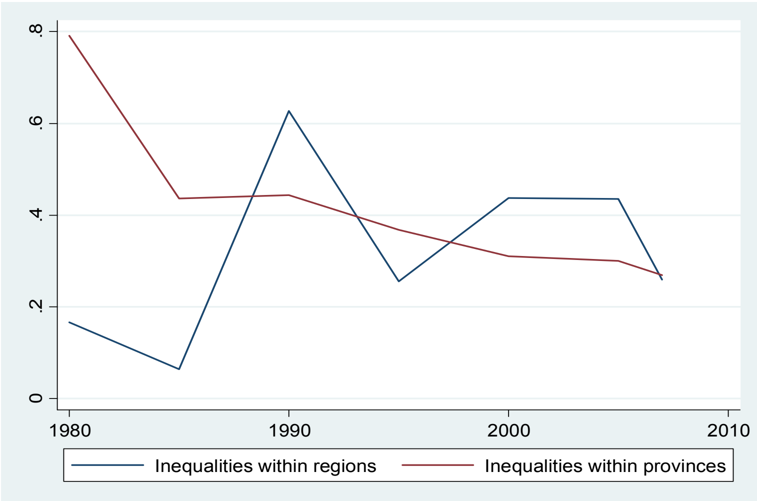
Source: own elaboration

3.6. Regional inequalities in the balance of transport infrastructure stocks.

The distribution of the gross capital stocks across provinces greatly depends on the investment decision made by different administrations. In Spain, up to the early eighties, almost all road investments were decided by the Ministry of Transportation that focused on extending the high-capacity network following a core-periphery pattern with Madrid situating in the center. From the late eighties onwards, the investment decisions were shared with regional administrations, resulting in more balanced investments across regions and provinces and the consolidation of a grid network in Spain. In fact, once the radial (spoke) links were consolidated, the Spanish Ministry of Transportation, along with regional administrations, implemented investments plans with the objective of promoting a more balanced regional economic growth and improving territorial convergence and cohesion. On the other hand, as previously discussed, the relative values of the imported capital stock from other regions heavily depends on the magnitudes of the trade flows and, therefore, those regions exporting more goods are the ones to be allocated more imported capital stock as their weights will be larger. Consequently, bringing all these factors together allow us to conclude that those regions that have benefited from large investments will tend to have larger internal stocks, and as anticipated, if they locate in the periphery and exhibit high trade-exporting-values they will also have large imported stocks. Both situations will generally result in positive capital balances.

Information about the inequalities in the balance between the used (internal and imported) and the endowed gross public capital stocks (or imported less exported stocks) across regions and provinces can be gathered by way of the Theil's index. Figure 6 shows that balance inequalities across provinces have fallen, but regional inequalities have risen, following a cyclic evolution that ends with similar levels of inequalities. So, we can observe that taking into account our definition of capital balance, the strategic plans developed by the Spanish Ministry of Transportation and regional administrations have resulted in a reduction in provincial inequalities, regardless of the region to which these belong. For this reason, the balance at provincial level shows a smooth path, unlike what happens with regions, whose evolution varies according to the periods, and depending on the provinces that are targeted over the years by the different administrations in the specific investments plans.

Figure 6 – Theil's index of inequalities in the capital stock balance across regions and provinces (1980 – 2007)



Source: Own elaboration

Looking at the inequality indices provides a useful, but partial, picture of the evolution of regional inequalities. More detail can be observed by constructing transition probability matrices that allow us to analyze changes over time in the relative position of regions and provinces within the distribution. Table 4 reports the transitions between the 1980 to 2007 distributions of the capital stock balance, dividing the sample into quintiles. The two first quintiles refer to provinces exhibiting a negative balance, while in the last two we can find provinces with a positive balance. Finally, the third quintile contains provinces with a balance close to zero, which may be either positive or negative.

The main diagonal of this matrix gives the proportion of provinces that were in the same range of the distribution during the 1980-2007 overall period. The large probabilities on the diagonal show the strong persistence in the sign of the balances, especially when the provinces are located in the extreme values where transitions are hardly observed. For instance, reading along the first row of the matrix, we can see that the probability of increasing the value of the capital stock balance is 15% for the next quintile and the probability reduces in the following quintiles to 1.67%. In the next row we can observe that the probability of reducing and increasing the balance is 24.07% and 18.52%, therefore moving to the previous and next quintiles. Finally, it decreases to 0.00% in the last quintile. The matrix shows the same process considering balance values closest to zero, and in the last two rows positive balance. Therefore, the probability of a province exhibiting the same value as that initially observed is very high, and this probability reduces when we consider a decrease or expansion in the balance increasingly large.

Table 4 – Transition probability matrix of the capital stock balance: (1980 – 2007)

	Balance between used stock and gross public capital stock				
	Q_1	Q_2	Q_3	Q_4	Q_5
Q_1	70.00	15.00	11.67	1.67	1.67
Q_2	24.07	55.56	18.52	1.85	0.00
Q_3	3.33	20.00	48.33	25.00	3.33
Q_4	5.56	5.56	18.52	55.56	14.81
Q_5	0.00	0.00	7.41	12.96	79.63

Source: Own elaboration

3.7. Distribution of spillover effects and territorial cohesion

In the strategic plans proposed by Spanish Ministry of Transportation, the investment decisions are driven by the objective of improving economic growth as well as territorial cohesion[6]. With this aim in mind public administrations have allocated more infrastructure investments in peripheral provinces since the nineties, so as to improve their accessibility both in absolute and relative terms. However, the analysis of the net (aggregate) capital stock balance reported in the last column of Table 3—complemented with the persistence of the rankings as shown in the transition matrix—suggests that less developed provinces exhibit in general a capital stock deficit by which a high share of their endowed infrastructure is exported, and these exports exceed the use (imports) of the capital stock of other provinces. This is an indication of more developed regions taking advantage of the capital stock existing in less developed regions to a larger extent than these last regions themselves. As a result, when outgoing spillovers resulting from the use of a province's capital stock by other provinces (exports) exceed the

[6] The present research uses the term "territorial cohesion" as in the Third Cohesion Report, as a synonym for ''territorial balance'' (EC, 2004; Camagni, 2009).

incoming spillovers from which that same province benefits (imports), this capital stock deficit contributes to regional disparity (Condeço et al. (2011)).

The matrix of used public capital stock presented in Table 2 allows the estimation of the provincial spillovers which are transferred from more developed locations to less developed ones (outgoing spillovers resulting in downstream effects to which we associate a positive sign since it works in favor of regions with lower GDPs) and vice versa (outgoing spillovers resulting in upstream effects to which we associate the negative sign since these transfers work against provinces with lower GDP). Particularly, we make use of the definition of the capital stock balance as introduced in eq. (14) , but instead of aggregating all capital stock imports and exports so as to calculate the overall (aggregate) net balance reported in the last column of Table 3, we now consider the bilateral balance between two provinces: $BKP_{P_p}^{t,P_q} = IMPKP_{P_p}^{t,P_q} - EXPKP_{P_p}^{t,P_q}$, where p and q are ordered according to their relative GDPs, with the less developed province p importing and exporting to the more developed province q. If $BKP_{P_p}^{t,P_q} > 0$ a positive spillover contributing to territorial cohesion is observed, since the poorer region makes use of the capital stock of the richer region to a larger extent than the richer province makes use of the poorer. Conversely, if $BKP_{P_p}^{t,P_q} < 0$ the opposite takes place and a negative spillover, both in sign and conceptually, takes place. We can make us of the data on the first two provinces presented in Table 2 to exemplify this relationship. For Cádiz and Almería, both provinces situated in the Andalusia region, $BKP_{P_p}^{t,P_q}$ = 13,257 − 23,189 = − 9,923, and therefore a negative spillover is observed.

We have calculated all the $N{\cdot}(N{+}1)/2 = 46{\cdot}(46{+}1)/2 = 1{,}081$ bilateral capital stock balances between the 47 Spanish provinces in 2007, whose summary statistics are reported in Table 5. The results show that the mean spillover is negative, as well as the median, and with the sum of the negative spillovers exceeding that of the positive by 103.2%. Since the negative spillovers double positive ones, it is clear that given the infrastructure endowments and the bilateral trade flows, the investments made over the years have resulted in a situation where the capital stock existing in less developed locations is being used to a larger extent by more developed locations. Nevertheless, we can qualify these results further by weighting each bilateral capital stock balance by the difference in *per capita* GDPs between the two provinces, normalized by the average GDP difference for all Spanish provinces. In this way, the larger (smaller) the GDP gap between the richer and poorer region, the larger (smaller) the weight for the bilateral relationship. As a result, the second column in Table 5 reports the summary statistics for the following bilateral relationship:

$$WBKP_{P_p}^{t,P_q} = BKP_{P_p}^{t,P_q} \cdot \left[\left(GDP_q - GDP_p \right) / \sum (GDP_q - GDP_p) / 1{,}081 \right], \tag{17}$$

where $\sum (GDP_q - GDP_p) / 1{,}081$ = 5,225.7 €/*p.c*. Weighting the capital stock balances by the GDP differences aggravates the magnitude of the negative spillovers against the poorest regions since the mean value increases by 47.4%, with the sum of the negative spillovers exceeding that of the positive values by 279.1%. For our particular example concerning Cádiz and Almería: $WBKP_{P_p}^{t,P_q}$ = – 9,923 · [(21,317 – 18,578) / 5,225.7] = – 5,201, and the weighted magnitude is smaller than the unweighted one. An expected result because both provinces belong to the same region and therefore their GDP levels do not differ to a large extent. Overall, the inclusion of the GDP difference as weight reinforces the conclusion that poorer regions are not benefiting from the capital infrastructure existing in Spain as a whole—as the opposite is actually observed, and that the poorer the province the larger is its capital stock deficit (negative spillover) with respect to other provinces. Clearly, as we conclude in the following section, these results are compatible with the fact that the capital stock infrastructure is a significant input to economic growth, both for less and more developed provinces, but allows us to shed light on the fact that when the territorial cohesion objective is taken into account, the actual use of the capital stock in trade flows favors more developed regions.

Table 5 – Spillovers associated to the bilateral capital stock balances, 2007.

	$BKP_{P_p}^{t,P_q}$	$WBKP_{P_p}^{t,P_q}$
Mean	-6,148.8	-9,061.4
Median	-1,592.5	-1,008.3
Standard Deviation	44,564.6	44,065.3
Variation coefficient	-724.8	-486.3
Asymmetry	1.7	-9.6
Maximum	65,2624.3	196,148.9
Minimum	-41,2241.1	-920,246.8
Sum of positive values	6,439,661.4	3,510,156.7
Sum of negative values	-13,086,509.3	-13,305,483.1
Difference	-6,646,847.9	-9,795,326.4

Source: Own elaboration

4. The direct and spillover effects of transport infrastructure on production.

4.1 Data: sources and description

We now analyze the effects of used public capital stock on regional economic activity using the production function approach and estimate the alternative panel data regression presented in section 2 using individual information on the Spanish provinces and regions (*Comunidades Autónomas*) from 1980 to 2007. Data come from two main sources. Gross Domestic Product (GDP) and private labour (number of employees. *L*) from the Spanish National Institute of Statistics (*Instituto Nacional de Estadística*, INE). As anticipated in section 3 the series of productive (i.e., non-residential) private capital (*K*) are taken from the database compiled by Mas et al. (2010). All variables are expressed in 2000 constant values. Regarding the public capital stocks of road transport infrastructure our calculations at the regional and provincial level make it possible to perform an analysis of the effects on production of the internally used road network infrastructure (direct effect) and the spillover effects derived from the road network infrastructure that is imported, thereby taking into account these two geographical dimensions. As the rest of the variables, including the ancillary values of trade flows employed to estimate the used capital stock of infrastructure, we express the road network capital stock (both internal and imported) in monetary terms. Therefore, we estimate a production function introducing inputs on homogeneous monetary units and prove the robustness of the results using our database. Table 6 shows the descriptive statistics corresponding to variables used in the production function analysis.

Table 6 - Descriptive statistics

Variable	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Gdp (thousands of euro in 2000 constant prices)	112,442	183,783	8,668	1,458,253
Labour (thousands of employees)	314	453	34	3,463
Private Capital (thousands of euro in 2000 constant prices)	4.04e+07	6.78e+07	3.016.760	5.39e+08
Used Capital Stock (thousands of euro in 2000 constant prices)	947,420	899,359	94,691	6,753,727

Source: Own elaboration

As anticipated this study employs data covering the period from 1980 to 2007. This period is of special interest given that it coincides with an increase in the decentralization of public functions as Spain joined the European Community. Both events gave rise to substantial growth in public investment, intended to improve road infrastructure. The production function was estimated using a panel of data on regional GDP and the labor and capital stock variables presented in Table 6. Recalling section 2, and as in most empirical studies, it is accepted that the underlying technology of the production function is of a Cobb-Douglas type. Based on this function, we analyze the contribution of the used internal and imported capital stock as additional as specified in equation (5).

4.2. The direct effect of transport infrastructure in production.

We have performed two sets of regressions with regional and provincial data. In the first set the results obtained by the traditional approach excluding the variables capturing the spillover effects is presented (Tables 7 and 8). Subsequently, we enhance these regressions by including the capital stock variables to which the spillover effects are associated (Tables 9 and 10).

Tables 7 and 8 report the estimates of the production function by regions and provinces, respectively, with the total gross public capital stock in road infrastructure published by Mas et al. (2010) following the perpetual inventory method, and our internally used capital stock, and ignoring spillover effects; i.e., keeping the inventory stock of adjacent regions and the imported stock out of the specification. The R-squared and the F statistic of joint significance show that all the estimated equations are significant. Additionally, the model has been estimated by means of the fixed effects estimator because both the F test of individual effects and Hausman´s test (Hausman, 1978) allow rejection of the null hypothesis, so we can capture unobservable heterogeneity (Baltagi, 2008).

Table 7 – Regional production function (1980 – 2007)

	Gross Public Capital Stock (IVIE) (***Fixed Effects model***)	**Used Capital Stock** (***Fixed Effects model***)	**Used Capital Stock** (***IV Two - Step GMM***)
Constant (C)	0.67 (2.99)**	0.43 (1.78)**	
Employment ($\ln L_{it}$)	0.16 (3.08)**	0.12 (2.17)**	0.18 (2.56)**
Private Capital ($\ln K_{it}$)	0.51 (14.00)**	0.57 (13.17)**	0.39 (4.58)**
Gross Public Capital Stock ($\ln KP_{it}$)	0.11 (5.15)**		
Used Capital Stock ($\ln INTKP_{it}$)		0.08 (2.54)**	0.23 (3.28)**
Joint Significance Test F	F(3.87) = 1,204.48	F(3.87) = 986.24	F(3.87) = 642.01
R^2	0.96	0.96	0.96
Individual Effects Test F	F(14.87) = 54.28	F(14.87) = 44.35	F(14.87) = 34.62
Test Hausman	$\chi^2(3) = 74.30$	$\chi^2(3) = 54.50$	$\chi2(3) = 9.56$
Underidentification Test (Kleibergen-Paap rk LM statistic)			$\chi^2(1) = 7.91$
Weakidentification Test (Kleibergen-Paap rk Wald F statistic)			19.63 [16.38/8.96]
Overidentification Test (Sargan - Hansen J statistic)			0.00

T-statistic in parenthesis
In brackets critical value computed by Stock and Yogo (2005) and 10/15% maximal IV size
*Parameter significant at 90%
**Parameter significant at 95%
Source: Own Elaboration

Table 8 - Provincial production function (1980 – 2007)

	Gross Public Capital Stock (IVIE) (*Fixed Effects model*)	Used Capital Stock (*Fixed Effects model*)	Used Capital Stock (*IV Two - Step GMM*)
Constant (C)	0.41 (2.96)**	-0.05 (-0.40)	
Employment ($\ln L_{it}$)	0.21 (8.11)**	0.15 (5.91)**	0.15 (5.58)**
Private Capital ($\ln K_{it}$)	0.52 (23.01)**	0.62 (36.83)**	0.59 (17.40)**
Gross Public Capital Stock ($\ln KP_{it}$)	0.08 (6.28)**		
Used Capital Stock ($\ln INTKP_{it}$)		0.01 (1.09)	0.05 (1.54)*
Joint Significance Test F	F(3.279) = 3,432.12	F(3.279) = 3.009.35	F(3.279) = 2,564.87
R^2	0.96	0.96	0.97
Individual Effects Test F	F(46.279) = 38.37	F(46.279) = 35.68	F(46.279) = 34.59
Test Hausman	$\chi^2(3) = 428.21$	$\chi^2(3) = 295.05$	$\chi^2(3) = 444.70$
Underidentification Test (Kleibergen-Paap rk LM statistic)			$\chi^2(1) = 24.01$
Weakidentification Test (Kleibergen-Paap rk Wald F statistic)			32.69 [16.38/8.96]
Overidentification Test (Sargan - Hansen J statistic)			0.00

T-statistic in parenthesis
In brackets critical value computed by Stock and Yogo (2005) and 10/15% maximal IV size
*Parameter significant at 90%
**Parameter significant at 95%
Source: Own Elaboration

In the first column we have estimated the production function including the standard gross public capital stock magnitude, while in the second column we consider the internally used capital stock as the measure of the road network public capital stock that regions use in their internal commercial flows. In both cases, at regional and provincial level, looking at these results we confirm that the estimated coefficients for labor and private capital are consistent with other production function studies, which are around the expected shares of these two inputs in the aggregate output. The gross public capital stock coefficient is positive and significant, with values of 0.11 and 0.08 for regions and provinces, respectively. The elasticity of the internally used capital stock on the private sector (second column) shows that, although the impact is limited in provinces, it is positive and significant al regional level.

Moreover, to address any endogeneity problem associated to the internally used capital stock, the third column corresponds to an instrumental variable estimation following the two-step GMM method (Baum et al., 2003; Schaffer, 2010), which provides both an autocorrelation-robust covariance matrix as well as standard errors that are robust to heteroskedasticity and autocorrelation. For fixed-effects estimation the covariance matrix and regression statistics are adjusted for the number of fixed effects, similar to the formulation of a cluster-robust covariance matrix for the fixed-effects model as originally proposed by Arellano (1987).

Wooldridge (2002), by contrast, use an adjustment which is somewhat conservative in this context.

An instrumental variable must satisfy two requirements: it must be correlated with the included endogenous variables and orthogonal to the error process. Generalized Transport Costs (GTC) calculated by Zofío et al. (2011) with respect to Zaragoza and Madrid are used as instruments, both for the regional and provincial specifications, respectively, as an approximation to the degree of peripherality measured by the access to economic activity through the road network infrastructure. Tables 7 and 8 report some diagnostic testing of the IV regressions. The rank LM test by Anderson and Kleibergen-Paap for under-identification returns chi-squared values with one degree of freedom of 7.91 and 24.01 respectively, implying that the null hypothesis of under-identification is rejected by the data, and that the excluded instrument is relevant, meaning that it is correlated with the endogenous regressor. We also report the Stock and Yogo (2005) weak instrument test based on Kleibergen-Paap's rank Wald F statistic for robust estimation (Kleibergen and Paap, 2006). The statistics are greater than the critical values provided by Stock and Yogo (2005)[7], so the selected instruments are not weak or poor predictors of the endogenous variables (as the bias of the IV estimator is below the 10% threshold). The second requirement for a valid instrument set, the orthogonality between the instrument and the error term, is tested by means of a Hansen Test for overidentifying restrictions (Hansen, 1982). Under the null hypothesis that the instrumental variables are valid, the Hansen test is distributed as a chi-square with degrees of freedom equal to the number of overidentifying restrictions. The Sargan and Hansen-J statistics for over-identifying restrictions is 0.00 in both cases. Thus, given that the pre-testing broadly confirms the validity of the two instruments we introduce corrections in the internally used capital stock by the degree of peripherality, taking into account that the center of economic activity is situated in Zaragoza for the regional regression and Madrid for the provincial regression[8]. The spatial distribution of the regions and provinces determines the use of different instrumental variables. In northern Spain there are many small Autonomous Communities, while in the south the opposite can be observed. For this reason, at regional level the geographical center is situated in the northwest and, specifically, in Zaragoza. For the provincial disaggregation, since all provinces are of similar size the center moves to Madrid.

[7] Stock and Yogo (2005) classify a group of instruments as weak, or "performing poorly", if the bias of IV estimator relative to the bias of the OLS estimator exceeds several possible thresholds (in this study we use 10% and 15% maximal IV sizes).

[8] The distance to Zaragoza as instrumental variable for market access in a regression of GDP has been applied to Spanish data by López-Rodríguez et al. (2011). This study suggests the existence of a "core-periphery" structure in the Iberian Peninsula, in which the center agglomerates the economic activity and is situated in the triangle País Vasco–Gerona, Gerona–Valencia and Valencia–País Vasco, along with the capital, Madrid. This kind of clustering follows the argument made in Marquez and Hewings (2003) and Marquez et al. (2003, 2006).

The results using the instrumental variable two-step GMM method show a more intensive effect of the internally used capital stock, especially at regional level. As we saw in the previous section, the estimation of the used capital stock is conditional to the optimal itineraries minimizing the generalized transportation cost, so the degree of peripherality determines the intensity in the use of the road networks in commercial flows. Therefore, introducing this correction, the coefficient associated to the internally used capital stock improves considerably, being more intensive at regional level than the effect of the totally endowed road network.

Additionally, the coefficients corresponding to both the gross public capital stock and the internally used capital stock are lower using higher levels of territorial disaggregation. The reason for this is the increasing role of the spillovers effects as the territorial disaggregation increases. Thus, provinces can benefit from the infrastructure located on the rest of provinces situated in the same region, due to the fact that the surrounding and nearest provinces are the most related through trade. In addition, when producing benefits in the area where they are located, transport infrastructures facilitate mobility between different areas, which in turn may involve spillover effects. A series of studies have attempted to estimate the economic impact of transport infrastructure and test whether or not there are wide scale spillovers (e.g., Holtz-Eakin, 1991, and Munnell, 1992). However, their approach only includes the overall endowed gross capital stock of the adjacent regions in the regressions, except for Cantos et al. (2005) who also weight that stock by trade data. Nevertheless, none of them consider the actual stock that being really used, as our approach does by introducing the optimization procedure presented in the third section that weights the stock that is really used in trade, by the relative magnitude of those flows.

4.3. The spillover effects of transport infrastructure on production.

To identify the magnitude and significance of the spillover effects, we perform equivalent regressions using our new definitions and aggregates of internal and imported capital stock and compare the results with those that are equivalent to those in the literature. With this aim we incorporate in our regressions the variable that measures the spillover effects associated to the imported capital stock, and, as in the previous subsection, we test the presence of spillover effects in transport infrastructure taking into account different level of geographical disaggregation; Tables 9 and 10 show the estimation results at the regional and provincial levels.

The first column corresponds to the standard specification including own gross public capital stock published Mas et al. (2010), and the stock corresponding to adjacent regions and provinces (which on average import about 50% of the stock that is exported from adjacent regions, as discussed in section 3.5), in line with the methodology used in other estimates reported for the Spanish economy (Cantos et al. (2005), Delgado and Álvarez (2007) and Álvarez and Delgado (2012)). In these cases, it is assumed that territorial proximity is the most important criterion in defining spillover effects, and therefore adjacent regions are those benefiting most the production activity of the region analyzed. This is the standard approach in the literature. In order to obtain a more accurate measure of this impact, in the second column we have estimated the production function including our internally used capital stock and our alternative measure capturing the spillover effects and corresponding to the imported capital stock, which takes into account the capital stock localized in all the remaining regions and provinces, weighted by trade flows. This measure of spillovers effects allow us to introduce the rest of regions and provinces, not only the adjacent, considering the volume of trade.

As reported, the R-squared and F statistic of joint significance show that all the estimations are significant. Additionally, the models have been estimated by means of the fixed effects estimator, given the values of both the F test of individual effects and the Hausman test. At the regional as well as the provincial level the coefficients for private labor and private capital are consistent with other production function studies. If we look at the results shown in the first column, the effect of the gross public capital stock is positive and statistically significant at provincial level, whereas spillover effect is more intense at regional level. We then test the sign and magnitude of the spillover effect by analyzing the value of coefficients associated to imported capital stock (second column), observing a positive relationship. However, the coefficient of the internally used capital stock is positive and significant at regional level, which signals that the benefits of the internally used capital stock are less important than the spillover effects as the geographical disaggregation increases.

The third column shows the estimates following the instrumental variables two-step GMM method. The under identification and the Sargan and Hansen-J statistic for over-identifying restrictions confirm the validity of the GTC with respect to Zaragoza and Madrid as appropriate instrumental variables at the regional and provincial level when correcting for peripherality. The weak identification statistics are greater than the critical values for a 10% bias of the IV estimator for provinces and 15% for regions. We obtain similar coefficients for the internally used and imported capital stocks. Consequently, the results show robustness.

Table 9 - Regional production function with spatial spillovers (1980 – 2007)

	Gross Public Capital Stock (IVIE) (*Fixed Effects model*)	Used Capital Stock (*Fixed Effects model*)	Used Capital Stock (*IV Two - Step GMM*)
Constant (C)	0.93 (3.67)**	1.00 (3.64)**	
Employment ($\ln L_{it}$)	0.19 (3.57)**	0.10 (1.94)**	0.12 (2.00)**
Private Capital ($\ln K_{it}$)	0.42 (7.56)**	0.51 (11.46)**	0.47 (7.43)**
Gross Public Capital Stock ($\ln KP_{it}$)	0.04 (1.00)		
Gross Public Capital Stock adjacent regions ($\ln KP_{it}$ -A)	0.14 (2.09)**		
Used Capital Stock ($\ln INTKP_{it}$)		0.06 (2.02)**	0.09 (1.69)**
Imported Capital Stock ($\ln IMPKP_{it}$)		0.07 (3.66)**	0.06 (3.56)**
Joint Significance Test F	F(4.86) = 939.33	F(4.86) = 848.51	F(4.86) = 731.06
R^2	0.93	0.95	0.97
Individual Effects Test F	F(14.86) = 55.91	F(14.86) = 42.17	F(14.86) = 41.08
Test Hausman	$\chi^2(4) = 19.18$	$\chi^2(4) = 91.43$	$\chi^2(4) = 1{,}243.43$
Underidentification Test (Kleibergen-Paap rk LM statistic)			$\chi^2(1) = 6.63$
Weakidentification Test (Kleibergen-Paap rk Wald F statistic)			13.32 [16.38/8.96]
Overidentification Test (Hansen J statistic)			0.00

T-statistic in parenthesis. In brackets critical values computed by Stock and Yogo (2005) and 10/15% maximal IV size.
*Parameter significant at 90%
**Parameter significant at 95%
Source: Own Elaboration

Table 10 - Provincial production function with spatial spillovers (1980 – 2007)

	Gross Public Capital Stock (IVIE) (*Fixed Effects model*)	Used Capital Stock (*Fixed Effects model*)	Used Capital Stock (*IV Two - Step GMM*)
Constant (C)	0.56 (3.59)**	0.65 (3.71)**	
Employment ($\ln L_{it}$)	0.22 (8.40)**	0.19 (7.41)**	0.19 (7.34)**
Private Capital ($\ln K_{it}$)	0.48 (17.61)**	0.53 (22.78)*	0.53 (18.05)**
Gross Public Capital Stock ($\ln KP_{it}$)	0.06 (3.40)**		
Gross Public Capital Stock adjacent provinces ($\ln KP_{it}$ -A)	0.05 (2.05)**		
Used Capital Stock ($\ln INTKP_{it}$)		-0.004 (-0.31)	0.002 (0.07)
Imported Capital Stock ($\ln IMPKP_{it}$)		0.07 (5.48)**	0.07 (4.51)**
Joint Significance Test F	F(4.278) = 2,604.65	F(4.278) = 2.499.55	F(4.278) = 2,352.90
R^2	0.96	0.96	0.97
Individual Effects Test F	F(46.278) = 37.72	F(46.278) = 29.50	F(46.278) = 29.46
Test Hausman	$\chi^2(4) = 151.19$	$\chi^2(4) = 386.38$	$\chi^2(4) = 806.73$
Underidentification Test (Kleibergen-Paap rk LM statistic)			$\chi^2(1) = 16.73$
Weakidentification Test (Kleibergen-Paap rk Wald F statistic)			24.37 [16.38/8.96]
Overidentification Test (Hansen J statistic)			0.00

T-statistic in parenthesis. In brackets critical value computed by Stock and Yogo (2005) and 10/15% maximal IV size
*Parameter significant at 90%
**Parameter significant at 95%
Source: Own Elaboration

When we consider the road network gross public capital stock provided by Mas et al. (2010) we obtain that in both cases the capital stock in adjacent regions and provinces favors production, more intensively at regional level given the elasticity values: 0.14 versus 0.05, while the own (endowed) gross public capital stock is significant only in case of the provincial analysis: 0.06. Therefore, when following the standard approach using the gross capital stock in the Spanish case, the fact that the elasticity of the spillover effect at regional level is larger than at the provincial level is counterintuitive and stands against previous results for other countries. These results are corrected when using our new stock aggregates since the observed elasticity values are greater at the provincial level as expected: 0.07 versus 0.06—and the internally used stock loses significance. For this reason, we believe that the present study proposing these new capital stock definitions and measures, extending the concept of the spillover effect by taking into account the rest of regions and provinces and weighting the strength of their relations by their bilateral commercial flows, are validated by the results. Summarising our results, the availability of this newly designed data base enables us to identify the magnitude and significance of the used capital stock effect on economic activity. Firstly, the evidence of a positive effect on economic activity associated to both the used capital stock as well as the imported capital stock, is confirmed at the regional. Secondly, with regard to the results obtained at provincial level, an important qualification is introduced, as the evidence presented shows that the imported capital stock exceeds in value the positive impact of the internally used capital stock, which, in addition, is not significant. So, the importance of spillover effects increases along with geographical disaggregation[9].

5. Conclusions

This study combines network analysis and econometric techniques to evaluate the impact of transport infrastructure on productivity, taking into account the spillover effects associated to the use of the public capital stock of infrastructure existing in other regions. Given availability of statistics, we employ Spanish data to illustrate our methodology, and focus on the road network and freight transportation between 1980 and 2007. In order to do so, we introduce new concepts and definitions of the road network public capital stock in monetary terms that take into account the real use of the stock in the commercial flows through optimal—least cost—itineraries. In particular, the new aggregate of imported capital stock from the rest of regions and provinces can be associated in the regression analysis to the spillover effects. With

[9] This is a common line of explanation to justify the existence of spillover effects. Studies performed on a lower than national scale obtains infrastructure elasticity lower than those at national level (García-Milá et al. (1992), Holtz-Eakin and Schwartz (1995) and Boarnet (1998)).

this procedure we can account for the fact that some roads are used in numerous commercial relations, whereas other may exhibit a residual contribution when channeling interregional trade flows (and thus will generate few spillovers). This provides the justification to consider the information on the real use that a region makes it of its own infrastructure (internally used capital stock) as well as on the infrastructure of other regions that it uses for its exports (imported capital stock).

By proposing these definitions we can also determine and analyze the net balance between the used capital stock, which includes internally used and imported capital stock, and the endowed or installed total gross public capital stock provided by Mas et al. (2010) following the OECD methodology based on the perpetual inventory method. A region or province with a positive balance makes an intensive use of the capital situated in other regions or provinces to export, and therefore, it is expected that it will profit from them. therefore receiving positive and significant spillover effects. The analysis indicates that regions and provinces with a positive balance are locations: (i) with GDP above the national average and presenting larger trade (export) flows, thereby making extensive use of the road network, and (ii) that situate in the periphery of the Iberian peninsula—a result justified by the fact that those regions (and corresponding provinces): Galicia, Basque Country, Catalonia, and Valencia, and therefore do not belong to extensively used corridors of the road network. A relevant exception is Madrid that situating in the center also presents a large share of trade flows.

Regarding the regression results, the availability of this new database enables us to identify the internally used capital stock effect on economic activity and compare it to the elasticity of the spillover effect (imported capital stock). Results confirm the importance of both magnitudes on aggregate production and that the internally used capital stock is relevant for production as well as that situating in other regions and provinces by way of the spillover effect. The results obtained at the provincial level proves the existence of strong spillover effects exceeding the positive impact of the internally used capital stock in the province itself, mainly in the case of provinces exhibiting a positive capital stock balance, which as remarked above are those situating in the periphery of the Iberian peninsula and Madrid, and are connected with other major economic centers through their own infrastructure and that existing in other provinces. The evidence supports recent literature on the existence of spillover effects, which increases along with the geographical disaggregation of the data. A result that is not observed in the Spanish case when performing estimations equivalent to those already proposed in the literature and using the gross (unweighted by trade and according to the optimal itineraries) capital stock aggregates.

These findings have important implications for policy makers. Overall, the empirical evidence presented in this study supports the hypothesis that the infrastructure actually used has an important impact on the aggregate economic activity, and generates relevant spillover effects across regions and provinces. Moreover, we observe that the spillover effect is higher than that corresponding to the internally used infrastructures at provincial level. The poorest provinces in Spain normally represent the target in the investment strategic plans developed by Ministry of Transportation in recent years, so as to improve territorial cohesion and promote a more balanced growth. The process of convergence in the capital stock balance as shown by the Theils's index shows that these efforts have succeeded at the provincial level. Nevertheless, overall inequalities still persist despite these efforts as shown by the distribution of the capital stock balance and the transition matrix. Our cohesion analyses based on unweighted bilateral balances show that richer locations benefit more from the existing stock at national level, as they import the stock from poorer regions to a larger extant than poorer regions make use of theirs (a results that is aggravated when considering as weights GDP differences). As anticipated, and from a geographical perspective, the poorest regions exhibiting a pass-through pattern by situating in trade corridors have not been able to benefit from network improving investments, since they export a large share of their endowed capital stock, and therefore it is the richest regions those profiting from it in their trade flows. In fact, this is the main reason why positive capital stock balances (surpluses) are observed in the rich Madrid province and other developed peripheral provinces, with spillover effects that are higher than those corresponding to their own infrastructure when a provincial disaggregation is considered. Therefore, we conclude that investment in infrastructure has contributed to reduce capital stock unbalances, which nevertheless persist as it is the richest provinces with large trade flows those benefiting most from the existing public capital stock of transport infrastructure at national level.

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