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EVIDENCE ON THE COMPLEX LINK BETWEEN INFRASTRUCTURE AND REGIONAL GROWTH[1]

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ABSTRACT

Most studies analysing the infrastructure impact on regional growth show a positive relationship between both variables. However, the public capital elasticity estimated in a Cobb-Douglas function, which is the most common specification in these works, is sometimes too big to be credible, so that the results have been partially desestimated. In the present paper, we give some new advances on the real link between public capital and productivity for the Spanish regions in the period 1964-1991. Firstly, we find out that the association for both variables is smaller when controlling for regional effects, being industry the sector which reaps the most benefits from an increase in the infrastructural dotation. Secondly, concerning to the rigidity of the Cobb-Douglas function, it is surpassed by using the variable expansion method. The expanded functional form reveals both the absence of a direct effect of infrastructure and the fact that the link between infrastructure and growth depends on the level of the existing stock (threshold level) and the way infrastructure is articulated in its location relative to other factors. Finally, we analyse the importance of the spatial dimension in infrastructure impact, due to spillover effects. In this sense, the paper provides evidence of the existence of spatial autocorrelation processes that may invalidate previous results.

KEYWORDS: Infrastructure, Regional Growth, Spatial Dependence, Varying Parameters

JEL: H54, E23, C23

RESUMEN

La mayoría de los estudios que analizan los efectos de las infraestructuras en el crecimiento económico han mostrado una relación positiva entre ambas variables. No obstante, la elasticidad del capital público obtenida mediante la teoría neoclásica (funciones Cobb-Douglas), que es la más común en estos trabajos, suele resultar demasiado grande como para ser creíble, por lo que los resultados han sido parcialmente desestimados. En el presente trabajo, se ofrece evidencia sobre algunos aspectos referidos al complejo vínculo entre infraestructuras y productividad para las regiones españolas en el período 1964-1991. En primer lugar, se ha encontrado que la asociación entre ambas variables resulta más pequeña cuando se tienen en cuenta los efectos regionales, siendo la industria el sector que recibe mayores beneficios de los aumentos en la dotación infraestructural. En segundo lugar, se ha superado la rigidez de la función Cobb-Douglas mediante el uso del método de expansión de variables. La forma funcional expandida nos revela la ausencia de un efecto directo del capital público así como el hecho de que el vínculo entre infraestructuras y crecimiento dependa tanto del nivel de stock existende de las mismas (nivel umbral) como de la forma en que las infraestructuras se articulan en su localización en relación al resto de factores. Finalmente, se analiza la importancia de la dimensión espacial en el impacto de las infraestructuras debido a los efectos spillover. En este sentido, el presente trabajo ofrece evidencia de la existencia de procesos de autocorrelación espacial que pueden llegar a invalidar resultados previos.

1. Introduction

Although the role of public capital in prompting growth has long been debated at the ideological level by the proponents of opposing worldviews, it was not until the late eighties that the first group of studies dealing with infrastructure effects on output performance appeared.[2] Aschauer (1989) and Munnell (1990a) found a positive relationship between the two variables at the national level in the US, while other references such as Munnell (1990b), Eisner (1991), Holtz-Eakin (1992) and García-Milà and McGuire (1992) found that in spite of a reduction in the public capital elasticity when one descends to a regional level, positive results were maintained. Nevertheless, the values for this relationship, mainly obtained through the use of a Cobb-Douglas production function, were to high to be credible, so that the methodology was criticized, among other things, for being rigid, for omitting relevant variables and for presenting an unclear direction of causation.[3] Some of these criticisms have been empirically rejected, but the controversy remains.

In the present paper new advances on the link between infrastructure and regional growth are presented. After presenting a brief review of the recent infrastructure literature in section 2, it is assumed that the effect of infrastructure on productivity depends on three issues: firstly, the various types of public infrastructure, basic and social in our case, may not have the same kind of impact on output since they are thought to pursue different purposes, greater accessibility in the former case and a healthier, better trained human capital in the latter; secondly, not all the sectors in an economy obtain the same benefits from infrastructure increase or improvement; finally, the link depends on the level of economic development in the region considered and on the amount of the existing public capital stocks. In sections 3 and 4 evidence regarding these three factors is showed for the Spanish regions. On the other hand, since the most widely defended idea today argues for an indirect effect of infrastructure (Martin and Rogers, 1995; Holtz-Eakin and Lovely, 1996) through changes in the activity location, especially in the geographical location of the classical inputs, a functional form capturing effects of substitutability and complementarity between private and public inputs is used in section 4.

Furthermore, we believe that the spatial dimension is an essential factor in the study of productivity impacts of infrastructure investments. The network characteristic of most infrastructures, especially those devoted to transport and telecommunications, supposes that any piece of a network is related and

[2] There are some references before the late eighties: see Mera (1973), Eberts (1986), Da Silva *et al.* (1987) and Holtz-Eakin (1988).

[3] For a review of the main criticism of the use of the Cobb-Douglas production function to test for the impact of public capital on productivity growth, see Moreno (1996).

subordinate to the entire network, increasing the interrelationships between regions, which are known as spillover effects. Hence, part of the infrastructure benefits (if they really exist) would felt beyond the limits of the region where it is located. This interdependence makes it necessary to carry out a spatially oriented analysis, where the use of some spatial autocorrelation tests will permit the detection of interregional externalities. Moreover, the problems these externalities may cause the traditional econometric framework are pointed out in section 5. Finally, section 6 presents some concluding remarks and lines for future research.

The empirical analysis in this paper is focused on the effect of the public capital stock on the growth of Spanish regional economies (NUTS II level) during the period 1964-1991. It is worth remembering that both the level of government capital endowment and the level of economic activity in most Spanish regions in the early sixties was far below that of other Western economies. Although both figures have undergone a significant increase during the period under consideration, this behaviour is not completely homogeneous in all regions; it will be shown here how the infrastructure effect varies according to its spatial allocation. Therefore, the empirical results in the paper may be understood as the effect of infrastructure on the takeoff of less-developed economies in the EU which are opening and modernizing their productive structure as a consequence of the Single European Market.

2. Recent infrastructure literature

In the context of the European Union (EU) the interest of public capital analysis has grown given the increase of the funds assigned to finance infrastructure investment projects in less-developed regions in order to promote growth and hence the convergence and cohesion within the territories of the EU. It is well known that in response to the different levels of income and welfare observed in the EU after the accession of Greece, Spain and Portugal, the European institutions adopted a group of measures to achieve the real integration of peripheral areas within the Community. Among these measures, basic infrastructure investments in Objective 1 regions accounted for 35% of the total expenditure for the Structural Funds between 1989 and 1993.

Notwithstanding the importance that EU ascribed to infrastructure, it was more a matter of conviction than the result of analytical stydies; indeed, the real effects of these investments are far from being clearly identified. In this regard, recent studies accept that public capital is a necessary, although not sufficient, condition for economic growth (Looney, 1992; Day and Zou, 1994; Button *et al.*, 1995). In other words, its lack or insufficiency could generate bottlenecks in the normal working of the economic system due to increases in the production costs and the worsening in the quality of the services, with an adverse effect on both the competitivity of the economy and consumers' welfare. Rietveld and Boonstra (1995) argue that infrastructures are increasingly considered as instruments to ensure that an economy is strong enough to face international competition. Moreover, Forslund and Johansson (1995) see infrastructure as a potential for the region which is not always exploited, in much the same way as Glomm and Ravikumar (1994), who consider that not all the public capital enters the production process in each firm, but only the needed amount to ensure a good aggregate use of the private production inputs.

Nevertheless, it must be noted that although there is consensus on the need for a certain level of infrastructural provision, once this level is reached, different results and conclusions are obtained. In this regard, some authors do not deny the existence of a link between publicly provided inputs and economic growth, but do not find evidence for it. For instance, Holtz-Eakin (1994) and García-Milà *et al.* (1996) criticize the initial findings on positive infrastructure effects in the US case on econometric grounds, presenting estimations of regional production functions that use standard techniques to control for state-specific characteristics, revealing essentially a zero role for public capital. Furthermore, Crihfield and Panggabean (1995) using a neoclassical growth model observe that public capital has a weak effect on growth in per capita product of US metropolitan economies both by means of indirect action (factor markets) and by direct action (rates of public investment). Ciccone and Hall (1996) reach the same conclusion when explaining differences in labour productivity across US states in a model that accounts for spatial density effects.

On the other hand, Martin and Rogers (1995) and Holtz-Eakin and Lovely (1996) have highlighted the mechanism by which infrastructure affects firms and markets. Through the construction of general equilibrium and Krugman type models, their findings reveal that public infrastructure has no direct effect on increasing aggregate productivity, but alters it through increases in the number and variety of manufacturing establishments, concluding that infrastructure plays a subtle role in changing the relative attractiveness of location for firms. Besides, according to the results obtained in the Martin and Roger's study, a larger infrastructural endowment will not necessarily enhance convergence, due to the different effect of domestic and international infrastructures on industrial location. Improvements in domestic infrastructure in a poor region will always bring firms to those regions (mainly when the cost is assumed by a third party). However, firms will tend to relocate in high activity regions when international public capital is improved and when poor regions have a low level of domestic infrastructure. Therefore, in early stages, the use of public investment to deepen an integration process may increase disparities, since regions with weak competitive positions may be adversely affected (Rietveld, 1995). In that way, the increasing disparities can be clearly seen since, for instance, the high-speed rail and highways have augmented accessibility between central regions, and the end of the regulation policies in air transport have reinforced the primacy of the main airports in Europe (De Rus *et al*, 1995).

All these different conclusions about the role of public investments show the complexity of the link between infrastructure and economic growth. Hence, in the present paper we try to give results which point out some of the conditions that affect the relationship between both variables.

3. The role of different types of public capital. Sectoral effects

(i) Analytical framework: The neoclassical model

The basic specification used in the literature about the contribution of public capital in regional growth is the Cobb-Douglas production function which relates output (Y) with the amounts of labour (L), private capital (Kp) and public capital in infrastructure (Kg):

0

where A_t is a measure of exogenous technological progress taking into account the specific time effects in total product and *i* and *t* indexes represent regions and time periods. Each exponent in the function is the output elasticity of the respective input.[4] In this model it is supposed that government provides private producers with services directly, in other words, it does not employ taxes. Therefore, public capital is a factor whose productivity is not paid for, but is transferred to the rest of productive inputs.[5]

Nevertheless, before estimating these functional forms, we will consider the way in which public capital is included in the production function. We include two different types of public capital: basic infrastructures (roads and highways, water and urban structures among others), which are the ones expected to be more directly related to the production process, and social infrastructures (health and education), which are expected not to have a direct effect on growth, but will

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[4]The basic issue in the study of public capital effects is the estimation of ã, its sign and its quantitative importance.

[5]The sum of all the exponents in equation (1) is the type of returns to scale (RTS). If this addition is bigger than one, either most of the firms have increasing returns to scale or there exist external economies, operating in a complementary way to the three types of conventional externalities (Marshall, 1920). This reasoning in favour of scale economies due to public provision suggests that the production function presents constant RTS in private inputs and increasing RTS in all inputs (including public capital).

affect the steady-state level.[6] We thus have the following funcional form, where small letters represent variables in logarithms, *Kgb* and *Kgs* are basic and social public capital respectively, and *e* is a disturbance term:

0

Following the infrastructure literature (e.g. Aschauer, 1989), it is possible to reparametrize equation (2) in order to test the type of returns to scale (RTS) in all inputs, so that:

0

The lack of significance of the coefficient accompanying labour indicates constant RTS in all inputs (both private and public). This specification is similar to the *impayed factor model* given by Meade (1952). In a similar way, we can test the type of RTS in private factors:

0

Again, the lack of significance of the labour coefficient implies constant RTS in private inputs, obtaining the *atmosphere model*. In addition, in order to test if different components of public capital have different effects on output, we propose to test the kind of RTS for productive factors (both private and basic public) by analyzing the significance of the parameter accompanying labour in expression (5):

0

Thus, increasing RTS in all factors and constant returns in private factors would indicate that public capital really causes scale economies in productivity; however, increasing RTS in all factors and constant returns in productive factors would mean that it is only the social component of public

[6] In fact, some empirical studies (García-Milà and McGuire, 1992; Mas *et al.*, 1995b) have demonstrated that basic public capital has a significant influence on the productivity variation.

capital which plays a significant role in production scale economies.

Continuing with the way public capital is considered and given that the sizes of the Spanish regions are very heterogenous, we use a measure of public capital related to the surface of the region in the basic capital case, and to the population in the case of social capital. Therefore, our basic public capital variable is basic infrastructure stock per square meter in each region and the social public capital variable is social infrastructure stock per person in the region. This standardization is made to reflect the fact that infrastructures are important not because they are a direct part of the production process, but because they make production easier by providing a greater accessibility to firms (e.g. bigger stock of transports per area) or training and educating workers better (more schools and hospitals per capita). This approach allows a better assessment of the impact of public capital.

The availability of observations of several regions at different points in time permits estimation by panel data techniques. These techniques present the advantage of including in the specification of the error term both *a regional specific component* controlling for the unobservable characteristics of each region in a way that each one enters the function depending on its own peculiarities (resource endowment, industrial mix, etc.), and *a time specific component* accounting for the changes in the overall economy in each period reflecting cyclical effects and changes in the technology.[7] There are several methods of estimation given by the theory of panel data: firstly, introducing differences across regions through differences in the constant term, we obtain the fixed effects model estimated by least squares dummy variables (LSDV); secondly, considering the regional specific effect as a component of the error term, the random effects model with a correlation process between error terms is obtained; a generalized least squares method (GLS) is used then.[8] In order to choose the most accurate estimation method, the F-statistic, Breusch and Pagan's Lagrange Multiplier and Hausman tests are considered (Greene, 1993; Baltagi, 1995).

The use of both the fixed and the random effects models may provide better estimates than the OLS method, since they take into account the characteristics of

[7]The inclusion of a linear trend as an approximation to the level of technology (Aschauer, 1989; Mas *et al.*, 1995b) and the use of the unemployment rate as a measure of the economic cycle (Munnell, 1990b; Andrews and Swanson, 1995) were initially considered in our work. However, these alternatives were rejected and the use of time effects preferred. The former is a rather inaccurate way of assessing technological change. As for the unemployment rate, in Spanish regions it does not reflect a measure of the cycle alone; indeed, it mainly reflects regional sectoral differences, as unemployment in Spanish regions has a large structural component. This means that increases in this variable may be caused by people leaving agriculture and not finding a job in other sectors, but not because of a recessive phase in the economy. This way, including a time specific term in the error structure avoids the problems of considering these variables, while accounting for the same kind of effects.

[8]The random effects are assumed to be uncorrelated with the other regressors in the model to avoid inconsistency. Otherwise, the LSDV would be chosen.

each region that are likely to be present in any regional study. In fact, Holtz-Eakin (1994) and García-Milà *et al.* (1996) argue that the initial studies of public capital impact that did not control for regional effects obtained a large, positive and significant coefficient for public capital because they used the wrong estimation method. Hence, the positive relationship between regional growth and infrastructure in some studies could be the result of a spurious correlation, as a result of not considering these controls. This is true of the US economy, but what can be said of the Spanish regions, given the lower public capital endowment and economic development?. The remainder of the section will consider this controversy.

(ii) Data and empirical results

Data used here refer to the regions of Spain (NUTS II level) for the period 1964-1991, with two main sources. Private Gross Value Added at factor cost and private labour (total number of employees) are obtained from "Renta Nacional de España y su Distribución Provincial" [National Wealth of Spain and its distribution by provinces, BBV] published every two years.[9] Series of private and public capital stocks are taken from "El Stock de Capital en la Economía Española" [The Capital Stock in the Spanish Economy].[10] As basic public capital we have considered the monetary stock of roads and highways, railway, harbours and maritime signalling, airports, water and sewage facilities, and urban structures. For the social component we consider the stock of health and education. All variables are expressed at constant prices of 1990, having 14 temporal and 17 cross-section observations.

The results of the estimation for equations 3, 4 and 5 are shown in table 1 (columns (1), (2) and (3), respectively) for each estimation method (OLS, LSDV, GLS). However, in all cases the LM test indicates the need to introduce regional characteristics, so that the OLS results are not robust. Moreover, the Hausman test does not reject the null hypothesis of orthogonality between regressors and regional effects, taking the GLS estimation as the most appropriate one.[11] It is worth noting the main conclusions obtained if compared with similar studies:[12]

1. The use of different methods of estimation may produce different results. So, not considering regional specific components in the error term (OLS estimation) may result in a greater impact than the real one (GLS estimation) for

[9]There is only one exception, a three year gap after 1964. From 1967 onwards, data for every two years are provided.

[10]These stocks have been calculated by using the Perpetual Inventory Method (see Mas *et al.*, 1995a). Thus, we use data gathering public capital stocks (not investments) in monetary terms.

[11]In all cases considered in this paper, the random effects model is chosen, while controlling for shocks to the production function through the use of fixed time specific effects.

[12]Some other studies analysing the impact of infrastructure on economic growth in the Spanish case are Argimon *et al.* (1993), De la Fuente and Vives (1994), Serra and García-Fontes (1994) and Mas *et al.* (1995b).

basic public capital on regional productivity (0.145 as against the real figure of 0.044). Social public capital is equally insignificant in both cases. Then, in contrast to what happens in the USA economy (Holtz-akin, 1994; García-Milà *et al.*, 1996) where controlling for state effects reduces or invalidates public capital impact, in the Spanish case the use of panel data techniques presents more credible values, not only for basic public capital elasticity, but also for labour and private capital shares. In conclusion, exploiting the cross-sectional information in data provides more efficient estimates for parameters. Furthermore, in order to prove that the high R^2 cannot be explained by autocorrelation, the LM-test for first-order serial correlation in a random effects model given in Baltagi (1995, p.91) is used. When we apply this test to the GLS regressions (the finally chosen one), we are not able to reject the null hypothesis of absence of autocorrelation, since the LM statistic equals 0.00245.

2. The parameter accompanying basic public capital seems robust given its constant significance with a value of around 0.044, so that an increase of 1% in the stock of basic public capital would increase labour productivity by 0.044%, a very modest effect. However, although panel data estimations reduce basic public capital effect, it is still significant and positive. In our belief, this is due to the fact that at the beginning of the period under consideration Spanish regions were lacking in infrastructure; as the provision increased, it had a positive influence on productivity growth. Conversely, with large initial infrastructure endowment, the US states would have reached a saturation point.

On the other hand, social public capital is not generally significant, whereas the type of RTS in productive inputs gives social infrastructure an important role as external economies. In our opinion, this lack of unanimity in the results on social infrastructure can be a consequence of the different role they have depending on the level of development in the region under consideration. In regions with a strong private activity, social capital may be gathering, on the one hand, part of the effect of human capital (a well-educated and healthy labour force is supposed to be more productive than one without such advantages, Munnell, 1990b) and on the other hand, agglomeration economies (better educational and health services are concentrated where there is a greater population density). In regions with a low private activity, larger social infrastructures would not have this effect, and would mean great public expense that would cause distortion in private activity.

In conclusion, although public capital seems to have had a positive impact on Spanish productivity growth, this impact is far lower than that reported in earlier public capital studies, and indeed is in line with the most recent ones, which conclude that the role of infrastructure is a subtle one. In addition, this impact is mainly due to basic public capital, since nothing can be concluded from the social component.

3. Constant RTS in GLS estimation are not rejected for all inputs, given the lack of significance of the coefficient accompanying employment (á+â+$ã_1$+$ã_2$-1), while decreasing RTS are obtained for private (á+â=0.857) and productive inputs (á+â+$ã_1$=0.902), concluding that both public capital components are important for regional productivity since the external economies they generate permit obtaining increases in returns.[13]

4. Private capital and labour elasticities are approximately 0.5 and 0.45, the latter obtained as (á=1-â-$ã_1$-$ã_2$); this result is striking, since in US studies the labour share is bigger than the private capital share (0.60 and 0.30 respectively). The most similar study to ours is Mas *et al*. (1995b) in which using the same series, although without considering the energy sector, the elasticities are 0.57 for labour and 0.42 for private capital. In our belief, this greater importance of private capital in the Spanish case is explained by the increase in the *Kp/L* ratio throughout the period under consideration. For instance, this ratio average is 13.5% in the case of Extremadura (one of the poorest and most agricultural regions) and 6.68% for Madrid (one of the richest). Undoubtedly, these figures are the consequence of the nature of the period under consideration, during which the Spanish economy underwent a modernization and capitalization process with large reductions in the labour share, which has been substituted by private capital, increasing labour productivity.

All these results are obtained from the aggregate economy, but do all the sectors obtain the same benefit from an increase in public investments? According to some studies (García-Milà and Marimón, 1995; Mas *et al.*, 1995c) large-scale specialization in industrial activities and in different kind of sale services has a positive and significant influence on the global efficiency of the Spanish economy. According to these authors, sectoral composition is the real explanation of productivity differences between Spanish regions. Consequently, if it were demonstrated that public capital has a different effect in each economic sector and, if it were true that industry benefits more (as signalled by some reports, such as Holtz-Eakin and Lovely, 1996), the use of an infrastructure policy to develop the economy by stimulating sectors with a promising future would be justified.

In order to test these claims, we estimate the production function for the main economic sectors, agriculture, industry (including energy), services and building. Results are shown in table 2. Infrastructures seem not to have had a significant effect on productivity in the building sector, whereas high significant values are obtained for agriculture. However, this last result is hard to credit, due

[13] Although not presented in the paper for reasons of space, the use of the absolute value of public capital stock instead of the one related to surface and population causes slight changes in the estimation of the type of RTS and a negligible impact on the nature and significance of the parameter estimates.

to the small R^2 obtained in the estimations, and the theoretical unlikelihood of agriculture obtaining benefits from infrastructure, since this sector does not take advantage of scale economies. Conversely, industry and services maintain most of the results obtained for the aggregate economy: significance of basic public capital (with a value between 0.07 and 0.10 for industry and between 0.03 and 0.04 for services) and lack of significance for the social component. Also, although increasing RTS are obtained without considering public capital, infrastructures slightly increase RTS as well. According to these results, in our belief infrastructure is not a real externality acting together with conventional ones, but is an extra effect on growth, since it is a source for external economies in industries (Caballero and Lyons, 1989).

Hence, it is clear that public capital has a greater role in industrial productivity than in any other economic sector, especially in the period considered in which Spain experienced processes of growth and liberalization. In our belief, public capital has increased the accessibility of firms and reduced costs, making this expansion process possible; this is consistent with the idea that infrastructure is a necessary condition for growth. However, though infrastructure's performance on industry is better than in the other sectors, its role is a subtle one nonetheless; we may therefore hold that the main impact of infrastructure is not direct, but acts through variations in the amounts of private inputs. This issue is considered in the next section.

4. Infrastructure and output: Direct or indirect link?

The Cobb-Douglas production function is a very restrictive functional form since it does not permit the introduction of substitutability and complementarity relationships between inputs. In fact, the public capital effect depends not only on its own quantity, but on those of the rest of productive inputs as well, since its effect is conditioned by the development level in the area. Therefore, with the aim of introducing all these cross effects between inputs, we apply the Expansion Method to the functional form applied up to this point (see Casetti, 1972; Casetti and Poon, 1995).[14]

The initial equation is the Cobb-Douglas production function written as (variables are given in logarithms and subindexes are avoided for the sake of simplicity):

$$y = \acute{a}_0 + \acute{a}_L\, l + \acute{a}_{Kp}\, kp + \acute{a}_{Kgb}\, kgb + \acute{a}_{Kgs}\, kgs \qquad (6)$$

It can be said that the coefficients in (6) are variables in the sense that the

[14] This technique is concerned with the measurement of parametric instability in econometric models.

impact of any input on productivity depends on the current amount of all the other production factors. Considering this issue, we have the next expansion function, being *j* each factor (the intercept term is not considered):

$$\acute{a}_j = \hat{a}_{0j} + \hat{a}_{Lj}\, l + \hat{a}_{Kpj}\, kp + \hat{a}_{Kgbj}\, kgb + \hat{a}_{Kgsj}\, kgs \qquad (7)$$

Then, according to the Expansion Method we insert (7) in (6) and obtain the terminal model:

$$\begin{aligned} y = \; & \acute{a}_0 + (\hat{a}_{0L} + \hat{a}_{LL}\, l + \hat{a}_{KpL}\, kp + \hat{a}_{KgbL}\, kgb + \hat{a}_{KgsL}\, kgs)\, l + \\ & (\hat{a}_{0Kp} + \hat{a}_{LKp}\, l + \hat{a}_{KpKp}\, kp + \hat{a}_{KgbKp}\, kgb + \hat{a}_{KgsKp}\, kgs)\, kp + \\ & (\hat{a}_{0Kgb} + \hat{a}_{LKgb}\, l + \hat{a}_{KpKgb}\, kp + \hat{a}_{KgbKgb}\, kgb + \hat{a}_{KgsKgb}\, kgs)\, kgb + \\ & (\hat{a}_{0Kgs} + \hat{a}_{LKgs}\, l + \hat{a}_{KpKgs}\, kp + \hat{a}_{KgbKgs}\, kgb + \hat{a}_{KgsKgs}\, kgs)\, kgs \end{aligned} \qquad (8)$$

In expansion formulations, not all the parameters can be estimated since there are two cross-products associated with the same two parameters. One of the approaches used in the literature is to assume that $\hat{a}_{gm} + \hat{a}_{mg} = \hat{a}'_{gm}$ where *m* and *g* are two different inputs ($m \neq g$), getting:[15]

$$\begin{aligned} y = \; & \hat{a}_0 + \hat{a}_L\, l + \hat{a}_{Kp}\, kp + \hat{a}_{Kgb}\, kgb + \hat{a}_{Kgs}\, kgs + \\ & \hat{a}_{LL}\, l^2 + \hat{a}_{KpKp}\, kp^2 + \hat{a}_{KgbKgb}\, kgb^2 + \hat{a}_{KgsKgs}\, kgs^2 + \\ & \hat{a}'_{LKp}\, l\, kp + \hat{a}'_{LKgb}\, l\, kgb + \hat{a}'_{LKgs}\, l\, kgs + \\ & \hat{a}'_{KpKgb}\, kp\, kgb + \hat{a}'_{KpKgs}\, kp\, kgs + \hat{a}'_{KgbKgs}\, kgb\, kgs \end{aligned} \qquad (9)$$

In this expression, single parameters indicate *the type of relationship between each factor and output*, quadratic terms give information about *scale economies* for each input and cross-products terms indicate the *substitutability or complementarity* between factors. Hence, this function captures the non-additivity of the economic growth. Production growth is not the result of the addition of the individual effects of the input increments; rather, it increases or decreases according to the relationships between inputs. The results obtained from the estimation of equation (9) are shown in table 3.[16]

According to the GLS results, the shares of labour and private capital are very similar to those obtained whit the Cobb-Douglas function (0.37 and 0.60 respectively) but in this case neither basic public capital nor the social component have a significant effect on output. Public capital seems thus to have no direct

[15]This way, we can determine the relationship between each pair of variables and their influence on output regardless of which variable influences the other.

[16]In this case, the results of the LM and Hausman tests also indicate the need to consider individual characteristics, specifically the random effects model (GLS estimation).

effect on regional growth. However, private and basic public capital are complements (although the relationship is not significant), whereas private and social public capital maintain a relationship of substitutability.[17] Therefore, the use of this expanded function lends support to the recent idea of the absence of a direct impact of basic infrastructures on output. Nevertheless, although this macroeconomic framework finds a hidden relationship between infrastructure and growth, it does not let us determine what the real link is. In spite of the fact that complementarity and substitutability relationships are obtained, it is not possible to identify the direction of causation between each pair of variables. However, the non-existence of a direct link makes us think about the presence of an indirect one, through more subtle channels of relationship that should not be studied through aggregate functions but through microeconomic models.

Going on with the complex link between infrastructure and growth, it is commonly accepted that the output effect of an increase in the public capital stock depends on the size of the existing network, the degree of network congestion, and the level of economic development in the region. Hence, on the one hand, additions to infrastructure networks would not have the same impact on output growth as the construction of the network (presence of decreasing returns for public capital). On the other hand, adding capacity to an uncongested network would not affect private productivity, while the benefits from an increase in the amount of public capital would be large when congestion is high. Some of these aspects can be analyzed through the type of RTS for inputs according to results from equation (9). There appear to be decreasing returns for basic public capital (negative sign), indicating that it is a factor with a threshold level which, once reached, reduces returns. Hence, it could be said that although infrastructure in Spain has had a significant role during the period analyzed, it has decreased with time, and is unlikely to persist with the same strength in the future.

However, can we say that infrastructure in Spanish regions has reached a threshold level? In other words, do Spanish regions already have the necessary public capital for their development? These questions can be answered by estimating the output elasticity with respect to basic public capital ($\partial \ln Y / \partial \ln Kgb$). In figure 1 the relationship between basic public capital stock and its elasticity is shown for years 1964 and 1991 (the beginning and the end of the sample). Although one would expect an inverse association between the two variables a priori, results provide little evidence of it. However, some important conclusions emerge concerning the changes in the role of infrastructure depending on the

[17] All these conclusions must be treated with caution. In fact, several authors considering similar functions (Da Silva *et al.*, 1987; Munnell, 1990b; Pinnoi, 1994; Andrews and Swanson, 1995) have obtained different results, not always consistent and coherent with economic theory. However, the function obtains certain conclusions that are difficult to achieve by other means.

spatial economic development. Firstly, in 1964 two regions, Madrid and País Vasco, present high elasticities with high relative public capital stocks, due to their being highly industrialized regions that really needed all the public stock they had; in other words, these regions had an important endogenous potential that could still be exploited by providing more infrastructures (certain *bottleneck* problems in infrastructure use). Nevertheless, at the end of the period, the elasticity of País Vasco has decreased, due to the recession that set in mature industries during the seventies, in which this region is specialized. Secondly, some regions, such as Castilla-León, Castilla-Mancha, Extremadura and Andalucía had relative low sizes of public capital and low elasticities, both in 1964 and 1991. They are among the least developed regions in Spain, so although the public sector has provided a better infrastructure to *stimulate* them, these regions have not combined increases in public capital with other factors such as an adequate industrial mix, human capital, business culture, or connexions with dynamic centers, etc. In other words, they have not benefited from the public capital stock to attract dynamic economic activity, which is a proof of the necessary, although not sufficient, condition of public capital. Finally, Murcia, Rioja, Baleares and Canarias present high elasticity values with low public capital stocks in 1964 as well as in 1991, so that their potentiality is still being developed. In these regions it seems that infrastructures permit prompting the private activity so that public investments should *accommodate* ongoing spatial economic developments.

Therefore, although figure 1 does not present the inverse relationship one might expect, this is because public capital does not have an individual effect, but depends on its connexions with other factors. So, the same public investment policy can have different effects in different locations because of the way infrastructure is articulated in those locations relative to other factors. Hence, as pointed out by Hulten and Schwab (1992), the fragility of the statistical analysis is not surprising if considering the complex nature of the link between infrastructures and growth.[18] In general, "factors need to be conceptualized as processes and structured together interactively rather than just added up" (Massey and Meegan, 1985). The same problem concerns space, as will be seen in the following section.

5. The importance of the spatial dimension in infrastructure impact analysis

"The Whole is more than the sum of the parts, in that, not only does the interrelation of parts bring out latent characteristics in each, as in any complex, but

[18]To this complexity of the link infrastructure-growth we should add that productivity studies completely ignore the benefits for consumers, which are often larger than for firms (Rietveld, 1995).

the complex as a whole takes on a new character not explainable out of the parts" (Hartshorne, 1939). This quotation can be directly applied to the network characteristic of some infrastructures, supposing that any piece is subordinate to the entire network, increasing the interrelationships between regions. The importance of the spatial dimension in infrastructure studies was considered after noting the reduction in public capital effect when descending to the territorial level (Deno and Eberts, 1989; Eberts, 1990; Munnell, 1990b; García-Milà and McGuire, 1992). It made economists suspect the existence of spillover effects that would spread public capital impact among the rest of the regions, especially the nearest ones. This result can be due either to the network structure of some infrastructures, or to the fact that regions are administrative delimitations, so that linkages forward and backward are cut, attributing regions with an inadequate infrastructural effect. Thus, some studies of the regional Spanish case (e.g. Mas *et al.*, 1995b) have demonstrated that effects on productivity depend not only on the infrastructure itself but also on the overall provision throughout the country, especially in the contiguous regions. Conversely, Holtz-Eakin and Schwartz (1995) obtain no evidence in favour of the idea that the US highway stock has significant effects on productivity across states. However, the fact that there is no empirical consensus on the existence/absence of spillovers in the infrastructure impact may be the result of not considering the appropriate analytical framework.

In our belief, the explicit consideration of the interdependencies between regions as regards infrastructure effects is essential, given their possible political and econometric implications. Politically, if public capital stocks belonging to a region influenced growth in neighbouring regions, public investment and production aids should be oriented to relate each other with great coordination and planning. Moreover, if these effects are significant, the decision that public capital should be supplied by a local entity could imply suboptimal provisions, justifying the existence of "central agencies" to supply this kind of goods. Econometrically, because of the existence of spillover effects, there may be a lack of independence within cross-section data (different regions) suggesting the presence of a spatial dependence process in the model. This is defined as the existence of a functional relationship between what happens at a point in space and in the rest of locations. The main difference between dependence in space and dependence in time is that whereas the latter is unidirectional (the present is just explained by past) spatial dependence is multidirectional in character, since the value of a variable is explained by values of itself in different places. The main problem concerning the presence of a spatial autocorrelation process in a regression model is the invalidation of standard econometric techniques (Anselin, 1988a).[19] Hence, being

[19]If the origin of spatial dependence is in the endogenous variable of the model, the LS estimates would be biased and inconsistent. Alternatively, if it appears to be in the error term, we could have inefficiency of the LS

aware of the main drawbacks of spatial dependence and suspecting that spillovers may appear in the study of regional infrastructure impact, it is of vital importance to test the presence of this effect in our model. Specifically, we use several tests in univariate and multivariate approaches for three years, 1964, 1977 and 1991, having 17 cross-section observations for each.[20] In fact, although so few observations do not make test results robust, the following analysis seeks only to illustrate, in general, the problems involved in using cross-section data, and in particular, the importance of spatial effects when infrastructures are considered.

(i) Univariate approach: Global and local spatial dependence

As stated above, the presence of a spatial dependence process implies that the value of a variable at a geographical point is functionally related to the value of the same variable in other locations, $Y_i = f(Y_1, Y_2, ..., Y_R)$. In the case of spatial autocorrelation being positive, similar characteristics would be spatially concentrated; if it is negative, the phenomenon would be disseminated throughout the space. Hence, by using spatial dependence tests for the variables, we can determine their spatial distribution, both globally and locally. The former is concerned with the presence of spatial dependence as has previously been defined (concentration/dispersion) and the latter denotes the existence of local spatial clusters where the analyzed variable is not randomly distributed. In all these tests the null hypothesis is spatial independence, and the weight matrix representing the interaction between regions has been chosen on the basis of geographical contiguity.

In order to test the presence of global spatial dependence in the variables used in our paper, the standardized Moran's I statistic (Moran, 1948) is used. The results are shown in table 4. Values are not significant in any case except for the social component of public capital in 1977 and 1991. A possible explanation for this lack of significance is the fact that this test is assymptotically distributed, whereas we only have 17 cross-section observations, and so probably the dependence process cannot be captured.[21]

Although the presence of a global spatial dependence process has only been accepted for social capital, a local spatial association process may appear, so that there would be clusters where there is not a random distribution of the cross-

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estimates leading to an underestimation of the error term and the variance of the parameters, giving rise to the invalidation of *t* statistics.

[20]For the expressions of all the spatial autocorrelation tests used in this paper, see Appendix 1.

[21]Despite the fact that only a few observations are available, some ideas about the signs of the obtained test values may be pointed out: labour productivity and private capital seem to present positive values increasing over the period (except for private capital in the last year), so that, especially for productivity, its values would be more concentrated in the nineties than in the sixties. Similar results are obtained for social capital, showing a significant and positive spatial dependence in 1977 and 1991. With respect to basic public capital, the negative values obtained (although not significant) suggest the existence of a central-peripheric system among Spanish regions.

section series but an important concentration or dispersion of their values. To answer this last issue, two local indicators of spatial association (LISA) are computed: Moran's I_i (Anselin, 1995) showing the existence of an association or concentration of similar ($I_i>0$) or dissimilar ($I_i<0$) values for a variable around a region *i*; and the G_i statistic (Getis and Ord, 1992) indicating concentration of large ($G_i>0$) or small values ($G_i<0$) around a region *i*. In tables 5 and 6 we present results for public capital stock in its two components.[22] As regards basic public capital, in three years, 1964, 1977 and 1991, there are two main focus of high values, in Madrid and País Vasco, throughout the period, whereas the main low values are concentrated in the South of Spain (Andalucía, Castilla-Mancha and Extremadura). Social public capital offers similar, high values in all the Northern Spanish regions and low values in the Mediterranean regions (Andalucía, Baleares, Murcia and Valencia). In conclusion, public capital (especially its basic component) seems to present a concentration of good infrastructural endowment in zones where a considerable expansion process has taken place since 1964 and some other areas, such as the Southern regions where the growth process has not been so important, with small values of infrastructure stocks. These results imply the lack of a random distribution of the series among the Spanish regions because of the existence of important linkages and interrelationships among them.

(ii) Multivariate approach: Spatial dependence in the error term and in the dependent variable

As a consequence of the presence of a local spatial association process, some kind of spatial dependence may appear in the regressions used in previous sections. For this reason, and aware of the important problems it can suppose, three tests are applied to the OLS estimation of the Cobb-Douglas function (equation 3) for three separate years, 1964, 1977 and 1991. Firstly, Moran's I test (Z(I); Cliff and Ord, 1972) and the Lagrange Multiplier of the errors statistic (LMERR; Burridge, 1980) were applied to test the null hypothesis of lack of spatial residual correlation. Finally, the Lagrange Multiplier test for the null hypothesis of non-existence of any significant spatial lag of the endogenous variable was used (LMLAG; Anselin, 1988b).

As shown in table 7, the assumption of spatial independence is rejected in all cases if the Moran statistic is considered, and quite high (though not significant) values for LMERR were reached in 1964 and 1991. All these values

[22]Although not presented for lack of space, the same two tests are applied for productivity and private capital. Labour productivity presents a center-peripheric scheme: the capital of Spain (Madrid) concentrating high values, spatial concentration of low values in the southern regions, and high ones in the North East. A similar scheme is obtained for private capital even though in this case concentrations of big values along the Mediterranean Sea are obtained. Similar results on the presence of spatial dependence on several economic variables at the EU level are obtained in López-Bazo *et al.* (1996), showing the importance of space in economy.

are positive, indicating the presence of a spatial dependence process in the error term caused by the concentration of similar values.[23] On the other hand, it is not possible to reject the null hypothesis of independence by the introduction of a spatial lag of the dependent variable in any case. Once again, it is worth noting that the results obtained in this section must be treated with caution since these tests are asymptotically distributed.[24] However, it seems quite clear that the variables used in the equations estimated in our work are not randomly distributed in the space and, therefore, there is a residual spatial dependence process in our estimations. Hence, the omission of the explicit consideration of this dependence in our specifications implies the inefficiency of the estimated regression, so that the infrastructure effect could be wrongly analyzed as far as its significance is concerned.

(iii) Weight matrix specification in spatial dependence tests

One issue to consider when computing the spatial dependence tests is the fact that the weight matrix is the main topic representing the potential interaction among regions and, therefore, the presence or absence of spatial dependence depends on it. Hence, the correct determination of its elements is a highly controversial aspect in Spatial Econometrics.[25] Although the general criterion is physical contiguity (giving rise to a binary and symmetric matrix where its elements would be 1 in case of two regions being in contact and 0 otherwise), this definition presents certain problems: firstly, the symmetric character of the contiguous matrix is debatable, because it supposes that the influence that region *j* receives from region *i* is the same as that received by *i* from *j*, whereas the influence between two regions is not always reciprocal in its intensity; secondly, because interrelationships are not only due to geographical proximity. For these reasons, even though the contiguity matrix seems to be the best suited matrix in the study of the infrastructure effects, we also used another criterion to test if results are sensitive to the weight matrix specification. It is based on the trade relationships maintained between regions, so that in case of a region *i* accounting for more than the 8% of the trade of region *j*, the interaction between these two regions is considered important. In that way, two regions far from each other can be interdependent. The results obtained by using this trade matrix are very similar to the contiguity ones; the conclusions do not change at all,[26] indicating that the results are robust regardless of the weight matrix.

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[23] Although this concentration is probably due to spillovers, we cannot affirm this conclusively throughout this analysis. It would be necessary to introduce these effects as spatial lagged variables.

[24] For a deep study of finite sample properties of tests for spatial dependence in regression models see Anselin and Florax (1995, 21-74), and Anselin *et al.* (1996).

[25] The possible impacts of misspecification of the spatial weight matrix are reviewed in Florax and Rey (1995).

[26] These results are not reported, but are available from the authors upon request.

In conclusion, there appears to be a spatial dependence process in the error term of the Cobb-Douglas estimation (probably due to the lack of random distribution of the cross-section series), so that the results obtained herein and in some other studies not considering spatial effects when studying infrastructure impact must be taken with caution. Besides, further research should be devoted to a spatially oriented analysis, introducing the infrastructure spillover effects throughout Spatial Econometrics specifications that can be reestimated efficiently (see Anselin, 1988a).

6. Conclusion

In Spanish regions it has been demonstrated that infrastructure is a development factor with a positive but very modest effect on productivity, which is decreasing in time. In fact, the differences in infrastructure impact depending on regional and sectoral development, the reduction in this impact when the size of the infrastructural network increases, and the presence of interdependencies among regions have been shown to be some of the issues that make the link between infrastructure and growth so complex. In addition, it has been seen that the effect of a certain infrastructure is higher if it is placed in an industrial area with high agglomeration economies, showing how the effect of public capital depends on the spatial distribution of infrastructure network. Besides, even though the infrastructure is placed in a specific region, the network characteristic of most of them and the consequent interrelationships between regions imply the presence of spatial association processes, making it necessary to introduce the spatial dimension in any thorough study of the impact of government investment. This externality may justify the presence of supraregional agencies with the aim of avoiding suboptimal provisions.

However, as has been seen, the use of aggregate infrastructure data disguises its real effect on regional productivity growth. Hence, most of the infrastructure, especially the basic one representing a higher volume of resources, affects basically the industrial sector; however, others such as telecommunications could have a differential effect on services, especially on high-tech ones. For this reason, it is necessary to carry out more disaggregated analysis, both in the different sectors and in the types of infrastructure.

Notwithstanding the complexity of the link infrastructure-growth, in our belief, there is little support for a special role for infrastructures in prompting aggregate productivity, but there is little question that they are an ingredient for long term economic development. Public capital is a general condition for potential activity in a region in that it does not exert a primary effect on development, but is a requisite for it. Therefore, it does not seem desirable, from a political point of view, that the process of decreasing public deficit, one of the Maastricht requisites, should mean a cut in public infrastructure policy. New developments in the EU policies should renew interest in ensuring that infrastructure policy should, at least, not hinder economic development. Cuts in the budgetary deficit should be made in a way that the impact on social welfare and the economic situation were minimal. This is especially relevant for Spain, a country that is less developed than others in Europe, and whose main purpose is to reduce disparities in relation to them. However, this kind of policy taken alone does not ensure that new industrial activity will reach the regions, if it is not accompanied by measures to improve human and technological capital, among others.

Several lines for future research can be pointed out. Firstly, the use of formal economic models to make more precise the microeconomic links between infrastructure and development will permit the consideration of the role of public capital in the dynamics of firm creation and destruction. Secondly, a focus on the deepening of the infrastructure differential effect on several private manufactures will show how public capital may affect the regional reindustrialization while considering the changes in manufacturing variety. Finally, since new developments in treating infrastructure impact need to give a more important role for geography and space, it is necessary to introduce spillover effects and interregional externalities through the use of spatial autocorrelation processes, considering the effect of centrifugal/centripetal forces.

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