REGIONAL PRODUCTIVITY VARIATION AND THE IMPACT OF PUBLIC CAPITAL STOCK: AN ANALYSIS WITH SPATIAL INTERACTION, WITH REFERENCE TO SPAIN

MIGUEL GÓMEZ-ANTONIO
BERNARD FINGLETON

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Regional productivity variation and the impact of public capital stock: an analysis with spatial interaction, with reference to Spain

Miguel Gómez-Antonio[a]
Bernard Fingleton[b]

[a] Department of Public Finance and Fiscal System,
Universidad Complutense de Madrid,
Campus de Somosaguas s/n.,
Pozuelo de Alarcón,
28223-Madrid, Spain.
Tfno: 0034 91 394 30 20
Fax: 0034 91 394 24 31
mga@ccee.ucm.es
(Corresponding author)

[b] Department of Economics, Strathclyde University, Glasgow, Scotland.
Sir William Duncan Building
130 Rottenrow
Glasgow G4 0GE
Scotland
Tfno: +44 (0)141-548 3857
Fax: +44 (0)141-548 4445

Abstract:

In this paper we examine whether variations in the level of public capital across Spain's Provinces affect productivity levels over the period 1971-2001. The analysis is motivated by contemporary urban economics theory, involving a production function for the competitive sector of the economy ('industry') which includes the level of composite services derived from 'service' firms under monopolistic competition. The outcome is potentially increasing returns to scale resulting from pecuniary externalities deriving from internal increasing returns in the monopolistic competition sector. We extend the basic production function by introducing public capital stock as an additional argument, leading to a simple and empirically tractable reduced form linking productivity level to density of employment, human capital and public capital stock. The model is also extended to include additional and necessary factors representing technological externalities which go unrepresented in the basic model. Using the methodology of spatial econometrics, we find plausible estimates for returns to scale and for the various covariates, but the effect of public capital is not significantly different from zero. This reflects some of the earlier research findings which also leave the question of the impact of public capital as yet unresolved.

JEL Code: C21, R11, R12.
Keywords: Public capital, urban economics, spatial econometrics.

1. INTRODUCTION

When, in 1973, American productivity stagnated, researchers considered various causes, such as the escalation of energy prices, a deleterious impact caused by the level of social regulation, adverse changes in labour quality and enhanced obsolescence rates of private capital stock. However, they did not pay much attention to the fact that public infrastructure investment had been decreasing since the early sixties. The first author that emphasized the relation between infrastructure and private productivity was Ratner (1983). He introduced public capital stock as an input in the aggregate production function, and found that it had a small but significant effect on the level of production. Aschauer (1989a) also found a similar (albeit larger) effect, and by breaking public capital stock down into its constituent parts was able to show that the components with the biggest impact on productivity were transport infrastructure, energy and water supply. Subsequently, Aschauer (1989b) estimated a panel data model for seven industrialized countries, obtaining similar results with a first differences specification. However Evans and Karras (1994), again using panel data for seven countries, found that the effect of infrastructure on economic growth differed according to the set-up of their model.

From a regional perspective, Munell (1990a) estimated an amplified production function, with panel data for the American states. When the model was specified with the variables in levels and without fixed effects, the impact of public capital on productivity was positive and significant, but smaller than the one estimated by Aschauer. In a second step Munell broke down public capital stock into its different types. The results pointed out that road and water supply infrastructures were the factors that created bigger impacts.

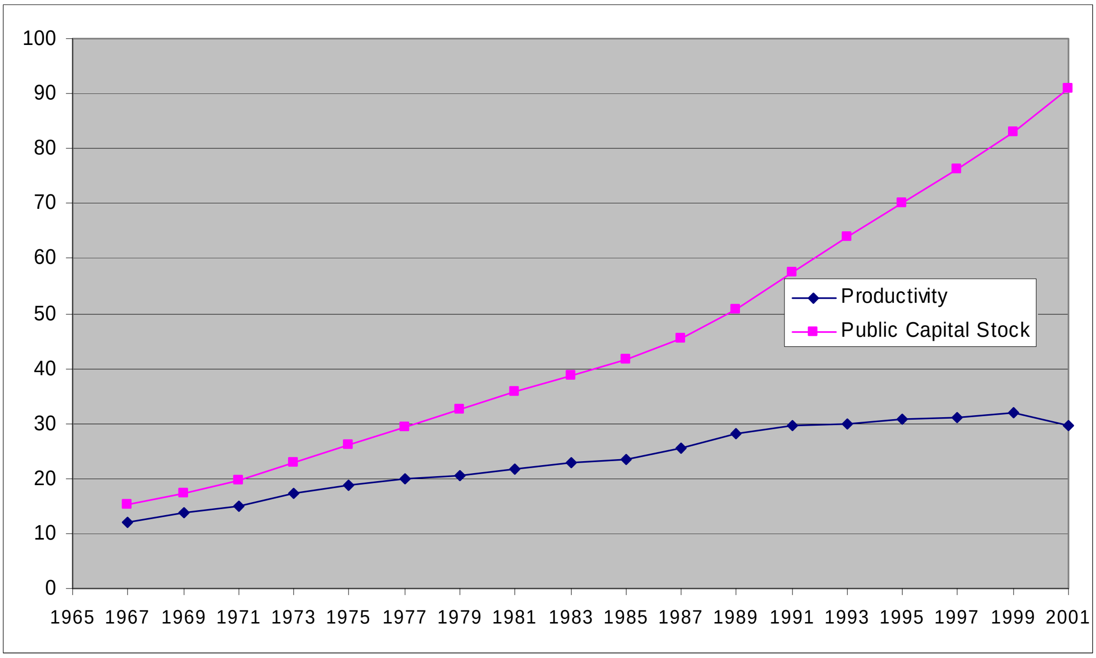
A more pessimistic conclusion was presented by García-Milá, McGuire and Porter (1996). Their paper estimated for the period 1970-1983 a Cobb-Douglas production function with data for the 48 American states. The best model specification was the one with variables in first differences and with fixed effects by state. Nevertheless, the results indicated that there is no relation between public capital stock and productivity. Along the same lines Holtz-Eakin (1994), after analysing different specifications, rejected the use of first differences and concluded that once fixed regional effects are considered in the specification, public capital stock becomes non significant.

Holtz-Eakin and Schwartz (1995), Kelejian and Robinson (1997), and Cohen and Morrison (2002) analysed the effect of road infrastructures for the United States economy, concluding that when regional data are used the effects of public capital stock on growth decreases due to presence of spillover effects. If spillovers were, indeed, present, part of the effect of public capital would be underestimated because the benefits generated from the infrastructure would not be confined inside the region. Even so, Cohen and Morrison (2002) finds an empirically significant coefficient for the spillover effects. A common finding in the literature is that spillovers across states are either unimportant or significantly negative. Public infrastructure in one region could have a negative effect on those areas that are the region's closest competitors for labour and mobile capital, attracting these factors towards the region in which the infrastructure is being built.

For the Spanish economy, several papers have analyzed the importance of spillover effects of public capital. Mas et Al (1996) determined a significant and positive spillover effect; Aviles, Gómez and Sanchez (2003) applied duality theory to overcome the limitations of the neoclassical production function to test for their existence, obtaining a positive and significant coefficient. Pereira and Roca-Sagales (2003) estimated an autoregressive vector model showing the same results. Moreno et al. (2007) paid special attention to the importance of the spillover effect of different public infrastructures on manufactures productivity, obtaining a negative spillover for transport infrastructures that counterbalance their positive effects inside each region.
In short, the literature on the effects of public infrastructure is inconclusive, although there is a general consensus on the need for a certain level of public infrastructural provision; the results obtained differ substantially once this level is achieved. More recent studies have partially discredited the results obtained in early research. Many researchers agree that the apparently positive impact of public capital stock might be due to inadequate model specifications which cause spurious relations or fail to appropriately control for region or country heterogeneity.

The period analysed in this paper is 1971-2001, which is particularly relevant due to the substantial transformation of the Spanish economy during this time. At the beginning of the period, the level of government capital endowment and economic activity in the Spanish regions were far below those of the rest of the European economies. However since Spain joined the European Union, there has been a very intensive period of capital investment by the Spanish government, and in the three decades under study, the ratio of public to private capital almost doubled with no perceptible effect due to economic cycles.

Figure 1: Evolution of productivity and public capital stock 1967-2001



Source: Own elaboration utilising data from FUNCAS and IVIE.

This paper departs from the previous literature because we use a different theoretical approach, departing from the neoclassical production function. The model is rooted in contemporary Urban Economics theory, which provides formal general equilibrium solutions with each agent solving a clearly defined economic problem within the context of a monopolistic competition market structure. One of the most relevant aspects of this theory is the allowance of increasing returns to scale. By incorporating imperfect competition, increasing returns and externalities in the form of market interdependence, there is an added realism in these models, without compromising rigour and the logic of a closed general equilibrium approach.

The paper is divided into the following sections. Section 2 is dedicated to specify the theoretical background of the model and to derive the specific reduced form that is going to be estimated. Section 3 details the data set and the data sources utilised for the estimation procedure. Section 4 gives and comments the main results obtained in the estimation and section 5 concludes.

2. THE MODEL: THEORETICAL BACKGROUND

At the core of this model is the concept of increasing returns to scale, which has become popular in recent years within both urban and geographical economics (Rivera-Batiz, 1988; Abdel-Rahman and Fujita, 1990; Quigley, 1998; Fujita et al 1999; Fingleton 2003b). All these literature allows increasing returns in the region or city while at the same time the decision problem for each actor is explicitly stated as one of profit or utility maximization. Due to the increase in diversity or variety in producer inputs with increasing region size can yield external scale economies, even though firms are just earning normal profits. The monopolistic competition model developed by Dixit-Stiglitz allows an equilibrium solution in the context of competitive producers but with increasing returns to the economy as a whole.

The model in this paper, following Rivera-Batiz (1988) and Abdel-Rahman and Fujita, (1990) considers two sectors, industry (including manufacturing and traded services) and producer services and follows the arguments of the urban economic literature. The non-traded producer service sector (hereafter 'services') comprises local services that are not traded in national or international markets and are identified as the array of inputs requirements that industry demands, in term of repair and maintenance of all kinds, transportation and communication services, advertising, engineering and legal support, etc. In this paper we modify the production function in the industry sector by introducing explicitly public capital stock as an additional argument. We assume a monopolistic competition market structure for services, which is a direct result of the fact that the market for services are generally highly competitive, and face relatively minor barriers to entry and exit, while at the same time consumers and producers have highly specialized demands making each service sector firm differentiated with respect to the others. So firms in the service sector are assumed to be typically numerous, small, independent and heterogeneous. Industry on the other hand is assumed to have a competitive market structure, and demands a wide array of different types of services performing highly specialized tasks.

We will obtain a simple and empirically tractable reduced form linking productivity level to density of employment, human capital and public capital stock, similar to one of the extensions of the model estimated in Ciccone et al (1996)[1]. In addition, the model is extended to include additional and necessary factors representing technological externalities (for example knowledge spillovers) which go unrepresented in the basic model outlined above.

The Dixit-Stiglitz theory of monopolistic competition provides the reason why an increase in service labour maps to an increase in service variety, rather than more of the same variety. Monopolistic competition envisages a large number of services firms producing differentiated services and firms freely entering the sector until profits go to zero. The existence of fixed costs means that firms prefer to concentrate on a single variety and reap internal economies of scale; there is no advantage in a variety's production being split between two or more firms. On the other hand if there were no fixed costs, average costs would not decrease with increasing output so no internal economies of scale would be realized. Since each firm is the producer of its own differentiated services, the ensuing monopoly power allows prices to be a mark up on marginal cost. The number of firms supplying services is an endogenous variable in the model instead of being an ad-hoc restriction. There is an equilibrium level of output and therefore equilibrium labour requirement per service firm that is a constant, and as will be stated later we have an equilibrium number of firms. These equilibrium values depend on exogenous parameters.

From now on we follow Fingleton (2004) in order to get to an empirical tractable reduced form, but develop the model by introducing public capital stock as an additional input in the production function of industry sector. We derive the reduced form linking output *(Q)* to the intensity of activity in a unit area given by the total labour force *(N),* the amount of public capital stock *(* K_P *)* and land (*L*). By substituting the level of composite services *I* into the Cobb-Douglas production function we obtain the industry production technology. In this the level of industry output *(Q)* is a function of the input of industry labour *M, I*, K_P and *L*. Note that industry is competitive, with constant returns to scale.

$$Q = (M^{\beta} I^{1-\beta})^{\alpha} K_P^{\nu} L^{1-\alpha-\nu} \tag{1}$$

For simplicity the level of composite services is determined by the CES production function.

$$I = \left[\int_{d=1}^{D} i(d)^{\frac{1}{\mu}} \partial d \right]^{\mu} \tag{2}$$

In which *i(d)* is the "typical" output of a service variety, and there are *D* varieties. The level of monopoly power in the service sector is given by the exogenous

[1] He found public capital does not affect productivity significantly at the state level for the United States.

parameter μ[2]. The higher μ is the less one service substitutes for others and the more monopoly power the producer of that service has. As μ increases, we see rising monopoly power and falling elasticity of substitution. More monopoly power enhances the level of composite services providing an input to industry output. As μ falls back towards 1, the level of composite services approaches the number of firms times the equilibrium level of output per firm.

Since we assume a very large number of varieties we approximate the continuous integral by the discrete summation. At equilibrium *i(d)* is a constant across all varieties and therefore we can reduce the summation to a product as follows:

$$I = \left[\sum_{d=1}^{D} i(d)^{\frac{1}{\mu}} \right]^{\mu} = \left[D i(d)^{\frac{1}{\mu}} \right]^{\mu} = D^{\mu} i(d) \tag{3}$$

Broadly speaking, services are relatively labour intensive. We thus assume, for simplicity that each firm producing composite service uses only labour[3] as an input whose requirements are given by

$$\tilde{L}_i = a i(d) + s \tag{4}$$

Where *s* represent the fixed labour input requirement and *a* the marginal input requirement. Following the Chamberlinian framework, the technology used by all firms is considered identical, implying that *a* and *s* are the same for all the composite service sector firms.

Given the simplified form in equation 3, we substitute for *I* and use the equilibrium values for the number of varieties *D* and *M* to obtain the relationship between *Q*, *N*, K_P and *L*. We will write the equation in terms of production per unit area, so we restrict *L* = 1, eliminating land as an input since $1 = 1^{1-\alpha-\upsilon}$: By doing this we are implicitly including the effect of congestion in the equation, since by eliminating land production will be less than it would otherwise be.

$$Q = (M^{\beta} I^{1-\beta})^{\alpha} K_P^{\nu}$$

$$I = D^{\mu} i(d)$$

$$Q = \left[M^{\beta} \left(D^{\mu} i(d) \right)^{1-\beta} \right]^{\alpha} K_P^{\nu}$$

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[2] This is the substitution parameter of the CES production function, which determines the elasticity of substitution, the price elasticity of demand, and the internal returns to scale given by the average cost to marginal cost for producer services in equilibrium.

[3] We expect in line with Abdel-Rahman and Fujita that the introduction of other factors such as capital or land would not essentially change the main conclusion of the framework. Even though the service sector also utilises public capital stock, because it is a non remunerated factor, the cost function of the firm will not be altered and therefore the approach adopted remains unaltered. Our aim is to quantify the relation between public capital stock and growth in the industry sector, assuming that both sectors are affected by the existing endowment of public capital stock.

Assume that the economy is at a competitive equilibrium and workers are paid the value of their marginal product. At equilibrium the wage rate (w) equal to the marginal product of M labour is given by

$$w = \frac{dQ}{dM} = \frac{Q\alpha\beta}{M} \tag{5}$$

Assume also that the share of Q going to all labour (N, equal to industry plus services) is given by α , from standard Cobb-Douglas theory. Hence wages (considered to be the same as for industry) times number of workers as a share of Q is

$$\frac{wN}{Q} = \alpha \tag{6}$$

The assumption here is that the inputs are (all types of) labour (coefficient α), capital and land and the marginal product of each input (wages, returns on capital and land rents) are given by the respective derivatives, and the shares are the marginal products times the amounts (of labour, capital, land) as a proportion of total output Q. The marginal product of all types of labour is

$$w = \frac{Q\alpha}{N} \tag{7}$$

From this it follows that

$$\begin{aligned} \frac{wM}{wN} &= \frac{Q\alpha\beta}{Q\alpha} \\ \frac{M}{N} &= \beta \end{aligned} \tag{8}$$

Hence service workers (N-M) as a share of total workers is $1-\beta$.

At equilibrium all firms are the same size so the number of firms D is the total services workforce, $(1-\beta)N$, divided by the workers per service firm.

$$D = \frac{(1-\beta)N}{ai(d)+s} \tag{9}$$

So utilising equilibrium values we have:

$$\begin{aligned} Q &= \left[(\beta N)^{\beta} \left[\left(\frac{(1-\beta)N}{ai(d)+s} \right)^{\mu} i(d) \right]^{1-\beta} \right]^{\alpha} K_P^{\nu} \\ Q &= N^{\beta+\mu\alpha(1-\beta)} \beta^{\beta\alpha} i(d)^{\alpha(1-\beta)} \left(ai(d)+s\right)^{-\mu\alpha(1-\beta)} \left(1-\beta\right)^{\mu\alpha(1-\beta)} K_P^{\nu} = N^{\gamma} \Phi K_P^{\nu} \end{aligned} \tag{10}$$

Where:

$$\gamma = \beta\alpha + \mu\alpha(1-\beta) = \alpha[1+(1-\beta)(\mu-1)]$$
$$\Phi = \beta^{\beta\alpha} i(d)^{\alpha(1-\beta)} \left(ai(d)+s\right)^{-\mu\alpha(1-\beta)} \left(1-\beta\right)^{\mu\alpha(1-\beta)} \tag{11}$$

Increasing returns to scale are implied by $\gamma > 1$, so from equation (11) it is apparent that this will occur if $\beta < 1$ and $\mu > 1$ provided α is not too small. This means that assuming that the loss of production as a result of restricting land is not too severe, then we also need differentiated intermediate goods to be relevant to the output of the competitive sector ($\beta < 1$) and for them to be imperfect substitutes for each other ($\mu > 1$) with a degree of monopoly power. With a higher enough μ and a low enough β, the production function could have increasing returns, where the favourable effect of density outweighs the congestion effects.

In order to move closer to a convenient reduced form, we log-linearize equation (7) by taking natural logarithms, hence

$$\ln w = \ln Q + \ln\alpha - \ln N \qquad \textbf{(12)}$$

And substituting for Q gives

$$\ln w = \gamma \ln N + \ln\Phi + \nu \ln K_P + \ln\alpha - \ln N$$
$$\ln w = k_1 + (\gamma - 1)\ln N + \nu \ln K_P \qquad \textbf{(13)}$$

And assuming the number of labour efficiency units (N) is equal to the total employment (E) times the level of efficiency (A), we have

$$\ln w = k_1 + (\gamma-1)\ln E + (\gamma-1)\ln A + \nu \ln K_P \tag{14}$$

The Level Of Efficiency

We assume that the level of efficiency depends on 'within region' effects and effects that spillover from 'neighbouring' regions. Within regions, assume that what is important is the level of human capital (H) plus an autonomous rate reflecting "learning by doing" which proceeds regardless of the other factors. Regions with relatively better-developed human capital are expected to make faster technical progress since human capital facilitates research, development and the spillover of knowledge. We will utilise as indicator of human capital the number of people with high degree level qualifications in the region. The spillover effect is determined by a so-called weights matrix, W, which is a square n by n matrix for n regions with cell values denoting the strength of interregional interaction, and zeros on the main diagonal.

Combining the factors outlined above produces the following specification:

$$\ln A_i = b_0 + b_1 H_i + \rho \sum_{r=1}^{R} W_{ir} \ln A_r + \varepsilon \qquad \textbf{(15)}$$

Or in matrix terms, and rearranging,

$$\ln A = (I - \rho W)^{-1}(Xb + \varepsilon) = (I - \rho W)^{-1} Xb + (I - \rho W)^{-1}\varepsilon \qquad \textbf{(16)}$$

In which X is the n by k matrix of right hand side variables (the constant and H) and ε is an independent and identically distributed disturbance term representing measurement error and exogenous shocks to the level of efficiency, hence

$$\varepsilon \sim N(0, \Omega^2)$$

The contribution to area *i's* efficiency level is given by row *i* of vector *Wln(A)* which contains the sum of the weighted efficiency levels of other provinces. Note that by making *ln(A)* depend on *Wln(A)* and not simply the constant and *H*, we capture the totality of the effects influencing the efficiency level, including those represented by the random shocks. Assuming that $|\rho| < 1$, then $(I - \rho W)^{-1} = \sum_{i=0}^{\infty} \rho^i W^i$, with W^0 equal to the identity matrix I, W^2 equal to the matrix product of W and W, and in general W^i equal to the matrix product of W^{i-1} and W. This means that

$$\ln A_i = Xb + \varepsilon + \rho W Xb + \rho W \varepsilon + \rho^2 W^2 Xb + \rho^2 W^2 \varepsilon$$
$$+ \rho^3 W^3 Xb + \rho^3 W^3 \varepsilon + ...$$
$$\ln A_i = \sum_{i=0}^{\infty} \rho^i W^i (Xb + \varepsilon)$$

This shows that $\ln A_i$ is equal to the weighted sum of the matrix products[4] of the matrices W^i (i = 0,…,∞) and exogenous variables X and ε. The log level of efficiency $\ln A_i$ in Province *i* depends on level of human capital (*H*) and on shocks ε in regions *i,j,k,l*,...The actual mechanism causing evidently remote interactions is the direct mutual interaction between Province *i* and its 'neighbours' as defined by *W*, as indicated by the presence of $\sum_{r=1}^{R} W_{ir} \ln A_r$ in equation (15), so that a high (low) efficiency level in Province *i* causes, and is a response to, high (low) efficiency in 'nearby' Provinces.

This specification has rather important implications for the estimation method, leading to an endogenous spatial lag in the reduced form and the methodology of spatial econometrics.

The *W* Matrix

In order to determine the spillover effect we considered different possibilities for the elements of the weights matrix. The hypothesis is that regions with fast technical progress occurring in neighbouring regions will also experience faster technical progress than would otherwise be the case, and vice versa for regions with slower neighbouring technical progress. The implication of this is that the rate of

[4] Note that as i becomes large, W^i tends to a matrix in which each cell in a column contains the same value, columns differ, and each row of W^i is identical. This means that the matrix products tend to constant vectors.

technical progress in distant regions will have less impact, so that "who your neighbours are" is important due to the impedance of information flow across space.

We considered different alternatives when selecting the weights matrix[5]. A first order binary geographical contiguity matrix was constructed in which the elements are one when regions share a common border, and zero otherwise[6]. However, from a theoretical point of view we feel that the weight matrix should take into account not only contiguity, but the distance between the different provinces, as well as the size of the province. Thus we adopt a W matrix in which the value allotted to cell (i,j) is a function[7] of the road distances d_{ij} between the capitals of the provinces and the GDP of the region in 1971.

$$W_{ij} = \frac{GDP_j}{d_{ij}^2} \qquad i \neq j$$

$$W_{ij} = 0 \qquad i = j$$

Thus we also take into account the (economic) size of the (remote) province in order to measure the interaction between regions. Size is considered relevant because of the extensive trade and labour market that a large and diverse local economy naturally generates[8].

The Reduced Form

Following Fingleton (2006), combining equations 14 and 16 gives

$$\begin{aligned}
&\ln w = k_1 + (\gamma-1)\ln E + (\gamma-1)(I-\rho W)^{-1}(Xb+\varepsilon) + v\ln K_P \\
&(I-\rho W)\ln w = (I-\rho W)k_1 + (I-\rho W)(\gamma-1)\ln E + (\gamma-1)(Xb+\varepsilon) + (I-\rho W)v\ln K_P \\
&\ln w = \rho W\ln w + (I-\rho W)k_1 + (\gamma-1)(\ln E - \rho W\ln E) + c_0 + c_1 H + v\ln K_P - \rho W v\ln K_P + \psi \\
&\psi \sim \mathrm{N}(0,(\gamma-1)^2\Omega^2)
\end{aligned} \qquad (17)$$

Or

$$\begin{aligned}
&\ln w = \rho W\ln w + (I-\rho W)k_1 + (\gamma-1)(\ln E - \rho W\ln E) + c_0 + c_1 H + v(\ln K_P - \rho W\ln K_P) + \psi \\
&\psi \sim N(0,\ (\gamma-1)^2\Omega^2)
\end{aligned} \qquad (18)$$

Consistent estimation of the model is not possible via OLS because of the presence of the endogenous variable *Wlnw* on the right hand side of equation 18. Moreover we also may have two-way causation involving employment density and

[5] See Fingleton (2001 a, b) for further discussion of alternative assumptions about W.
[6] The elements of the main diagonal are set to zero by convention.
[7] This way of capturing interactions weighted by distance is used very often in spatial econometrics literature. Fingleton (2004, 2005) utilises and scalar that reflects the commuting of people between different regions. As this information is not available for the Spanish provinces we weighted using the square to make relation more intense as the distance becomes shorter.
[8] The estimation results were similar when we use different W matrices, the coefficient varied slightly and all the signs were as expected from theory.

productivity/wage rates[9], with employment density increasing (due to migration and enhanced participation rates) as wage rates increase. So employment density is also likely to be an endogenous variable. Although Hausman's test pointed to the exogeneity of employment density, in order to guard against any potential inconsistency not detected by this test we decided to use instrumental variables. We assume that human capital (lagged by 10 years) and productive public capital stock (lagged by one year) are exogenous, since they pre-date the year of analysis.

To obtain consistent estimations, we used Two Stage Least Squares (2SLS). In fact, estimations of similar models (see Fingleton 2000, 2001a,b) via a variety of different methods and different instruments produced very similar results, suggesting that endogeneity is a relative minor phenomenon. The instrumental variables are the fitted values as a result of regressing the spatial lag variable and *[lnE – ρWlnE]* on a set of instruments. Following Anselin´s (1988) suggestions about the choice of instruments we selected four instruments leading to exact identification. The first one is the variable E_I and it is defined by the three group method (described in Leser (1966), Koutsoyiannis (1977), Johnston (1984), and Kennedy (1992)). E_I takes a value of 1, 0 or -1 according to whether the employment density variable is in the top, middle or bottom third of its ranking which ranged from 1, the province with the lowest employment density, to 50. We assumed that no correlation exists between E_I and ψ induced by measurement error and by simultaneity. For the second and third instruments we utilized public and human capital, respectively, which are two exogenous variables within the model, and as the last instrument we chose the two periods temporal lag of the endogenous variable.

The first stage involves regressing *[lnE – ρWlnE]* and the endogenous lag *Wlnw* on the instrumental variables (E_I, H, $\ln K_P, \ln E_{t-2}$, and $\ln w_{t-2}$)[10] to obtain the fitted values that we are going to use as instruments. The endogenous right hand side variables are then replaced by instruments equal to the fitted values of the first stage regressions in each iteration. This way we obtain an estimation of ρ. The second iteration uses estimated ρ to recalculate the endogenous variable *[lnE – ρWlnE]*. Then 2SLS is carried out again to obtain revised parameter estimates. The third iteration is based on the estimated ρ from the second iteration and so on, until the parameter estimates converge.

The restriction in equation 18 relating to ρ is caused by the spillover of labour efficiency levels between provinces. To take into account this constraint we use iterated 2SLS, with each iteration providing an updated value for ρ from the *Wlnw* term which was then used to update the variables *ρWlnw* and *[lnE – ρWlnE]* for the subsequent iteration, until ρ reached a steady state as in Fingleton (2003). At the first iteration, with no initial estimate for ρ, we assume an arbitrary value for ρ =1. In order to avoid an explosive model, the estimated value of ρ should be in the interval $1/e_L <$

[9] As there is no data available on wages at the Province level we proxy the wage level by the productivity level.

[10] In the case of *Wlnw* the regressors are the instrumental variable E_I as explained previously, the exogenous variables in the model (human and public capital) and the two years lag of log productivity. Likewise for the *[lnE- ρWlnE]* we use the same regressors but replace the last instrument by the two years lag of the log of the density of employment.

$\rho < 1/e_U$, where e_L and e_U are the largest negative and largest positive eigenvalues of W respectively. This region of parameter space is devoid of singular points, but the matrix $(I- \rho W)$ becomes singular at the points $\rho = 1/e_L$ and $\rho = 1/e_U$ where $1/e_L$=-0.3912 and $1/e_U$=0.3396. The range of ρ is automatically bounded in the Maximum Likelihood estimator but can fall outside this stable range and thus encounter singular points under 2SLS estimation. Fortunately, the instrumental variable estimated ρ lies within the stable bounds.

Unfortunately, we have no value for k_1, so the variable $(I-\rho W)k_1$ is, by necessity, omitted from all the estimated equation.

3. DATA

In order to analyze the impact of public capital stock on productivity at four different stages of Spain's economic growth, the model defined by equation 18 was fitted to cross-sectional series for the Spanish provinces[11] for the years 1971, 1981, 1991 and 2001, which covers a period of substantial economic transformation. In 1971 the level of government capital endowment and economic activity in the Spanish regions was far below that typical of most Western European economies, but this is no longer the case.

We proxy the wage level by the productivity level based on Gross Value Added, in thousands of constant (1995) euros, data which were provided by Fundación BBVA (*La Renta Nacional de España y su Distribución Provincial*) until 1997, and theerafter by Fundación de las Cajas de Ahorro Confederadas (FUNCAS) [12] as documented in their "*Balance Económico Regional".*

The employment density variable (*E*) is constructed by dividing the total employment, taken from "*La Renta Nacional de España y su Distribución Provincial",* by the provincial area in square kilometres. Data on the geographic area of each province and on population were provided by the *Office of National Statistics* (INE).

Our human capital variable (*H*) is the proportion of people in each province with higher education, data published in "*Human Capital in Spain and its distribution by provinces (1964-2004)"* by *Instituto Valenciano de Investigaciones Económicas* (IVIE).

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[11] Spanish provinces correspond to level 3 of the Nomenclature of Territorial Units for Statistics (NUTS) of EUROSTAT, the Statistical Office of the European Union. The average surface of a representative province is 10,120 km^2 (range 1,980 km2 to 21,766 km^2).

[12] In order to make the Gross Value Added and employment series homogeneous we took the rates of growth of the variable in FUNCAS database and applied it to the variable produced by FBBVA. Previously we had to transform the valued added into constant euros of 1995 using the Implicit Index Prices facilitated by both organisations.

Finally, the productive public capital stock (K_P) was taken from the publication "*Capital Stock in Spain and its distribution by territories (1964-2003)"*[13] which detailed work done by FBBVA in collaboration with IVIE.

4. ECONOMETRIC RESULTS

The results of the IV estimation for years 1971, 1981, 1991 and 2001 are summarized in Tables 1 and 2. These give the results of fitting versions of the equation (18) model, with various restrictions on the parameters. In column *a*, results of 2SLS estimates for the basic Urban Economics model are given, that is, we make productivity depending on the employment density variable plus a constant. The parameters ρ, c_1, and ν are restricted to zero in this specification. The estimates show that employment density is highly significant regardless of year, but the presence of significant residual autocorrelation suggests that there are omitted spatially autocorrelated variables leading to omitted variable bias. Moreover, the fact that R^2 and the explanatory power of the employment density variable decays in time suggests that this simple specification becomes increasingly inappropriate through time. As we move towards 2001, while employment density continues to growing steadily, it appears that productivity growth stagnated from the early nineties[14] . A reason for this could be that growth concentrated in the labour intensive construction and service sectors, so that output growth was at the same rate as employment growth with no appreciable growth in labour productivity.

In column *b* of Tables 1 and 2, we extend the basic model to include the labour efficiency variable (*H)* and the logarithmic of public capital stock ($\ln K_P$) but we maintain the restriction that ρ is equal to zero. Hence the hypothesis in this model is that labour efficiency depends simply on the intra-regional determinants of labour efficiency, essentially educational attainment (*H*), and that inter-regional interactions are null, an assumption we relax in our final model. The model estimated in column *b* is:

$$\ln w = c_0 + (\gamma - 1)\ln E + c_1 H + \nu \ln K_P + \psi$$
$$\psi \sim \mathrm{N}(0, (\gamma - 1)^2 \Omega^2)$$

(19)

Under model (19), and indeed all three model specifications, labour efficiency has a significant positive effect on wage levels across all time periods. However while public capital appears to have a positive effect, it is not significant, although evidently model (19) is also mispecified, as shown by the significant residual autocorrelation indicated in Tables 1 and 2.

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[13] New methodology which differentiates different measures of public capital stock depending on the analysis is going to be carried out. We use productive public capital stock as is the indicator that better captures its impact on productivity.
[14] Estrada et al (2006).

Our final (iterative) 2SLS estimates (column *c*) are of the model described by equation 18 with no restriction imposed on ρ. The overall fit of the model, as measured by R^2 is higher than for the other models, and remains comparatively high even for 2001. The parameter estimate of all but one of the variables is significantly different from zero and correctly signed, indicating that a Province's productivity increases in its human capital and employment density and is positively spatially autocorrelated. The γ-1 estimate being significantly greater than zero indicates increasing returns[15] to employment density as a result of pecuniary externalities, with the elasticity taking a similar value to that published previously in the literature, see for example Fingleton (2006) for UK local authority districts and Ciccone (2002) for the European economies. The spatial spillover parameter ρ is very significantly different from zero, indicating strong positive correlation of wage/productivity levels according to the spatial structure defined by *W*. The underlying cause of this, according to theory leading to our reduced form, is the interaction of labour efficiency levels across region boundaries.

Finally, note that the effect of public capital is not significantly different from zero, thus reflecting some of the research findings summarised in the Introduction, notably Holtz-Eakin and Lovely (1996) and Martin and Rogers (1995) who find that there is no significant relation between public infrastructure and growth.

Table 1: Estimates of empirical model for years 1971 and 1981

	Year 1971			Year 1981		
Regressors	**2SLS (a)**	**2SLS (b)**	**2SLS (c)**	**2SLS (a)**	**2SLS(b)**	**2SLS (c)**
Constant	2.201945 (23.74925)	1.217748 (1.468738)	1.434598 (10.09397)	2.728383 (33.71229)	1.055344 (1.138493)	2.093400 (24.45784)
Log Employment density $\ln E$	0.156990 (5.458798)	0.094142 (2.305446)	------	0.109327 (4.275407)	0.025302 (0.612828)	------
$\ln E\text{-}\rho W\ln E$	------	------	0.236587 (11.11157)	------	------	0.057220 (4.921287)
degree level qualifications H	------	16.647118 (2.883137)	10.856762 (3.072335)	------	10.166286 (2.111614)	15.648398 (7.183572)
Log public capital $\ln K_P$	------	0.064657 (1.024033)	------	------	0.113886 (1.671589)	------
$\ln K_P\text{-}\rho W\ln K_P$	------	------	0.007399 (0.934567)	------	------	0.005989 (1.126718)
Endogenous Spatial lag $W\ln w$	------	------	0.000063 (8.159297)	------	------	0.000065 (12.30493)
Residual variance	0.0380	0.0314	0.0122	0.0352	0.0291	0.0072
R. square	0.3830	0.5122	0.8149	0.2758	0.4258	0.8613
Correlation	---	---	0.9027	---	---	0.9281
N degrees of freedom	48	46	45	48	46	45
Moran's I to Residual	4.85834328 (0.000001)	4.19992477 (0.000026)	3.20497033 (0.001350)	4.23067934 (0.000023)	2.99446016 (0.002749)	1.01802004 (0.308668)
Residual autocorrelation*	---	---	0.44747455 (0.503536)	---	---	0.09310601 (0.760265)

Notes: t ratios given in brackets beneath the estimates coefficients. In the case of residual autocorrelation test marginal probability is in brackets
* For 2SLS Anselin and Kelejian (1997) test for residual correlation either with or without endogenous lag.

[15] Note that, except for 1971, this effect is concealed when no account is taken of spillovers when *H* and K_P are included (estimates *b*).

However we would not want to dismiss the hypothesis of significant public infrastructure effects too readily. From the econometric perspective, it is possible that collinearity involving the spatial lags $W \ln w$, $\ln E - \rho W \ln E$ and $\ln K_P - \rho W \ln K_P$ could be concealing significant effects. Also the effects of public infrastructure may be indirect, sector-specific and time-specific. For instance while Holtz-Eakin and Lovely (1996) find that infrastructure has no significant direct effects, they do find evidence that public capital may alter productivity through its effect on the number and variety of manufacturing establishments in the local manufacturing base. Likewise Moreno et al. (2007) demonstrate that public capital has a greater effect on Spain's industrial productivity than on any other economic sector, particularly during the period when Spain experienced rapid economic growth, and increased openness to trade and greater economic liberalization. The mechanism allowing this could be that public capital increases industrial firms' accessibility and reduce their costs, thus allowing productivity gains. In fact there may be a more complex relationship between public capital and productivity, involving both positive and negative spillovers in public capital stock which are mutually self-cancelling, thus eliminating a positive impact due to public capital. A high level of public capital in one Province could attract mobile factors away from competing Provinces. Another reason for a weak public capital effect could be that the different components of public capital have different and possibly contrasting effects which when taken together cancel themselves out. The effect of public capital on productivity may depend on the type of public infrastructure, so that local infrastructure has a different impact on private productivity than does transport infrastructure. There are thus many reasons to retain an interest in the possible effect of public capital and to reconsider the hypothesis that it will have an effect in further detail, using different data and methodologies.

Table 2: Estimates of empirical model for years 1991 and 2001

	Year 1991			Year 2001		
Regressors	**2SLS (a)**	**2SLS (b)**	**2SLS (c)**	**2SLS (a)**	**2SLS (b)**	**2SLS (c)**
Constant	3.184048 (53.968263)	2.034062 (2.936374)	2.603966 (24.35057)	3.154941 (53.71668)	2.083123 (3.054556)	2.711344 (8.786862)
Log Employment density $\ln E$	0.063063 (3.421771)	-0.001966 (-0.064513)	------	0.068047 (3.950110)	0.009198 (0.297586)	------
$\ln E$-$\rho W \ln E$	------	------	0.053134 (5.672148)	------	------	0.072678 (3.725396)
degree level qualifications H	------	5.320834 (2.725864)	6.615522 (7.773036)	------	3.173071 (3.113470)	2.119276 (2.344306)
Log public capital $\ln K_P$	------	0.075897 (1.557238)	------	------	0.066958 (1.431212)	------
$\ln K_P$-$\rho W \ln K_P$	------	------	0.009727 (1.350355)	------	------	0.006462 (0.320898)
Endogenous Spatial lag $W \ln w$	------	------	0.000038 (13.22693)	------	------	0.000028 (4.221230)
Residual variance	0.0196	0.0160	0.0033	0.0184	0.0151	0.0111
R. square	0.1961	0.3700	0.8634	0.2453	0.4037	0.5714
Correlation	---	---	0.9352	---	---	0.7559
N degrees of freedom	48	46	45	48	46	45
Moran's I to Residual	4.28178416 (0.000018)	1.93261737 (0.053283)	3.99370564 (0.0000650	4.19541097 (0.000027)	1.52657036 (0.126867)	3.81551459 (0.000135)
Residual autocorrelation*	---	---	3.56128916 (0.059142)	---	---	1.4721658 (0.225004)

Notes: See table 1

However, we should reiterate that we found no such effect in the present study, and the best-fitting model appears to be an adequate representation of the data. We tested the residuals produced by the (iterative) 2SLS estimates for spatial autocorrelation using the appropriate statistic developed by Anselin and Kelejian (1997). The test statistic indicates that there is no dependence in the residuals, and the overall goodness-of-fit as given by the R^2 and the square of the correlation between the observed and fitted values suggest that the model is an adequate explanation of the data.

5. CONCLUSIONS

In this paper we have examined the effect of public capital on the variation in wage (productivity) levels across the Spanish provinces, over the period 1971-2001. Earlier studies like Dolado et al (1994), Gorostiaga (1999), and Díaz et al (2006) which are somewhat inconclusive regarding the impact of public capital. The analysis is motivated by contemporary urban economics theory and the methodology of spatial econometrics, which leads to a reduced form in which wage levels depend on 'nearby' wage levels, employment density, educational attainment and public capital, with spillovers across Province boundaries. Endogeneity and constraints on parameter values lead to an iterative 2SLS estimation routine. The model supports the theory motivating the reduced form, so that there does appear to be increasing returns to scale. Moreover, we have evidently uncovered significant heterogeneity across time, with the elasticity of productivity with respect to employment density being much higher in 1971 than in later periods. This may reflect the fact that growth in the more recent periods has been driven by services and construction, where production is labour intensive, and therefore the scope for productivity growth is less. There are also significant effects due to educational attainment which support the thesis that labour efficiency is highly relevant to wage variations across Provinces. The model estimates also indicate that there is a significant relationship between wage levels and 'nearby' wage levels, thus supporting the necessity for a spatial econometric approach. But, having controlled for these effects, there is no significant effect due to public capital. However we remain cautious in our conclusion that public capital is irrelevant because of the evidence from other studies and because the econometric techniques that we have employed in this study may not have been capable of revealing the effect. We are conscious that the estimates may be affected by the presence of multicollinearity, and by a more complex relationship between public capital and productivity. In particular there might be negative spillovers in public capital stock which are counteracting the positive impact of infrastructure in the province. Public infrastructure in one Province could have a negative effect on those Provinces that are the Province's closest competitors for labour and mobile capital attracting these factors towards the Province in which the infrastructure is being built. Another possible explanation of the non significant coefficient of public capital stock is contradictory effects involving the different components of public infrastructure that cancel themselves out in aggregate. It is possible that the effect of infrastructure on productivity depends on the type of public infrastructure, so that local infrastructure has a different impact on private productivity than does transport infrastructure. The comparison of the return to different types of infrastructure is on our research agenda for the future.

Further work is needed, either based on new data or new methodology, or both, and this might indeed show the hypothesised public capital effect(s). In particular, given the existence of panel data, it would seem apt to follow up this analysis using panel techniques that take account of spatial effects, for example as suggested by Kapoor, Kelejian and Prucha(2007), Baltagi et. al. (2003), Baltagi and Li (2004, 2006), Baltagi et al. (2007) and Fingleton (2008).

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