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

BY

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

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Abstract:

In this paper we examine whether variations in the level of public capital across Spain's Provinces affected productivity levels over the period 1996-2005. 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 production function by also making (log) labour efficiency a function of (log) total public capital stock and (log) human capital stock, 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 further extended to include technological externalities or spillovers across provinces. Using panel data methodology, we find significant elasticities for total capital stock and for human capital stock, and a significant impact for employment density. The finding that the effect of public capital is significantly different from zero, indicating that it has a direct effect even after controlling for employment density, is contrary to some of the earlier research findings which leave the question of the impact of public capital unresolved.

JEL Code: C21, R11, R12.

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1. INTRODUCTION

One way that the World's current economic malaise can be addressed is by an enhanced level of investment by Governments that is focussed on the public infrastructure. Of course, the impact of such a policy needs to be evaluated in order to see whether it is cost effective. This paper contributes the literature on policy impact evaluation by examining the extent to which public infrastructure investment can potentially enhance productivity, using the recent history of investment in the Spanish regions as a guide to likely impacts elsewhere. There is no single approach to evaluating the impact of public infrastructure on productivity growth, and four main approaches have appeared in the literature, namely the cost function or dual approach, autoregressive vectors (VAR) models, frontier analysis and the production function approach. As will become evident, our approach comes closest to a production function approach, but is sufficiently different to be considered to be a fifth approach to the problem.

Under the dual approach most of the analyses show that public investment reduces entrepreneur costs¹. However, evidence using VAR models is more ambiguous. For instance the papers by Flores de Frutos (1998) and Batina (1999) show a positive effect, whereas Otto and Voss (1996) and Voss (2002) find a negative impact. Application of frontier analysis to the Spanish case suggests a positive effect². But the most frequently applied approach is

¹ Bosca et al (2002), Moreno et al (2002), Avilés et al (2003), and Cohen and Morrison (2004), Matmazakis (2007).

² Maudos et al (1998), Martín and Suárez (2000), Pedraja et al (2002), Salinas- Jiménez (2004) and Delgado and Álvarez (2007).

based on the neoclassical production functions, commencing with Ratner's (1983) analysis of the relation between infrastructure and private productivity in the US economy. Ratner 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. Subsequently Aschauer (1989a) also found a similar (albeit larger) effect, and by breaking public capital stock down into its constituent parts, he 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 under 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, much of the analysis has been carried out for the American states and for the Spanish regions³. In the case of the US, 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 Aschauer (1989a) estimate. Building on this, Munell (1990b) broke down public capital stock into its different types, showing that the biggest impacts were attributable to road and water supply infrastructures. In contrast, García-Milá et al (1996), who

³ There are very few countries where regional public investment data are available, one exception are Germany and Italy, where recently Marrocu and Paci (2010) obtained a positive and significant but variable public investment effect on production.

estimated, for the period 1970-1983, a Cobb-Douglas production function with data for the 48 American states, found no relation between public capital stock and productivity given the presence of region fixed effects. Likewise Holtz-Eakin (1994) concluded that, once fixed regional effects are introduced, public capital stock is not significant.

With regard to the Spanish regions, most papers suggest a positive effect, for example, Marquez et al (2009), De la Fuente (2008), Cantos et al (2005), Ezcurra et al (2005), Moreno et al (2002), Boscá et al (2002), Mas et al (1996), Bajo-Rubio and Sosvilla-Rivero (1993), Flores de Frutos et al (1998) and Gómez-Antonio and Fingleton (2010). However some papers, such as Gorostiaga (1999) and Gonzalez-Páramo and Martinez (2003) do not find a significant effect of public capital stock on economic growth. One of the reasons suggested in the literature for the inconclusiveness of the results is that many analyses do not take into account the existence of spillover effects. Negative as well as positive inter-regional spatial spillovers may occur, for instance Mas et al (1996), using the production function approach, and Avilés *et al* (2003), based on duality theory, find positive spillovers. Pereira and Roca-Sagales (2003), applying a vector autoregressive model, show similar results. Moreno and López-Bazo (2007) interestingly obtain a negative spillover effect due to transport infrastructure that counterbalances its positive effect on manufacturing productivity within each region. The existence of negative spillovers suggests that a region's public capital raises its comparative advantage, thereby attracting production factors from other regions.

With regard to the results obtained in countries other than Spain, Holtz-Eakin and Schwartz (1995) provide no evidence of spatial infrastructure spillovers in the US context. However, Owyong and Thangavelu (2001) find that US public capital positively affects Canadian productivity. Cohen and Morrison (2004) and Bronzini and Piselli (2009), also find significant positive spatial spillovers for the US, and Italy, respectively. However, Boarnet (1998) using data for California's counties, finds that the output of counties is negatively affected by neighbouring counties' infrastructure, likewise Sloboda and Yao (2008) for the US, and Pereira and Andr az (2006) for Portuguese regions.

To summarise the above, 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 the decade from 1996 to 2005. We avoid analysing earlier data because of the substantial transformation of the Spanish economy over the longer period, which makes model specification particularly difficult. For instance, in a fixed effects panel, the fixed effects may not capture some variables that vary over time given a longer time period, leading to omitted variable bias. We thus restrict our period of analysis to a

shorter time-span during which we have greater confidence that our model will be appropriate.

As mentioned above, our approach differs from the four approaches that can be found in the literature, and can be seen as a fifth approach that extends the public capital literature by basing the evaluation of public infrastructure on a different theoretical paradigm to that which dominates the literature, namely neoclassical constant returns to scale technology. Our 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 distinctive aspects of this theory is the possibility 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. To our knowledge this theory has not previously underpinned attempts to test the impact of public capital.

In addition to the direct effect on productivity of the mechanisms embodied in our urban economics theory, we also allow for the direct within-province effects of variations in worker efficiency, and also for spillovers in efficiency levels across provinces, with efficiency depending on the level of public capital and also the level of human capital. Spillover effects operating across provinces are technological externalities that could also play a key role in regional economic performance, since changes in one region may affect over regions, cascading across the whole country and rebounding back to the

initial province. These impacts might be positive or negative. For example, changes in one region could affect production in other regions by raising the comparative advantage of that region compared with others, and could therefore attract production factors from other locations where output or productivity might as a consequence diminish. On the other hand there are reasons to believe that capital investment in neighbouring provinces might have a positive impact on productivity within a given province as it might enhance connections such as roads, railways or airports.

Although our approach differs somewhat from that of the previous literature, nevertheless our main conclusions are in line with what has been found previously for the Spanish economy. We find that, controlling for inter-province heterogeneity, human capital and spillover between provinces, public capital, in our case working via labour efficiency, has a significant positive direct impact on the level of GDP per worker. The presence of the spillover effect enables us to avoid model misspecification which would otherwise occur if we chose to ignore spatial interaction, and therefore we are able to obtain unbiased estimates and also take into account the total impact effect. Within the positive spillover of labour efficiency, there may be a negative spillover effect of public capital, as has been detected in some other papers, but our model set-up does not allow us to identify this specifically and it is not a focus for our investigation in this paper. The positive spillover effect we identify is the net effect of the spillover of public and human capital spillover and of other unmodelled factors captured by model disturbances.

The paper is divided into the following sections. Section 2 specify the theoretical background of the model and 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 comments on 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). All of this 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, increasing density of economic activity 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 approach adopted differs from pro-competitive effects leading to agglomeration. Porter (1990, 1998) suggests that competition causes firms to be better innovators or faster adopters of others' innovations than they otherwise would be, which enhances the growth rate. To ensure full access to competitors' spillovers, an optimal strategy is for firms in the same sector to cluster together. A similar competitive stimulus is provided by Jacobs (1969) externalities, but based on spillovers between sectors.

The model in this paper, following Rivera-Batiz (1988) and Abdel-Rahman and Fujita (1990), and Ciccone and Hall (1996), considers two sectors, industry (including manufacturing and traded services) and producer services and follows the arguments of some of the urban economics 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 input requirements that industry demands, such as repair and maintenance of all kinds, transportation and communication services, advertising, engineering and legal support, etc. We assume a monopolistic competition market structure for services⁴, 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

⁴ 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.

market structure, and demands a wide array of different types of services performing highly specialized tasks.

In order to get to an empirically tractable reduced form we follow closely the presentation of the model given in Fingleton (2001, 2003, 2004). First we derive the reduced form linking output (Q) to the intensity of activity in a unit area given by the total labour force (N) and land (L). Capital, in the form of public capital or human capital comes through via its impact on labour efficiency. 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 and L . Note that industry is competitive, with constant returns to scale.

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

For simplicity the level of composite services is determined by the CES production function. This is what determines the level of composite services I . It is not simply the sum of each firm's output; it is more, depending on the number of separate varieties. The assumption is that there is a 'love of variety', which means that the varieties produced by differentiated firms results in a higher level of composite services than would otherwise be the case from firms with identical, perfectly substitutable, products.

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

In (2) $i(d)$ 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

parameter μ ⁵. 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:

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

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

$$L_i^+ = ai(d) + s \quad (4)$$

In (4), 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.

⁵ 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.

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 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 $1 = 1^{1-\alpha}$: 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.

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

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

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

If we 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

$$w = \frac{dQ}{dM} = \frac{Q\alpha\beta}{M} \quad (5)$$

If we 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, we have wages (considered to be the same as for industry) times number of workers as a share of Q is

$$\frac{wN}{Q} = \alpha \quad (6)$$

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

$$w = \frac{Q\alpha}{N} \quad (7)$$

From this it follows that

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

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.

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

So utilising equilibrium values we have:

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

Where:

$$\begin{aligned} \gamma &= \beta\alpha + \mu\alpha(1-\beta) = \alpha[1 + (1-\beta)(\mu-1)] \\ \Phi &= \beta^{\beta\alpha} i(d)^{\alpha(1-\beta)} (ai(d) + s)^{-\mu\alpha(1-\beta)} (1-\beta)^{\mu\alpha(1-\beta)} \end{aligned} \quad (11)$$

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

$$\ln w = \ln Q + \ln \alpha - \ln N \quad (12)$$

And substituting for Q gives

$$\begin{aligned} \ln w &= \gamma \ln N + \ln \Phi + \ln \alpha - \ln N \\ \ln w &= k_1 + (\gamma - 1) \ln N \end{aligned} \quad (13)$$

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

$$\ln w = k_1 + (\gamma - 1) \ln E + (\gamma - 1) \ln A \quad (14)$$

The Level of Efficiency

In line with Fingleton (2003b) 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), the level of public capital (K), 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. Likewise superior infrastructures (communications, urban facilities, health facilities, etc.) will provide the basis for a more efficient labour force. We will utilise as indicator of human capital the number of people with high degree level qualifications in the region. Public capital measures will be outlined below. The spillover effect is determined by the scalar parameter ρ and 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. This idea of capturing spillovers by means of a weight matrix has been widely used in the literature, since the appearance of spatial econometrics techniques, for instance under a neoclassical production function approach in Moreno and López-Bazo (2007).

Combining the factors outlined above produces the following specification:

$$\ln A_i = b_0 + b_1 \ln H_i + b_2 \ln K_{pi} + \rho \sum_{r=1}^R W_{ir} \ln A_r + \varepsilon \quad (15)$$

Rearranging, and assuming $(I - \rho W)$ is non-singular, we obtain the equivalent matrix expression

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

In which X is the n by k matrix of right hand side variables (the constant, $\ln H$ and $\ln K$) and ε is an independent and identically distributed disturbance term representing measurement error and exogenous shocks to the level of efficiency, hence, $\varepsilon \sim iid(0, \Omega^2)$

Part of the contribution to area i 's efficiency level is given by row i of vector $W \ln(A)$ which contains the sum of the weighted efficiency levels of other provinces. Note that by making $\ln(A)$ depend on $W \ln(A)$ and not simply on the constant, $\ln H$ and $\ln K$, we capture the totality of the effects influencing the efficiency level, including those represented by the random shocks. Assuming that $|\rho| < 1$, given our preferred (standardised) W matrix (see

below) it then follows that $(I - \rho W)^{-1} = \sum_{i=0}^{\infty} \rho^i W^i$, 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

$$\begin{aligned} \ln A_i &= Xb + \varepsilon + \rho W Xb + \rho W \varepsilon + \rho^2 W^2 Xb + \rho^2 W^2 \varepsilon \\ &\quad + \rho^3 W^3 Xb + \rho^3 W^3 \varepsilon + \dots \\ \ln A_i &= \sum_{i=0}^{\infty} \rho^i W^i (Xb + \varepsilon) \end{aligned}$$

This shows that $\ln A_i$ is equal to the weighted sum of the matrix products⁶ of the matrices $W^i (i = 0, \dots, \infty)$ and exogenous variables X and ε . The log level of efficiency $\ln A_i$ in Province i depends on levels of $\ln H$ and $\ln K$ and on shocks

⁶ 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.

ε in regions i, j, k, l, \dots . 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.

The W Matrix

We considered several alternatives candidates as our preferred weights matrix⁷ W . A first order binary geographical contiguity matrix, in which the elements are one when regions share a common border, and zero otherwise⁸, is one option considered. However, while this may prove informative in helping to detect localised cross-border spillovers, the main aim of this paper is simply to explore the existence of a direct causal effect using a more general approach to modelling spatial interaction effects, via W , that would otherwise not be present in our specification⁹. Thus we adopt a W matrix in which the value allotted to cell (i, j) is a function¹⁰ of the road distances d_{ij} between the

⁷ See Fingleton (2003a) for further discussion of alternative assumptions about W .

⁸ The elements of the main diagonal are set to zero by convention.

⁹ If the basic theoretical model was New Economic Geography rather than our urban economics specification, then that would automatically capture spatial dependencies based on the size of economies, similar to those embodied in our W matrix as defined below.

¹⁰ This way of capturing interactions weighted by distance is used very often in spatial econometrics literature. Fingleton (2003b) hypothesized that the efficiency of the labour force employed within an area will be in part determined by commuting, the frequency of which falls as distance increases. The rate at which this fall-off in commuting frequency occurs is

capitals of the provinces and the GDP of the region¹¹. Since we subsequently standardise the W matrix so that the total in each row sums to 1, the resulting standardised matrix will be the same irrespective of whether we include both origin and destination provinces in our equation, or whether we just include the destination.

$$\begin{aligned}
 W_{ij} &= \frac{GDP_j^{\alpha^+}}{d^{\beta^+}} & i \neq j \\
 W_{ij} &= 0 & i = j \\
 \alpha^+ &= 1; \beta^+ = 2
 \end{aligned}$$

Thus we also take into account the (economic) size of the (remote) province in order to measure the interaction between regions. Economic size (GDP) is considered relevant because of the extensive trade and labor market that a large and diverse local economy naturally generates.¹²

embodied within the matrix W , which is determined by the varying rate of decline-with-distance of commuting in each individual area. So a scalar that reflects the commuting of people between different regions is selected to weight distances. 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. Additionally, controlling for distance, we assume that commuting between provinces will be greater the larger the provincial economies.

¹¹ We use, somewhat arbitrarily, the GDP in 1971, but other years could have been used with very little impact on the outcome. Using a previous year ensures that the resulting W matrix comprises fixed exogenous quantities with no possibility of feedback from the level of productivity.

¹² The estimation results were similar when we used different W matrices, the coefficient varied slightly and all the signs were as expected from theory. The alternative W s were obtained using $\alpha^+ = 2; \beta^+ = 2$ and $\alpha^+ = 1; \beta^+ = 3$.

The Reduced Form

Combining equations 14 and 16 gives

$$\begin{aligned}\ln w &= k_1 + (\gamma - 1)\ln E + (\gamma - 1)(I - \rho W)^{-1}(Xb + \varepsilon) \\ (I - \rho W)\ln w &= (I - \rho W)k_1 + (I - \rho W)(\gamma - 1)\ln E + (\gamma - 1)(Xb + \varepsilon)\end{aligned}\quad (17)$$

On rearranging, making the exogenous variables explicit, and introducing a time subscript, we then have

$$\begin{aligned}\ln w_t &= \rho W \ln w_t + (I - \rho W)k_1 + (\gamma - 1)(\ln E_t - \rho W \ln E_t) + c_0 + c_1 \ln H_{t-1} + c_2 \ln K_{t-1} + \psi \\ \psi &\sim N(0, (\gamma - 1)^2 \Omega^2)\end{aligned}\quad (18)$$

Consistent estimation of the model is not possible via OLS because of the presence of the endogenous variable $W \ln w$ on the right hand side of equation 18. Moreover we also may have two-way causation involving employment density and our dependent variable, with employment density increasing (due to migration and enhanced participation rates) as wage rates increase. Consequently the composite variable $(\ln E - \rho W \ln E)$ is likely to be endogenous also. Note that this composite variable entails a parameter restriction because of the presence of ρ . In order to guard against any potential inconsistency, our model is estimated using instrumental variables¹³. We assume that human capital and public capital stocks are exogenous, in the case of human capital (H) this is because we assume complex determinants of educational attainment levels, so that any direct feedback from wage levels

¹³ Specifically we use the `xtivreg` available in Stata for estimating panel data models with endogenous variables.

will be relatively weak. We note that in Spain inter-province migration in response to wage differentials is not strong. In the case of Public capital stock (K), the assumption is that this is mainly controlled by government policy and this is not driven by wage levels. However we also decide to lag these variables by one year, guaranteeing exogeneity, since they pre-date the year of analysis. These assumptions are supported by model diagnostics, as explained subsequently. Over-identification is achieved by additional instrumental variables, namely the spatial lags of our exogenous variables together with three other measures of public capital, namely social, local and transport infrastructure, each again lagged by one year. We subsequently test for the legitimate exclusion and validity of these instruments.

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, in which each iteration provides an updated value for ρ from the $W \ln w$ term which is then used to update $(\ln E - \rho W \ln E)$ for the subsequent iteration, until ρ reaches a steady state as in Fingleton (2003b). At the first iteration, with no initial estimate for ρ , we assume an arbitrary value for $\rho = 0$. In order to avoid an explosive model, the estimated value of ρ should be in the interval $\frac{1}{e_L} < \rho < \frac{1}{e_U} = 1$, where e_L and $e_U = 1$ 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 these singular points and beyond¹⁴. As explained in Fingleton (2003b), because here we are using a standardized W matrix, $(I - \rho W)k_1$ is a constant.

3. DATA

Our analysis is based on a panel of data for the decade 1996 to 2005, with the individuals comprising the Spanish provinces¹⁵. We confine attention to this decade because earlier periods cover an era of substantial economic transformation. For example in the 1970s and 1980s the level of government capital endowment and economic activity in the Spanish regions was far below that typical of most Western European economies, but by the mid-1990s this was no longer the case. In 1980 per capita public capital stock endowment was only 40% of the average of the European Union, but this figure increased to 60% in 1990 and reached 89% in 2005. Since Spain joined the European Union, there has been a very intensive period of capital investment by the Spanish government, and in the decade under study, the ratio of public to private capital increased constantly with no perceptible effect due to economic cycles. This progress can be explained not only because the large amount of

¹⁴ The range of ρ is automatically bounded in Maximum Likelihood estimator but under 2SLS can fall outside this stable range and thus encounter singular points. Fortunately, in our estimates the estimated ρ lies within the stable bounds.

¹⁵ 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 km² (range 1,980 km² to 21,766 km²).

funding received from the structural funds¹⁶, as the European Union has devoted a substantial fraction of its regional policy funding (known as the Structural Funds) to the financing of infrastructure projects, but also as a consequence of a higher domestic rate of growth of public investment in Spain¹⁷.

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 thereafter by Fundación de las Cajas de Ahorro Confederadas (FUNCAS)¹⁸ 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).

¹⁶ During the period analyzed Spain has received a sustained increasing amount of funding from the Structural and Cohesion funds. During the period 1994-1999 Spain received the “Delors II” package and during 2000-2006 the “Agenda 2000” package, receiving a yearly average amount of 5.900 and 8.900 million of Euros respectively.

¹⁷ Eurostat reported for the period 1995-2005 an average rate of growth of public investment in Spain of 3.37% while in the euro area it was of 2.5%. This higher rate has been sustained throughout the decade even though public expenditure has reduced as a proportion of GDP. At the same time provincial differences have also been reduced during the period thanks to the Structural and Cohesion funds. Most of the Spanish regions were Objective 1 regions and received European funds to finance infrastructure projects.

¹⁸ 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.

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 (1977-2007)*” by Instituto Valenciano de Investigaciones Económicas (IVIE).

Public capital stock (K) was taken from the publication “*Series Históricas de Capital Público en España y su distribución territorial 1900-2005*” which detailed work done by FBBVA in collaboration with IVIE.

Our excluded instruments comprise three separate elements of public capital stock, namely the transportation infrastructure, the social infrastructure stock and the local public capital stock. Transportation includes airports, ports, road and railways infrastructures, the social infrastructure includes public capital stock in education and health facilities and local public capital stock comprises local government infrastructures of various kinds, infrastructure relating to water supply and management, plus other residual investments. Our assumption is that these have an indirect effect working via urbanisation, overall public capital and human capital, but they have no direct individual effect on wage levels. We test this exclusion assumption below. Our additional instruments are obtained by the matrix product of matrix W and the vectors of $\ln K$ and $\ln H$. As with the exogenous variables, all instruments are lagged by one year.

¹⁹ To satisfy the diagnostic tests described below, the matrix product $W \ln K$ has been dichotomised, being equal to 1 for values exceeding the median value, and 0 otherwise.

4. ECONOMETRIC RESULTS

The results in Table 1 show the estimates²⁰ of the panel model with fixed province effects, estimated with endogenous variables $W \ln w$ and $(\ln E - \rho W \ln E)$, and iterating to satisfy the constraint on the parameter ρ . Our analysis rests on the assumption that these two variables are indeed endogenous, that $\ln K$ and $\ln H$ are exogenous, and that the instruments are valid. Our diagnostic tests support these assumptions. In our endogeneity test²¹, the null hypothesis is that $W \ln w$ and $(\ln E - \rho W \ln E)$ are exogenous, and we reject this null since the test statistic is equal to 31.779, which is highly significant when referred to the χ^2_2 distribution, with the two degrees of freedom being determined by the fact that there are two variables under test. The test of the exogeneity of $\ln K$ and $\ln H$ is provided by the C statistic²². The null hypothesis is that the full set of instruments, including the included instruments $\ln K$ and $\ln H$ are exogenous. Under the null, the test statistic is distributed as χ^2_2 (again with two degrees of freedom appropriate for a two variable test). Rejecting this null in favour of the alternative would indicate that the included ‘exogenous’ variables, which are the specific instruments being tested, are endogenous, but the test statistic is equal to 2.418, with p-value equal to 0.2985 in χ^2_2 . We therefore fail to reject the null and conclude

²⁰ After having eliminated the spatial lag of log total capital as an instrument, as is necessary in order to pass the test of over-identifying restrictions.

²¹ This is an option (endog) available within Stata’s `xtivreg2` command (Schaffer, 2010), and under conditional homoscedasticity, the test statistic is equal to that provided by a Hausman test.

²² Option `orthog` in `xtivreg2`.

that we have no evidence that $\ln K$ and $\ln H$ are endogenous. Our initial assumption that $\ln K$ and $\ln H$ are exogenous has support from our diagnostic tests.

Table 1: Fixed effects panel estimates with endogenous regressors (T=10, n=47)

REGRESSORS	Parameter Estimates#	
		Standard error
Productivity Spatial Lag $W \ln w$	0.1806355 ** (4.28)	0.0421943
Employment Density $(\ln E - \rho W \ln E)$	0.1055751 ** (3.40)	0.0310767
Public Capital $\ln K$	0.1386397 ** (7.26)	0.0190934
Human Capital $\ln H$	0.0180546 ** (2.14)	0.0084188
R squared	0.5265	
Estimation Method	Instrumental variables	
Instruments	$\ln_Kh, \ln_Ktot,$ $WX_ln_Ktot, WX_ln_Kh, \ln_Ktpte, \ln_Ksoc,$ \ln_Kloc	

Notes:

z-ratios given in brackets beneath the estimates

**, * Significant at 5% and 10% level, respectively

² Between fixed effects and covariates

Time sub-indices have been omitted from the table and from the comments to simplify notation.

The test of the overall validity of the instruments is related to the C statistic described above. In fact the test statistic, the Sargan-Hansen statistic, is calculated twice in order to obtain the C statistic. The C statistic is the difference between the Sargan-Hansen test statistic calculated for the full set of instruments and the Sargan-Hansen test statistic calculated for the reduced set of instruments (that is excluding those that are suspected of being

endogenous). The Sargan-Hansen test statistic for the reduced set is equal to 0.221 (p-value equals 0.6384 in χ_1^2) and the Sargan-Hansen test statistic for the full set of instruments is equal to 2.639, which has a p-value of 0.4507 in the appropriate χ_3^2 reference distribution (five excluded instruments minus two endogenous variables). The latter provides our test of over-identifying restrictions²³, with the null being a hypothesis of valid instruments, which is not rejected thus indicating that the instruments are appropriate. We would reject if instruments are correlated with the disturbances, or if excluded instruments should be included in the set of regressors, so that the model is misspecified. This provides justification for our exclusion of the instruments transportation infrastructure, the social infrastructure stock and the local public capital stock from the model specification.

While our instruments appear to be valid, they could still be weak and therefore lead to biased estimates and inference. However we find that our instruments are strong. Our test statistic is the Cragg-Donald Wald F statistic which is referred to the critical values given by Stock and Yogo (2005). The critical values are determined by the number of instruments and by the number of included endogenous variables, and also by the maximum amount of bias that is acceptable, where bias is relative to bias under OLS. The value of 13.889 lies between the 10% and 5% maximal instrumental variables relative bias critical values of 8.78 and 13.97, being close to the 5% value. We conclude

²³ Also obtained by the Stata command `xtoverid`, see Schaffer and Stillman (2010).

that the maximum bias in our estimator is less than 10% of the bias that would be incurred by OLS estimation. The second element of our test of weak instruments relates to the size of the test. If the true size of the conventional Wald test, with nominal size of 5%, exceeds this by a certain amount, in our case by a maximum of 10%, so that the true size is up to 15%, then we would also conclude that we had weak instruments. The test statistic lies between the critical values for 15% and 10% maximal size (nominal size plus size distortion), equal to 11.22 and 19.45 respectively. With size distortion of no more than 10%, and our earlier evidence of small relative bias, we conclude that our instruments are not weak.

To summarize, our main result given in Table 1 is that public capital has a significant positive effect on productivity, with an elasticity equal to approximately 0.14, having controlled for employment density, human capital, labour efficiency spillovers, and for the significant effects of province heterogeneity captured by the fixed effects.

Effects of public capital stock

There are several channels through which public investment is usually considered to affect regional per capita income. Macroeconomists typically emphasize three “conventional” channels. Public investment is considered to have a direct productivity effect on private production inputs and to have a complementarily effect on private investment. In the short term, however, it is hypothesised that public investment might crowd out private spending, and adversely affect growth if it persists. In this paper we hypothesise that the effect of public capital operates through its effect on worker efficiency, in the same way as human capital. However we acknowledge that the effects of

public infrastructure may work through diverse channels and 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 and López-Bazo (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. Also, as we have indicated above, Moreno and López-Bazo (2007) and others suggest a more complex relationship between public capital and productivity which involves a negative spillover effect. However we are unable to identify this in our model set-up which simply captures the net effect of public and human capital and unmodelled spillovers as part of the labour efficiency spillover. In this paper we focus on the direct effect of public capital, which we find is significant and positive.

This leads to one additional consideration, the evaluation of true total effects in models involving spatial processes, as highlighted by LeSage and Pace (2009). Assuming that our parameter estimates apply equally to a single cross-section, when we take account of the spillover effects on account of the presence of the spatial lag $W \ln w$ with $\rho \neq 0$ in the model, then the derivative

$\frac{\partial \ln w_t}{\partial \ln K_{t-1}} \neq c_2 = 0.1386$ as implied by Table 1. It can be shown that the total

effect is given by $\frac{\partial \ln w_t}{\partial \ln K_{t-1}} = (I - \rho W)^{-1} I c_2$, and since this is a matrix, it is

recommended that we consider the mean total effect given by

$$N^{-1} \sum_{ij} \frac{\partial \ln w_{it}}{\partial \ln K_{jt-1}} = N^{-1} \iota'(I - \rho W)^{-1} I c_2 \iota, \text{ in which } N = 47, \iota \text{ is an } N \text{ by } 1 \text{ vector of}$$

ones, I is an N by N identity matrix and $\rho = 0.1806355$ as given by Table 1. Evaluating this quantity gives an implied mean total effect equal to 0.1692, compared with 0.1386 given $\rho = 0$. These results are broadly within the range of variation of the elasticities obtained in other papers. Mas *et al* (1994, 1996) obtained an elasticity associated with productive public infrastructures of 0.23 and 0.08, respectively. However in other papers the reported elasticity is lower, as in Goerlich and Mas (2001) which reported an elasticity of 0.02 or Boscá *et al* (1999) who obtained an output elasticity of 0.026 for public infrastructures (0.035 in the long run).

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 1996-2005. The analysis is underpinned 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. Endogeneity and constraints on parameter values lead to an iterative 2SLS panel estimation routine. The model supports the theory motivating the reduced form, so that there does appear to be increasing returns to scale. There are also significant positive 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, supporting the hypothesis of positive spatial spillovers and the necessity for a spatial econometric approach.

Although the theoretical provenance of our paper is somewhat different, Ashauer’s hypothesis has not been rejected for the Spanish economy during the period analyzed. However we remain cautious in our conclusion that public capital is relevant, for we are conscious that the estimates may be affected by a more complex relationship between public capital and productivity, involving both positive and negative impacts of public capital stock, which are concealed when we simply observe is the net effect of the spillover of labour efficiency, which embodies the effect of public capital.

Further work is needed to detangle the spillover effects of the variables affecting the labour efficiency level, either based on new data or new methodology, or both. Therefore in terms of policy involvement at a national scale, in the absence of more detailed information on how the spillover effects of public investment balance out, we still have to be prudent about the global effects on economic activity. In the presence of negative spillovers, provinces might be competing with each other attempting to obtain more infrastructures than would otherwise be provided. By altering infrastructure investment relative to that of neighbouring regions, each region has the ability to modify the size of its infrastructure stock at the expense of its neighbour. If some regions follow a “beggar-thy-neighbour” policy, all regions will be dragged into fiscal competition. This can lead to gaming behaviour among regions in a national economy. If local and national governments ignore the possible

existence of negative spillovers and overestimate the positive effects of public policies, this can lead to inefficiency.

The comparisons of the return to different types of infrastructure are on our research agenda for the future.

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