

Analysing the Impact of Public Capital Stock Using the NEG Wage Equation: A Panel Data Approach

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Abstract

This paper examines the relationship between the level of public infrastructure and the level of productivity using panel data for the Spanish provinces over the period 1984-2004, a period which is particularly relevant due to the substantial changes occurring in the Spanish economy at that time. The underlying model used for the data analysis is based on the wage equation, which is one of a handful of simultaneous equations which when satisfied correspond to the short-run equilibrium of New Economic Geography theory. This is estimated using a spatial panel model with fixed time and province effects, so that unmodelled space and time constant sources of heterogeneity are eliminated. The model assumes that productivity depends on the level of educational attainment and the public capital stock endowment of each province. The results show that although changes in productivity are positively associated with changes in public investment within the same province, there is a negative relationship between productivity changes and changes in public investment in other regions.

JEL Classifications: H54, R11, R15, C21

Keywords: spatial economics, public infrastructure, productivity, panel data, economic geography

1. INTRODUCTION

The World Bank (1994) has referred to public capital as the one of the “wheels of economic growth”. This claim appears to be one that could be the basis for much empirical research, for it is evident that nowadays the role of public investment is very much in the spotlight as a possible way out of the current global economic downturn. Indeed, there has been considerable debate and several empirical studies to date about the potential impact of public capital on private sector economic performance. Since the beginning of the current economic crisis in August, 2007, many renowned institutions and economists have suggested the need for an expansive fiscal policy to alleviate the worldwide economic recession. At a time when falling demand is causing many private-sector employers to invoke cutbacks, public investments which directly create jobs can generate demand and possibly help to break the downward economic spiral.

Public investment is widely used to promote the development of poorer regions. This is especially true since the 1970s, when other alternative mechanisms were found to be of limited effect and costly from a budgetary and efficiency perspective. It is particularly significant in the euro area now that monetary policy is the responsibility of the European Central Bank.

There are several channels through which public investment affects regional per capita income. It has a direct effect due to the multiplier process that the impact of demand might have in the economy, mainly during slumps, and an indirect effect attracting private investment to the area. Public investment can also have longer-lasting effect on a region’s economic development by inducing structural changes. It is therefore one of the main instruments in regional policy designed to reduce regional disequilibria. Macroeconomists typically emphasize three “conventional” channels through which public infrastructure may affect growth. Public investment has a direct productivity effect on private production inputs and a complementarity effect on private investment. Public capital in infrastructure may raise the marginal productivity of all factor inputs (capital and labour), thereby lowering marginal production costs and increasing the level of private production. In turn, this scale effect on output may lead, through the standard accelerator effect, to higher private investment, thereby raising production capacity over time and making the growth effect more persistent. In the short term, however, public investment could cause a crowding out effect on private spending through the financial system. An increase in the stock of public capital in infrastructure may have an adverse effect on activity, to the extent that it displaces (or crowds out) private investment. This short-run effect may develop into an adverse growth effect if the drop in private capital formation persists over time. As Agénor and Moreno Dodson (2006) maintain, crowding-out effects may take various forms. For instance, if the public sector finances the expansion of public capital through an increase in distortionary taxes, the fall in the expected net rate of return on private capital may lower the propensity to invest. A similar, and possibly more detrimental, effect on private capital formation may occur if the increase in public infrastructure outlays is paid for by borrowing on domestic financial markets, as a result of either higher domestic interest rates (in countries where

market forces are relatively free to operate) or a greater incidence of credit rationing in the private sector. Moreover, if investment-induced expansion in public borrowing raises concerns about the sustainability of public debt over time and strengthens expectations of a future increase in inflation or explicit taxation, the risk premium embedded in interest rates may increase. By raising the cost of borrowing and negatively affecting expected after-tax rates of return on private capital, an increase in the perceived risk of default on government debt may have a compounding effect on private capital accumulation. In particular, private investors may revise their investment plans downwards because of anticipated hikes in tax rates to cover the increase in public investment. If so, despite the direct and complementarities effects mentioned above, the net effect of an increase in public infrastructure may well be to hamper, rather than foster, economic growth. The importance of each effect might depend on the initial stock of the economy, the diversity of productive structures and the degree of maturity of infrastructure systems.

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. Studies are divided on both the magnitude and direction of the net effect of infrastructure on economic growth. The first author to detect a positive relationship between public infrastructure and productivity was Ratner (1983) though it was Aschauer (1989) who established that a decline in public investment was the main cause of the productivity slowdown in the United States in 1970s and 1980s. 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. Empirical papers with a regional dimension showed a smaller impact of public investment on productivity, which it is argued might be a consequence of the existence of spatial spillover effects.

Most empirical analyses use neoclassical production functions to quantify the public infrastructure effect on economic activity. Using this approach, some papers established a positive effect, including Munell (1990, 1993), Ford and Poret (1991), Bajo-Rubio and Sosvilla-Rivero (1993), Otto and Voss (1994), Mas *et al.* (1996) and Cantos *et al.* (2005). Others established a negative effect, such as McMillin and Smyth (1994), Otto and Voss (1996) and Voss (2002) and others find no significant effect of public investment on economic activity; this is true of Tatom (1991), Batina (1999), Holz and Eakin (1992), Evans and Karras (1994), Baltagi and Pinnoi (1995), García-Mila and McGuire (1992) and Gómez-Antonio and Fingleton (2008), among others.

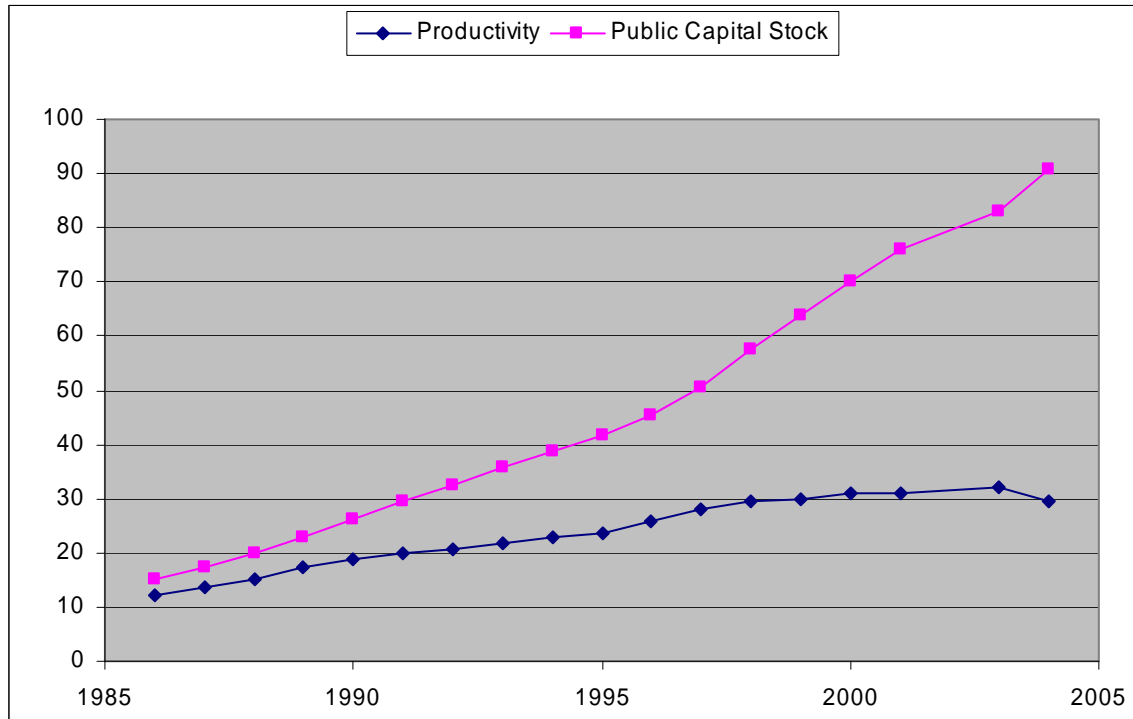
Many researchers had for a long time insisted that increasing returns were essential for a proper understanding of spatial disparities in economic development, but this was given new impetus by the development of a formal theoretical framework, based on a monopolistic competition market structure model (Dixit and Stiglitz, 1977). The typical model proposes an 'industry' sector in which firms have fixed costs and hence internal increasing returns, leading to increasing returns at the aggregate level. This development

of increasing returns based on micro-economic foundations, by proponents of New Economic geography and related models in urban economics, led to the integration of increasing returns models within mainstream economics. 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. Empirical research within New Economic Geography (NEG) did not really take off until very recently. A few papers use urban economics as a theoretical basis for analysing the relationship between public investment and economic growth, like Martin and Rogers (1995) and Martin (1999) but, to our knowledge, no study has empirically quantified this relationship using NEG theory.

The wage equation is one of the most successful equations deriving from New Economic Geography. This equation formally links nominal wage levels to market potential, which is a long-established concept that goes right back to the work of Harris (1954) and is at the core of NEG theory. The key element is that firms have different levels of market potential according to their level of access to their own and neighbourhood markets, with access depending on trade costs, the size of the markets, and the competition, with good market access associated with higher wage levels. In this paper we will control for a variety of determinants of wage levels other than the pecuniary externalities of the basic model as set out by Fujita, Krugman and Venables(1999), including public capital stock.

The main aim of this paper is to test Aschauer's hypothesis and quantify the impact of public capital stock on productivity, something which, as far as we know, has not been attempted in the context of NEG theory. The Spanish economy provides an interesting case study as it has undergone a sustained period of growth in the last 40 years, together with a large increase in public investment figures. The period analysed in this paper is 1984-2004, which is particularly relevant due to substantial changes in 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 other European economies. Since Spain joined the European Union, however, there has been a very intensive period of capital investment by the Spanish government with no perceptible slowing of investment due to economic cycles.

Figure 1: Evolution of productivity and public capital stock 1986-2001



Source: Authors' calculations 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. Our empirical model has as its basis the theoretical arguments of New Economic Geography. Our model specification allows us to estimate the effects of spillovers operating across geographical space. Most of the literature on public capital has focused on whether or not public infrastructure has positive productivity effects, but relatively little attention has been paid to the fact that the presence of public capital may shift economic activities from one location to another. The issue of possible spillovers from public capital has received little consideration.

The results show that changes in provincial productivity are positively associated with changes in public investment within the same province but negatively associated with such changes in other regions. This is a surprising result, even though previous papers, like Boarnet (1998) for the Californian counties and Lopez-Bazo *et al.* (2007) for the Spanish provinces, also found a negative spillover effect of public infrastructure investment. Negative spillovers we suggest involve mainly private capital as a result of private investment decisions, rather than labour, and this migration of mobile factors will be induced by better stocks of infrastructure. The larger stock of private capital will enhance labour productivity and hence wages.

The paper is organised as follows. Section 2 briefly sketches the theoretical model; section 3 is concerned with issues related with the data. Section 4 details the empirical model and its estimation, and finally section 5 gives some concluding remarks.

2. THE THEORETICAL MODEL

The New Economic Geography theory assumes imperfect competition, increasing returns and pecuniary externalities. The dynamics are path-dependent, determined by the initial conditions and by assumptions made about exogenous parameters resulting in multiple equilibria.

The theory used here is set out by Fujita *et al.* (1999), which is the basic two-region two-sector core-periphery model. The economy is divided into two sectors, the competitive sector (C) and the monopolistically competitive sector (M), allowing transport costs for the M sector and assuming zero trade costs¹ for the C sector.

Preferences are Cobb-Douglas, so:

$$U = M^\theta C^{1-\theta} \quad (1)$$

in which θ is the expenditure share in M goods and under the normalizations employed is also the equilibrium number of workers per firm and the equilibrium output per firm.

Also we use a CES sub-utility function for varieties in M , so that the quantity of the composite good M is a function of the $h=1 \dots x$ varieties $m(h)$,

$$M = \left[\sum_{h=1}^x m(h)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{1-\sigma}} = \left[\sum_{h=1}^x m(h)^{\frac{1}{\mu}} \right]^\mu = x^\mu m(h) \quad (2)$$

Where x is the number of varieties, σ is the elasticity of substitution for M varieties and at equilibrium $m(h)$ is a constant across all x varieties.

The model reduces to five simultaneous non-linear equations. The first one, and the one we use in this paper, involves a simple relationship between the M sector nominal wage level (w_i^M) and the market potential variable. In the short run the equilibrium wage in the monopolistically sector is occasioned by the fast entry and exit of firms driving profits to zero.

¹ This could occur if the C sector is concerned more with moving information than goods, or if the sector is characterised by lack of bulk products, so that transport is a negligible part of overall costs.

$$w_i^M = \frac{\bar{W}_i^M}{E_i^M} = \left[\sum Y_r (G_r^M)^{\sigma-1} (\bar{T}_{ir})^{1-\sigma} \right]^{1/\sigma} = P^{1/\sigma} \quad (3)$$

In equation (3) i denotes region, \bar{W}_i^M is area i total M wage bill, E_i^M is the M workforce, and the summation is over the set of regions including i . The transport cost is denoted by \bar{T}_{ir} , G_r^M is a price index in M , Y_r is the income and σ is the elasticity of substitution for M varieties.

In this theory, goods in sector C are freely transported and produced under constant returns. Therefore C wages and price indexes are constant across regions, so the five simultaneous equations are reduced to three (equations 4, 5 and 6). Following Fujita *et al* (1999), the M price index is given by

$$G_i^M = \left[\sum \lambda_r (w_r^M \bar{T}_{ir})^{1-\sigma} \right]^{1/(1-\sigma)} \quad (4)$$

in which the number of varieties produced in region r is captured by λ , which is equal to the share in region r of the total supply of M workers.

Income is given by

$$Y_r = \theta \lambda_r w_r^M + (1-\theta) \phi_r w_r^C \quad (5)$$

Y_r depends on the nominal M sector wage rate w_r^M , the C sector wage rate w_r^C , the number of M varieties λ_r and the equivalent number of C varieties ϕ_r . It also depends on θ which is the total number of M workers adding across all regions, although $0 < \theta < 1$ since it is measured on a scale such that the overall number of workers in the economy is equal to 1. Consequently the total number of C workers in the economy is $1 - \theta$. Taking logs to equation 3 the basic wage equation is

$$\ln w_i^M = \frac{1}{\sigma} \ln P_i \quad (6)$$

Wage rates are also assumed to depend on factors other than market potential. We assume that an important factor is the level of efficiency of workers (A_i). We assume that technology is homogeneous across areas and the difference in the ability of workers to apply this technology is what makes production more efficient. Our initial assumption is that efficiency depends on the extent of upper level education and on the public capital stock endowment within each province.

Introducing these additional variables means that we have a departure from the traditional reliance on purely pecuniary externalities. However in the real world a range

of factors will play a part in determining observed wage rates, and not taking them into account will bias the econometric estimates that are obtained.

The extended wage equation becomes:

$$w_i^M = \frac{\bar{W}_i}{E_i^M} = P_i^{1/\sigma} A_i \quad (7)$$

Other researchers have also considered additional variables to extend the basic NEG equation, as for example Combes *et al* (2005). This equation, as shown by Head and Mayer (2006), can be obtained from micro assumptions, by introducing a labour quality adjusted production function for the firm.

In addition, we also assume that the level of efficiency within a given province is related to the level in other provinces that are nearby, due to spillover effects across space. This means that the level of efficiency is dependent on covariates X and on ‘nearby’ efficiency levels denoted by the matrix product $W \ln(A)$. Written in general matrix notation, the vector for efficiency level is

$$\begin{aligned} \ln A &= \rho W \ln A + Xb + \xi \\ \xi &\sim N(0, \Omega^2) \\ (I - \rho W) \ln A &= Xb + \xi \\ \ln A &= (I - \rho W)^{-1} (Xb + \xi) \end{aligned} \quad (8)$$

In which X is an n by k matrix of exogenous variables (with columns equal to 1, and variables $\ln H$ and $\ln K$), b is a k by 1 vector of coefficients, the matrix product $W \ln(A)$ is an n by 1 vector with scalar coefficient ρ , and vector ξ represents excluded variables which behave as random shocks.

Variable H is a measure of human capital, whereas K denotes productive public capital stock. Both are assumed to be the fundamental determinants of the level of labour efficiency within a province, alongside unmodeled factors represented by ξ . A higher level of human capital (as reflected by educational attainment) will enhance the efficiency of labour, and likewise it is assumed that labour efficiency will be increased by superior public capital stock in the form of better transport infrastructure, and publicly provided services such as water, electricity and health services. The endogenous variable $W \ln(A)$ represents the additional contribution to efficiency which is assumed to be due to ‘nearby’ provinces. The hypothesis is that regions with high labour efficiency levels occurring in neighbouring regions will also incur higher labour efficiency than would otherwise be the case, and vice versa for regions with lower labour efficiency. A possible reason for this could be that labour is mobile and carries its efficiency level to other provinces mainly as a result of commuting. The implication of this is that labour

efficiency in distant regions will have less impact, so that “who your neighbours are” is important.

To conceptualise the spillover phenomenon, observe that it implies the spatial spillover of the exogenous variables, going to infinity, since for W with elements less than 1 and $|\rho| < 1$, under the Leontieff expansion model (8) is equal to

$$\ln A = (I - \rho W)^{-1}(Xb + \xi) = \left(\sum \rho^i W^i\right)(Xb + \xi) \quad (9)$$

in which the summation is from $i = 0$ to ∞ , $W^0 = I$, and in general W^i is the matrix product of W^{i-1} and W . We re-express this as

$$\ln A = Xb + \rho W Xb + \rho^2 W^2 Xb + \rho^3 W^3 Xb + \rho^4 W^4 Xb \dots \quad (10)$$

Suppose that instead of the endogenous spatial lag $W \ln A$, we simply use the exogenous lags (WH, WK) to capture the spillover across province boundaries of the effects of variables H and K . This simplifies our estimation routine, but at the expense of omitting the unmodelled effects ξ . Alternative assumptions such as this are considered in more detail below.

We considered different alternatives when selecting the matrix W , but preferred to adopt a (standardised²) first order binary spatial contiguity matrix in which the elements are one when provinces share a common border, and zero otherwise³. Other definitions, based on the quantitative ‘distance’ between the different provinces, as well as the (economic) size of provinces were also tried, but these involved major assumptions also and resulted in less well-fitting models.

On taking logs of equation (7), ignoring subscripts and writing $a_1 = \frac{1}{\sigma}$, we obtain

$$\begin{aligned} \ln w^M &= a_1 \ln P + \ln A + w \\ w &\sim N(0, \Pi^2) \end{aligned} \quad (11)$$

in which w represents measurement error.

Then substituting for $\ln A$ gives

$$\ln w^M = a_1 \ln P + (I - \rho W)^{-1}(Xb + \xi) + w \quad (12)$$

² With rows summing to 1.

³ The elements of the main diagonal are set to zero by convention.

Multiplying through by $(I - \rho W)$ gives

$$(I - \rho W) \ln w^M = (I - \rho W) a_1 \ln P + (Xb + \xi) + (I - \rho W)w$$

which when rearranged is equal to

$$\begin{aligned} \ln w^M &= \rho W \ln w^M + a_1 (\ln P - \rho W \ln P) + a_0 + a_2 \ln H + a_3 \ln K + \xi + (I - \rho W)w \\ \xi &\sim N(0, \Omega^2) \end{aligned} \quad (13)$$

Various reduced models can be derived from this specification. Consider first the assumption that the stock of productive public capital has no effect on labour efficiency, so that $a_3 = 0$, hence

$$\ln w^M = \rho W \ln w^M + a_1 (\ln P - \rho W \ln P) + a_0 + a_2 \ln H + \xi + (I - \rho W)w \quad (14)$$

Next, assume that there is no inter-Provincial spillover of efficiency levels (A). This means that ρ is restricted to zero, and we can test this hypothesis by fitting the model

$$\begin{aligned} \ln w^M &= a_1 \ln P + a_0 + a_2 \ln H + a_3 \ln K + \psi \\ \psi &= w + \xi \end{aligned} \quad (15)$$

Also, assume that there is neither inter-Provincial efficiency level spillover nor a direct public capital effect, in which case the model becomes

$$\ln w^M = a_1 \ln P + a_0 + a_2 \ln H + \xi + \psi \quad (16)$$

Next, assume that there is spillover but this does not involve the totality of the causes of efficiency variation but simply involves the exogenous lags, so that there are no spillovers of unmodelled effects acting on A and embodied in the ξ , hence

$$\ln w^M = a_1 \ln P + a_0 + a_2 \ln H + a_3 \ln K + a_4 W \ln H + a_5 W \ln K + \psi \quad (17)$$

This model can be reduced further, for example we can also test the hypothesis that the effect of public capital stock does not spill over but that human capital does by assuming $a_5 = 0$, hence

$$\ln w^M = a_1 \ln P + a_0 + a_2 \ln H + a_3 \ln K + a_4 W \ln H + \psi \quad (18)$$

Although not pertaining to the main hypothesis of this paper, that there is a significant effect due to $\ln K$, a further simplification is to assume that $\ln A$ is zero, so that neither public capital stock nor human capital has any effect of the level of wages, which depend only on the pecuniary externalities one associates with the basic NEG theory, so that

$$\ln w^M = a_1 \ln P + a_0 + w \quad (19)$$

with the constant retained to allow for autonomous wage growth due to unexplained productivity increases that are constant across provinces.

3. DATA

In order to analyze the impact of public capital stock on productivity the empirical model was fitted to the period 1985-2001 for the Spanish provinces⁴.

For each year we represent w_r^M by province r 's gross value added (GVA) in industry sectors (including building and energy activities) divided by r 's industrial employment. GVA is measured in thousands of constant (2000) euros, data which were provided by FBBVA (*La Renta Nacional de España y su Distribución Provincial*) until 1997, and thereafter by Fundación de las Cajas de Ahorro Confederadas (FUNCAS)⁵ as documented in "*Balance Económico Regional*". We attribute the difference between wages and GVA per worker to measurement error, which is represented by w in equation (11).

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).

Finally, the productive public capital stock (K) was taken from the publication "*Capital Stock in Spain and its distribution by territories (1964-2003)*"⁶ which detailed work done by FBBVA in collaboration with IVIE. This variable is essentially composed of two elements, namely the transportation infrastructure and the local public capital stock, since these two are assumed to be the productive part of overall public capital stock. Transportation includes airports, ports, road and railways infrastructures, and local public capital stock comprises local government infrastructures of various kinds, infrastructure relating to water supply and management, plus other residual investments.

The Market Potential variable (P) is constructed using the kernel of equation (3), which we repeat here with the assumed trade cost function in place, hence

⁴ 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).

⁵ 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 2000 using the Implicit Index Prices facilitated by both organisations.

⁶ New methodology.

$$\begin{aligned}\bar{T} &= e^{\tau D_{ir}} \\ P_i &= \sum_r Y_r (G_i^M)^{\sigma-1} (e^{\tau D_{ir}})^{1-\sigma}\end{aligned}\quad (20)$$

This is a function of the M sector price index, which with the trade cost function is $G_i^M = [\sum_r \lambda_r (w^M e^{\tau D_{ir}})^{1-\sigma}]^{\frac{1}{1-\sigma}}$, so that for province i the price index depends on the wage rate w^M multiplied by trade cost $e^{\tau D_{ir}}$ and on the number of M varieties produced in area r denoted by λ_r , summing across all provinces.

In order to calculate trade cost $e^{\tau D_{ir}}$, we use straight line distances between Provincial capitals, denoted for origin i and destination r by D_{ir} , scaled by τ which is equal to 0.001.

Distances within provinces are estimated using the convention that

$$D_{ii} = \frac{2}{3} \sqrt{\frac{area_i}{\pi}} = \frac{2}{3} R \quad (21)$$

where $area_i$ is the number of square km in province i . This is 2/3rds of the radius R of a circle with area equals to that of province i , and is equal to the average distance from the centre of all points within a circle. The trade cost function produces non-negative scalars greater than 1, that are multiplied by the wage rates to allow for the additional cost of transport within and between provinces in calculating the price index.

As shown by equation (5), income Y_r depends on the nominal M sector wage rate w_r^M , the C sector wage rate w_r^C , the number of M varieties λ_r and the equivalent number of C varieties ϕ_r . It also depends on θ which is the total number of M workers adding across all regions, although $0 < \theta < 1$ since it is measured on a scale such that the overall number of workers in the economy is equal to 1. Consequently the total number of C workers in the economy is $1 - \theta$.

In order to calculate the income given by equation (5), we also need the wage w_r^C , which represents the average wage in non-industrial C sectors. Since the C sector incurs no trade costs, this is constant across provinces in any one year. It is obtained as the sum of non-industrial GVA divided by sum of non-industrial employment, in both cases summing across provinces in any one year. Also the total number of M workers in the whole economy θ is taken as the overall share of total employment in each year that is engaged in M activities, which is equal to the total industry employment divided by total

employment. The quantity λ_r is equal to province r 's share of the total number of M (industry) workers in the economy. Likewise ϕ_r is equal to the proportion in province r of the total number of workers in non-industrial sectors in the economy.

The final quantity needed to calculate P_t is the elasticity of substitution of M sector varieties σ . Rather than estimate this value, it is assumed to equal 6.25, which is a central value among the range of estimates provided by the literature⁷, and equal to the mid-point of the range given by Head and Mayer (2003). Neither of the two main alternative approaches to obtaining the value of σ is feasible in the current context. One is direct nonlinear estimation, as carried out for example by Mion (2004) and Brakman *et al* (2006), but this would be difficult to operationalise given the iterative estimation methods used here. The other alternative is the two-step linear estimation approach of Redding and Venables (2004), but this relies on bilateral trade flows which are unavailable for Spain's provinces. Anderson and van Wincoop (2004) summarize various estimates, which are largely within the range 5 to 10.

4. RESULTS

The advantages of panel models are well known, most significantly they allow one to control for country-specific heterogeneity and the simplest way to do this is by introducing fixed effects (using either dummy variables or equivalently mean deviations, to allow for different intercepts). Given also that we have data for 20 years, it is also important to control for changes that has affected all provinces equally as the Spanish economy has adjusted through time, we therefore routinely include individual (province) and year fixed effects in all our specifications.

Our most complex model is equation (13), which for year t is

$$\ln w_t^M = \rho W \ln w_t^M + a_1 (\ln P_t - \rho W \ln P_t) + a_0 + a_2 \ln H_t + a_3 \ln K_t + \xi_t + (I - \rho W) \omega_t$$

in which the log of M sector productivity is denoted by $\ln w_t^M$, which is an $n \times 1$ vector at time t , W is the $n \times n$ standardised contiguity matrix, so that on multiplication the resulting $n \times 1$ vector $W \ln w_t^M$ is the spatial lag of $n \times 1$ vector, P_t is market potential, and $W \ln P_t$ is the spatial lag of market potential. Also the $n \times 1$ vector $\ln H_t$ is the log of our measure of human capital and equivalently $\ln K_t$ denotes public capital stock. Finally the specification includes an $n \times 1$ vector of errors ξ_t plus the moving average error process given by $(I - \rho W) \omega_t$. In practice, for simplicity, we drop the assumption of a moving average error process in favour of independent identically distributed errors,

⁷ Head and Ries (2001) estimate values ranging from 7.9 to 11.4, the range is 5 to 10 in Harrigan (1993), 3 to 8.4 in Feenstra (1994), and there are point estimates of 9.28 in Eaton and Kortum (2002) and 6.4 in Baier and Bergstrand (2001).

assuming they are $N(0, \sigma^2 I)$. All other models fitted are nested within this specification, as a result of setting parameter ρ and the a parameters to zero.

Model 1 in table 1 estimates our closest approximation to the equation (13) specification, but there are some differences between this ideal and the model estimated, due to practical problems and available software, although the estimates obtained remain informative. The estimates were obtained using the ML approach initially developed by Elhorst (2003) with the likelihood function accommodating the endogeneity of the spatial lag $W \ln w_t^M$. For simplicity, table 1 omits the estimates of the time and individual fixed effects, focussing on the variables of substantive interest. Note also that we have allowed for the parameter restrictions involving ρ , using an iterative routine to ensure that the parameter equalities are satisfied. The iterations commence with $[\ln P_t - \rho_1 W \ln P_t]$ defined by assuming an initial value of ρ denoted by ρ_1 , which allows subsequently estimation as the coefficient on $W \ln w_t^M$. In the next iteration this estimated $\rho = \rho_2$ gives an update of vector $[\ln P_t - \rho_2 W \ln P_t]$, leading to another estimate $\rho = \rho_3$, and so on. The iterations terminate at iteration k where $\rho_k - \rho_{k-1} < 0.00001$.

Table 1: Estimates¹ using ML and 2SLS

| REGRESSORS ⁸ | Parameter Estimates | | | |
|--|-----------------------------|--|--|---|
| | Model 1* Iterative ML | Model 2 [#] 2SLS | Model 3 [#] 2SLS | Model 4 [#] 2SLS |
| Productivity Spatial Lag [$W \ln w^M$] | -0.001989 (-0.04) | -0.2091008 (-0.66) | 0.0878546 (0.76) | -0.2981043 (-1.32) |
| Market Potential [$\ln P - \rho W \ln P$] | 0.278367 (10.64) | 0.2656505 (4.73) | 0.2364588 (3.08) | 0.3099267 (6.58) |
| Public Capital [$\ln K$] | 0.095090 (3.66) | 0.0785483 (2.04) | 0.1064016 (3.51) | 0.0660099 (1.95) |
| Human Capital [$\ln H$] | 0.039581 (4.25) | 0.0409199 (4.06) | 0.0353291 (3.29) | 0.0465434 (4.53) |
| R squared | 0.9577 | 0.8498 | 0.8516 | 0.8471 |
| Shwartz criterion (SC) | 49.6411 | | | |
| Akaike criterion (AIC) | 15.4776 | | | |
| Error variance | 0.0018 | | | |
| F test (46,870) ^Φ | | 200.70 | 203.02 | 197.41 |
| Squared Correlation ² | 0.957703 | | | |
| Instruments | | $\ln P - W \ln P$ $\ln K$ $\ln H$ $W \ln K$ $W \ln H$ Temporal dummies | $W \ln w^M$ $\ln K$ $\ln H$ $W \ln K$ $W \ln H$ Temporal dummies | $\ln K$ $\ln H$ Temporal dummies $\text{rank}[\ln P - \rho W \ln P]$ $\text{rank}[\ln P - \rho W \ln P]$ |

Notes:

*t-ratios given in brackets beneath the estimates

[#] z-ratios given in brackets beneath the estimates

¹ Spatial and time period fixed effects included in each model

² Between fitted and actual productivity

⁸ Time sub indexes have been omitted from the table and from the comments to simplify notation.

- Model 2: 2SLS instrumenting endogenous spatial lag
 - Model 3: 2SLS instrumenting compound market potential variable
 - Model 4: instrumenting both endogenous spatial lag and compound market potential variable
- ^Φ F test of the null that all fixed effects are zero (value).

One way in which we have deviated from the equation (13) template is by assuming that P_t is exogenous, whereas in reality construction of P_t introduces two-way causation involving w^M . In addition, P_t may possess measurement error for two reasons. One is the assumption that we have defined the M sector appropriately. The second reason is that we are assuming that the elasticity of substitution σ is equal to 6.25.

With these caveats in mind, the estimates suggest that there are highly significant and direct (within-province) effects due to market potential, public capital stock and human capital, but importantly the suggestion is that there are no inter-Provincial spillovers of worker efficiency levels (A) *per se* since ρ is not significantly different from zero.

An important initial finding for our purposes is the indication that the effect of public investment on productivity is positive and highly significant. However, we remain cautious in our interpretation and look for supporting evidence via the use of different estimation techniques that do not have such strict distributional assumptions and which attempt to take care of any simultaneity or measurement error bias by the use of instrumental variables.

Model 2 in table 1 gives equivalent 2LSLS estimates, instrumenting for the endogenous $W \ln w_t^M$. Again an iterative process ensures that parameter constraints hold. The resulting estimates in model 2 indicate that ρ is not significantly different from zero. In this case the instruments are the ‘exogenous’ variables $\ln P_t - \rho W \ln P_t$, H and K , the spatial lags given by the matrix product of W and H and K , denoted by WH and WK , and the year dummies. Thus, while there appear to be significant direct effects due to human and public capital, evidently productivity is unaffected by efficiency level spillovers from contiguous provinces. As shown in table 1, comparing models 1 and 2, the coefficients signs, the coefficient estimates and their significance levels are all very similar, the main difference being that the market potential variable, which, although still very important, decreases in level of significance.

We obtain similar results when instrumenting the market potential variable. The model 3 estimates in table 1 are the outcome of instrumenting $\ln P_t - \rho W \ln P_t$ using the same instruments as for model 2 except that $W \ln w_t^M$ replaces $\ln P_t - \rho W \ln P_t$. Note that instrumenting both $\ln P_t - \rho W \ln P_t$ and $W \ln w_t^M$ simultaneously using these instruments produces insignificant estimates, presumably because of the effects of collinearity on parameters and standard error estimates, so we do not report these results. However if we use the ranks of the variables $\ln P_t - \rho W \ln P_t$ and $W \ln w_t^M$ as their instruments, then the model 4 estimates are obtained.

The estimates presented in table 1 represent spillover effects by the endogenous lag $W \ln w_t^M$, in other words we base our models on equation (13). However none of our models produces a significant effect due to $W \ln w_t^M$. We next turn to modelling spillovers by means of exogenous spatial lags, as exemplified by equation (17). This builds on the fact that most of the literature on the effects of public investment focuses on whether or not infrastructure has productive effects and pays relatively little attention to how productive public capital might shift economic activity from one place to another. There are reasons to believe that public investment in neighbouring provinces might have a positive impact on productivity within a given province, given connections such as roads, railways or airports. On the other hand, negative spillovers might exist perhaps due to the migration of factors to locations with superior infrastructure stocks. Public investment in one region could have a negative effect on other regions that are its closest competitors for labour and mobile capital. It is argued that spillovers might be one of the causes behind the different effects of public investment on productivity. Many researchers argue that positive spillovers could explain why studies of national time-series data typically find larger output elasticities for public capital than elasticities estimated by papers that analyse regional data. The existence of positive spillovers could be responsible for the apparently low impact of public investment on regional productivity. As equation (17) shows, our analysis of spillovers explicitly involves human and public capital variables, namely the exogenous lags WH and WK . The estimates are given in table 2.

Table 2: Models with exogenous lags

| REGRESSORS | Parameter Estimates | | |
|--------------------------------------|--|--|----------------------|
| | Model 5 [#] | Model 6 [#] | Model 7 [#] |
| Market Potential [lnP] | 0.2080611 (11.89) | 0.2108861 (3.05) | 0.2838018 (11.60) |
| Public Capital [lnK] | 0.1852316 (6.36) | 0.1849532 (6.31) | 0.1792644 (6.24) |
| Spatial Lag Public Capital [WlnK] | -0.3572691 (-6.87) | -0.3575304 (-7.01) | -0.362532 (-7.17) |
| Human Capital [lnH] | 0.0357592 (3.77) | 0.0358972 (3.30) | 0.0419196 (4.45) |
| Spatial Lag Human Capital [WlnH] | -0.0006924 (-0.04) | ... | ... |
| R squared | 0.8587 | 0.8588 | 0.8603 |
| F test (46,870) ^Φ | 227.99 | 228.89 | 231.47 |
| Instruments | lnK lnH WlnK WlnH Temporal dummies sqkm | lnK lnH WlnK WlnH Temporal dummies | |

Notes:

[#] z-ratios given in brackets beneath the estimates

Spatial and time period fixed effects also included in each model

^Φ F test of the null that all fixed effects are zero.

The estimates for model 5 show that the variable market potential (P) has a significant effect on (our proxy for) productivity, indicating that high levels of market potential

correspond to higher wage rates. Since market potential is endogenous, it is instrumented by H , K , WH , WK and by the time dummies, plus an additional instrument $sqkm$ equal to the surface area of each province in square km (to allow identification). Both determinants of labour efficiency within each province (H , K) are statistically significant, but while the exogenous lag WH is insignificant, there is a highly significant WK effect, which also happens to be negative.

Given the insignificance of human capital spillovers WH , we next estimate model 6 having eliminated WH , and it is apparent that the results are effectively the same, as shown in table 2. Model 6 is our preferred specification, with insignificant lag WH and additional instrument $sqkm$ omitted. Note that we do not reject the null that the coefficient on $\ln P$ is not significantly different from σ^{-1} , where $\sigma = 6.25$ is the value assumed in the construction of $\ln P$. This provides empirical support for our a priori assumption regarding the value of σ . The test statistic equals 0.54 which has a p -value of 0.46 in the appropriate null distribution, which is the χ_1^2 distribution. The magnitude of the elasticity of public infrastructure for the Spanish regions is 0.18, within the range of variation of the elasticities obtained in other papers. In Mas *et al.* (1994, 1996), the elasticity associated with productive public infrastructures is 0.23 and 0.08, respectively. Goerlich and Mas (2001) reported an elasticity of 0.02 and Boscá *et al.* (2006) obtained an output elasticity of 0.026 for public infrastructures (0.035 in the long run). We can be quite confident in interpreting the results obtained, as the coefficients sign and significance do not change when the spillover of human capital is not considered in the estimation.

The sign on spatial infrastructure spillovers is also inconclusive in the literature. Holtz-Eakin and Schwartz (1995), for the US, provide no evidence of spatial infrastructure spillovers. In contrast, Pereira and Roca-Sagalés (2003), Cohen and Morrison (2004) and Bronzini *et al.* (2008) find significant positive spatial spillovers for Spain, the US and Italy, respectively. Most interestingly, Boarnet (1998), using data for California's counties, found that the output of counties is negatively affected by neighbouring counties' infrastructure. Sloboda and Yao (2008) for the US, Delgado and Alvarez (2007) for the Spanish economy, and Pereira and Andraz (2006) for Portuguese regions, argue that public capital provided in a particular region raises the comparative advantage of that region compared with others, and could therefore attract production factors from other locations where output or productivity might consequently decrease. The development of new network infrastructure may alter the location decisions of firms, increasing investments and outputs in some provinces while causing disinvestments and possible job losses for others.

In our study we find that both determinants of labour efficiency within each province (H , K) are statistically significant, and while the exogenous lag WH is insignificant, there is a highly significant spatial lag for WK , which is negative. This finding is surprising because, as mentioned earlier, most of the previous literature suggests a positive or non-significant effect on public investment spillovers, but not a negative one. However there is now growing evidence of negative effects, first by Boarnet (1998) with reference to California counties and later by Kelejian and Robinson (1997) and Chandra and

Thompson (2000). Likewise Lopez-Bazo *et al.* (2007) arrived at the same conclusion using a different theoretical approach for the Spanish provinces. The explanation has to do with the fact that when the public sector decides to invest in one province, it attracts capital and possibly labour from nearby regions causing a negative spillover effect. The argument given by Lopez-Bazo *et al.* (2007) is that there appears to be negative spillover effects across regions in transport capital investment that actually counteract their positive effects inside each region (typically one would expect good road and rail connections in neighbouring provinces to be beneficial). They suggest that the magnitude of negative spillovers exceeds that of positive ones across a relatively short distance, so that would be internalised within a larger area.

Another interesting outcome derived from our model is the absence of spillover effects in the human capital variable. This result suggests that labour is not commuting in large volumes between provinces. It is probably explained by the fact that, as labour is typically concentrated in the capital of the province, and capitals tend to be fairly centrally located within their respective provinces, on the whole distances between capitals are too great and transport costs too high to allow mass commuting. On the other hand, were we to estimate the model using municipalities, we are more likely to encounter positive spillovers in human capital because of the lower costs of commuting.

Finally, model 7 gives the corresponding OLS estimates, in which the larger coefficient on $\ln P$ is significantly different from σ^{-1} , with test statistic equal to 25.61, which has a *p-value* which is exceedingly small in χ_1^2 . This adds further support to our preference for the model 6 parameter estimates obtained by treating $\ln P$ as endogenous.

5. CONCLUSIONS

The relationship between public infrastructure and productivity has been analysed using a model based on New Economic Geography theory, with a version of the so-called wage equation estimated using a spatial panel, with fixed time and province effects, to control for spatial public investment spillovers between contiguous Spanish provinces. The substantive conclusion we come to as a result of this analysis is that there is evidence in support of the wage equation involving market potential, human capital and public capital, with significant positive effects on the wage level, which we adopt as our proxy for the level of productivity.

The wage equation has provided us with a satisfactory theory on which to base our analysis of the impact of public capital, which we show to be an important variable, with 1% increase inducing nearly 0.18% increase in productivity. This result is effectively unchanged under different model specifications, pointing to the robustness of our estimates. In contrast the elasticity associated with human capital is much smaller, although it is still statistically significant. These conclusions are made in the context of fixed year and province effects in our model, so that we are controlling for unmodeled heterogeneity in the effects we report. The productivity impact attributable to public

capital is particularly important at a time when falling demand is leading many private-sector employers to shed labour and reduce their level of production. Public investments, which create jobs directly can generate demand and help to break a downward economic trend, are seen not to be wasteful, for they raise productivity also.

Additionally, an interesting outcome of our analysis is that there is a significant spillover effect involving public capital in 'nearby' provinces, which turns out to be negative in sign. What we find is that if the weighted average of the level of public capital in surrounding provinces is high, then a province's wage level is reduced. We can interpret this as an effect of competition from neighbours. Public capital provided in one place is thought to enhance the comparative advantage of that place relative to others not receiving the capital investment. As argued by Boarnet (1998), negative output spillovers can result when mobile factors of production migrate to competing locations with the best infrastructure stocks. The negative spillovers of public investment might explain the results obtained in some previous papers which found a non-significant effect of public investment on a national level.

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