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Public infrastructure and the performance of manufactures: Short and long run effects

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ABSTRACT

We develop a theoretical framework that allows determining a wide range of infrastructure effects both in the short and long run. While the ones in the short run have already been analyzed, we derive the elasticities concerning the long run by allowing adjustments in the quasi-fixed inputs towards their optimum levels. By considering the impact of infrastructure on private investment decisions, it is observed how, apart from the direct effect on costs in the short run, infrastructures present an indirect channel of influence (in the long run) through its effect on private capital. The model is applied to the manufactures in the Spanish regions.

Keywords: Public Infrastructure, Long-run vs. Short-run Equilibrium, Manufacturing Costs
JEL Classification: H54, O47

RESUMEN

En el presente artículo se desarrolla un marco teórico que permite determinar un amplio rango de efectos de las infraestructuras, tanto en el corto como en el largo plazo. Mientras que los efectos en el corto plazo han sido analizados en otros trabajos, aquí se derivan las elasticidades referentes al largo plazo permitiendo ajustes en los inputs cuasi-fijos hacia sus niveles de equilibrio. A través de la consideración del impacto de las infraestructuras en las decisiones de inversión privadas, se observa cómo además del efecto directo en los costes en el corto plazo, las infraestructuras presentan un canal indirecto de influencia (en el largo plazo) a través de sus efectos en el capital privado. El modelo se aplica al caso de la industria manufacturera de las regiones españolas.

1. INTRODUCTION

Most studies analyzing public capital impact on output and productivity have used neoclassical production functions (Aschauer, 1989; Munnell, 1992; Garcia-Milà and McGuire, 1992 among others). Their results generally support a positive effect of public capital, but the range of results is too large to be conclusive and many deficiencies have been signaled thereafter. The production function has been considered inaccurate due to the restrictions imposed on the technology and the firms' behavior as well as for not taking into account private input prices that would affect the intensity in which they are used. In order to overcome part of these problematic issues the use of the duality theory has been suggested. The duality theory through the estimation of cost and profit functions allows us to examine the complementary or substitutability relationship between private and public factors as well as the marginal effect of infrastructure on the firms cost structure.

The present paper follows the line of research based on the duality theory with the main purpose of enabling a better understanding of the linkage between the publicly provided input and the nature of the manufacturing production process. The methodology considered is a cost function that allows us to disentangle the total effect of public capital into the different effects on the various private factors. Among the studies that have used cost functions aggregated with public capital we can point out those from Berndt and Hansson (1992) for the Swedish case, Nadiri and Mamuneas (1994) and Morrison and Schwartz (1996) for the US, Conrad and Seitz (1992) and Seitz and Licht (1995) for the German economy, Sturm (1997) for the Netherlands, and Moreno *et al.* (1997a), Avilés *et al.* (1997) and Boscá *et al.* (1998) for Spain.

However, this paper extends these approaches to the consideration of the effect of infrastructure on private capital location. Taking this effect into account, we will distinguish two different effects of public infrastructure on costs. First, a direct channel affecting variable costs. Second, an indirect one coming from changes in private capital intensities. Former papers using cost functions have only considered the direct effect of public capital, with the exception of Morrison and Schwartz (1996) who consider a long run effect through an indirect channel due to output adjustments. However, in the present paper we are able to measure the long run effects of infrastructure through private capital adjustments, since this quasi-fixed input is allowed to adjust in the long run in response to changes in public capital. This long run cost effect through altering capital intensities has been considered in Nadiri and Kim (1996) and Bernstein and Yan (1997) in order to estimate the effects of R&D spillovers on the cost and production structure. Nevertheless, as far as we know, it has not been used when computing public infrastructure effects on production costs.

In our opinion, this latter point is especially important for the study of the impact of infrastructure investments. An improvement in the endowment of public capital may have two effects. It increases profitability of the production process in the existing firms and, as a consequence, it makes more attractive the location of new economic activities. Thus, we define a short run effect experienced by firms that are already producing, and this is due to cost reductions in variable inputs as a consequence of the new public capital stock. Further, we define a long run effect by which higher profitability promotes new investments in private capital, increasing the size of the existing firms or allowing more firms to operate in the economy. This may not only change the spatial distribution of activity, as pointed out by Martin and Rogers (1995), but may also provoke sectoral restructuring in the economy in line with the theoretical ideas in Holtz-Eakin and Lovely (1996).

When analyzing public capital effect using the duality theory one may use either a total cost function or a variable cost function. In the former case, one is assuming that all factors of production can be costlessly adjusted so that firms instantaneously determine long run factor demands. In this case, the long run effect of public capital through changes in private capital stock would not be distinguishable. However, in the latter case, it is considered that adjustment costs beyond the control of firms do not allow inputs to adjust instantaneously to their long run equilibrium levels. Rather than assuming these ideas a priori, in the present paper we use the test developed by Schankerman and Nadiri (1986) to acknowledge into the possible divergence of private capital from its static equilibrium values. This way, the most appropriate cost model according to the analyzed economy can be taken into consideration.

Finally, empirical models studying the impact of infrastructure on growth suffer from strong multicollinearity. As stated in Chunrong and Cassou (1997) this may cause misleading conclusions on the significance and size of the effect. The problem is exacerbated when applying the duality theory because of the use of very general functions (such as the translog) which include a large number of parameters. In order to avoid this problem, we increase the cross-section variability by descending to both a regional and sectoral level. This way, we also yield additional insights about the variability of public capital effects across economic sectors and regions. In fact, Seitz and Licht (1995) claim that their results obtained from the estimation of a cost function in the regional German case could be affected by the great differences existing in the sectoral structure of manufacturing industry across the federal states in Germany. In accordance to these ideas, the present paper takes into consideration both a sectoral and regional disaggregation in the Spanish case during the eighties to implement the model.

The paper is outlined as follows. In the second section the model based on the duality theory assuming that firms do not instantaneously adjust their capital stock to their optimal level is presented. The expressions for public capital elasticities both in the short and long run are derived as well. Section third describes an empirical model following a translog specification and the main econometric issues in order to apply it. The database used to implement the model and the empirical results for the manufactures in the Spanish regions are subsequently presented and discussed in section 4. Finally, some concluding remarks and suggestions for further research are given in section 5.

2. FIRM BEHAVIOR MODEL WITH PUBLIC CAPITAL

Short and Long Run Cost Functions

A cost function is a mathematical representation of the cost-minimizing problem faced by firms. In this framework, it is possible to explicitly include public capital in order to take into account the cost effect of this kind of external factor.

Let's consider a production function, where Y is the output and X_i ($i=1,\dots,r$) the i-th input:

$$Y = f(X_1, X_2, \dots, X_r) \tag{1}$$

It is assumed that the firm is constrained to accept a vector of input prices, $P_1,\dots,P_r$, so that the optimization problem firms face implies deciding the amount of inputs that minimizes the cost of producing a given output, $\bar{Y}$. Then, we can obtain a group of demand functions for private inputs:

$$X_i = f_i(P_1, \dots, P_r, \bar{Y}) \tag{2}$$

Being X_i^* the optimal amount of input, the level of optimum cost, that is, the solution to the optimization problem yields a cost function that is dual to the production function, being dependent on input prices and output:

$$C^*(P_i, \bar{Y}) = \sum_i P_i \cdot X_i^* = f(P_1, \dots, P_r, \bar{Y}) \tag{3}$$

where * denotes values at the equilibrium. A detailed description of cost function properties can be found in Chambers (1988).

In such a framework, we are assuming that all factors of production can be costlessly adjusted so that the firm instantaneously determines long run factor demands. This is the static equilibrium hypothesis for production factors. Nevertheless, rather than assuming that all inputs adjust instantaneously to their long run equilibrium values, there are reasons to believe in the absence of such an adjustment mechanism for some factors. We can think of costs of investment and disinvestment, price controls and regulations, credit rationing, and institutional constraints that are out of the control of an individual firm in the short run. This is the partial static equilibrium situation. The inputs that are in static equilibrium are referred to as variable inputs, and the remaining ones are designated as fixed or quasi-fixed inputs. Basing on these ideas, we adopt a framework that distinguishes variable from quasi-fixed inputs, where the latter adjust only partially to their full equilibrium levels within one time period. Therefore, we consider short run cost functions apart from long run cost functions. In the former ones, the presence of some inputs fixed at values other than their full equilibrium level implies that there are adjustment cost associated with changing their quantities. In this case, the goal of the firm is to minimize the cost of variable factors conditional on a given stock of quasi-fixed factors. In the latter, all inputs are at their full equilibrium values in any period.[1]

Since the purpose of the paper is to obtain public capital elasticities, we focus on a production function aggregated with public capital as an unpaid factor. This aspect must be taken into account when obtaining the corresponding cost function. This way, the variable cost function we are using includes public capital as a fixed input:

$$VC ? VC(P_L, P_M, \bar{Y}, \bar{Kp}, Kg) \quad (4)$$

where we consider two variable private inputs, labor (L) and intermediates (M) which appear in the cost function through their prices, P_L, and P_M respectively; and a quasi-fixed input, private capital, $\bar{Kp}; \bar{Y}$ is output and Kg is public capital

[1] Partial static equilibrium and full static equilibrium are often referred to as long-run and short-run equilibrium, respectively. In such a case, it is assumed that movements from partial equilibrium to full equilibrium need input adjustments that take place with the passage of time. In the present paper we use both denominations although we will rather use the distinction between short and long run.

(external input). Public infrastructure is therefore considered as an unpaid fixed input in the production process, on which firms have little or null control. Therefore, this cost function permits the combination of internal scale economies in the production process due to private inputs (both variable and quasi-fixed) and external scale economies, if existing, provided by the public input. That is, scale economies in a cost function are now outlined including this new argument, so that publicly provided infrastructures could affect the shape of the average cost curve.

The total short-run cost function is the sum of the variable cost and the cost of the existing private capital:

$$SC = VC + P_{Kp}\,\bar{Kp} \tag{5}$$

As regards these specifications, after increasing or improving public capital endowment, firms adjust the decisions on the amounts of the different variable private inputs used in the production process according to their substitutive or complementary relationship with infrastructures, given the existing amount of quasi-fixed inputs. This is the short run effect of infrastructure investments in the production process. However, in a longer run firms decide the optimal amount of physical capital for the new endowment of public capital as well. Then, in the long run investments in infrastructure may have an additional effect through changes in the decisions of private capital location and the possible consequent cost variation effect of private capital.

Assuming that variable input prices are exogenous to the producer, and applying Shephard's Lemma, it is possible to obtain the unique vector of the different variable inputs that minimize costs (cost-minimizing demands):

$$X_i = \frac{\partial VC}{\partial P_i} = f(P_L, P_M, \bar{Y}, \bar{Kp}, Kg) \tag{6}$$

Furthermore, we can calculate each factor share (Z_i), that is, the percentage of the cost supposed by the *i*-th input:

$$Z_i = \frac{P_i \cdot X_i}{VC} = \frac{\partial \ln VC}{\partial \ln P_i} = \frac{\partial VC}{\partial P_i}\frac{P_i}{VC} \tag{7}$$

Equation set (4) and (7) constitutes the solution to what can be defined as the short run equilibrium related to variable factors, constrained to fixed values for Y, Kp and Kg.[2] That is, the preceding functions, and consequently the short run solution, are not independent of the quasi-fixed factors. From these functions we can obtain the required short run elasticities for fixed and quasi-fixed inputs.

On the other hand, the long-run demand for quasi-fixed factors, Kp^* in our case, is given by the envelope conditions. Minimizing total short run cost for Kp:

$$\frac{\partial SC}{\partial Kp} = \frac{\partial VC}{\partial Kp} + P_{Kp} = 0$$

$$\Rightarrow P_{Kp} = -\frac{\partial VC}{\partial Kp} \tag{8}$$

This means that the demand for Kp depends on prices of variable inputs, the fixed quantities of output and public capital, and its own price. Let

$$Kp^* \equiv g(P_L, P_M, P_{Kp}, \bar{Y}, Kg) \tag{9}$$

be the solution to (8). Substituting (9) into (5), we get the long run cost function:

$$C^* = VC^*(P_L, P_M, \bar{Y}, g(P_L, P_M, P_{Kp}, \bar{Y}, Kg), Kg) + P_{Kp} \cdot g(P_L, P_M, P_{Kp}, \bar{Y}, Kg) \tag{10}$$

$$= f^*(P_L, P_M, P_{Kp}, \bar{Y}, Kg)$$

Thus, equations (4), (6) --or (7)-- and (9) characterize the long-run equilibrium. Long run elasticities will be obtained based on them. From (10) it is worth noting that Kg may affect long run cost in different ways: by a direct channel affecting variable cost, and by an indirect channel through its effect on Kp. The latter will include an extra effect on variable cost, by the

[2] The use of demand functions or factor share functions is equally correct. So, alternatively, we could talk about the set (4) and (6).

complementarity/substitutability relationship between private capital and variable inputs, and the direct effect of *Kp* on costs. These effects through changes on private capital will only appear in the long run solution, being the main difference between short and long run elasticities.

Short and Long Run Elasticities

From the functions previously described it is possible to assess the impact of public and private capital investments on costs, output, variable input demands and returns to scale. Both, the elasticities of public and private capital in the short and long run are presented. The change in short run costs due to a marginal addition to the infrastructure stock is the short run cost elasticity with respect to Kg:

$$\varepsilon^{SR}_{SCKg} = \left(\frac{\partial SC}{\partial Kg} \frac{Kg}{SC} \right)_{Kp = \overline{Kp}} = \left(\frac{\partial VC}{\partial Kg} \frac{Kg}{SC} \right)_{Kp = \overline{Kp}} \tag{11}$$

where superscript SR denotes short run. Though not specified during all the analysis, the output is always supposed to be fixed, so that all the elasticities are computed considering a fixed amount of Y ($\bar{Y}$).

Hence, it is possible to obtain measures of the short run implicit willingness of private manufactures to pay for public capital, which is known as (short run) *infrastructure shadow price*. It is defined as the reductions in variable costs due to an increase in the public capital stock. As long as this value is positive, firms benefit from having additional infrastructures, since they permit obtaining variable cost savings.[3] Short run infrastructure shadow price may be specified as follows:

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[3] In this framework we are considering that firms do not pay for public capital, since it is supposed to be an exogenous input. Nevertheless, even though firms do not face the direct costs of accumulating this input, firms do pay for infrastructure in terms of taxes, so that there would exist a social cost to get an adequate public capital endowment. From this perspective, the shadow price obtained through this theoretical model will exaggerate the social impact of public infrastructure.

$$S^{SR}_{Kg} = -\frac{?VC}{?Kg}\Big?_{Kp ? \bar{Kp}} \; ? \; ?^{SR}_{VCKg} ?? \frac{VC}{Kg} ? \qquad (12)$$

Where

$$?^{SR}_{VCKg} \; ? \; \frac{?VC}{?\,Kg}\frac{Kg}{VC}\Big?_{Kp ? \bar{Kp}}$$

This measure will be positive as long as public capital supposes benefits in terms of substitution relationships with variable inputs, in other words, as long as public infrastructure represents efficiency changes in terms of decreases in variable input utilization and thus variable costs. Hence, following Nadiri and Mamuneas (1994), it can be said that firms will adjust their production decisions with respect to their own factors according to the relationship between them and public sector capital. This is what these authors call *the factor bias effect* of public capital, which can be computed as the short run infrastructure elasticity of the conditional demand for variable inputs:

$$S_{Kg} = -\frac{?C}{?Kg} \qquad (13)$$

The relationship between public capital and variable inputs can be of substitutability or complementarity, that is, public capital can be factor saving ($?^{SR}_{XiKg}$<0), using ($?^{SR}_{XiKg}$>0), or neutral ($?^{SR}_{XiKg}$=0). Thus, as stated before, a positive shadow price would imply a net substitutive relationship between public capital and variable inputs. In other words, if there is an increase in the publicly provided input and it is substitutive (complementary) to variable inputs, the infrastructure increase will reduce (increase) industrial variable costs and, therefore, the shadow price will be positive (negative). Specifically, based on the variable cost function and differentiating it with respect to public capital, we decompose the cost saving effect provided by public capital into the effects on the demand for the variable factors:

$$S^{SR}_{Kg} = -\left(\frac{\partial VC}{\partial Kg}\right)_{Kp=\overline{Kp}} = -\sum_i P_i \left(\frac{\partial X_i}{\partial Kg}\right)_{Kp=\overline{Kp}} \qquad i \in L, M \tag{14}$$

where it is shown how infrastructure shadow price is dependent on the value of the relationship between public capital and variable inputs.

Moreover, it is commonly thought that these increases in public capital stocks will intensify private economic performance. The impact of infrastructures on the level of production can be computed as the infrastructure elasticity with respect to output thanks to the application of the envelope theorem, obtaining the relationship between the dual and primal scope:

$$\varepsilon^{SR}_{YKg} = \left(\frac{\partial Y}{\partial Kg}\frac{Kg}{Y}\right)_{Kp=\overline{Kp}} = \frac{S^{SR}_{Kg}}{\varepsilon^{SR}_{SCY}\,\frac{SC}{Y}}\,\frac{Kg}{Y} \tag{15}$$

whereas the magnitudes of the returns to scale are obtained as:

$$RTS^{SR} = \frac{1}{\varepsilon^{SR}_{SCY}} = \frac{1}{\left(\frac{\partial \ln SC}{\partial \ln Y}\right)_{Kp=\overline{Kp}}} \tag{16}$$

Finally, in case of private capital not being in its long-run equilibrium level, the same exact effects that have been presented for public capital can be obtained for the private input, since it should be considered as a quasi-fixed factor. Therefore, we can compute ε^{SR}_{SCKp}, ε^{SR}_{XiKp} and ε^{SR}_{YKp} as well as the shadow price, S^{SR}_{Kp}. If the quasi-fixed factor was not in its levels of static equilibrium, its shadow price would be higher (lower) than the price of the services it provides, having a clear situation of infra-investment (supra-investment) in private capital. This idea can also be viewed through the ratio optimal private capital stock to observed private capital stock, Kp^*/Kp. If the value of the ratio is higher than 1 then the stock of private capital in the economy is lower than the optimal.

Regarding long run effects of public capital, they are obtained in much the same way as the described above for the short run. However, variations in cost and variable inputs demand caused by changes in the stock of private capital, as a response to variations in infrastructure endowment, must be added to the short run effect. This latter effect may foster the short run effect or, on the contrary, balance or even inverse it. In this sense, the total or long run cost elasticity to public capital has the following expression:

$$?^{LR}_{CKg} = \frac{d\ln C}{d\ln Kg} ? \left. \frac{dC}{dKg}\frac{Kg}{C} ? \right?_{Kp?Kp^*} = ?^{SR}_{SCKg} ? ?^{SR}_{SCKp} ?^{LR}_{KpKg} \qquad (17)$$

where

$$?^{LR}_{KpKg} ? \frac{d\ln Kp^*}{d\ln Kg} ? \frac{?\ln Kp^*}{?\ln Kg} ? ?_i \frac{d\ln Kp^*}{d\ln X_i}\frac{?\ln X_i}{?\ln Kg} ? ?_{Kp^*Kg} ? ?_i ?_{Kp^*Xi} ?^{SR}_{XiKg} \quad i ? L,M$$

where superscript LR denotes long run. The expressions corresponding to $?_{Kp^*Kg}$ and $?_{Kp^*Xi}$ are necessary in order to obtain the effect of public capital in the long run. Since for many of the flexible functional forms used in the duality theory it is not possible to get a close expression for Kp^*, the former expressions corresponding to $\frac{?\ln Kp^*}{?\ln Kg}$ and $\frac{d\ln Kp^*}{d\ln X_i}$ must be computed using a system of derivatives of implicit functions. The first derivative is obtained through the implicit function of equation (9) whereas the second is obtained using a system of implicit functions from equations (4) and (9) in which costs and private capital responses to variations in variable inputs are determined simultaneously. Finally, $?^{SR}_{XiKg}$ is the same short run factor bias effect. In this model, $?^{LR}_{KpKg}$ acquires special relevance as it summarizes the location effect of public capital investments. That is, it indicates the extend to which improvements in the public capital endowment in an economy promote private activity. Needless to say, this is one of the main objectives when public investments aim at spurring economic development, although, so far, it has been neglected by the literature analyzing this topic.

Long run shadow price of infrastructures and factor bias will be evaluated in Kp^* as well, that is, these measures will include changes in variable inputs due to movements in private capital stock as a result of the new infrastructure endowment:

$$S^{LR}_{Kg} = ?^{LR}_{VC\,Kg} ?? \frac{VC}{Kg} ?? ? \underset{i}{?} \; ? \; P_i \, ?^{LR}_{X_i Kg} \qquad i ? L, M \tag{18}$$

where:

$$?^{LR}_{X_i Kg} = \frac{d \ln X_i}{d \ln Kg} ? \frac{? \ln X_i}{? \ln Kg} ? \underset{i}{?} \frac{? \ln X_i}{? \ln Kp} \frac{? \ln Kp^*}{? \ln Kg} ? ?^{SR}_{X_i Kg} ? \underset{i}{?} \; ?^{SR}_{X_i Kp} ?^{LR}_{KpKg} \qquad i ? L, M \tag{19}$$

with $?^{SR}_{XiKg}$ and $?^{SR}_{XiKp}$ as in the short run, and $?^{LR}_{KpKg}$ as expressed above. It can be observed how the long run substitutive/complementary relationship may be decomposed into both a direct ($?^{SR}_{X_i Kg}$) and an indirect effect, which results from the interaction between the long-run location effect of public capital ($?^{LR}_{KpKg}$) and the substitution/complementary relationship between variable inputs and the quasi-fixed factor ($?^{SR}_{XiKp}$).

The same applies to the output elasticity to Kg in the long run, which now considers variations in output due to the adjustment to the optimal private capital stock:

$$?^{LR}_{Y Kg} \; ? \; \frac{dY}{dKg} \frac{Kg}{Y} \underset{Kp ? Kp*}{??} \; ? \; \frac{S^{LR}_{Kg}}{?^{LR}_{CY} ? \frac{C}{Y}} \frac{Kg}{Y} \tag{20}$$

where $?^{LR}_{CY}$ is:

$$?^{LR}_{CY} ? \frac{d \ln C}{d \ln Y} ? \frac{? \ln SC}{? \ln Y} ? \frac{? \ln SC}{? \ln Kp} \frac{d \ln Kp^*}{d \ln Y} ? ?^{SR}_{SCY} ? ?^{SR}_{SC\,Kp} ?^{LR}_{KpY} \tag{21}$$

where

$$?^{LR}_{KpY} ? \frac{d \ln Kp^*}{d \ln Y} ? \frac{? \ln Kp^*}{? \ln Y} ? \underset{i}{?} \frac{d \ln Kp^*}{d \ln X_i} \frac{? \ln X_i}{? \ln Y} ? ?_{Kp^* Y} ? \underset{i}{?} \; ?_{Kp^* Xi} ??_{XiY}$$

obtaining $?_{Kp^{*}Y}$ from the implicit function of expression (9), and $?_{XiY}$ from equation (7) for both variable inputs. Analogously to the short-run case, the returns to scale in the long term are recovered as the inverse of $?^{LR}_{CY}$.

Part of these long run elasticities can be obtained for private capital as well though the explanation is somehow different. Thus, private capital will not only have a direct effect on costs in the short run, but also an indirect one through adjustments in variable inputs in response to private capital variations:

$$?^{LR}_{CKp} = \frac{d\ln C}{d\ln Kp} = \frac{?\ \ln C}{?\ \ln Kp} ? \ ?_{i} \frac{?\ \ln SC}{?\ \ln X_i}\frac{d\ln X_i}{d\ln Kp} ? \ ?^{SR}_{SCKp} ? \ ?_{i} \ ?_{SCX_i} ?^{LR}_{X_iKp} \qquad i ? L,M \tag{22}$$

where $?_{SCXi}$ is obtained through the system of derivatives of implicit functions from equations (7) and (9) as stated aboved, and $?^{LR}_{X_iKp}$ from equation (7) for both variable inputs. Referred to the latter, it is worth noting that the effect of private capital on the variable inputs in the long run is exactly the same one as in the short run, $?^{SR}_{X_iKp}$. The rest of long run effects for private capital are obtained in much the same way as for the public capital case.

3. EMPIRICAL SPECIFICATION AND ECONOMETRIC ISSUES

Empirical Specification

The empirical work made in this paper in order to test the effect of public capital endowment on manufacturing costs is based on a translog cost function, a general second degree polynomial in logs, with the following form:

$$\ln VC ? ?_0 ? \ln P_M ? ?_L \ln \frac{P_L}{P_M} ? ?_Y \, lnY + ?_{Kp} \ln Kp ? ?_{Kg} \ln Kg + ?_T t ? 0.5 ? ?_{LL} \ln^2 \frac{P_L}{P_M}$$

$$+ ?_{YY} \ln^2 Y + ?_{KpKp} \ln^2 Kp ? ?_{KgKg} \ln^2 Kg ? ?_{TT} t^2 \; ? ?_{LY} \ln \frac{P_L}{P_M} \ln Y \qquad (23)$$

$$+ ?_{LKp} \ln \frac{P_L}{P_M} \ln Kp ? ?_{LKg} \ln \frac{P_L}{P_M} \ln Kg + ?_{LT} \ln \frac{P_L}{P_M} t ? ?_{YKp} \ln Y \ln Kp$$

$$+ ?_{YKg} \ln Y \ln Kg + ?_{YT} \ln Y \, t ? ?_{KpKg} \ln Kp \ln Kg ? ?_{KpT} \ln Kp \, t ? ?_{KgT} \ln Kg \, t$$

where t is a time trend which summarizes technological change, as in, for instance, Morrison and Schwartz (1996).

This functional form permits the consideration of a great range of substitution possibilities while accommodating to any production technology without being necessary to impose a priori restrictions on returns to scale.[4] Intermediate prices are included as a relative factor to ensure the function is homogeneous of degree one in factor prices. Besides, any kind of a priori returns to scale are imposed. For ease of notation, variables in equation (23) and subsequent ones do not carry any kind of subscripts referred to the observations.

Applying Shephard's Lemma to equation (23) we obtain the share equations for variable inputs on variable costs. For the two variable factors we consider only one equation is independent, given that factor shares sum to one. Thus, we have:

$$Z_L = \frac{P_L ?L}{VC} = \frac{? \, lnVC}{? \ln P_L} = ?_L + ?_{LL} \ln \frac{P_L}{P_M} + ?_{LY} \ln Y + ?_{LKp} \ln Kp + ?_{LKg} \ln Kg + ?_{LT} t \qquad (24)$$

$$Z_M \; ? 1 ? Z_L$$

[4] Guilkey *et al.* (1983) demonstrates the translog form superiority over alternate functional forms in Monte Carlo studies. However, some other studies about public capital effects have considered other functional forms, such as a Generalized Leontief or a Generalized Cobb-Douglas restricted cost function. In this sense, it would be worth studying the sensitivity of the results to these different specifications.

Therefore, the short-run equilibrium is denoted by equations (23) and (24). On the other hand, the long-run equilibrium condition for private capital can be expressed as:

$$? Z_{Kp} ? ? \frac{P_{Kp} ? Kp^{*}}{CV} = \frac{? lnCV}{? \ln Kp} = ?_{Kp} ? ?_{KpKp} \ln Kp + ?_{LKp} \ln \frac{P_L}{P_M} + ?_{YKp} \ln Y + ?_{KpKg} \ln Kg ? ?_{KpT} t \qquad (25)$$

The long-run equilibrium is represented by equations (23), (24) and (25). From the estimation of these equations we will obtain the main effects of public and private capital both in the short and long term.

Econometric Issues

For empirical implementation purposes the models have to be imbedded within a stochastic framework. In order to do this we consider that errors in cost and variable factor demands are due to errors in optimization, and the ones in the long run represent unanticipated information that becomes available after the time the investment decision is made. The models specified both in the short (system of equations 23 and 24) and in the long run (system of equations 23, 24 and 25) are initially estimated using the iterative Zellner technique for Seemingly Unrelated Regressions (SUR) imposing the equality restrictions among parameters across the different equations. However, in order to select the model to be estimated, the two theoretical aspects commented in section 2 are going to be tested in our model: an investigation into departure of quasi-fixed inputs from their static equilibrium levels and whether firms are equating variable input demands to the optimal quantities in each time period (Shephard's lemma).

First, being aware of the short run fixity of some inputs, such as private capital in the present case, the distinction between short and long run specifications must be well accounted for. With this purpose, we use the test developed by Schankerman and Nadiri (1986) to acknowledge into the possible divergence of quasi-fixed factors from their static equilibrium levels. Let $?_0$ be the parameter estimates vector in the cost function alone (eq. 23), $?_1$ the parameter vector in the demand (or share) functions for variable input function (eq. 24) and $?_2$ the parameter vector obtained from the estimation of the quasi-fixed inputs (eq. 25). The test is constructed under the null hypothesis that the fixed factors are at their static equilibrium levels, so that $?_2 \; ? \; ?_0$. In fact, when considering the partition of the vector $?_0 = (?_0^1, ?_0^2)$ where the elements of $?_0^1$ appear in (23) but not in (25) under the null, then one can specify the null hypothesis as $?_2 = ?_0^2$. This way, the estimator of the long run equilibrium model (let's say $\hat{?}$) imposes the restriction implied by the test, whereas the estimator of the short-run equilibrium model (say $\tilde{?}$) does not impose any restriction. The constraint estimator $\hat{?}$ is consistent under the null but not under the alternative hypothesis, while the unconstrained estimator $\tilde{?}$ is consistent under both, the null and the alternative. Schankerman and Nadiri (1986) construct a Hausman test, based on a comparison of the values in $\tilde{?}$ testing the null that firms are in the long run equilibrium:

$$N(\tilde{?} \; ? \; \hat{?})'\hat{V}^{?1}(\tilde{?} \; ? \; \hat{?}) \; ? \; ?_q^2 \qquad (26)$$

where N is the number of observations, $\hat{V}$ is the consistent estimator of V, with $V = V_1 - V_2$, being V_1 the asymptotic covariance matrix for $\tilde{?}$ and V_2 the asymptotic covariance matrix for $\hat{?}$. The test is distributed as a chi-square with degrees of freedom equal to the number of restrictions, *q*, the number of parameters in vector $?_0^2$.

Second, neoclassical production theory implies that the cost share equations are derived from the cost function given that firms select the amount of variable inputs that minimize variable costs. Parameters in (24) are, therefore, the same as those in (23). In most of the empirical works using duality theory these restrictions associated to the Shephard's lemma are imposed a priori without being previously tested. However, if data do not fit such restrictions it would be a signal of the violation of some assumptions such as the cost-minimizing behavior and the non-fixity of those factors considered as variable. As a result, from a statistical point of view one would be imposing values on the estimates which would be against the data, so that, if the parameters of the derived cost share equation could not be considered the same as those of the cost function, the computation of the effects based on the parameters would not be accurate. To avoid this problem, we test for the validity of the Shephard's lemma in the cost function which means testing for the adequacy of the data with the model. In order to implement the test $?_0$ is again the parameter vector in the cost function equation, but now let $?_0^1$ be the vector of parameters from the cost function that appear in the variable input demand function, and $?_0^2$ the rest of the parameters in the cost function. $?_1$ is still the parameter vector in the variable input share functions. This way, the null hypothesis would indicate that the share and cost equations yield the same parameters, $?_0^1 = ?_1$. The alternative hypothesis is $?_0^1$? $?_1$. In order to test the validity of the Shephard's lemma, we test the appropriateness of the linear restrictions of the coefficients in a SUR model.

A final econometric issue is the multicollinearity problem that may appear when estimating flexible functional forms. In order to avoid this problem, we increase the cross-section variability by descending to a regional and sectoral level at the same time. This way, we consider a panel data set for the manufacturing sectors in the Spanish regions for the period 1980-1991. This allows accounting for unobservable sectoral and regional differences in the exogenous cost level across the observations.

4. EVIDENCE FOR THE SPANISH CASE

Data

For our empirical analysis we use annual data in 12 manufacturing sectors[5] in 15 regions of Spain (NUTS II level, without the island regions) from 1980 to 1991, for all the variables excepting public capital stock. Data for this magnitude are only measured for the aggregated regional economies, so the variability is confined to the regional dimension. Data have been obtained from two main sources. First, output, intermediates, labor costs and the number of workers are available for 89 manufacturing sectors which are obtained from the Spanish Industrial Survey (IS). Second, series of private and public capital stocks are taken from "El Stock de Capital en la Economía Española" (The Capital Stock in the Spanish Economy, FBBV, 1995) being calculated by using the perpetual inventory method. These series of stocks are available for all the Spanish regions and in the case of private capital disaggregated in 13 broad manufacturing sectors. Then, the 89 manufacturing sectors of the IS were appropriately aggregated to match with the 13 sectors for which data on stocks of private capital were available. However, due to the high sectoral and territorial disaggregation of the data in the IS and for confidentiality reasons missing values are supplied for some of these sectors in some regions when it is necessary to comply to the statistical secret guaranteed by the survey. The incidence of missing data in the 13 broad manufacturing sectors at a regional level is only important in the sector gathering office equipment, precision and optics, so that we finally decided not to consider it. Thus, the twelve manufacturing sectors finally considered in the present study are shown in table 1.

[5] In the empirical implementation, we have focus on the manufacturing sector given the results in several theoretical (Holtz-Eakin and Lovely, 1996) and empirical (Moreno *et al*., 1997b) studies where it is obtained that public capital has a more evident economic impact on the manufacturing sector than in the rest.

Data provided by the IS are given in nominal values, being necessary to use a sector-specific producer price index to deflacte them. Since the deflaction is initially made for 89 sectors and then we aggregate to 12 sectors, it is ensured that the real input series are deflacted after considering the importance of each sector in each group. All variables are then used at constant 1990 prices.

Price for employment (P_L) is obtained by dividing labor costs by the number of employments. The index price of intermediate inputs (P_M) is measured by dividing the nominal intermediate input series by the constructed real intermediate input series. The rental rate of private capital (P_{Kp}) is computed as $P_{Kp} = q(r+d)$, where q is the private capital investment deflactor obtained from FBBV (1995), r is the discount rate for more than two year government bonds, and d is the private capital depreciation rate, the latter calculated according to the formula $d_t = 1 - \frac{Kp_t - I_t}{Kp_{t-1}}$, with I_t as private capital investment.[6] Private capital is measured by the total net capital stocks of manufacturing industry in each region. Public capital stock includes the net monetary stock of core infrastructures, that is, roads and highways, railway, harbors and maritime signaling, airports, water and sewage facilities, and urban structures.[7] Since public infrastructures are not supposed to have an immediate effect on industrial activity, the public capital stock variable enters the model with one period lag.

In table 2 the evolution of the main magnitudes in the Spanish manufactures during the eighties is shown. Costs, both total and variable, and output show a net positive growth that is not equally distributed throughout the period. During the first half of the eighties, the average annual growth rate is negative, becoming positive and high during the second half. The same

[6] Following the idea given by Berndt and Hansson (1992), corporate taxes are not included in the private capital price measure. For further information on factor prices for capital inputs, see the concept of the user cost of capital developed by Jorgenson (1963).

[7] Basic public infrastructure has been demonstrated to have a positive impact on regional productivity in the Spanish regions (e.g. Mas *et al.*, 1996), in contrast to social public infrastructure whose effect is not as clear.

evolution is shown by private production factors, although with a different intensity. Whereas labor and intermediates show a dramatic decrease during the first eighties, the fall in private capital is lower, probably due to the fact that enterprises were not able or did not consider convenient to adjust their private capital stock to the economic cycle. This is reinforced by the behavior in the expansive phase when private capital increases at lower rates than in the case of output. Although this would point out certain boarding and hoarding of private capital, which could advise some correction of private capital stocks considering its use, as far as we know, information on the use of capital is not available for our sample. However, at least part of such effects is substantial to the elasticities in which private capital is involved. Finally, public capital stock presents an important increase during the period although the cyclical behavior is observed by the different intensity of growth in the expansive and recessive phase.

Main Results

In order to select the appropriate model we implement the two tests signaled above. The value of the test proposed by Schankerman and Nadiri (1986) indicates a strong rejection of static equilibrium for private capital and thus, rejection of the assumption of long-run equilibrium (338914; p:0.000). The appropriate model to estimate is, therefore, the set of equations (23) and (24). Nevertheless, when testing the validity of the Shephard's lemma in the cost function it is obtained that the restriction is rejected (76.37; p:0.000). As far as we know, most of the empirical works do not test the validity of this lemma whereas the few ones testing it have strongly rejected it (Appelbaum, 1978 for the USA; Doménech, 1993 for the Spanish banking sector). Thus, although in some papers the utilization of the restricted SUR model is justified (Morrison and Schwartz, 1996) because it imposes structure and robustness to the model, we do not consider it accurate, given the result of the test, since the estimates would not be consistent. Therefore, we estimate the system without imposing the restrictions, using the estimation of the parameters for the cost equation to obtain the optimal demand function for the variable and fixed inputs.

The Hausman test rejecting its null hypothesis points out the estimation of the model including regional and sectoral fixed effects as the most accurate, instead of simply pooling the data or estimating the parameters in a random effect model. The estimated parameters are shown in table 3. The null of joint non-significance of the parameters affecting public capital is strongly rejected. Moreover, since we are interested in assessing on the variability of the cost effects across manufacturing sectors and regions, we have implemented several F-homogeneity tests in order to get a sense of the necessity of considering specific sectoral and regional unobservable effects. The null hypothesis that the coefficients of the regional and sectoral dummies are zero is rejected, suggesting that the same input endowments and factor prices may cause different cost levels depending on the sector and region, due to the technology and efficiency in each one. In fact, this seems to be the case in several studies analyzing scale economies, market power or technological levels (Suárez, 1992 and Velázquez, 1993 for the regions in Spain; Caballero and Lyons, 1990 for the European industry; Caballero and Lyons, 1992 and Burnside, 1996 for the US industry) where they have obtained great differences across industries and regions. Given these findings, it could seem relevant to obtain the individual estimation of the cost function for each sector (considering regional and time variability) and for each region (considering sectoral and time variability). Nevertheless, in doing so, we would probably face the problem of a certain degree of multicollinearity that functions considering cross-products of the variables encounter. For this reason, we rather prefer estimating the functions with the whole panel data set in order to increase variability while controlling for regional and sectoral differences through the consideration of different levels in the intercept term. This way, the estimates obtained will be reliable, and still we can obtain specific elasticities for public capital and scale economies for each region and sector, offering interesting conclusions for the orientation of policy making referred to public capital investments.

Based on the resulting estimated parameters, the effects mentioned in section 2 about public and private capital impact on economic performance are measured by calculating the required derivatives. Even though all the indicators below have been measured for each region and sector in every year, we only present some general averages. Concretely, we present four of them: regional, sectoral, temporal and global. They have been obtained by weighting the elasticity of each observation by the rate that the output in this specific observation represents over the global output in the region, sector, or time period respectively.

Short run effects

The cost elasticity with respect to public capital in the short run, $?^{SR}_{SCKg}$, (table 4) has a positive average (0.027) indicating that when public capital stock increases 1%, private production cost increases 0.027%. This indicates that, in general terms, manufactures did not benefit from a reduction in costs with the increases of public capital stocks during the eighties in all the Spanish regions. The variability of the elasticity is very small across regions and higher across sectors. Figure 1 represents a three-dimensional plot that synthesizes the response in costs when the values of public and private capital stocks change within the range of the variables in the sample and according to the parameters obtained in the estimation of the cost function. It is shown how increases in public capital stock lead to variable cost reductions when the levels of public and private stock are not high. However, once a certain endowment threshold is gained, ulterior increases in the stock of public capital end up augmenting costs proportional to the existing stock of private capital. According to the figure and the results in table 4, it can be concluded that all regions and manufacturing sectors in Spain had reached this threshold level during the eighties.

The measures of the implicit willingness of private sector to pay for infrastructures according to the values of the elasticity $?^{SR}_{SCKg}$ follow the same pattern, with a negative price average. This negative sign for infrastructures shadow price in the short term implies a net complementary relationship between public capital and variable inputs. This can be observed analyzing the type of relationship between public capital and each variable factor, in other words, obtaining the infrastructure elasticity of the conditional demand for labor and intermediates. On average, from the results it can be concluded that infrastructure capital is labor saving and intermediate using for all regions and sectors throughout the period. Indeed, there has been a general conclusion in the literature in favor of a substitutability relationship between labor and public capital (Berdnt and Hanson, 1992; Nadiri and Mamuneas, 1994; Seitz and Licht, 1995) indicating that public infrastructure investment allows firms to produce the same output with lower labor costs. However, two aspects are worth pointing out. First, the elasticities for labor are bigger than for intermediates indicating that public capital effect reducing labor can be of a certain importance (with a global average of -0.157) while the effect on intermediates is relatively low (0.06). Second, the variability across sectors, regions and time periods for intermediate elasticity is really low.

All these results concerning infrastructures have equally been obtained for private capital. In general terms, it can be said that although there is also a significant difference across regions and sectors, the average of the estimated elasticity of production cost with respect to private capital stock is 0.039. However, there is a cost reducing effect associated with the supply of private capital in the cases of Murcia, La Rioja and Extremadura. As a consequence, except for these three cases, private capital shadow price is negative, which can be disentangled in a substitution relation with intermediates (average elasticity of -0.097) and a complementary relationship between private capital and labor (average elasticity of 0.253).

Long-run effects

As it has been signaled in section 2, public capital may influence private costs and input demands in the long term through changes in private capital, which is considered to be fixed in the short term. According to the results in table 5, the elasticity of costs with respect to public capital in the long run continues being positive, with a slightly higher magnitude than in the short run (although it is higher in some cases and lower in others) and with an important sectoral differentiation.[8] It is also worth noting that this elasticity has moved conversely to the business cycle.

If we disentangle this general long-run effect, the *location effect of public capital* turns out to be negative that is, increases in public infrastructure have led to global private capital reductions, with an average elasticity of –0.130 in the short run and -0.167 in the long run (table 6). This result indicates that infrastructure investments have not been able to promote private investment along the analyzed period but the opposite. And this decline in private capital leads to general cost reductions so that part of the short run effect of infrastructure on costs is reversed. As a whole, this makes $?^{LR}_{CKg}$ very similar to $?^{SR}_{SCKg}$. It is worth noting that most part of the location effect is obtained in the short run, with a very small regional variation. Nevertheless, at a sectoral level, the sectors of Food, drinks and tobacco, Transport material, Metallic products and metalwork, Non-metallic minerals and products, and Chemistry present an extreme value. The most favorable situation for the location effect would have been when public capital would have attracted private investment and thus translated into cost reductions. However, the present negative relationship may

[8] Sector 8, which is Food, drinks and tobacco, presents extreme results for some of the elasticities. As a consequence, and in order to check this is not affecting the general results, the same estimation has been done without considering the data for this sector. However, since the set of effects changed only slightly, we consider preferable to present the results including this sector.

be a consequence of the restructuring process in some sectors in specific regions in the analyzed period, together with continued increments of public capital endowments in these regions, as shown by private and public capital evolution in table 2. Besides, for other sectors and regions, the effects of the business cycle could explain this negative relationship. On the other hand, this result could be understood, at least in part, as evidence of a crowding-out effect so government financial requirements could detract private investment according to the traditional argument.

Also, in the long term, the global average cost elasticity with respect to private capital (table 5) has turned into a negative value, –0.025, being negative in all sectors and regions. Firms are therefore willing to pay for a higher investment in private capital, as shown by an average shadow price of 0.03. We reach a similar conclusion when analyzing the ratio optimal and real private capital. The average value for this ratio is 2.026, indicating that firms are below the optimal level of private capital. Analyzing the temporal evolution of this ratio, although it begins with a value of 2.17, a reduction is produced in the mid-eighties, and increases again at the end of the decade. It seems, therefore, that the evolution of the ratio, with values over the unity, has experienced a similar evolution to the business cycle.

Finally, as regards the output effects, it must be pointed out that the returns to scale are slightly increasing for the Spanish manufactures, with an average value of 1.13 in the short run, increasing in the long term till 1.20. However, there is large variability especially across sectors, which is in line with the estimates for the returns to scale in some other studies using a primal approach.

5. CONCLUSIONS

In the present paper we have theoretically derived the long run effects of public infrastructure on cost and production performance from a dual approach. Previous works aiming at analyzing those effects have just considered short run responses through adjustments in variable inputs. On the contrary, herein we have allowed infrastructure endowment to interact with private capital, which has been supposed to be a quasi-fixed input. The motivation has been the belief that infrastructures may alter the performance of an economy not only through effects on variable inputs (short run) but also through a *location effect*, by which it may modify the total amount of private capital in the economy. Furthermore, the effects of private capital have also been derived for the short and long run. It allows us to compare the contribution to cost saving of both types of capital.

Applied to the Spanish regional manufactures, the present paper has estimated a cost function in a translog form, rejecting the accuracy of the Shephard´s lemma as well as the existence of long run equilibrium for private capital based on the results of several statistics. The dual approach leads us to conclude that, in average, the relationship between infrastructure and cost variations is positive, both in the short and long run. However, a threshold level in the existing public capital stock is observed, so that for low levels of public capital improvements in such stock are translated into cost reductions, whereas once this threshold level is surpassed, ulterior investments cause manufacturing activity to be more costly. Both, the results and the observation of the existing stocks along the period, reveal that this threshold was obtained for most Spanish regions at the beginning of the eighties. Finally, according to the elasticities referred to the location effect of public capital, the results show that the investments in infrastructures during this decade in Spain were not able, in general terms, to enhance private investment. This indirect effect of public capital, neglected when applying the approach traditionally used so far, is one of the most meaningful when assessing policies aiming at promoting development in less favored regions. Among the different explanations for its value in our case, one may think of the coincidence between continued increases in public capital going along with reductions in private capital in some regions and sectors, the traditional crowding-out effect, and the fact that some infrastructure investments, such as transports and communications, could exacerbate agglomeration economies hurting the less-developed regions.

Further, regional and specially sectoral variability of the effects is far from being negligible. As a consequence, conclusions on the effects of infrastructure investments based on aggregate results may be misleading. These differences in sectoral responses would support the sectoral restructuring advocated by some theoretical models on the impact of publicly provided inputs of production.

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Table 1. Description of the manufacturing groupings

S1	Metallic minerals and first transformation of metals
S2	Non metallic minerals and products
S3	Chemistry
S4	Metallic products and metalwork
S5	Agricultural and industrial machinery and equipment
S6	Electric machinery and material
S7	Transport material
S8	Food products, alcohol, drinks and tobacco
S9	Textiles, leather and shoes
S10	Paper and derivatives and printing
S11	Rubber and plastic derivatives
S12	Wood, cork and derivatives and other manufactures

Table 2. Evolution of the main magnitudes for manufactures (Spain, 1980-1991)

	SC	VC	Y	L	M	Kp	Kg
1980	17642725	16728047	19631286	2230329	24940231	11038002	6959795
1981	17165044	16161906	18883656	2078208	21287213	10934479	7033186
1982	16412582	15385034	18034353	1940444	17998205	10792445	7158079
1983	17061297	15710503	18478547	1888674	16535701	10589600	7428800
1984	16774517	15383552	18064788	1793935	14636095	10400768	7705198
1985	16737355	15417679	18247481	1702248	13718291	10289424	7932187
1986	16776266	15664091	18789110	1685525	13441986	10221182	8216566
1987	18473829	16835434	20312746	1683256	14313403	10265005	8532317
1988	20171572	18577380	22302117	1712042	15472698	10389349	8878993
1989	21635853	19998629	23881279	1753598	15934209	10625602	9320821
1990	22647357	20846814	24740422	1777382	16216936	10902753	9928209
1991	23242546	21527560	25441617	1761201	16391786	11334278	10746074
AAGR 80-91	2.32%	2.12%	2.18%	-1.95%	-3.44%	0.22%	3.69%
AAGR 80-85	-0.87%	-1.35%	-1.21%	-4.40%	-9.48%	-1.16%	2.20%
AAGR 86-91	5.58%	5.44%	5.18%	0.73%	3.36%	1.74%	4.57%

NOTE: AAGR is the average annual growth rate. All variables but labor are given in million of 1990 pesetas. Labor represents the number of workers.

Table 3. Estimation of the cost function

Coefficient	Estimate	t-Student	Coefficient	Estimate	t-Student
$?_{0}$	0.903	0.29	$?_{LY}$	-0.027	-1.98
$?_{L}$	0.463	3.67	$?_{LKp}$	0.069	4.74
$?_{Y}$	1.188	17.26	$?_{LKg}$	-0.043	-3.63
$?_{Kp}$	-0.314	-4.68	$?_{LT}$	-0.010	-4.18
$?_{Kg}$	-0.061	-0.11	$?_{Ykp}$	-0.0257	-3.12
$?_{t}$	-0.098	-3.68	$?_{Ykg}$	-0.017	-2.63
$?_{LL}$	0.003	0.09	$?_{YT}$	-0.001	-0.43
$?_{YY}$	0.026	3.05	$?_{KpKg}$	0.020	3.36
$?_{KpKp}$	0.027	3.31	$?_{KpT}$	0.002	2.02
$?_{KgKg}$	0.009	0.20	$?_{KgT}$	-0.001	-0.66
$?_{TT}$	0.008	17.95			

R^2 for the model: 0.995

Specification tests:

(F_1): F(3,2083)=11.63
(F_2): F(25,2083)=335.63
(F_3): F(14,2083)=8.45
(F_4): F(11,2083)=82.09

NOTES: The regression includes sectoral and regional fixed effects whose coefficients are not supplied to save space. Total number of observations: 2160. *F_1:* Global significance test for public capital parameters*; F_2:* Significance test for regional and sectoral dummies*; F_3:* Significance test for regional dummies*; F_4:* Significance test for sectoral dummies.

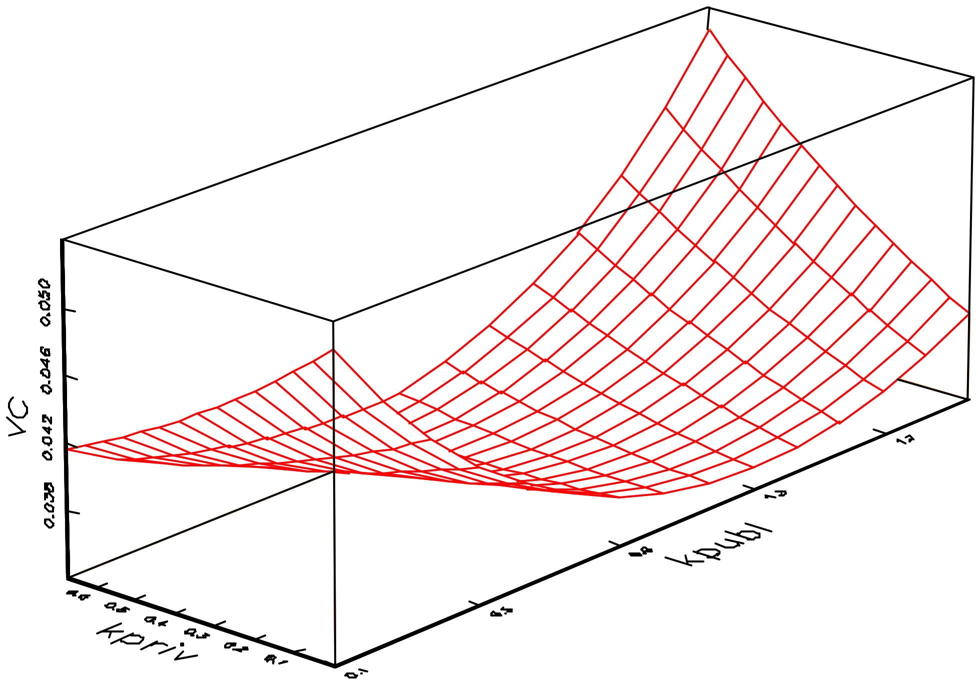

Figure 1. Behavior of costs in Spanish manufactures

Table 4. Public and private capital effects in the short run

	$?_{SCKg}$	S_{Kg}	$?_{LKg}$	$?_{MKg}$	$?_{SCKp}$	S_{Kp}	$?_{LKp}$	$?_{MKp}$
				GLOBAL AVERAGE				
	0.027	-0.011	-0.157	0.060	0.039	-0.041	0.253	-0.097
				REGIONAL AVERAGE				
AND	0.037	-0.012	-0.162	0.059	0.050	-0.052	0.262	-0.096
ARA	0.021	-0.005	-0.171	0.058	0.031	-0.036	0.277	-0.093
AST	0.024	-0.012	-0.145	0.064	0.034	-0.032	0.235	-0.104
CANT	0.014	-0.007	-0.138	0.064	0.010	-0.010	0.223	-0.103
C-L	0.021	-0.007	-0.171	0.058	0.042	-0.048	0.277	-0.093
C-M	0.031	-0.007	-0.176	0.058	0.014	-0.013	0.284	-0.093
CAT	0.031	-0.015	-0.150	0.061	0.049	-0.053	0.242	-0.098
VAL	0.033	-0.010	-0.160	0.059	0.031	-0.031	0.259	-0.095
EXT	0.034	-0.006	-0.189	0.058	-0.002	0.002	0.306	-0.093
GAL	0.029	-0.009	-0.170	0.058	0.016	-0.016	0.274	-0.094
MAD	0.015	-0.006	-0.154	0.060	0.044	-0.050	0.248	-0.097
MUR	0.025	-0.009	-0.176	0.059	-0.015	0.012	0.284	-0.095
NAV	0.010	-0.003	-0.160	0.059	0.014	-0.014	0.258	-0.095
PV	0.027	-0.011	-0.141	0.063	0.055	-0.057	0.227	-0.102
RIO	0.013	-0.004	-0.176	0.058	-0.008	0.007	0.284	-0.093
				SECTORAL AVERAGE				
S1	0.040	-0.018	-0.172	0.087	0.056	-0.050	0.278	-0.140
S2	0.032	-0.005	-0.164	0.066	0.041	-0.045	0.264	-0.106
S3	0.033	-0.011	-0.169	0.071	0.048	-0.054	0.273	-0.114
S4	0.030	-0.008	-0.203	0.073	0.029	-0.031	0.327	-0.118
S5	0.004	-0.001	-0.116	0.030	0.018	-0.025	0.188	-0.049
S6	0.007	-0.002	-0.151	0.038	0.021	-0.024	0.243	-0.061
S7	0.024	-0.011	-0.274	0.097	0.061	-0.080	0.442	-0.157
S8	0.115	-0.060	-0.664	0.261	0.025	-0.024	1.072	-0.422
S9	0.032	-0.010	-0.183	0.059	0.005	-0.005	0.295	-0.095
S10	0.014	-0.003	-0.117	0.040	0.029	-0.032	0.189	-0.065
S11	0.008	-0.001	-0.091	0.029	0.022	-0.024	0.147	-0.048
S12	0.024	-0.003	-0.137	0.042	0.007	-0.007	0.221	-0.068
				TEMPORAL AVERAGE				
1980	0.019	-0.008	-0.123	0.066	0.050	-0.045	0.199	-0.106
1981	0.023	-0.009	-0.127	0.065	0.046	-0.043	0.205	-0.105
1982	0.026	-0.010	-0.131	0.064	0.042	-0.038	0.212	-0.103
1983	0.029	-0.012	-0.137	0.063	0.036	-0.039	0.221	-0.101
1984	0.033	-0.013	-0.142	0.061	0.030	-0.032	0.230	-0.099
1985	0.035	-0.013	-0.148	0.060	0.028	-0.028	0.239	-0.098
1986	0.032	-0.012	-0.156	0.059	0.032	-0.027	0.252	-0.096
1987	0.028	-0.011	-0.164	0.058	0.034	-0.042	0.265	-0.094
1988	0.026	-0.011	-0.174	0.057	0.035	-0.042	0.281	-0.092
1989	0.024	-0.010	-0.183	0.056	0.038	-0.045	0.296	-0.091
1990	0.022	-0.009	-0.193	0.055	0.044	-0.056	0.312	-0.089
1991	0.021	-0.008	-0.204	0.055	0.050	-0.059	0.329	-0.088

The Spanish regions included in the analysis are: Andalucía (AND), Aragón (ARA), Asturias (AST), Cantabria (CANT), Castilla-León (C-L), Castilla-la-Mancha (C-M), Cataluña (CAT), Valencia (VAL), Extremadura (EXT), Galicia (GAL), Madrid (MAD), Murcia (MUR), Navarra (NAV), País Vasco (PV), La Rioja (RIO). Codes for sectors as described in table 1.

Table 5. Public and private capital effects in the long run

	$?_{CKg}$	S_{Kg}	$?_{LKg}$	$?_{MKg}$	$?_{CKp}$	S_{Kp}	Kp^*/Kp
			GLOBAL AVERAGE				
	0.029	-0.008	-0.179	0.080	-0.025	0.031	2.026
			REGIONAL AVERAGE				
AND	0.034	-0.009	-0.196	0.079	-0.012	0.017	1.684
ARA	0.025	-0.004	-0.196	0.078	-0.034	0.043	1.979
AST	0.022	-0.009	-0.173	0.082	-0.028	0.024	1.554
CANT	0.018	-0.006	-0.162	0.081	-0.050	0.045	1.775
C-L	0.025	-0.004	-0.195	0.079	-0.025	0.035	2.295
C-M	0.038	-0.006	-0.197	0.077	-0.041	0.039	2.205
CAT	0.033	-0.011	-0.168	0.081	-0.014	0.022	2.113
VAL	0.038	-0.008	-0.178	0.079	-0.030	0.035	2.144
EXT	0.041	-0.006	-0.225	0.076	-0.053	0.047	1.866
GAL	0.039	-0.008	-0.184	0.078	-0.040	0.041	2.589
MAD	0.018	-0.003	-0.173	0.081	-0.027	0.038	2.066
MUR	0.040	-0.009	-0.178	0.078	-0.066	0.055	2.736
NAV	0.020	-0.002	-0.175	0.079	-0.049	0.052	2.435
PV	0.021	-0.007	-0.172	0.081	-0.012	0.014	1.328
RIO	0.028	-0.004	-0.188	0.078	-0.068	0.065	2.764
			SECTORAL AVERAGE				
S1	0.034	-0.013	-0.212	0.109	-0.020	0.015	1.843
S2	0.025	-0.004	-0.213	0.085	-0.033	0.035	1.134
S3	0.026	-0.008	-0.215	0.091	-0.017	0.021	1.342
S4	0.035	-0.006	-0.233	0.097	-0.049	0.057	2.202
S5	0.006	-0.000	-0.135	0.043	-0.023	0.034	1.123
S6	0.011	-0.001	-0.158	0.051	-0.023	0.031	1.416
S7	0.033	-0.006	-0.306	0.131	-0.046	0.068	3.754
S8	0.181	-0.057	-0.676	0.349	-0.222	0.238	12.87
S9	0.045	-0.010	-0.195	0.079	-0.051	0.052	2.647
S10	0.012	-0.002	-0.147	0.054	-0.017	0.020	0.991
S11	0.007	-0.000	-0.114	0.040	-0.013	0.016	0.763
S12	0.029	-0.003	-0.155	0.057	-0.036	0.038	1.442
			TEMPORAL AVERAGE				
1980	0.022	-0.004	-0.144	0.090	-0.063	0.065	2.170
1981	0.025	-0.006	-0.148	0.087	-0.050	0.053	2.047
1982	0.029	-0.008	-0.151	0.085	-0.040	0.041	2.064
1983	0.031	-0.009	-0.160	0.082	-0.034	0.041	1.786
1984	0.036	-0.011	-0.164	0.080	-0.028	0.034	1.808
1985	0.039	-0.011	-0.168	0.079	-0.024	0.027	1.941
1986	0.039	-0.010	-0.171	0.079	-0.019	0.020	2.336
1987	0.030	-0.009	-0.190	0.076	-0.016	0.023	1.811
1988	0.030	-0.008	-0.195	0.076	-0.013	0.019	2.071
1989	0.028	-0.008	-0.204	0.075	-0.008	0.014	2.165
1990	0.024	-0.006	-0.219	0.074	-0.003	0.007	1.994
1991	0.022	-0.004	-0.229	0.074	0.003	0.001	2.124

Table 6. Location effect of public capital

	$?^{LR}_{KpKg}$	$?^{SR}_{KpKg}$	$?_{KpL}$	$?_{KpM}$
	GLOBAL AVERAGE			
	-0.167	-0.130	0.697	0.897
	REGIONAL AVERAGE			
AND	-0.178	-0.134	0.684	0.888
ARA	-0.178	-0.133	0.687	0.892
AST	-0.160	-0.127	0.706	0.910
CANT	-0.148	-0.117	0.719	0.927
C-L	-0.181	-0.138	0.682	0.881
C-M	-0.166	-0.121	0.700	0.915
CAT	-0.162	-0.131	0.700	0.896
VAL	-0.161	-0.124	0.701	0.905
EXT	-0.170	-0.115	0.696	0.926
GAL	-0.160	-0.121	0.706	0.916
MAD	-0.169	-0.136	0.693	0.886
MUR	-0.143	-0.108	0.724	0.941
NAV	-0.162	-0.126	0.704	0.906
PV	-0.170	-0.136	0.695	0.892
RIO	-0.158	-0.116	0.702	0.913
	SECTORAL AVERAGE			
S1	-0.206	-0.169	0.928	1.190
S2	-0.198	-0.144	0.747	0.976
S3	-0.198	-0.148	0.790	1.026
S4	-0.208	-0.155	0.861	1.119
S5	-0.116	-0.082	0.363	0.478
S6	-0.126	-0.091	0.447	0.584
S7	-0.284	-0.220	1.153	1.487
S8	-0.600	-0.489	3.165	4.060
S9	-0.163	-0.119	0.725	0.945
S10	-0.135	-0.098	0.466	0.609
S11	-0.105	-0.077	0.337	0.440
S12	-0.130	-0.091	0.518	0.681
	TEMPORAL AVERAGE			
1980	-0.177	-0.164	0.680	0.848
1981	-0.170	-0.153	0.691	0.866
1982	-0.164	-0.144	0.698	0.881
1983	-0.160	-0.133	0.704	0.897
1984	-0.156	-0.125	0.708	0.908
1985	-0.155	-0.121	0.709	0.912
1986	-0.157	-0.123	0.706	0.907
1987	-0.165	-0.119	0.701	0.913
1988	-0.166	-0.119	0.700	0.914
1989	-0.169	-0.118	0.695	0.912
1990	-0.177	-0.119	0.687	0.909
1991	-0.182	-0.121	0.680	0.902