THE EFFECTS OF PUBLIC CAPITAL ON THE GROWTH IN SPANISH PRODUCTIVITY

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The aim of the article is to provide new evidence concerning the effect of public capital on productivity growth in Spain. To this end, the article follows the growth accounting approach, which, in addition to measuring both the direct and indirect effects of public capital on the total factor productivity, allows for assessing whether there is a distinctive impact of public capital across economic sectors. The results lead to three main conclusions: (1) Public capital has a strong influence on growth when we use data from the whole economy; (2) this influence varies across sectors, being more relevant in the exposed sectors (industry) than in sheltered sectors (agriculture, construction, and services); and (3) irrespective of the definition used for public capital, these basic results remain unchanged. (*JEL* C30, E62, H54, O47, O52)

I. INTRODUCTION

Productivity growth has slowed down during the last two decades in most Organisation for Economic Co-operation and Development (OECD) countries. This fact has been accompanied by a decline in public capital spending as a share of gross domestic product (GDP). Spain and Portugal are exceptions. To promote long-term equality among countries within the European Union, these countries undertook extensive programs to upgrade their stock of public capital. As a result, gross public capital formation in Spain (as a share of GDP) is currently one of the highest in the EU area (see Table 1). On average, the real value of the country's public capital stock grew by 7.2% during 1986–91, which is considerably above that of most of the OECD countries (Sturm, 1998).

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Various authors have tried to determine the effects of public capital on productivity. Starting from the seminal paper by Aschauer (1989), it became increasingly common to believe that a link between public capital and productivity exists. The underlying tenet is that a decrease in the growth rate of public capital spending will be accompanied by a fall in the rate of growth of total productivity. This has generated a vast body of literature, attempting to identify the influence of public investment on the evolution of productivity.[1] Such influence has been traditionally investigated using two

1. The contribution of this idea to a full explanation of the issue is highly valuable; however, it is unlikely that the worldwide slowdown in productivity growth is due to just one single cause.

ABBREVIATIONS

- ADF: Augmented Dickey-Fuller Test
- GDP: Gross Domestic Product
- GMM: Generalized Method of the Moments Estimation
- IV: Instrumental Variables
- KGPR: Productive Public Capital
- KGT: Total Public Capital
- OECD: Organisation for Economic Co-operation and Development
- OLS: Ordinary Least Squares
- PP: Phillips-Perron Test
- SUR: Seemingly Unrelated Relationships
- TFP: Total Factor Productivity

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TABLE 1
Gross Fixed Public Capital Formation/GDP (%)

	1970	1975	1980	1985	1990	1995	2000
Spain/EU EU = 100	53.1	59.5	50.9	112.8	161.3	143.4	131.3

Source: Banco de España (2001).

different approaches.[2] The production function approach, followed by Aschauer (1989), Ford and Poret (1991), and Munnell (1992) among others, includes public capital as an additional productive factor to the classical inputs of labor and private capital. Assuming a specific production function, generally a Cobb-Douglas with constant returns to scale and a competitive environment, the coefficient accompanying the public capital variables reflects the (direct) effect of public capital on output.

A second procedure, often referred to as the behavioral approach, has been used in Conrad and Seitz (1994), Nadiri and Mamuneas (1994), and Morrison and Schwartz (1996) among others. This consists of deriving a cost function from a firm's dual problem of minimizing costs, where the public capital stock is included as an unpaid fixed input. The translog or the generalized Leontief specifications are usually used to approximate the cost function. From the estimation of such equations, several elasticities, which fully describe the underlying production function, can be computed.

The production function approach has been questioned, and some problems of an econometric nature have been pointed out (endogeneity, nonstationarity, omission of variables, measurement error, etc.). The rigid relationship between public and private capital implied in the Cobb-Douglas form has also been brought into question (see Sturm, 1998, for a detailed discussion of these problems). The imposition of a determined specification in the production function approach may cause bias on the estimates of the impact of public capital, as Berndt and Hanson (1992) have pointed out. On the other hand, the behavioral approach allows for any degree of complementarity or substitutability between fixed and flexible inputs. However, this property also induces the biggest problem; the flexibility of the functional form requires a tremendous amount of information to be included in the database (user costs of private and public capital, intermediate inputs, and its prices, etc.). Furthermore, there may be collinearity problems between the regressors, and the estimates are also very sensitive to the specific functional form chosen.

The results of these studies generally asserted the positive effects of public capital, but the range of results was too variable to be conclusive and many deficiencies were subsequently identified due to econometric and specification problems (Pfähler et al., 1996).[3] Once these problems had been rectified, a number of negative results were published, leading to the conclusion that the positive outcomes of earlier studies were poorly founded (Holtz-Eakin, 1994; Garcia-Milà et al., 1996). Nevertheless, studies on the Spanish economy reveal some more optimistic results (see Table 2). To summarize, not only the analyses of the impact of public capital carried out by means of the estimation of aggregate production functions but also those estimations using a dual approach based on cost functions have always obtained a positive impact of infrastructures for the whole Spanish economy. The results of Bajo and Sosvilla (1993), García-Fontes and Serra (1994), González-Páramo (1995), Más et al. (1994a, 1994b, 1995, 1996), and De la Fuente (1996), by means of the estimation of production functions, and Moreno et al. (1997) and Boscá et al. (1999, 2001), using a dual approach based on cost functions, show an important effect of public capital on output growth, especially when an infrastructure series is employed. A policy measure could be directly derived from such outcomes: "A higher amount of public investment will result in higher growth in output."

One first shortcoming of the studies using the production function approach is that the elasticity estimated in a Cobb-Douglas function, which is the most common specification, is sometimes too big to be credible. A second difficulty, common to both approaches, is that

2. Other less extended approaches include the estimation of vector autoregressive models, cross-sectional studies using country-level data, and calibrated structural models.

3. Indeed, the two approaches have been criticized on various grounds. The most serious objections are related to the assumed causality between public capital and output, the specification of the estimated model, and the time-series characteristics of the data.

TABLE 2
Productivity Effects of Public Capital in Spain

Study	Aggregation Level	Specification	Data	Output Elasticity of Public Capital
Bajo and Sosvilla (1993)	Spain	Cobb-Douglas; log-level	Time series 1964–88	0.19
García-Fontes and Serra (1994)	Spain	Cobb-Douglas; log-level	Time series 1964–88	0.27
Argimón et al. (1994)	Spain	Cobb-Douglas; log-level	Time series 1964–89	0.59
Argimón et al. (1994)	Spain	TFP	Time series 1964–89	0.13
González-Páramo (1995)	Spain	Cobb-Douglas; log-level	Time series 1964–88	0.51
Mas et al. (1994a)	17 Spanish regions (manufacturing)	Cobb-Douglas; log-level	Panel data 1980–89	0.21
Mas et al. (1995)	17 Spanish regions	Cobb-Douglas; log-level	Panel data 1980–89	0.24
Mas et al. (1996)	17 Spanish regions	Cobb-Douglas; log-level	Panel data 1980–89	0.09
De la Fuente (1996)	17 Spanish regions	Cobb-Douglas; log-level	Panel data 1980–90	0.15
Boscá et al. (1999)	17 Spanish regions	Cost function	Panel data 1964–91	0.085
Moreno et al. (1997)	4 sectors	Cobb-Douglas; log-level	Panel data 1964–91	0.0–0.14
Gil et al. (1998)	3 sectors	Cost function	Panel data 1964–91	0.14
Fernández and Polo (1999b)	7 sectors	Cobb-Douglas; log-level	Panel data 1964–91	0.0–0.30

the use of aggregate data to examine the impact of infrastructure on growth cannot be considered reliable enough to implement such recommendations. Indeed, the magnitude of the effects of public capital may vary very widely across economic sectors (see Moreno et al., 1997; Gil et al., 1998; Fernández and Polo, 1999b). The likely sectoral variability in the effects of public capital endowments would suggest that the industrial mix of the economy must be taken into account when deciding the location of these investments.

In this article, some new advances are given about this issue with three main purposes. First, rather than calculating the effects of public capital on productivity on the basis of a general production function, we start from a more specific production function to capture the effect through its influence on total factor productivity (TFP). Once we have obtained the TFP as a residual between the actual output growth and the accounted output growth due to traditional input growth, we regress such residual series against the public capital stock to capture both the direct and indirect effects on growth. Eberts (1990), Hulten and Schwab (1991, 1993), and more recently Ramírez (2000) are examples of what is known as the sources of growth analysis, or, more commonly, the accounting growth methodology. Although the methodology does have some disadvantages, these can be dealt with easily.[4] It does have two clear advantages: alleviating the simultaneity bias existing in the production function approach and capturing both the direct and indirect effect of public capital on output using a limited data set.

Second, once the effects on the aggregated output have been considered, the results of the contribution of public capital to the sectoral output are shown. In this way, the authors are able to include the differences in the impact on the different industries. The authors do believe that it is desirable to extend the study to the disaggregate level because, in addition to the gain in degrees of freedom, sectoral data could reveal some information that aggregation is unable to show. Finally, because public capital is a loose term for many different concepts, depending on the items included, this article considers alternative definitions for the public capital variable, ranging from the basic infrastructure series to an overall concept of public capital (which may include investment in social public capital, such as health or education) to obtain more robust estimates.

The results obtained lead to three main conclusions: (1) Public capital has a strong influence on growth when we use data from the whole economy; (2) this influence varies across sectors, being more relevant in the exposed

4. It can be argued that the accounting growth approach imposes an a priori specific production function and then biases the estimation. However, by comparing TFP growth with public capital growth, one can find indications for the importance of these biases. For a detailed description of the accounting growth approach, see Hulten and Schwab (1991). For a comparison of different approaches, see Sturm (1998).

sectors (industry) than in sheltered sectors (agriculture, construction, and services); and (3) irrespective of the concept of public capital used in the estimation, the basic results remain unchanged.

The rest of the article is structured as follows. The next section outlines the growth accounting methodology. Section III describes the database and carries out the stationarity analysis of series. Section IV presents the estimated results for the whole economy. Proving the existence of a positive correlation between the rate of public capital accumulation and the sectoral TFP growth rate completes the analysis. Finally, section V gives conclusions.

II. PUBLIC CAPITAL AND PRODUCTIVITY

Meade (1952) observed that public capital can affect output growth in two different ways. There is a direct effect when the use of public capital results in higher output, that is, public capital acts as an additional productive factor. But there is also an indirect effect, in which the use of public capital enhances the productivity of private inputs (labor and private capital). These different channels cause the production function approach to yield biased estimates of the impact of public capital. This problem is circumvented when using the growth accounting approach, because comparing TFP growth with public capital growth allows for the identification of these biases.

The analysis starts from the neoclassical production function:

$$(1) \qquad Y_t = A_t F(K_t, L_t),$$

where, as usual, Y is the amount of output, and L and K stand for the two classical factors, labor and capital. A represents the TFP or multifactor productivity, that is, that portion of income which is not explained by capital and labor. Operating as usual, the well-known Solow's residual equation is obtained.

$$(2) \qquad A^* = Y^* - \pi_k K^* - \pi_1 L^*,$$

where A^* represents the contribution of technical progress (TFP), and π_k, π_l are the relative share of profits and the relative share of wages in the total output, respectively. In a competitive economy (for which it is assumed that each input is paid the value of its marginal product) these relative shares coincide with the output elasticities to inputs. In equation (2) the TFP can be estimated as a residual because all other terms are directly observable. (TFP also captures, apart from the rate of change of technical efficiency, any other items, such as errors in measurement and omitted variables.)

A first assessment of the importance of TFP to Spanish growth can be obtained from calculating its value for the period 1964–91, when the average rate of GDP growth was 3.84%. TFP played a crucial role in the growth process, contributing more than 56% to growth, whereas capital added about 40% and labor did not contribute at all. This result indicates that during the period under study, growth in the private sector was primarily driven by productivity growth.

The existence of a general relationship between the growth rate of the TFP and that of the public capital stock can be established as follows. First assume a general relation $A_t \equiv TFP_t = B_t Kg^{\gamma}{}_t$ where Kg represents the public capital stock. It is assumed that the public capital-net index of technology, B_t, increases at a constant exponential rate γ_0 starting from some initial value B_0, so that $B_t = B_0 \exp\{\gamma_0 t\}$. In addition to measurement errors, this captures the influence of various activities, such as human capital accumulation or research and development spending; these contribute to the accumulation of knowledge, but a complete formal representation of the corresponding processes would be overwhelming (see Aschauer, 1989). This formulation leads to the appearance of a deterministic trend when computing the growth rates of the series.

With simple manipulation (see Diewert, 1976) one gets

$$(3) \qquad \ln(TFP_t/TFP_{t-1}) = \gamma_0 + \gamma \ln(Kg_t/Kg_{t-1}),$$

where γ_0 and γ are regression coefficients. Coefficient γ is expected to be positive and significant, indicating that public investment is augmenting productivity growth.

The empirical model is completed with the inclusion of two different additional variables. The first variable, the capacity utilization rate, is added to control the influence of the business cycle. This practice is based on the argument that the results obtained for the growth in TFP may be underestimated because the capital stock, rather than the flow of capital services, has been used. This is a consequence of data limitations both for the sectoral and the national economy. As a second variable, the first and second differences of private capital are included to check Wolff's (1991) hypothesis. According to this hypothesis, part of the technological progress may be incorporated in the new capital stock. Hence, private capital accumulation must be directly correlated with productivity growth. Before presenting the model, the next section briefly comments on the data.

III. STATIONARITY ANALYSIS

The study covers the period 1964–91 using annual data. This period offers a sufficiently long time-series data set both for public and private capital. The available information allows for the consideration of seven main sectors in the Spanish economy; these are agriculture and fishing (sector 1), energy (sector 2), mining and chemicals (sector 3), metal products and machinery (sector 4), manufactures (sector 5), construction (sector 6), and private services (sector 7). The data for employment (in number of workers) and total output (measured as the gross added value at factor costs) come from the Spanish Central Bank (Banco de España) and the Ministry of Economy and Finance (Ministerio de Economía y Hacienda), respectively. Private capital stock is taken from the series published by the Fundación Banco Bilbao-Vizcaya (1995). Two different possible definitions of public capital,[5] also provided by Fundación Banco Bilbao-Vizcaya, are included. First, the productive public capital, here called KGPR, includes roadways, harbors, waterworks, and urban infrastructures; second, the total public capital, here called KGT, is defined as KGPR plus public capital in health and education. They are constructed from the investment series by using the perpetual inventory method. Finally, the aggregate capacity utilization rate is taken from the MOISEES model (Molinas et al., 1990).[6]

To compute the TFP as the Solow residual, the authors have to include estimates for the relative share of profits and of wages in total output. The basic information (wages and total income) that the Spanish National Accounts (Contabilidad Nacional Analítica de España) provide is enough to calculate these relative shares. However, the wages/total output ratio is an incorrect proxy for the relative share of labor because it does not take into account self-employment or labor income other than wages. Therefore, the authors propose a correction that tries to include self-employment and consists of dividing the wages/total output ratio by the number of wage earners as a proportion of total workers. A second difficulty with the Spanish National Accounts is that the labor income share is not provided at the same level of detail as the rest of the data, and the authors have to assume that this value is the same for the three industrial sectors (mining and chemicals, metal products, and machinery and manufactures).[7]

A common econometric problem with time-series modeling is the likely existence of unit roots in the variables used. Nonstationary series invalidate many standard results (see Engle and Granger, 1987). The equation to be estimated in this work is in dynamic form, which means that series are first-differenced. This means that only the null of nonstationarity in the first differences has to be tested. Economic series are, by their nature, of order of integration two at most. Therefore, after one differencing they become at most of order one. Common unit root tests can be used to easily check the series' order of integration (see Charemza and Deadman, 1997, for more details).

Applying augmented Dickey-Fuller (ADF) or Phillips-Perron (PP) unit root tests to our data showed that the series used, in log differences, are of order zero or one.[8] The capital utilization rate and the aggregate and sectoral

5. In fact, we considered up to four alternative definitions for public capital coming from different databases. All of them gave very similar estimated results. To save space, we only present the final estimates for just two possible definitions, which were the most appropriate in terms of their coverage and length.

6. MOISEES is the Spanish acronym for Search and Simulation Model for the Spanish Economy, a macroeconometric model elaborated by the Ministry of Economy and Finance. It is used to describe the structural behavior of the Spanish economy, and it provides a useful tool to appraise the implementation of policy measures. See Molinas et al. (1990).

7. The labor income share is 0.77 for agriculture, 0.30 for energy, 0.55 for industry, 0.74 for construction, and 0.52 for services.

8. The order of the lag in the ADF test was determined by choosing a fairly generous value and then successively eliminating all the lags that were found to be nonsignificant (see Banerjee et al., 1993). To save space, all these results are not shown, but are available from the authors on request.

TABLE 3
Testing Constant Return to Scale

Dependent Variable (ΔTFP_t)		***KGT***			***KGPR***	
A. Aggregate estimation						
$\Delta\ln(Kg)_t$		0.392			0.342	
		(3.18)			(2.78)	
$\Delta\ln K_t$		−0.075			−0.028	
		(−0.50)			(−0.20)	
E-G		−5.24			−5.19	
	$\Delta\ln(Kg)_t$	$\Delta\ln K_t$	E-G	$\Delta\ln(Kg)_t$	$\Delta\ln K_t$	E-G
B. Sectoral estimation						
Agriculture and fishing	0.14	0.15	−9.38	0.03	0.22	−9.31
	(0.26)	(0.45)		(0.07)	(0.68)	
Energy	0.48	−0.19	−4.95	0.58	−0.18	−4.95
	(3.63)	(−1.06)		(2.05)	(−0.87)	
Mining and chemicals	0.39	0.38	−4.36	0.44	0.37	−4.41
	(1.84)	(1.58)		(1.69)	(1.42)	
Metal products and machinery	0.39	0.22	−5.03	0.44	0.19	−4.92
	(1.82)	(0.68)		(1.70)	(0.56)	
Manufactures	0.56	−0.29	−5.95	0.63	−0.31	−5.93
	(3.78)	(−1.68)		(3.59)	(−1.72)	
Construction	0.22	−0.12	−3.61	0.28	−0.14	−3.62
	(1.09)	(−1.35)		(1.27)	(−1.51)	
Private services	0.27	−0.16	−4.18	0.12	−0.14	−4.22
	(1.90)	(−1.53)		(0.74)	(−1.47)	

Notes: Estimates for the intercepts are not shown. *t*-Statistics in parentheses. E-G is the Engle-Granger cointegration test. Critical values are −4.10 at 5% and −4.64 at 1%. Variables: Kg_t: public capital; K_t: private capital; *KGT:* total public capital; *KGPR:* productive public capital.

TFP series were found to be stationary. However, the series for capital (public and private) needed a further differencing to become stationary.[9] This situation must be carefully considered when making estimations to avoid the risk that spurious correlations may misinform any inference (Engle and Granger, 1987).

IV. TFP AND PUBLIC CAPITAL: AN EMPIRICAL ANALYSIS

In this section, the following equation is estimated for the Spanish economy to identify the effect of public capital investment on TFP growth.

$$(4)\qquad \ln(TFP_t/TFP_{t-1}) = \gamma_0 + \gamma\ln(Kg_t/Kg_{t-1}) + \gamma_1\ln(Cu_t/Cu_{t-1}) + \gamma_2\ln(K_{t-1}/K_{t-2}) + \epsilon_t.$$

9. This result is not surprising. Fernández and Polo (1999b) also find that Spanish public capital series are of order two. Sturm (1998) reports values of Dutch public capital series indicating that they are stationary only in the second differences.

Changes in the degree of the capacity utilization rate and private capital growth (one period lagged) have been added to equation (4). A second lagged value of private capital, to test Wolff's hypothesis, consistently gave nonsignificant results and was therefore not included. As indicated earlier, the dependent variable is stationary, whereas some of the independent variables are not. Therefore, to make consistent inferences there must be at least one cointegrating relationship among these nonstationary variables. Whether cointegration is satisfied or not is tested in all regressions run throughout the article, by using the Engle-Granger test (see Charemza and Deadman, 1997). The null of no cointegration is usually rejected.

To compute TFP, a production function presenting constant returns to scale is assumed. There is a clear loss of generality in this assumed functional form, which may cause serious biases in the estimates. To appraise the extent of these biases, the hypothesis of constant returns to scale is tested following Hulten and Schwab (1991, p. 81). The results of this test are presented in Table 3, in which significance of the private capital coefficient is studied. They do not reject the null hypothesis. Consequently, the consideration of this assumption will result in more efficient estimates and will be imposed when computing the TFP throughout the article. (This finding is very common for the Spanish case, either in aggregate, regional, or sectoral terms; see Argimón et al. [1994]; Mas et al. [1996]; Boscá et al. [1999].)

One of the major advantages of the present approach is that it avoids the endogeneity bias arising from the simultaneous determination of the amount of output and of inputs in the production function approach. Furthermore, by estimating an equation like (4) we can control the biases induced by measurement errors and/or omitted variables. Therefore, the ordinary least squares (OLS) estimation is preferred to the instrumental variables (IV) or generalized method of the moments (GMM) estimation.[10]

Estimated values for different assumptions about the true relationship between output growth and accumulation of public capital are now presented.

A. Aggregate Estimation

One single time-series equation for the whole Spanish economy is included here. Using OLS we estimate an equation such as

$$(5) \qquad \Delta tfp_t = a_0 + \beta_g \Delta kg_t + \beta_{cu} \Delta cu_t + \beta_k \Delta k_{t-1} + \nu_t,$$

where the lowercase letters represent the logs of the corresponding variables. The estimation results are reported in the upper half of Table 4. Irrespective of the definition of public capital employed, we find similar results. The degree of capacity utilization and public capital investment coefficients are significantly positive. Lagged private capital is nonsignificant at any significance level, and Wolff's hypothesis is therefore rejected. These results fit well with those found in Argimón et al. (1994), which use both different series of public capital and different relative share of wages in total output, and with the general result obtained in all the work devoted to the Spanish case (see Table 2).

10. As expected, the IV or GMM estimates do not substantially differ from the OLS (shown in the tables). Thus, they are not given here, but are available from the authors on request.

TABLE 4
Aggregate and Pool/Panel Estimates

Dependent Variable (*TFP*)	***KGT***	***KGPR***
A. Aggregate estimation		
Δkg_t	0.32	0.34
	(3.53)	(3.22)
Δcu_t	0.23	0.24
	(2.49)	(2.48)
Δk_{t-1}	−0.001	0.009
	(−0.02)	(0.09)
SE	0.0138	0.0139
DW	1.95	1.95
EG	−5.21	−5.24
B. Pool/panel estimation		
Δkg_t	0.38	0.40
	(5.44)	(4.72)
Δcu_t	0.28	0.30
	(3.74)	(3.85)
Δk_{t-1}	−0.29	−0.21
	(−3.10)	(−2.90)
EG	−4.45	−4.81

Notes: *t*-statistics in parentheses. Estimates are robust to problems of heteroscedasticity and serial correlation (Newey-West procedure). When DW or LM tests suggest the possible existence of problems of serial correlation, we correct for first-order autocorrelation estimating by NLS (Marquardt algorithm). SE is the standard errors of the estimation. EG is the Engle-Granger cointegration test, with critical values at −3.74 at 5% significance level, −4.29 at 1%, −4.10 at 5%, and −4.81 at 1%, respectively. *KGT:* total public capital; *KGPR:* productive public capital. Variables: kg_t: public capital in logs; k_t: private capital in logs; cu_t: capacity utilization rate in logs.

The premise of asymmetric behavior of structurally different sectors suggested that it would be useful to carry out the study of the impact of public capital on productivity at a disaggregate level. The performance of the production process, costs structure, employment, gross added value, and so on, largely justifies this premise. We now investigate this possibility by looking into the seven main sectors of the Spanish economy.

B. Sectoral Estimation

The study of the sectoral impact of public capital investment on productivity growth is undertaken in two alternative ways. First, the authors use sectoral information but impose (without testing), common parameters for explanatory variables across sectors. If a common parameter is considered for each regressor, they are estimating a pool. When the authors assume that differences across sectors can be captured by the value of an intercept, they are estimating a panel. The availability of sectoral data enables us to improve estimates because of their higher variability relative to aggregate data. However, the imposition of a common behavior of variables across sectors may not be innocuous, and the estimates would then become biased. This leads the authors to study the sectoral influence of public capital by following a second approach.

This article estimates sectoral equations, allowing all coefficients of explanatory variables to vary across sectors, and establish whether one can accept the null of a common slope across sectors. The system of sectoral equations can be estimated by OLS, if one believes that there is no relationship among different sectors or, more reasonably, considering seemingly unrelated relationships (SUR) when they think that contemporaneous correlations among sectors may arise in the joint estimation. In all cases, the authors allow for different structures of the variance–covariance matrix, estimating with the general procedure proposed by White (1980), which corrects unknown structures of heteroscedasticity and serial correlation. As before, endogeneity bias does not appear to be relevant, and thus IV or GMM estimation do not substantially alter the results.

The authors face, consequently, a double estimation procedure. First, they assume constant elasticities across sectors. Although this assumption will be tested within the second procedure, it seems interesting to start with it because the authors can then make some comparisons with the outcome obtained in the aggregate case and with other previous studies. Further, this exercise allows assessment of whether the group-effect bias (Moulton, 1986) is affecting the estimates or not.[11] Second, the authors estimate sectoral equations and test whether some coefficients are the same across sectors.

Constant Elasticities across Sectors. The authors estimate a pool (common parameter for all variables including the intercept),

$$(6)\qquad \Delta tfp_{it} = a_0 + \beta_g \Delta kg_{it} + \beta_{cu} \Delta cu_{it} + \beta_k \Delta k_{it-1} + \nu_{it},$$

and a panel (sectoral heterogeneity is assumed to be captured by fixed effects),

$$(7)\qquad \Delta tfp_{it} = a_{0i} + \beta_g \Delta kg_{it} + \beta_{cu} \Delta cu_{it} + \beta_k \Delta k_{it-1} + \upsilon_{it}.$$

However, when estimating equation (6), the common intercept is not significant. The panel estimation finds that the fixed effect becomes significant only in the first sector (agriculture). This is due to the fact that the TFP_1 series is stationary around a constant and a deterministic trend in levels; both an intercept and a trend must then appear in the regression equation. The series are, in any case, cointegrated (results not shown, but available from the authors on request). The results presented in the lower half of Table 4, therefore, can be interpreted as coming either from a pool or from panel estimation. Public capital investment and the rate of utilization of capital still exert a positive influence that is slightly higher than in the aggregate estimation. On the other hand, lagged private capital enters with a negative coefficient, not only refuting Wolff's hypothesis but running counter to it. Even though one might conjecture that this is due to some congestion problems or to some kind of trade-off or substitutability between the two types of capital, it seems more reasonable that this result arises mainly from the incorrect imposition of common slopes across equations. The article will prove that the null of common elasticities across sectors is strongly rejected and that unrestricted estimation, where lagged public capital is not significant in most cases, is then preferred.

Sectoral Equations. The highest degree of heterogeneity is achieved when estimating individual regressions. All parameters are allowed to vary across sectors. This means working with an equation, such as

$$(8)\qquad \Delta tfp_{it} = a_{0i} + \beta_{gi} \Delta kg_{it} + \beta_{cui} \Delta cu_{it} + \beta_{ki} \Delta k_{it-1} + \xi_{it}.$$

11. When one of the independent variables is more aggregated than the dependent variable, the disturbances belonging to the same group may be correlated. This generates standard deviations to be downward-biased, and then t-statistics to be biased upward, so that the variables are spuriously found as significant. To control this source of bias, a cell-mean estimation or the use of panel data are generally applied (see Moulton, 1986).

TABLE 5
Sectoral Estimates

Dependent Variable (*TFP*)	(S.1)	(S.2)	(S.3)	(S.4)	(S.5)	(S.6)	(S.7)
A. KGT sectoral estimation							
Δkg_t	−0.57	0.35	0.63	0.52	0.50	0.28	−0.07
	(−1.20)	(3.03)	(3.41)	(2.57)	(4.70)	(1.93)	(−0.90)
Δcu_t	−0.079	0.76	0.54	0.70	0.28	0.15	0.15
	(−2.24)	(2.80)	(2.56)	(3.00)	(2.74)	(0.58)	(1.65)
Δk_{t-1}	−1.79	—	—	—	−0.40	−0.14	—
	(−2.40)				(−2.27)	(−1.94)	
B. KGPR sectoral estimation							
Δkg_t	−0.59	0.40	0.71	0.57	0.46	0.31	−0.08
	(−1.47)	(3.06)	(4.30)	(4.36)	(2.38)	(1.82)	(−0.77)
Δcu_t	−0.81	0.78	0.64	0.93	0.24	0.21	0.17
	(−2.30)	(2.84)	(2.94)	(3.40)	(2.52)	(0.82)	(1.83)
Δk_{t-1}	−1.66	—	—	—	−0.69	−0.15	—
	(−2.32)				(−2.96)	(−1.94)	

Notes: *t*-statistics in parentheses. In equations (S1), (S3), (S4), (S5), and (S7) an autoregressive parameter was included. Estimates are robust against problems of heteroscedasticity and serial correlation (Newey-West procedure). See also notes to Table 4.

Table 5 shows the SUR estimates of sectoral coefficients for the two alternative definitions of public capital. The main point to be highlighted is that the null of common elasticities across sectors is strongly rejected by a Wald test for all cases.[12] It can be observed that productivity in exposed sectors (industry) is prompted by public capital, whereas more sheltered sectors (agriculture and services) receive no influence from public investment. In agriculture, productivity growth is mainly guided by a deterministic trend, which can capture effects from outside variables. In any case, the continued decreased in agriculture productivity since 1970 may mislead any inference. In services, only the rate of capacity utilization seems to have relevance in explaining the growth in productivity.

The results show a marked sectoral variation in the impact of public capital investment on productivity growth. Whereas sheltered sectors do not receive any (or very little) influence from public capital spending, industrial sectors show a high coefficient, averaging 0.50, reflecting the great importance of capital accumulation on industrial productivity growth. Thus, estimates show that aggregate estimation may hide important differences among sectors that are only unveiled when a sectoral estimation is carried out.

12. The test values of the null of common behavior across sectors are (when the public capital variable used is *KGPR*) $\chi^2_7 = 41.95$ for public capital and $\chi^2_7 = 22.33$ for the capacity utilization rate. When the variable *KGT* proxies the public capital, the values are $\chi^2_7 = 27.99$ for public capital and $\chi^2_7 = 22.33$ for the capacity utilization rate. The critical values are $\chi^2_7(0.05) = 14.1$ and $\chi^2_7(0.01) = 18.5$. The null of a common slope is then strongly rejected.

V. CONCLUSIONS

This article examines the influence of public capital spending on productivity growth in the Spanish economy during the period 1964–91. Throughout these years, public capital, as a share of GDP, has kept increasing, as has productivity. Various authors have tried to determine the effects of public capital on productivity. This has generated a vast body of literature attempting to identify the influence of public investment on the evolution of productivity on the Spanish economy, which reveals some optimistic results. To summarize, not only the analyses of the impact of public capital carried out by means of the estimation of aggregate production functions but also those estimations using a dual approach based on cost functions have always obtained a positive impact of infrastructures for the whole Spanish economy. Nevertheless, the elasticity estimated in a Cobb-Douglas function, which is the most common specification in these studies, is sometimes too big to be credible. Furthermore, the likely sectoral variability in the effects of public capital endowments would suggest that the industrial mix of the economy must be taken into account.

In this article, some new advances are given about this issue to obtain more robust estimates. First, it applies an alternative approach (the growth accounting methodology) to assess the effects of public capital investment on productivity growth. It presents two outstanding advantages with respect to other procedures: (1) It avoids the simultaneity bias in the production function approach and (2) uses a limited size of data to capture both the direct and the indirect effect of public capital in output. Second, provided that not all the sectors in an economy obtain the same benefits from public capital, it is concerned about the aggregate and sectoral levels. Finally, it considers alternative definitions for the concept of public capital, because the various types of public infrastructures may not have the same kind of impact. The results strongly suggest that public capital formation can be considered a relevant instrument to improve competitiveness by increasing private productivity.

Considering sectoral data for the seven main branches of the Spanish economy, public capital spending seems to be especially relevant in raising productivity growth only in industry and energy. The rest of the sectors, agriculture, construction, and services, show no (or very loose) links between the accumulation of public capital and productivity gain. In the authors' opinion, public capital has increased the accessibility of firms and reduced costs, making the expansion process and growth possible. This is consistent with the idea that infrastructure is a necessary condition for growth and suggests that a distinction between sectors is of importance because the effects of public infrastructures vary considerably across industries. Finally, these conclusions hold no matter which concept of public capital is used.

Two extensions to this work are immediately apparent. First, inclusion of information about variables related to endogenous growth, such as human capital or research and development spending. The use of these variables is subject to the availability of information in sectoral terms (for the whole Spanish economy, see Fernández and Polo, 1999a). The omission of these variables may bias upward the effect of public capital on productivity (the authors have tried to mitigate this bias by including a deterministic trend and by testing Wolff's hypothesis, which explains technical progress by private capital accumulation). Second, it would be of interest to study, at a higher disaggregate level, the effect of public capital on productivity. In particular the authors may be interested in studying the case of the sectors that make up both industry and services. To the industry branch belong, on one side, high capital-intensive or dynamic sectors (such as chemicals, transport, and office machines, among others) and, on the other side, low capital-intensive or lagging sectors (such as basis metal industries, metal products, and textiles, among others). Thus, it is to be expected that a different effect of public capital will exist in each type of industrial sector. Regarding services, new developments in telecommunications should be reflected in a higher influence of public capital on those sectors, such as finance and banking, which are strongly dependent on them. The influence of public capital on sectors such as tourism and transport would undoubtedly be relevant as well.

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