DOMESTIC AND CROSS-BORDER EFFECTS OF PUBLIC CAPITAL: A SVAR APPROACH FOR THE SPANISH REGIONS

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Abstract

Within the approaches that have been applied to assess the impact of public capital on economic growth, this paper estimates the dynamic effects of public infrastructures using a structural vector autoregressive (SVAR) methodology for the Spanish regions. From a methodological point of view, our work contains different innovative features with respect to the previous studies using VAR models. The most relevant contribution is to propose a new way (through bi-regional models) to estimate the spillover effects of public capital in a region on the economic growth of the rest of regions of the country. From a policy perspective, the results highlight how these new models could contribute to the allocation of public investments in order to give promote balanced regional growth, shedding new insights into the analysis of regional economic growth processes.

JEL classification: C32; E62; H54; R53

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1. INTRODUCTION

Over the last two decades, considerable attention has been paid to the impact of public capital on regional economic growth. The theoretical arguments pointing to the role of public capital on economic development are embodied in many of the "New Growth Theory" and "New Economic Geography" models. These models challenge traditional Neo-Classical Growth Models, which predicted regional convergence without a specific theoretical consideration of the role of public capital: steady-state income per capita is assumed to be independent of the initial conditions, no matter the size of the inherited differences in capital stock.

In contrast, Endogenous-Growth Theory was based on the existence of increasing returns and positive externalities (Romer 1986; 1990, Lucas 1988; 1993), where the existence of increasing returns could be explained by an intensive investment in knowledge, human capital or infrastructure (e.g., Barro, 1990). In this theoretical context, Barro and Sala-i-Martin (1992) analyzed the growth effects of the flow of productive government spending, while Turnovsky (1997) and Aschauer (2000) considered the growth effects of the stock of public capital. Therefore, the stock of public infrastructures could be among the significant variables conditioning the level and growth of regional productivity, and thus government policy, through its expenditure programs on public capital over space, would have the potential to affect the long-run growth rate of a regional economy.

On the other hand, in the early 1990s the models of the New Economic Geography provided explanations for the formation of a large variety of economic agglomerations in geographical space (Fujita and Krugman, 2004). This new line of research emphasizes the interaction among increasing returns to scale, transportation costs (broadly defined) and the movement of productive factors. According to Fujita and Thisse (2002), public expenditure is fundamental in both the reduction of transport costs and in the supply of local public goods, playing a key role in the critical trade-off between increasing returns and transport costs. The general belief is that public capital could increase the productivity of private factors, thereby generating a significant impact on growth. Accordingly, it becomes essential (from a policy evaluation point of view) to have a quantifiable measure of the impact of public investment on the growth performance of receiving economies.

The consideration of spillover effects is required in the analysis of the aggregate effects of the public capital provision at the regional level (see, for example, Holtz-Eakin and Schwartz, 1995; Boarnet, 1998; and Pereira and Roca-Sagalés, 2003). Spillover effects, understood as positive or negative externalities derived from the impact of the public capital provision in a region, have to be considered when investigating the effects of public capital in one region on the production of other regions.

In the present paper, the dynamic effects of public capital for the 17 regions that make up Spain are measured using a 'structural' VAR (SVAR) approach. The dynamic effects will be considered from both a domestic and a cross-border perspective. From a methodological point of view, our work contains several innovative features that can be viewed as a contribution to the existing empirical literature. First, the important issues of the stationarity of the data and the existence and estimation of cointegrating relationships in the long-run are addressed in the context of the new tools proposed recently for the analysis of panel data; these tools allow for heterogeneity in parameters and dynamics across regions.[1] In this sense, to our knowledge, none of the existing studies of the impact of public capital investment on the economic growth performance using multi-region panel data has applied panel integration and cointegration techniques to analyze the long-run determinants of regional growth processes. Secondly, based on our integration and cointegration results, we use vector error correction (VEC) models to produce consistent estimates of impulse responses, contrary to many researchers who have estimated unrestricted VAR models in levels or VAR models in first differences. These models might produce inconsistent estimates of impulse response functions. Thirdly, and most important, a new way (through bi-regional models) is proposed to estimate the spillover effects of public capital in a region on the economic growth of any another region, providing a new way to test for the existence of spillover effects. In the aforementioned SVAR context, the present study is the first attempt to investigate the spillover effects of the provision of public capital in a region on the production of every one of the rest of regions of the country. As a consequence, this investigation would be helpful in simulating the contribution to regional economic growth of the provision of public capital in a determined region and thus assist in formulating economic policies.

The remainder of the paper is organized as follows. In Section 2, a brief review of the theoretical and empirical literature on public capital and economic growth is presented, with special reference to the Spanish regional case. In Section 3, a brief description of the data properties is provided and the basic and extended empirical results are reported and discussed. Section 4 concludes the paper.

2. PUBLIC CAPITAL AND ECONOMIC GROWTH: A BRIEF REVIEW OF THE THEORETICAL AND EMPIRICAL LITERATURE (WITH SPECIAL REFERENCE TO THE SPANISH CASE)

Among the alternative methods used to provide an estimation of the impact of public capital on regional economic growth, the most common methods are the production function, the cost function and the vector autoregression (VAR) approaches. The production function approach

[1] To separate the long run behaviour from the short run dynamics it is necessary that the variables under consideration are nonstationary (typically integrated of order one, I(1)), so that the errors from the long-term cointegrating relationships could be stationary.

was first used by Aschauer (1989), where an estimate of the output elasticity of public capital stock is reported. Aschauer's "public capital hypothesis" suggests that public investment in infrastructure increases private productivity. This hypothesis has been confirmed by some authors, and rejected by others (see Sturm *et al.*, 1998, for a survey). Typical examples of the production function approach would be Munnell (1990), García-Milá and McGuire (1992), Holtz-Eakin (1994), and Evans and Karras (1994a, 1994b). In the Spanish case, Bajo and Sosvilla (1993), Mas *et al*. (1994), de la Fuente and Doménech (2006) and de la Fuente (2008) among others used this approach.

The single-equation regression model used by Aschauer has potential econometric problems like spurious regression due to non-stationarity of the data, possible misspecification of the production function, endogeneity and/or the direction of causality from public capital to productivity. With respect to the problem of the spurious regression, cointegration theory provides a means of approaching this problem, taking into account the non-stationarity problem. Missing variables makes reference to the possible omission of relevant variables like those indicates by the New Growth Theory (e.g., knowledge, human capital, R&D investment, etc.). Finally, the direction of causality, that is, the possible influence from economic growth on public capital, causing a problem of endogeneity, is one of the main drawbacks of the production function approach. Additionally, at the regional level, the estimation of the regional impact of public capital by means a production function would have to consider the existence of spillover effects (Kelejian and Robinson, 1997; Mas, 2000). Spillover effects, understood as externalities that lead to increasing returns to scale, could play a key role in regional economic performance. Hence, the impact of public capital provision in a region could have important effects on other regions. The existence of these spatial spillovers of public capital (positive or negative) could be attributed, among others, to the network characteristics of most elements composing the public capital (e.g., roads, railways, airports, urban structures, etc.), whereby changes in the stock of public capital in one region could affect production in other regions.

Another alternative empirical method employed to address the problem of the estimation of the impact of public capital on economic growth is the cost function approach, based on duality theory. The cost function approach measures the impact of public capital on economic growth in terms of cost-saving benefits, evaluating whether costs decrease with public capital provision.

Within this approach, the pioneer work of Deno (1988) stimulated studies at the regional level (e.g., Seitz and Licht, 1995; and Morrison and Schwartz, 1996). For the Spanish case, Boscá *et al.* (2002) obtained the shadow prices (reduction in variable costs of production due to an additional public capital investment) for the Spanish Regions, while Ezcurra *et al.* (2005) estimated regional cost functions for the regions of Spain examining the impact of infrastructure on productivity. The requirement of data for this type of approach is greater than in the case of the production-function approach, but the main advantage is that the cost-function approach is more flexible than the production-function approach.

In recent years, vector autoregressive (VAR) models have been estimated in order to test the significance of the dynamic effects of public capital on economic growth. In the context of the VAR models, the impulse response analysis is the fundamental tool to simulate the effect that an unexpected change of the public capital would have on another variable, for example, the value of regional production. The VAR approach presents some advantages with respect to the other approaches previously discussed. According to Kamps (2005): this approach does not assume, a priori, causal links between the model variables; it allows for the existence of indirect links between the variables; and provides the opportunity to test the number of long-run (cointegration) relationships among the variables under investigation. In other words, vector autoregression models facilitate testing the underlying causal relationship in the production function; they make possible the estimation of the long-term effect of a change of the public capital on output through consideration of the effects derived though the interactions of the model; and they allow explicit testing for the number of long-run relationships (the cointegration rank). In this sense, if the number of cointegration relationships is estimated consistently, the vector error correction (VEC) models produce consistent estimates of impulse response functions.

With respect to the empirical literature where the VAR methodology has been used to simulate the effects of unexpected changes in the public capital on regional macroeconomic variables for the case of the Spanish regions, a few studies like Pereira and Roca-Sagalés (1999, 2001) can be found. Further, Pereira and Roca-Sagalés (2003) investigated the existence of regional spillover effects of public capital formation in the economic regional system of Spain.

3. THE DYNAMIC EFFECTS OF PUBLIC CAPITAL ON THE SPANISH REGIONS: NEW EVIDENCE FROM STRUCTURAL VAR MODELS

This section describes an empirical application analyzing the domestic and cross-border effects of public capital for the Spanish regions. This empirical section is organized as follows. First, the data used to implement the structural-VAR (SVAR) approach for the Spanish regions are presented. Secondly, panel integration tests are applied to the data-set, and the empirical results for unit roots are reported. Next, to provide more efficient estimates, recent panel cointegration tests are employed as an alternative to the traditional tests, and the empirical results on the estimation of the long-run equilibrium cointegrating relationship are presented. Finally, individual and bi-regional structural-VEC (SVEC) models are estimated and the results of an impulse response analysis based on a set of identifying assumptions are shown.

<<insert figure 1 here>>

3.1. Spanish regions and data

Spain is a decentralized state of the European Union composed of 17 regions and Ceuta and Melilla, two Spanish North African cities that constitute the so-called Autonomous Communities.[2] In the present work, data availability will restrict the analysis only to the 17 regions in Spain (see figure 1). The Spanish regional system has a marked economic core-periphery pattern, with an unequal economic geography. Traditionally, the peninsular economic periphery is comprised of Castilla-León, Castilla-La Mancha and Extremadura while Madrid, País Vasco, Cataluña and Valencia make up the economic core. Galicia, Andalucía, Murcia, Baleares Island and Canarias Islands are also considered as “peripheral” regions; while Navarra, La Rioja, and Aragón may be considered as “core” regions. Finally, Asturias and Cantabria are historical “core” regions, but currently experiencing significant industrial restructuring processes.

Accordingly, the panel data-set contains 17 regions over the period 1972-2000, and for each region the variables used are the public net capital stock (*PK*), the private net capital stock, (*K*), the number of employed persons (*E*), and the real Gross Added Value, (*Y*). The regional series for *Y* have been drawn from the Instituto Nacional de Estadística (INE) of Spain and from the

[2] The Autonomous Communities have achieved the status of self-governed territories, sharing governance with the Spanish central government within their respective territories.

Hispadat database (see Pulido and Cabrer, 1994, and Cabrer, 2001) and the time series for *PK*, *K* and *E* have been taken from the Instituto Valenciano de Investigaciones Económicas (IVIE) of Spain. The regional public capital stock comprises public capital owned by the local, regional and national administrations, including transport infrastructures (roads, ports, airports and railways), water and sewage facilities and urban structures.

Table 1 displays selected summary indicators for the 17 Spanish regions, presenting some relevant data about the geographical distribution of the aforementioned variables for the (approximately) three decades comprising the database (1972-1980, 1981-1990 and 1990-2000). As the table shows, there are clear regional disparities in the geographical distribution of output, employment, and private and public capital stocks. These sharp disparities could be shown, for example, in the case of two regions like Madrid and Extremadura. Madrid has an area corresponding to 1.6% of the Spanish regional system. During the first (third) sub-period, Madrid produces 15.7% (16.6%) of the aggregate output, it has 12.1% (13.7%) of the total employment, 15.4% (15.3%) of private capital stock and 10.6% (10.0%) of public capital stock of Spain. Conversely, Extremadura, with 8.3% of the total area, during the first (third) sub-period account only for 1.7% (1.8%) of the Spanish output, it represents 2.7% (2.3%) of the total employment, 1.8% (1.9%) of private capital and 3.1% (3.3%) of public infrastructures of Spain.

<<insert tables 1, 2 here>>

In addition, the average ratios of public capital to output for the three sub-periods are displayed in table 2 for the 17 Spanish regions. The average ratio for Spain has increased, starting at 27.4% in 1972-1980 and reaching 43.0% in 1990-2000. Since the first sub-period, public capital as a share of total gross added value (GAV) has increased in all Spanish regions. There is no evidence of the existence of convergence regarding public capital to GAV ratios among the Spanish regions: the standard deviation of the public capital to GAV ratio increased from 12.5% during the period 1972-1980 to 16.5% in the last period 1990-2000. Besides, in all the periods, there are three regions that are under the Spanish average in terms of relative concentration of public capital: Baleares, Cataluña and Madrid. On the other side, Extremadura, Castilla-La Mancha and Castilla-León show a high percentage of public capital with respect to their respective outputs.

3.2. Testing for panel unit roots and cointegration, and estimation of the long-run equilibrium production function

The empirical analysis begins with an evaluation of the stationarity of the four variables of the database using panel unit root tests starts.[3] All panel tests used are based on the null hypothesis of the presence of a unit root in the series, with the exception of Hadri's (2000) test, whose hypothesis is that the series are stationary. The tests differ from each other on the restrictions imposed on the autoregressive process of each of the panel series. Thus, the tests of Levin, Lin and Chu (2002), Breitung (2000) and Hadri (2000) impose a common persistence parameter to all the series. Therefore, if the null is rejected, the alternative would be that all the series are simultaneously stationary for the first two tests and non-stationary for the latter. Alternatively, the tests of Im, Pesaran and Shin (2003) and the Fisher-type tests suggested by Maddala and Wu (1999) allow for the autoregressive parameter to change freely among the different regional variables under consideration. Therefore, the alternative hypothesis in these cases is the presence of a non-null proportion of stationary series of the total. The latter set of tests seem more adequate from an empirical point of view as they impose less restrictions on the data generating process.

<<insert table 3 here>>

A general overview of the statistics, presented in table 3, shows the evidence to clearly favor the hypothesis that the four basic variables considered behave as non-stationary variables, with a unit root at least for a non-negligible fraction of the 17 regions of the panel. Indeed, only for the variable *K*, in logs, do the test statistics show evidence favorable to the hypothesis of stationarity of the corresponding time series (in table 3 a deterministic linear trend is included in the specifications, but if not, the unit root hypothesis is clearly not rejected). Since the test results generally support the unit root hypothesis, from now it is assumed that all time series under consideration (all in log values) are integrated of order one. This makes it possible to distinguish between short-run and long-run relations, and to interpret the long-run relations as cointegrating relationships.

[3] The use of panel unit root tests is justified by the results from recent studies (see Banerjee (1999), Baltagi and Kao (2000) or Breitung and Pesaran (2008), among others), which suggest that unit root tests based on panel data are more powerful than those based on individual data.

To analyze the existence of cointegration between the four variables considered, three tests were applied. Two of then, those of Pedroni (1999, 2004) and Kao (1999), are residual-based tests which assume a single cointegrating vector; while the third test, of Maddala and Wu (1999), allows for multiple cointegrating relationships.[4] On the other hand, not all the tests used assume the same degree of individual heterogeneity; while the Pedroni and Maddala-Wu statistics allow the coefficients of each cointegration relation to vary freely for each region, the Kao approach assumes panel homogeneity.

<<insert tables 4, 5 and 6 here>>

The estimates of the various cointegration statistics are presented in tables 4, 5 and 6. As a general assessment of the values presented in these tables, one can deduce that there is considerable evidence pointing to the existence of cointegration between the real GAV and the input-production variables for the panel of 17 Spanish regions. Thus, in the case of the Pedroni statistics, all the three versions of the PP and ADF statistics strongly reject the non-cointegration hypothesis. The Fisher type and Kao statistics also corroborate the existence of a stable long-run relationship. Therefore, the overall evidence is consistently in favor of the existence of an aggregate production function as a long-run equilibrium relationship.[5]

The next step is to estimate the parameters of the detected long-run equilibrium production function. The estimated equilibrium relationship has the following expression:

$$y_{it} = \beta_{0,i} + \beta_1 e_{it} + \beta_2 k_{it} + \beta_3 pk_{it} + \beta_4 t + v_{it}$$

where $y = \log Y$, $e = \log E$, $k = \log K$ and $pk = \log PK$. Homogeneity in the slopes is assumed, fixed-region effects ($\beta_{0,i}$) are permitted in order to control for time-invariant regional heterogeneity, and a temporal trend (*t*) is introduced to take into account the time evolution of the technical progress.[6] Then, due to the homogeneity-slopes hypothesis assumed in the above

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[4] See Gutierrez (2003) for a Monte Carlo analysis of the statistical properties of these tests.

[5] With respect to the Maddala-Wu results, it is known that the Johansen tests –the kernel of the Maddala-Wu statistics- for the second and subsequent cointegrating vector suffer from substantial size distortions and tend to find multiple cointegrating vectors when the ratio of data observations to the number of parameters is relatively small (Maddala and Kim, 1998). This might explain the non rejection of the hypothesis of the presence of two cointegrating vectors both in maximal eigenvalue and trace statistics.

[6] Also, introducing a trend in the long-run relation ensures that the deterministic trend properties of the VEC models estimated later remain invariants to the cointegrating rank assumptions (Pesaran *et al*., 2000).

specification, the estimated relation must be interpreted as an average equilibrium production function for the panel of 17 Spanish regions.[7]

With respect to the technique chosen to estimate the equilibrium relationship, and given that ordinary least squares (OLS) estimates of the long-run model would suffer from asymptotic bias (Kao and Chiang, 2000), the so-called Dynamic Seemingly Unrelated Cointegrating Regressions (DSUR) method proposed by Mark *et al*. (2005) was used. This method allows for the efficient simultaneous estimation of panel cointegrating relationships with correlated disequilibrium errors, working with panel data in which, as in our case, the cross-sectional dimension is small or about the same order with respect to the length of the time series.

<<insert table 7 here>>

The results of the DSUR estimation of the average long-run production function are presented in table 7. According to these results, the elasticity of employment is around 0.35. Private capital and public capital show elasticities estimated as 0.32 and 0.10, respectively. In terms of statistical significance, magnitude and theoretical plausibility, the estimates obtained from the DSUR are very consistent, and are well within the range of estimates obtained by other authors. In this sense, one could point to the work of Kamps (2005) and Romp and de Haan (2005), among others, who have summarize information on international studies that have analyzed the dynamic effects of public capital, while Boscá *et al*. (2004) and Mas and Maudos (2005) present surveys of the Spanish experience about this topic.

3.3. Region-specific structural VEC models

The modeling exercise begins under the assumption that there are no spillover effects of public capital. This hypothesis allows us to estimate and test the domestic properties of the different region-specific models, analyzing the dynamics of the transmission of shocks from public capital to the rest of state variables (private capital, employment and output).

The reference VEC model for the region i (i=1,2,…,17) is given by:

[7] We also perform the long-run analysis on a region-by-region basis using the Johansen approach. Not surprisingly (due to the short span of data available at the single-region level), the Johansen individual-estimates of the long-run parameters were mixed and noisy, with some coefficients appearing as implausible. The poor results obtained in this case compels us to impose the homogeneity assumption in the estimation of the long-run equilibrium production function (see, among others, the works of Pesaran *et al*. (1999) and Baltagi *et al*. (2000) that consider the issue of pooling in detail, asking the question “To pool or not to pool?”).

$$A_i(L)\Delta X_{it} + C_i Z_{it} = E_{it} \quad , \quad A_{i0}E_{it} = B_i U_{it}$$

where $X_{it} = (pk_{it}, k_{it}, e_{it}, y_{it})'$ is the vector of endogenous variables; $Z_{it} = (1, \hat{\upsilon}_{i,t-1})'$ is the vector of predetermined variables, given in the empirical application by an intercept and the lagged estimated error correction term corresponding to the equilibrium relationship presented in table 6; $E_{it} = (e_{it}^{pk}, e_{it}^{k}, e_{it}^{e}, e_{it}^{y})'$ is the canonical errors vector from the reduced form; and $U_{it} = (u_{it}^{pk}, u_{it}^{k}, u_{it}^{e}, u_{it}^{y})'$ is the structural errors vector.[8] Matrix $A_i(L) = \sum_k A_{ik}L^k$ includes in our application a maximum of four lags, the optimal lag determined by the standard selection criteria AIC, HQ and SC, where the higher lag order is chosen based on these three information statistics.

With respect to the identification of the structural innovations, a standard recursive Cholesky-type decomposition scheme was used assuming that the relation between the canonical errors and the structural disturbances is given by the equation $A_{i0}E_{it} = B_i U_{it}$, where

$$A_{i0} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ a_{21}^{i} & 1 & 0 & 0 \\ a_{31}^{i} & a_{32}^{i} & 1 & 0 \\ a_{41}^{i} & a_{42}^{i} & a_{43}^{i} & 1 \end{bmatrix} \qquad B_i = \begin{bmatrix} b_{11}^{i} & 0 & 0 & 0 \\ 0 & b_{22}^{i} & 0 & 0 \\ 0 & 0 & b_{33}^{i} & 0 \\ 0 & 0 & 0 & b_{44}^{i} \end{bmatrix}$$

This identification scheme has the following implications: (i) innovations in public investment affect contemporaneously private capital, employment and real output, but the reverse is not true, (ii) shocks to private capital affect contemporaneously the employment and real GAV, but the reverse is not true, and (iii) unanticipated changes in employment affect contemporaneously the real GAV, but employment does not react contemporaneously to shocks in regional output. Therefore, the identified shocks are not subject in any case to the reverse causation problem.

The distinction between short- and long-run effects of public capital is important in regional growth analysis, since there is no reason to believe that public capital has the same spatial impact whether in terms of sign or magnitude of effects. In this sense, and with respect to the long-run

[8] To facilitate the interpretation of the estimated impulse responses, the endogenous variables (in logs) of the structural VEC models have been multiplied by 100. In this case, the accumulated impulse responses provide the percentage change in the level of the respective variable.

effects of public investment, Baxter and King (1993, p. 330) note: "*The response of output to an unexpected increase in public investment (which is known to be permanent, once it occurs) depends on (i) the direct effect of higher public capital, holding private capital and labor inputs fixed; and (ii) a supply-side effect due to the response of private capital and labor*". On the other hand, considering the short-run effects of public investment, these authors (p. 331) declare: "*An unexpected permanent increase in the flow of public investment introduces three forces which operate on the economy along its transition to the new steady state. First, there is a permanent increase in governmental absorption of resources, as with the basic government purchase studied above. Second, as the stock of public capital accumulates over time, it directly yields an increased flow of output. Third, the marginal product schedules for private labor and capital shift over time as a result of the rising stock of public capital, stimulating alterations in labor and private capital.*"

Obviously, this theoretical difference has important empirical implications. For example, Moreno *et al*. (2002) determine the short- and long-run effects of public infrastructure in the context of manufacturing industries in the Spanish regions using aggregated cost functions. In summary, one might venture to say that public capital could be a complement or substitute with respect to private capital and employment, conditioning the pattern of the output responses; further, the response could be different in the long- and short-run.

<<insert tables 8 and 9 here>>

Tables 8 and 9 show summary information about the effects of shocks in public capital installed inside each region displaying, respectively, the short-run and long-run elasticities of private capital, employment and real GAV obtained from the seventeen regional VEC models considered.[9] These estimates generate respectively the 0 year point and 25 year point percentage change in private capital, employment, and output per one-percentage point (impact or long-run)

[9] They are obtained by dividing the impact or long-run response of private capital, employment, and real GAV to a shock to public capital, respectively, by the impact or long-run response of public capital to a shock to public capital. In the computations, we set the response horizon $T = 25$ (since from the simulations it was possible to verify that for all regions the impulse responses converged to their long-run levels before 15 years) to ensure that for all regions the impulse responses have converged to their long-run levels.

change in public capital. Each point estimate in the tables is marked (or not) with an asterisk depending on the corresponding 68% confidence interval that does not include zero.[10]

Overall, the estimated effects suggest a highly significant pattern of responses of regional private capital, employment and output to innovations in public capital located in the region itself. The regional effects of innovations in public infrastructures on output, employment and private capital are now considered.

Starting from the **effects on output**, the short-run real GAV effects of public capital (table 7) show significantly positive responses in nine of the seventeen cases. This output response is statistically significant and negative in four regions located in the medium-upper zone of Spain (Aragón, Asturias, Castilla-León and Navarra), whereas four regions have no significant output responses (Cantabria, Extremadura, Murcia and País Vasco). For these regions exhibiting negative output responses, a possible explanation is that labor and private capital are altered by the rising stock of public capital. In other words, public capital and private capital could be substitutes in the short run, crowding out employment.

Regarding the long-run responses of output to a shock to public capital installed inside the regions (table 8), the general pattern is similar to the short-run responses: the results show that seven responses are significant and positive, four responses are significant and negative (Aragón, Asturias, Baleares and País Vasco), and six cases are not significant. The new steady state shows that, as in the case of the short-run, Aragón and Asturias have negative responses on output.

The results reported in tables 8 and 9 also show that all the significant and positive short-and long-run output elasticities are smaller than 1, indicating that an increase in public capital of a one percent will imply a less than one short- or long-run increase in the real GAV. The more than proportional negative output effects of public capital in Castilla-León (in the short term) and Asturias and País Vasco (in the long run) may be explained by the substitution effect of public capital on private output in these regions, accompanied by a negative elasticity of employment in the last two regions.

[10] The confidence intervals have been computed using Hall's percentile interval bootstrap procedure described in Breitung *et al*. (2004), and are based on 1000 bootstrap replications.

As general conclusion, the results would indicate that public capital is productive for most regions, indicating that public capital and private capital are complements in the long–run. Comparing our estimates with the (long term) ones reported in Pereira and Roca-Sagalés (2003), and considering both significance and sign of the elasticities, the present study only yields the same results in 7 of the 17 cases; specifically in the case of Andalucía, Asturias, Cantabria, Cataluña, Comunidad Valenciana, Galicia and Murcia. This lack of consensus between these results could be explained by two factors: the use of a different sample (1970-1995 in the case of the earlier paper and 1972-2000 in the present paper) and a different methodology (in this paper VEC models in levels are used to produce consistent estimates of impulse responses, whereas in Pereira and Roca-Sagalés VAR models in first differences are used which might produce –due to the non consideration of cointegration properties in the estimated systems- inconsistent estimates of impulse response functions).

As regards the short-run **responses of employment** to a shock to public capital (table 8), there are only two regions for which the short-run effects of public capital are negative and significant: Cataluña and País Vasco. In the rest of the regions, seven regions have significant and positive short-run effects, while eight regions have no significant effects. In the long run (table 9), the results indicate that public capital and employment are complements (significant and positive effects) for eight regions and present substitute characteristics for four regions, while the rest (five regions) have no significant effects.

The estimates for **private capital** elasticities are less conclusive, since in the short-run (table 8) they are positive for six regions and negative in the case of five regions. For the rest of the regions, these short-run measures are not statistically significant. In the long-run (table 9), the pattern is similar: significant and positive elasticities in the case of seven regions, significantly negatives in the case of eight regions, and no statistically significance in the rest of the remaining two regions. This would indicate that private capital and public capital could act as both complements and substitutes in the long-run.

In summary to this point, the long-term effects of public capital formation installed inside the Spanish regional system could lead to an increase in the long-run in both the regional real GAV and the regional employment. Nevertheless, if the aim is to increase private capital in the long-run, there is no empirical evidence about the appropriateness of the usage of an increase in public capital as an adequate policy measure to generate the required response from the private sector.

3.4. There exist spillover effects of public capital formation in the Spanish regional system? An assessment using bi-regional structural VEC models

According to the results obtained by Pereira and Roca-Sagalés (2003), there can exist important output spillover effects for each region derived from public capital installed in the rest of regions. This is the reason why these authors estimate region-specific models in which the first variable in the estimated VARs is the public capital installed in the rest of the country. This approach can be useful to establish the overall relevance of the spillover effects of innovations in public capital installed outside a region, but it would be helpful in formulating economic policies to locate these public capital innovation-effects in specific regions (not in aggregate terms as an extra-regional effect). In this sense, one of the main contributions of this paper is to uncover which regions could be fostered in their economic performance through spillover from public capital installed in other regions.

Consequently, in this sub-section the existence of regional spillover effects of public capital in Spain is investigated. The new approach proposed in this paper proceeds as follows: sixteen structural VEC models are estimated, providing insights into the relevance of the cross-border output effects from public capital installed in a reference region, which is going to be Madrid in this application.[11] This is achieved through the use of bi-regional models in which a shock to public investment in Madrid not only has a direct effect in the region itself but also indirect, spillover effects across regions, impacting the output of the rest of the Spanish regional economic system.

In Márquez *et al*. (2006) it was revealed that over the period 1972-2000 Madrid was the only region that presented significant positive influences in the evolution of its relative productive capacity in both the long-term and the short-term when the total production of Spain increases. This implies that Madrid is increasing its relative productive capacity in terms of the whole

[11] As stated previously, Madrid can be considered, in terms of geographic and socio-economic situation, as (one of) the kernel(s) of Spanish economy concentrating more than 13 percent of the aggregate Spanish public capital.

Spanish regional system.[12] Also, according to Márquez and Hewings (2003), the identified relationships between Madrid and its adjacent regional economies indicate that Madrid does not receive significant influences from its contiguous regions, while Madrid is producing significant dynamic externalities on its geographical neighbors (this result is also corroborated in Márquez *et al*. (2003), where the relevance of the response of the relative production shares of some Spanish regions to one generalized impulse from the relative share of Madrid is estimated). Given this pattern of geographical competition, significant spillovers from public capital installed in Madrid would be anticipated on some regions (adjacent or not) of the Spanish economic system.

Before introducing the bi-regional models, a methodological comment should be made. As stated previously, in this paper a different approach is followed that the usual one adopted in the empirical literature about the testing of spatial productivity spillovers from public capital. The usual approach to test for the existence of public capital spillovers is to add to the proposed region-specific model (a standard production function or a VAR system) some measure of the stock of public capital of the rest of regions of the country (see, for example, Holtz-Eakin and Schwartz (1995) for a production function application, or Pereira and Roca-Sagalés (2003) for a VAR empirical application). This methodology could be called a "*from all to one*" (or *push-in*) approach: a shock to public capital installed in other regions (all the regions except the reference region) could affect (positively or negatively) the region under consideration.

In the present paper, a different approach is proposed, one that might be considered of the type "*from one to all*" (or *push-out*): here, it is assumed that one innovation (new investment) in the public installed in one region could affect to the region itself but also it could spread out to the rest of regions of the country, affecting (positively or negatively) the output of each one of the regions of the country. Whereas in the traditional approach, the cross-border effects are derived from public capital installed in all the other regions (given as a measure of the aggregate spatial productivity of public capital), in this new approach, the output effects in each region are derived

[12] Complementarily, in Márquez *et al*. (2003) it is shown that when the national gross added value increases 1%, the region that has the higher percentage change in its relative share is Madrid, followed by Cataluña and the regions of the south-east of Spain. In addition, their empirical results show that these regions are sending negative agglomeration effects elsewhere as they capture share from the others regions over time, and also that the hypothesis about the existence of symmetric interregional spillover effects cannot be rejected for the regions with higher economic concentration in Spain, Cataluña and Madrid.

from innovations in the public capital stock of the reference region, and this could be interpreted as a measure of the individual spillover effects of public capital formation.

In formal terms, the bi-regional structural VEC models take the form

$$A_i^j(L)\Delta X_{it}^j + C_i^j Z_{it} = E_{it}^j \quad , \quad A_{i0}^j E_{it}^j = B_i^j U_{it}^j$$

where $X_{it}^j = (X_{it}, y_{jt})'$, X_{it} and $Z_{it} = (1, \hat{\upsilon}_{i,t-1})'$ are the vectors of state and explanatory variables for the region *i*; y_{jt} is the output of the external region *j*; $E_{it}^j = (E_{it}, e_{jt}^y)$ and $U_{it}^j = (U_{it}, u_{jt}^y)$ are the canonical and structural error vectors, respectively; and the matrices A_{i0}^j and B_i^j have the following expressions:

$$A_{i0}^j = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ a_{21}^i & 1 & 0 & 0 & 0 \\ a_{31}^i & a_{32}^i & 1 & 0 & 0 \\ a_{41}^i & a_{42}^i & a_{43}^i & 1 & 0 \\ 0 & 0 & 0 & a_{54}^j & 1 \end{bmatrix} \qquad B_i^j = \begin{bmatrix} b_{11}^i & 0 & 0 & 0 & 0 \\ 0 & b_{22}^i & 0 & 0 & 0 \\ 0 & 0 & b_{33}^i & 0 & 0 \\ 0 & 0 & 0 & b_{44}^i & 0 \\ 0 & 0 & 0 & 0 & b_{55}^j \end{bmatrix}$$

Implicit in the above matrix specification for A_{i0}^j is the assumption that, for each bi-regional model, the effect of shocks in the public capital installed in the reference region *i* affects the output of the region *j* in a indirect manner: as in the region-specific models, additions to public investment affect contemporaneously the domestic private capital, employment and real output, but have no direct effect (as a shock in private capital and employment) outside the region. The external effects, if any, are transmitted through the variation in the output in the reference region originated by the shock in public capital.

This assumption would imply that, for each model, the over-identifying parametric restrictions $\{a_{51}^j = 0, a_{52}^j = 0, a_{53}^j = 0\}$ will be verified. Then, in our application, we proceed by incorporating theses restrictions, if they are not rejected, in each estimated bi-regional model. Otherwise, the corresponding specification will be maintained as unrestricted. The results were that the over-identifying restrictions were not rejected for 12 of the 17 regions; namely, all except Aragón, Asturias, Castilla-León, Castilla-La Mancha and Comunidad Valenciana. Anyway, the restricted results obtained for these five regions were very similar to those presented in this work (unrestricted), thus providing some support for the validity of the restrictions entertained even for these regions.

<<insert table 10 and figure 2 here>>

The short-run and long-run output effects in each Spanish region, derived from unanticipated changes in public capital installed in Madrid, are reported in table 10. To show the results in a more comprehensive manner, in each row we present for each region both the qualitative and quantitative estimated effects.

The estimates of the short-run elasticities of regional output with respect to public capital installed in Madrid reveal that almost all the regions receive significant positive impulses (see table 10 and also figure 2). Only four regions (Baleares, Castilla-La Mancha, Extremadura and La Rioja) exhibit no significant short-run effects. From a long-run perspective, all the geographical neighbors of Madrid (Castilla-León, Aragón, Extremadura and Castilla-La Mancha) receive negative impulses from a shock in the public capital installed in Madrid, although in the Castilla-León and Aragón cases these effects while negative are not significant (see figure 3).

<<insert figure 3 here>>

There are important differences between the internal sectoral structure of Madrid and the aforementioned regions. In this regard, Ramajo *et al*. (2008) captured the interregional disparities of the productive system and the influence of low-productivity agricultural dependent regions, showing that European Union regions that do not receive Cohesion funds (like Madrid) benefit from neighbor regions with high shares of agricultural employment over total employment (this is the case of Castilla-León, Castilla-La Mancha and Extremadura). The negative output spillover effects may be explained by the mobility of input factors (private capital and employment) from these neighbor regions to Madrid, the region in which public capital would increase (Boarnet, 1998; Moreno and López-Bazo, 2007). With respect to the second-order (geographic) neighbors, the estimated long-run effects have mixed signs, although only in the cases of Cataluña and Murcia are these effects significant and positive.

Overall, these results suggest the existence of positive and negative spillover effects for some regions from capital installed in Madrid. This is not new evidence, since positive spillovers were found for the Spanish case, among others, by Pereira and Roca-Sagalés (2003), Cantos *et al*. (2005), Ezcurra *et al* (2005); whereas negative spillovers were found, for example, by Moreno and López-Bazo (2007) and Delgado and Alvarez (2005). The novelty is that this new approach facilitates the identification of which regions are affected by new investments in another region.

4. SUMMARY AND CONCLUSIONS

The effects of public capital on economic growth have received a great deal of attention in the recent economic literature. Within the approaches that have been applied to assess the impact of public infrastructures, this paper estimates the dynamic effects of innovations in public capital using a structural vector autoregressive (SVAR) methodology for the Spanish regions.

From a methodological point of view, the work contains different innovative features with respect to the previous studies using SVAR models. First, recently developed panel integration and cointegration tests are used to examine the long-run determinants of aggregate regional production. Thereafter, using a two-step approach (*a la* Engle and Granger, 1987) the detected cointegrating relation is first estimated and then the residuals from the long term relationship are used to estimate individual region-specific vector error-correction (VEC) models. Thus, the domestic dynamic properties of the estimated VEC models are investigated via impulse response functions that portray the effects of shocks to the public capital installed in one region on the rest of variables of the region. As general conclusion, the long-term effects of public capital formation installed inside the Spanish regional system could lead to an increase in the long-run in both regional real GAV and employment. Nevertheless, if the aim is to increase private capital in the long-run, there is no empirical evidence about the appropriateness of stimulating private capital via an increase in public capital as an adequate policy measure. In the short-run, private capital and public capital could act as both complements and substitutes, although employment seems to receive a predominantly positive stimulus in the short-run from public capital formation.

On the other hand, and due to the possible existence of spillover effects from public capital in one region on another regions (geographically adjacent or not), impulse response functions derived from bi-regional models are used to estimate the dynamic effects of additions to public capital installed in a reference region (in our application Madrid) on the economic growth of each one of the Spanish regions. The new approach reveals evidence about which regions are affected by new public investment in Madrid; almost all the Spanish regions receive significant positive impulses from public capital installed in this region (only four regions show no significant short-run effects). From the long-run perspective, all the geographical neighbors of Madrid (Castilla-León, Aragón, Extremadura and Castilla-La Mancha) receive negative impulses from a shock in the public capital installed in Madrid, although in the Castilla-León and Aragón cases, these effects while negative are not significant. In the case of the second-order (geographic) neighbors of Madrid, the estimated long-run effects have mixed signs, although only in the cases of Cataluña and Murcia are these effects significant and positive. Hence, these results suggest the existence of positive and negative spillover effects for some regions from capital installed in Madrid.

The results from this analysis suggest that analysts working with economy-wide models should pay increased attention to specifications of functional forms in the investment components of their models to capture the types of spatial dynamics revealed in this paper. Failure to do so might lead to estimation problems in the impact of potential spillover effects – both positive and negative – from changes in public investment in a regional system.

Finally, the bi-regional specifications proposed in this work are the beginning of a more general class of VAR models that would extend this line of research in several ways. The first natural extension would be the formulation of a "Spatial VAR" model. This "Spatial VAR" model would jointly specify both temporal dynamics (as in our region-specific SVAR models) and spatial dynamics (as in the standard spatial econometric models) in the line of Beenstock and Felsenstein (2008). Another development option would be to propose a "Global VAR" model for the Spanish regional system. The "Global VAR" would combine individual region SVAR models in a general specification in which the state variables of each region would be related to the state variables of the rest of regions (see Pesaran *et al*. (2004) and Dees *et al*. (2007) for a country application of this approach). The consideration of the extensions of the models proposed in this paper would provide new insights in the understanding of the effects of public capital at regional level.

REFERENCES

Aschauer, D.A. (1989): "Is Public Expenditure Productive?" *Journal of Monetary Economics*, 23, 177-200.

Aschauer, D.A. (2000): "Do States Optimize? Public Capital and Economic Growth," *Annals of Regional Science*, 34, 343–363.

Bajo, O. and Sosvilla, S. (1993): "Does Public Capital Affect Private Sector Performance? An Analysis of the Spanish Case 1964–1988," *Economic Modelling*, 10, 179–185.

Baltagi, B. and Kao, C. (2000): "Nonstationary panels, cointegration in panels and dynamic panels: A survey", *Working Paper* No. 16, Center for Policy Research, Maxwell School of Citizenship and Public Affairs, Syracuse University, USA.

Baltagi, B.H., Griffin, J.M. and Xiong, W. (2000): "To pool or not to pool: homogeneous versus heterogeneous estimators applied to cigarette demand," *Review of Economics and Statistics*, 82, 117-126.

Banerjee, A. (1999): "Panel Data Unit Roots and Cointegration: an Overview," *Oxford Bulletin of Economics and Statistics*, 61, 607-629.

Barro, R.J. (1990): "Government Spending in a Simple Model of Endogenous Growth," *Journal of Political Economy*, 98, 103-125.

Barro, R.J. and Sala-i-Martin, X. (1992): "Public Finance in Models of Economic Growth," *Review of Economic Studies*, 59, 645–661.

Baxter, M. and King, R.G. (1993): "Fiscal Policy in General Equilibrium," *American Economic Review*, 83, 315-333.

Beenstock, M. and Felsenstein, D. (2008): "Spatial Vector Autoregressions," mimeo, *Hebrew University of Jerusalem*, Israel.

Boarnet, M.G. (1998): "Spillovers and Locational Effects of Public Infrastructure," *Journal of Regional Science*, 38, 381-400.

Boscá, J.E., Escribá, F.J. and Murgui, M.J. (2002): "The Effect of Public Infrastructure on the Private Productive Sector of Spanish Regions," *Journal of Regional Science*, 42, 301-326.

Boscá, J. E., Escribá, F.J. and Murgui, M. J. (2004): "Efectos Macroeconómicos de las Inversiones en Infraestructuras Públicas," mimeo, University of Valencia, Spain.

Breitung, J. (2000): "The local power of some unit roots tests for panel data," in Baltagi, B. (ed.), *Nonstationary Panels, Panel Cointegration, and Dynamic Panels*, Amsterdam, Elsevier Science, 161-178.

Breitung, J., Brüggemann, R and Lütkepohl, H. (2004): "Structural Vector Autoregressive Modeling and Impulse Responses," in Lütkepohl, H. and Krätzig, M. (eds.), *Applied Time Series Econometrics*, New York, Cambridge University Press, 159-196.

Breitung, J. and Pesaran, M.H. (2008): "Unit Roots and Cointegration in Panels," in Matyas, L. and Sevestre, P. (eds.), *The Econometrics of Panel Data*, (Third Edition), Springer, 279-322.

Cabrer, B. (ed.) (2001): *Análisis Regional. El proyecto Hispalink*, Ediciones Mundi-Prensa, Madrid.

Cantos, P., Gumbau-Albert, M. and Maudos, J. (2005): "Transport Infrastructures, Spillover Effects and Regional Growth: Evidence of the Spanish Case," *Transport Reviews*, 25, 25-50.

Dees, S., Di Mauro, F., Pesaran, M.H. and Smith, V. (2007): "Exploring the international linkages of the Euro area: A global VAR analysis," *Journal of Applied Econometrics*, 22, 1-38.

De la Fuente, A., and Vives, X. (1995): "Infrastructure and Education as Instruments of Regional Policy: Evidence from Spain," *Economic Policy*, 20, 11–51.

De la Fuente, A., and Doménech, R. (2006): "Capital humano, crecimiento y desigualdad en las regiones españolas," *Moneda y Crédito*, 222, 13–78.

De la Fuente, A. (2008): "Inversión en infraestructuras, crecimiento y convergencia regional," *Documento de Trabajo* D-2008-05, Dirección General de Presupuestos (Ministerio de Economía y Hacienda), Spain.

Delgado, M.J. and Alvarez, I. (2005): "Network infrastructure spillover in private productive sectors: evidence from Spanish high capacity roads," *Applied Economics*, 39, 1583-1597.

Deno, K. (1988): "The Effects of Public Capital on U.S. Manufacturing activity: 1970 to 1987," *Southern Economic Journal*, 53, 400–411.

Engle, R.F. and Granger, W.J. (1987): "Co-Integration and Error Correction: Representation, Estimation, and Testing," *Econometrica*, 55, 251-276.

Evans, P. and Karras, G. (1994a): "Is Government Capital Productive? Evidence from a Panel of Seven Countries," *Journal of Macroeconomics*, 16, 271–279.

Evans, P. and Karras, G. (1994b): "Are Government Activities Productive? Evidence from a panel of U.S. States," *The Review of Economics and Statistics*, 76, 1–11.

Ezcurra, R., Gil, C. Pascual, P. and Rapún, M. (2005): "Public Capital, Regional Productivity and Spatial Spillovers," *Annals of Regional Science*, 39, 471–494.

Fujita, M. and Krugman, P. (2004): "The New Economic Geography: Past, Present and the Future," *Papers in Regional Science*, 83, 139-164.

Fujita, M. and Thisse, J.F. (2002): *Economics of Agglomeration: Cities, Industrial Location and Regional Growth*, Cambridge University Press, Cambridge.

García-Milá, T. and McGuire, T. (1992): "The Contribution of Publicly Provided Inputs to States' Economies," *Regional Science and Urban Economics*, 22, 229-241.

Gramlich, E.M. (1994): "Infrastructure Investment: A Review Essay," *Journal of Economic Literature*, 32, 1176-1196.

Gutierrez, L. (2003): "On the power of panel cointegration tests: a Monte Carlo comparison," *Economic Letters*, 80, 105-111.

Hadri, K. (2000): "Testing for stationarity in heterogeneous panel data," *Econometric Journal* 3, 148-161.

Holtz-Eakin, D. (1994): "Public Sector Capital and the Productive Puzzle," *Review of Economics and Statistics*, 76, 12–21.

Holtz-Eakin, D. and Schwartz, A. (1995): "Spatial Productivity Spillovers from Public Infrastructure: Evidence from State Highways," *International Tax and Public Finance*, 2, 459-468.

Im, K., Pesaran, M.H. and Shin, Y. (2003): "Testing for unit roots in heterogeneous panels," *Journal of Econometrics*, 115, 53-74.

Kamps, C. (2005): "The Dynamic Effects of Public Capital: VAR Evidence for 22 OECD Countries," *International Tax and Public Finance*, 12, 533-558.

Kao, C. (1999): "Spurious Regression and Residual-Based Tests for Cointegration in Panel Data," *Journal of Econometrics*, 90, 1–44.

Kelejian, H. and Robinson, D. (1997): "Infrastructure Productivity Estimation and its Underlying Econometric Specifications: a Sensitivity Analysis," *Papers in Regional Science*, 76, 115–131.

Krugman, P. (1991a): *Geography and Trade*, MIT Press, Cambridge.

Krugman, P. (1991b): "Increasing Returns and Economic Geography," *Journal of Political Economy*, 99, 483-99.

Levin, A., Lin, C.F. and Chu, C. (2002): "Unit roots tests in panel data: Asymptotic and finite-sample properties," *Journal of Econometrics*, 108, 1-24.

Lucas, R.E.Jr. (1988): “On the Mechanics of Economic Development,” *Journal of Monetary Economics*, 22, 3-42.

Lucas, R.E.Jr. (1993): “Making a Miracle,” *Econometrica*, 61, 251-272.

Maddala, G.S. and Wu, S. (1999): “A comparative study of unit root tests with panel data and a new simple test,” *Oxford Bulletin of Economics and Statistics*, 61, 631-652.

Márquez, M.A. and Hewings, G.J.D. (2003): “Geographical competition between regional economies: The case of Spain,” *Annals of Regional Science*, 37, 559-580.

Márquez, M.A., Ramajo, J. and Hewings, G.J.D. (2003): “Regional Interconnections and Growth Dynamics: The Spanish Case,” *Australasian Journal of Regional Studies*, 9, 5-28.

Márquez, M.A., Ramajo, J. and Hewings, G.J.D. (2006): “Dynamic effects within a regional system: an empirical approach,” *Environment and Planning A*, 38, 711-732.

Mas, M., Maudos, J., Pérez, F. and Uriel, E. (1994): “Capital Público y Productividad en las Regiones Españolas,” *Moneda y Crédito*, 198, 163–193.

Mas, M. and Maudos, J. (2005): “Infraestructuras y crecimiento regional en España diez años después,” in Villaverde , J. (ed.) *Competitividad regional en la Unión Europea ampliada*,” Instituto de Estudios Fiscales, Madrid, 143-167.

Mas, M., Pérez, F. and Uriel, E. (2000): “Estimation of the Stock of Capital in Spain,” *Review of Income and Wealth*, 46, 103–116.

Moreno, R. and López-Bazo, E. (2007): “Returns to Local and Transport Infrastructure under Regional Spillovers,” *International Regional Science Review*, 30, 47-71.

Moreno, R., López-Bazo, E., and Artís, M. (2002): “Public Infrastructure and the Performance of Manufacturing Industries: Short- and Long-run Effects,” *Regional Science and Urban Economics*, 32, 97-121.

Morrison, C.J. and Schwartz, A. E. (1996): “State Infrastructure and Productive Performance,” *American Economic Review*, 86, 1095–1111.

Munnell, A. (1990): “Why has Productivity Declined? Productivity and private investment,” *New England Economic Review*, Federal Reserve Bank of Boston, January-February, 3–22.

Pedroni, P. (1999): “Critical values for cointegration tests in heterogeneous panels with multiple regressors,” *Oxford Bulletin of Economics and Statistics*, 61, 631-652.

Pedroni, P. (2004): “Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis,” *Econometric Theory*, 20, 597-625.

Pereira, A. M. and Roca-Sagalés, O. (1999): “Public Capital Formation and Regional Development in Spain,” *Review of Development Economics*, 3, 281–294.

Pereira, A. M. and Roca-Sagalés, O. (2001): “Public Capital and Private Sector Performance in Spain: A Sectoral Analysis,” *Journal of Policy Modelling*, 23, 371–384.

Pereira, A. M. and Roca-Sagalés, O. (2003): “Spillover effects of Public Capital Formation: Evidence from the Spanish Regions,” *Journal of Urban Economics*, 53, 238–256.

Pesaran, M.H., Schuermann, T. and Weiner, S.M. (2004): “Modeling Regional Interdependencies Using a Global Error-Correcting Macroeconometric Model,” *Journal of Business and Economic Statistics*, 22, 129-162.

Pesaran, M.H., Shin, Y. and Smith, R.J. (1999): “Pooled mean group estimation of dynamic heterogeneous panels,” *Journal of the American Statistical Association*, 94, 621-634.

Pesaran, M.H., Shin, Y. and Smith, R.J. (2000): “Structural Analysis of Vector Error Correction Models with Exogenous I(1) Variables,” *Journal of Econometrics*, 97, 293-343.

Pulido, A. and Cabrer, B. (eds.) (1994): *Datos, Técnicas y Resultados del Moderno Análisis Económico Regional*, Ediciones Mundi-Prensa, Madrid.

Ramajo, J., Márquez, M.A., Hewings, G.J.D. and Salinas, M.M. (2008): "Spatial heterogeneity and interregional spillovers in the European Union: Do cohesion policies encourage convergence across regions?" *European Economic Review*, 52, 551–567.

Romer, P. (1986): "Increasing returns and long run growth," *Journal of Political Economy*, 94, 1002-1037.

Romer, P. (1990): "Endogenous Technological Change," *Journal of Political Economy*, 98, 71-102.

Romp, W. and de Haan, J. (2005): "Public Capital and Economic Growth: a Critical Survey," *European Investment Bank Papers*, 10/1, 40-71.

Seitz, H. and Licht, G. (1995): "The Impact of Public Infrastructure Capital on Regional Manufacturing Production Cost," *Regional Studies*, 29, 231–240.

Sturm, J. E. and de Haan, J. (1995):"Is Public Expenditure Really Productive? New Evidence for the USA and the Netherlands," *Economic Modelling*, 12, 60-72.

Sturm, J.E., Kuper, G.H., and de Haan, J. (1998): "Modelling Government Investment and Economic Growth on a Macro level: a Review," in Brakman, S., van Ees, H., and Kuipers, S.K. (eds.), *Market Behaviour and Macroeconomic Modelling*," MacMillan Press Ltd, London.

Turnovsky, S.J. (1997): "Public and Private Capital in an Endogenously Growing Economy," *Macroeconomic Dynamics*, 1, 615–639.

TABLES AND FIGURES

Table 1: Basic data for Spanish regions

	Area		GAV					
Regions	% km^2	Order	1972-1980	Order	1981-1990	Order	1990-2000	Order
AN	17,36	*2*	14,00	*3*	13,55	*3*	13,86	*3*
AR	9,45	*4*	3,35	*9*	3,46	*10*	3,31	*10*
AS	2,10	*10*	3,19	*10*	2,90	*11*	2,44	*11*
BA	0,99	*17*	2,12	*13*	2,27	*13*	2,27	*13*
CB	1,04	*15*	1,28	*16*	1,28	*16*	1,24	*16*
CL	18,59	*1*	6,61	*6*	6,36	*6*	5,81	*6*
CM	15,74	*3*	3,85	*8*	3,72	*8*	3,57	*9*
CN	1,48	*13*	2,77	*11*	3,46	*9*	3,72	*8*
CT	6,36	*6*	18,63	*1*	18,07	*1*	18,86	*1*
CV	4,61	*8*	9,52	*4*	9,88	*4*	9,79	*4*
EX	8,25	*5*	1,74	*14*	1,85	*14*	1,81	*14*
GA	5,86	*7*	5,75	*7*	5,91	*7*	5,57	*7*
MA	1,59	*12*	15,68	*2*	15,95	*2*	16,64	*2*
MU	2,24	*9*	2,14	*12*	2,30	*12*	2,33	*12*
NA	1,94	*11*	1,68	*15*	1,69	*15*	1,67	*15*
PV	1,40	*14*	7,09	*5*	6,61	*5*	6,34	*5*
RI	1,00	*16*	0,61	*17*	0,74	*17*	0,76	*17*
SPAIN			100		100		100	

	Employment					
Regions	1972-1980	Order	1981-1990	Order	1990-2000	Order
AN	14,43	*2*	14,07	*2*	14,61	*2*
AR	3,36	*9*	3,37	*10*	3,25	*10*
AS	3,28	*10*	3,05	*11*	2,55	*12*
BA	1,77	*14*	1,96	*14*	2,14	*14*
CB	1,45	*15*	1,39	*16*	1,29	*16*
CL	7,11	*6*	6,95	*6*	6,29	*6*
CM	4,34	*8*	4,25	*8*	4,11	*8*
CN	3,18	*11*	3,53	*9*	3,93	*9*
CT	16,70	*1*	16,61	*1*	17,65	*1*
CV	9,70	*4*	10,02	*4*	10,32	*4*
EX	2,74	*12*	2,49	*12*	2,32	*13*
GA	9,52	*5*	9,13	*5*	7,40	*5*
MA	12,05	*3*	12,89	*3*	13,67	*3*
MU	2,35	*13*	2,48	*13*	2,64	*11*
NA	1,39	*16*	1,43	*15*	1,51	*15*
PV	5,90	*7*	5,66	*7*	5,61	*7*
RI	0,73	*17*	0,73	*17*	0,70	*17*
SPAIN	100		100		100	

	Private Capital					
Regions	1972-1980	Order	1981-1990	Order	1990-2000	Order
AN	11,83	*3*	12,41	*3*	13,04	*3*
AR	3,16	*10*	3,18	*9*	3,15	*10*
AS	3,28	*9*	2,92	*11*	2,50	*13*
BA	2,36	*12*	2,52	*12*	2,94	*11*
CB	1,68	*15*	1,48	*15*	1,34	*16*
CL	6,11	*6*	6,41	*5*	6,07	*5*
CM	3,43	*8*	3,80	*8*	3,93	*8*
CN	2,88	*11*	3,14	*10*	3,49	*9*
CT	21,13	*1*	20,06	*1*	19,30	*1*
CV	10,02	*4*	11,03	*4*	11,43	*4*
EX	1,84	*14*	2,07	*14*	1,87	*14*
GA	5,31	*7*	5,45	*7*	5,32	*7*
MA	15,44	*2*	14,96	*2*	15,34	*2*
MU	2,16	*13*	2,30	*13*	2,51	*12*
NA	1,38	*16*	1,36	*16*	1,50	*15*
PV	7,42	*5*	6,24	*6*	5,56	*6*
RI	0,58	*17*	0,66	*17*	0,70	*17*
SPAIN	100		100		100	

	Public Capital					
Regions	1972-1980	Order	1981-1990	Order	1990-2000	Order
AN	14,95	*2*	15,56	*1*	17,21	*1*
AR	5,57	*9*	5,01	*9*	4,09	*9*
AS	3,29	*11*	3,35	*11*	3,30	*12*
BA	1,46	*15*	1,47	*16*	1,56	*16*
CB	1,32	*16*	1,49	*15*	1,59	*15*
CL	10,25	*4*	9,05	*4*	7,95	*5*
CM	5,67	*8*	5,40	*8*	5,52	*8*
CN	3,63	*10*	3,89	*10*	4,05	*10*
CT	14,98	*1*	13,73	*2*	13,50	*2*
CV	8,43	*5*	8,77	*5*	9,03	*4*
EX	3,07	*12*	2,96	*12*	3,33	*11*
GA	5,77	*7*	6,32	*7*	6,85	*6*
MA	10,61	*3*	10,63	*3*	9,99	*3*
MU	1,69	*14*	2,15	*13*	2,39	*13*
NA	1,93	*13*	2,04	*14*	1,96	*14*
PV	6,30	*6*	6,79	*6*	6,71	*7*
RI	1,09	*17*	1,38	*17*	0,96	*17*
SPAIN	100		100		100	

Table 2: Regional public capital stock as a percentage of GAV (averages for different periods)

Region	1972-1980	1981-1990	1990-2000
Andalucía	35,58	47,01	65,37
Aragón	55,51	59,06	65,00
Asturias	34,27	47,52	71,61
Baleares	22,94	26,51	36,16
Cantabria	34,35	48,07	67,36
Castilla-León	51,45	58,21	71,95
Castilla-La Mancha	49,02	59,44	81,41
Canarias	43,69	46,07	57,26
Cataluña	26,76	31,06	37,70
Comunidad Valenciana	29,50	36,36	48,64
Extremadura	58,66	65,42	96,99
Galicia	33,47	43,96	64,78
Madrid	22,62	27,22	31,58
Murcia	26,35	38,38	53,89
Navarra	38,75	49,07	61,94
País Vasco	29,77	42,17	55,74
La Rioja	60,20	76,01	66,55
SPAIN (Average)	27,35	33,63	43,02
Standard deviation	12,45	13,46	16,46
Minimum	22,62	26,51	31,58
Maximum	60,20	76,01	96,99

Table 3: Unit root tests for $\log Y$, $\log E$, $\log K$ and $\log PK$

	$\log Y$	$\log E$	$\log K$	$\log PK$
Null: Unit root (assumes common unit root process)				
Levin-Lin-Chu	2.201	8.162	-3.785***	3.445
Breitung	-2.424***	8.341	-2.487***	3.078
Null: Unit root (assumes individual unit root process)				
Im-Pesaran-Shin	0.026	8.381	-4.560***	0.993
Maddala-Wu ADF-Fisher	31.217	0.659	91.173***	26.392
Maddala-Wu PP-Fisher	40.984	0.971	96.893***	17.617
Null: No unit root (assumes common unit root process)				
Hadri	3.790***	9.371***	7.306***	6.634***

NOTES: 1) Probabilities for Fisher tests were computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality; 2) An * (**) [***] indicates rejection of the null hypothesis at the 10% (5%) [1%] significance level based on the appropriate critical values; 3) Exogenous variables: Individual effects, individual linear trends; 4) Automatic selection of lags based on MAIC criterion: 0 to 4; 5) Newey-West bandwidth selection using Bartlett kernel.

Table 4: Pedroni panel cointegration tests (Null Hypothesis: No cointegration)

	$v-stat$	$\rho-stat$	$PP-stat$	$ADF-stat$
Alternative hypothesis: common AR coefs. (within-dimension)				
Unweighted panel stats	0.964	-0.907	-5.187***	-5.353***
Weighted panel stats	-1.426	-0.684	-5.635***	-6.453***
Alternative hypothesis: individual AR coefs. (between-dimension)				
Group-mean stats		0.795	-4.525***	-4.542***

NOTES: 1) All of the panel and group statistics have been standardized by the means and variances given in Pedroni (1999) so that all reported values are distributed as $N(0,1)$ under the null hypothesis of no cointegration; 2) The panel-stats weighted statistics are weighted by long run variances (Pedroni, 1999, 2004); 3) An * (**) [***] indicates rejection of the null hypothesis at the 10% (5%) [1%] significance level based on the appropriate critical values (1.28, 1.64 and 2.33, respectively); 4) For the semiparametric *PP* tests the Newey-West (1994) rule for truncating the lag length for the kernel bandwidth has been used, and for the parametric *ADF* tests a step-down procedure starting from *K*=2 has been used; 5) The residuals have been estimated using the least squares estimator.

Table 5: Kao panel cointegration test (Null Hypothesis: No cointegration)

	$t-stat$
ADF	-4.347***

NOTES: 1) Probability has been computed assuming asymptotic normality; 2) An * (**) [***] indicates rejection of the null hypothesis at the 10% (5%) [1%] significance level based on the appropriate critical values; 3) Trend assumption: No deterministic trend; 4) Lag selection: Automatic 2 lags by SIC with a max lag of 2; 5) Newey-West bandwidth selection using Bartlett kernel; 6) The residuals have been estimated using the least squares estimator.

Table 6: Maddala and Wu Fisher-type panel cointegration tests (Null Hypothesis: number (*r*) of cointegration relationships)

	$Trace-stat$	$Max.eigen.-stat$
$r=0$	221.10***	185.00***
$r\leq 1$	76.26***	56.99***
$r\leq 2$	44.76	40.22
$r\leq 3$	44.96*	44.96*

NOTES: 1) Probabilities have been computed using asymptotic Chi-square distribution; 2) An * (**) [***] indicates rejection of the null hypothesis at the 10% (5%) [1%] significance level based on the appropriate critical values; 3) Trend assumption: Linear deterministic trend; 4) Lags interval (in first differences): 1 to 1.

Table 7: DSUR estimates for $y_{it}=\beta_{0,i}+\beta_1 e_{it}+\beta_2 k_{it}+\beta_3 pk_{it}+\beta_4 t+v_{it}$

$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$	$\hat{\beta}_4$

0.348*** [0.025]	0.315*** [0.029]	0.102*** [0.022]	0.010*** [0.001]

NOTES: 1) Cross-section SUR standard errors are given in brackets; 2) An * (**) [***] indicates rejection of the null hypothesis at the 10% (5%) [1%] significance level based on the appropriate p-values.

Table 8: Short-run effects of public capital (individual region models)

Region	Private capital	Employment	Real GAV
Andalucía	0.12*	0.59*	0.59*
Aragón	0.34*	0.49*	-0.27*
Asturias	-0.10*	-0.25	-0.49*
Baleares	0.01	0.45*	0.46*
Cantabria	-0.21*	-0.01	-0.09
Castilla-León	-0.23*	0.18	-1.05*
Castilla-La Mancha	0.09*	0.35*	0.93*
Canarias	0.37*	0.60*	0.73*
Cataluña	-0.14*	-0.21*	0.32*
Comunidad Valenciana	0.06	0.07	0.29*
Extremadura	0.05	-0.21	0.11
Galicia	0.10*	-0.10	0.32*
Madrid	0.05	0.23	0.58*
Murcia	0.01	0.41*	-0.01
Navarra	-0.07*	0.02	-0.16*
País Vasco	-0.02	-0.21*	-0.10
La Rioja	0.04*	0.52*	0.26*

NOTE: A (*) denotes that the corresponding 68% Hall percentile confidence interval does not include zero. The confidence intervals for individual regions are computed using a bootstrap procedure with 1000 replications.

Table 9: Long-run effects of public capital (individual region models)

Region	Private capital	Employment	Real GAV
Andalucía	-0.04*	0.27*	0.31*
Aragón	0.32*	0.01	-0.31*
Asturias	-0.87*	-0.65*	-1.92*
Baleares	0.66*	0.20	-0.14*
Cantabria	-0.15*	-0.08	0.48*
Castilla-León	-0.28*	0.57*	-0.09
Castilla-La Mancha	-0.15*	0.02	0.12
Canarias	0.62*	0.35*	0.11
Cataluña	0.05	-0.52*	0.32*
Comunidad Valenciana	0.18*	0.48*	0.59*
Extremadura	-0.55*	0.34*	0.04
Galicia	-0.42*	-0.32*	-0.47

Madrid	0.28*	-0.17	-0.07
Murcia	0.27*	0.51*	0.83*
Navarra	0.11	0.15*	0.15*
País Vasco	-0.44*	-0.46*	-0.43*
La Rioja	0.15*	0.32*	0.20*

NOTE: A (*) denotes that the corresponding 68% Hall percentile confidence interval does not include zero. The confidence intervals for individual regions are computed using a bootstrap procedure with 1000 replications.

Table 10: Regional GAV spillover effects of public capital installed in Madrid (bi-regional models)

a) Qualitative effects

Region	Short run effect (0 year point estimate)	Long run effect (25 year point estimate)
Andalucía	+	0
Aragón	+	0
Asturias	+	0
Baleares	0	0
Cantabria	+	0
Castilla-León	+	0
Castilla-La Mancha	0	-
Canarias	+	0
Cataluña	+	+
Comunidad Valenciana	+	0
Extremadura	0	-
Galicia	+	0
Murcia	+	+
Navarra	+	0
País Vasco	+	0
La Rioja	0	0

NOTE: A (+) or (-) indicates respectively significant evidence of positive or negative impulse response of real GAV in each region to a shock to public capital in Madrid.

b) Quantitative effects

Region	Short run effect (0 year point estimate)	Long run effect (25 year point estimate)
Andalucía	0.23*	-0.23
Aragón	0.28*	-0.08
Asturias	0.27*	0.19
Baleares	0.09	-0.19
Cantabria	0.80*	0.36
Castilla-León	0.17*	-0.26
Castilla-La Mancha	0.10	-0.57*
Canarias	0.26*	-0.08

Cataluña	0.35*	0.50*
Comunidad Valenciana	0.22*	0.27
Extremadura	-0.12	-0.49*
Galicia	0.31*	0.25
Murcia	0.43*	0.56*
Navarra	0.68*	0.15
País Vasco	0.40*	0.16
La Rioja	-0.28	-0.01

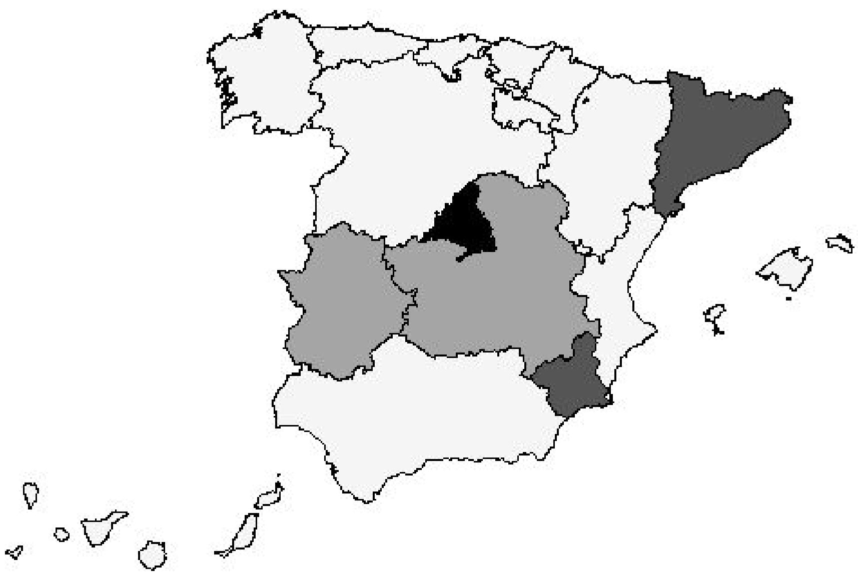
NOTE: A (*) denotes that the corresponding 68% Hall percentile confidence interval does not include zero. The confidence intervals for individual regions are computed using a bootstrap procedure with 1000 replications.

Figure 1: Spanish Regions

Figure 2: Short-run regional output spillover effects

Note: -Black color indicates the reference region (Madrid). -White color indicates a non-significant effect. -Gray color indicates a significant positive effect.

Figure 3: Long-run regional output spillover effects



Note: -Black color indicates the reference region (Madrid). -White color indicates a non-significant effect. –Clear gray color indicates a significant negative effect. –Dark gray color indicates a significant positive effect.