Does Regional Public Capital Crowd Out Regional Private Capital? A Multiregional Analysis for the Spanish regions(*)

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Abstract

The effects of public capital on economic growth have received a great deal of attention in the recent economic literature. In this context, our work is focused on the relationship between public and private capital at the regional level. Thus, the main purpose of this paper is to formulate a Multiregional Spatial VAR model for the Spanish regional system in order to both extend the class of VAR models applied in recent work on the topic and to reveal empirical evidence about the existence of crowding in and/or crowding out from Spanish regional public capital.

Keywords: Multiregional; Spatial Econometrics; Vector Autoregressions; Public capital; Private Capital, Spillovers.

AMS Classification: 62M10, 62M30, 91B72, 91B84

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¿Expulsa el capital público regional al capital privado? Un análisis multiregional para el caso español

Resumen

Los efectos del capital público sobre el crecimiento económico han recibido una gran atención en la literatura económica reciente. En este contexto, nuestro trabajo se centra en la relación entre capital público y privado a nivel regional. Así, el objetivo principal de este trabajo es formular un modelo multirregional espacial VAR para el sistema regional español con el fin de, tanto ampliar la clase de modelos VAR que se aplican en los trabajos recientes sobre el tema, como para proporcionar evidencia empírica acerca de la existencia de efectos *crowding-in* y/o *crowding-out* procedentes del capital público regional en España.

Palabras clave: Multiregional; Econometría Espacial; Vectores Autorregresivos; Capital Público*:* Capital Privado, *Spillovers*.

Clasificación AMS: 62M10, 62M30, 91B72, 91B84

1. Introduction

For a long time, economists have noted that public economic activity can displace private economic performance (see, for example, Keynes and Henderson, 1929).Thus, if the private sector contemplates public capital investment as a substitute for private investment and/or if the private sector perceives that the deficit created by public capital expenditure is tax-financed, an increase in government capital spending may crowd out private investment. On the other hand, the traditional complementary effect (e.g. Arrow and Kurz, 1970) emphasizes the positive impact of public capital on private activity (crowding-in effect). As the relationship between the two types of investments is either complementary or substitutive, such a relation, however, should be empirically analyzed. In this regard, as stated by Buiter (1977), this crowding effect of private economic activity by public economic activity is a multidimensional concept. Consequently, the economic impact of public investment will have a countervailing impact on private capital that, empirically, is related with both the significance and signs of public policy multipliers. Nevertheless, although the subject has a long history in macroeconomic theory and policy debate, there are still contributions at both the theoretical (for example, Besley and Persson, 2010) and applied contexts (Singh, 2012), indicating that it would be valuable to add more contributions to this field.

At regional level, the study of the interaction between public and private capital entails the consideration of spillover effects (Haugwout, 1998). The extant literature has attempted to address this issue using mainly vector autoregression (VAR) analysis. Moreover, the analysis of the issue of complementarity and substitutability of public capital to private capital in regional economies requires consideration of the spatio-temporal dynamics among the state variables of each region (Márquez *et al*., 2010). However, to our knowledge, there are no studies focusing on the estimation of the crowding effects of public capital combining different region-specific models in a multiregional framework in which the state variables of each region are related to the state variables of the rest of the regions.

This paper uses a multi-location approach to assess the impact of regional public capital on private capital. Specifically, a multiregional integrated spatial vector autoregressive (MultiREG-SpVAR) model is outlined that allows the investigation of spatio-temporal interdependencies across regions. A central contribution of this paper is the insight that one can employ a Multiregional Spatial VAR to estimate the crowding-out and/or crowding-in effects of regional public capital allowing for spatio-temporal interdependencies of regional variables across all regions, providing new insights into the functioning of the Spanish regional economic system.

The paper is organized as follows. In section 2, a brief review is presented regarding the theoretical background relative to the conceptual understanding of the relationship between public capital and private capital. In addition, a concise summary is provided of the different methods used to estimate macroeconomic shocks on regional economic growth together with some empirical evidence mainly concerned with exploring the extent and nature of this relationship for the Spanish regional economic system. Section 3 describes the methodology employed, while section 4 presents and analyses the data (and their properties) for the Spanish regional system. The empirical application in section 4 estimates the domestic and spillover crowding effects of public capital in the Spanish regional system, and a discussion of the main implications of the empirical results is provided. Finally, section 6 presents the conclusions and some summary remarks.

2. On the relationship between public and private capital: Theoretical background

Stimulated by traditional neoclassical growth theory, endogenous growth theory (e.g. Lucas, 1988), and the more recent new economic geography framework (e.g. Fujita and Krugman, 2004), the interaction between the accumulation of physical capital and economic growth has become an important subject of study. Physical capital accumulation is a factor of production that combines both private and public capital. In the last few decades, increasing attention has been given to the investigation of the potential impact of increased public sector capital on private investment (e.g. Nazmi and Ramirez, 1997; Sloboda and Yao, 2008). Likewise, the issue of whether public investment crowds out or crowds in private investment has been the subject of strong controversy in economic theory and policy (e.g. Atukeren, 2005, and Broer,2011). This controversy is based on the fact that an increase in public investment produces countervailing crowding-out and crowding-in effects. Thus, and according to Baxter and King (1993), the negative effect of the public capital financing cost on private sector resources could be compensated by the positive effect of an increase in public capital on the marginal productivity of private capital. As result, the response of private capital to an increase in public capital could be substitution (crowding out), complementary (crowding in), or independent (see, for example, Ramírez, 2000).

The substitution effect of public capital exists when a negative effect on the marginal productivity of private capital and labor counterbalances the positive effects derived from the increase of output. Studies like Barro (1981), Aschauer (1985) and Rossiter (2002), among others, provide support for this substitutability hypothesis. On the other hand, the complementarity hypothesis was shown, among others, by studies such as Aschauer (1989), Karras (1994) and Monadjemi and Huh (1998). According to these studies, an increase in public capital will increase output directly. Besides, public capital will increase private capital investment directly and the output indirectly (stimulating positively the marginal productivity of the private capital stock). Finally, as public capital increases the amount of both private and public capital per worker, the marginal productivity of labor increases, increasing output. In the case where public and private capital are independent, an increase in public capital will induce positive effects on both output and the marginal productivity of labor in the public sector. Therefore, and as stated by Aschauer (1989a), the question whether higher public capital accumulation "crowds out" private investment should be solved empirically, since opposing forces are presented[1] and the net effect can be positive, negative or neutral.

It should be noted that the crowding in/out debate involves taking into account that it is a complex concept. A comprehensive taxonomy, where the effects of public capital on private capital can be examined within a multidimensional context, was developed by Buiter (1977). Following this author, the time horizon considered (short run and long run) and the existence of both direct and indirect interactions of public and private capital and the issues of complementarity and substitutability of public capital to private capital provide the focus for evaluation. With respect to the time horizon considered, as public capital could be a complement or substitute with respect to private capital, it is important to highlight that the responses could be different in the long- and short-run (Baxter and King, 1993). On the other hand, the competition between the public and private capital can be both direct and indirect. Direct crowding in/out of private capital by public capital is the extent to which public capital can be subsumed under the private sector in considering the structural relationships of the economy. Indirect crowding in/out refers to the complementary/substitution of public economic activity for private economic activity coming out of the working of the entire model of the economy, that is, related to the reduced form derivatives.

Nevertheless, although the relationship between public capital and private capital has a long history, the empirical evidence is generally hampered by dimensionality constraints. The evaluation of the aggregate effects of public capital should contemplate the existence of both direct and indirect effects, and this is the reason why, 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. The VAR approach, although atheoretical in nature, allows for the existence of indirect links between the variables under study (Kamps, 2005), and this is an important advantage over other approach he

[1] The national investment rate can be raised above the expectation of rational agents by the increase of public capital, inducing an *ex ante* crowding out effect of private investment (and so, private capital accumulation). Simultaneously, the increase in the public capital stock can raise the return to private capital, producing crowding in on private capital accumulation.

used to analyze the role of public capital in the performance of private capital. Further, the VAR approach facilitates distinguishing different time horizons.

Although most of the studies on the role of public capital in the performance of private capital relied on approaches such Vector Auto Regression (VAR) models, it is also possible to find, among the commonest methods used, the production function and the cost function approaches.

Arrow and Kurz (1970) were among the first to employ a Cobb–Douglas aggregate production function where public capital was introduced as an input, starting the traditional complementary-effect across inputs. Using this type of function, the importance of public capital stock in raising the productivity of private capital was highlighted by the pioneering contributions of Aschauer (1989) and Munnell (1990, 1991, 1992). Later, this hypothesis was confirmed by some authors, but rejected by others (see Sturm *et al*. 1998, for a survey).[2] In the Spanish case, this approach has been used, among others, by Bajo and Sosvilla (1993), Mas *et al*. (1994), and De la Fuente (2008).

The other relevant approach has been the cost function. Following the pioneer work of Deno (1988), this approach is based on duality theory and it measures the impact of public capital on economic growth in terms of cost-savings benefits, evaluating whether costs decrease with public capital provision. For the Spanish case see, among others, Boscá *et al*. (2002) and Ezcurra *et al*. (2005).

Over the last years, considerable attention has been paid to the interaction between public capital and private capital (Bucci and Del Bo, 2012). This fact can be explained because the degree of complementarity/substitutability between the two types of capital may affect the optimal growth rate of the economy (Barro, 1990), and this is an important issue for policy makers. The majority of studies have focused on the research about this relationship for developed countries (e.g. Vos, 2002) and more recently, for the developing countries (e.g. Rashid, 2005).

Despite the presence of a large number of papers investigating the relative importance of private and public investments,[3] the number of studies on the interactions between regional public capital and regional private capital in regional economies is relatively small. This could be due to the lack of data as well as the fact that at regional level the relation between public and private capital is complicated and inherently intertwined. In this sense, a special feature of regional studies is that part of the effects generated from public capital formation within a region are not captured by only private capital within the same region. Thus, the formation of private capital in neighboring regions may benefit from the spillovers related to public capital; that is, spillover effects should be contemplated as part of the analysis of the crowding in/out effects of public capital formation.

In sum, the evaluation of the aggregate effects of regional public capital should contemplate the existence of both domestic (intra-regional) and spill-over effects. For a

[2] More recently, the importance of public capital stock in raising the productivity of private capital has been emphasized, among others, by authors like Cohen and Paul (2004) and Erden and Holcombe (2005).

[3] There exists a recent literature using aggregate-level data and empirical evidence at international level (see, among others, Badawi,2003 and Afonso and Aubyn,2010).

region, domestic crowding effects are the effects derived from public capital installed in the region itself, while the spillover crowding effects are effects on regional private capital installed outside the region derived from public capital installed in the region. Even then, the issue of spillover crowding effects has been ignored by the recent contributions trying to improve the measurement of the spillover effects of public capital. For example, Martínez-López (2006) showed the existence of a positive effect of public investment on private capital accumulation for the Spanish regions over the period 1965-1997.Pereira and Roca-Sagalés (2003) used VAR models to investigate the effects of public capital formation, but the spillovers are aggregated; that is, their methodology does not allow measurement of the effect of a shock in the public capital of a region on the state variables of other regions. An exception from the existing literature based on spillover effects to regional economies has been Márquez *et al.* (2010), where the methodology permits quantification of the extent to which output in every region within a country benefits from changes (or shocks) in the public capital stock of another region. Nevertheless, the approach presented by these authors does not allow estimation of the crowding effects of public capital combining different region-specific models in a multiregional framework in which the state variables of each region are related to the state variables of the rest of the regions. This exercise is needed not only for a better understanding of these interactions, but also for designing an appropriate response to regional fiscal policy.

3. Statistical Methodology: The multiregional spatial VAR (MultiREG-SpVAR) model[4]

To capture the interaction between public capital and private capital among the Spanish regions, a multiregional integrated spatial vector autoregressive model has been built following the Global VAR macroeconometric modeling approach proposed by Pesaran *et al.* (2004) and Dees *et al.* (2007).

In the proposed MultiREG-SpVAR model, the regions are considered as small open economies, though allowing for feedbacks between the variables of different regions: each region is linked with the others in the regional system under study by including external variables in its econometric specification, in such a way that all regions are potentially affected by developments in the other regions of the system. These external variables are spatial lags of the state variables that have been constructed using spatial weights, which specify the neighborhood set for each location.

Specifically, we consider N regions, indexed by i=1,2,…,N, and the SpVAR(p_i,q_i) multivariate Spatial VAR model for region i at time t (t=1,2,…,T) is formulated incorporating temporal as well as spatial dynamics as:

$$\mathbf{Y}_{it} = \mathbf{\Lambda}_{0i} + \mathbf{\Lambda}_{1i}\mathbf{t} + \mathbf{\Gamma}_{1i}\mathbf{Y}_{i,t-1} + \ldots + \mathbf{\Gamma}_{p_i i}\mathbf{Y}_{i,t-p_i} + \mathbf{\Phi}_{0i}\mathbf{Y}^*_{it} + \mathbf{\Phi}_{1i}\mathbf{Y}^*_{i,t-1} + \ldots + \mathbf{\Phi}_{q_i i}\mathbf{Y}^*_{i,t-q_i} + \mathbf{u}_{it} \quad [1]$$

[4] This section draws on Ramajo *et al.* (2013).

Where $\mathbf{Y}_{it} = (y_{1,it}, y_{2,it}, \dots, y_{G,it})'$ is the G x 1 vector of internal state variables, $\mathbf{Y}_{it}^* = (y_{1,it}^*, y_{2,it}^*, \dots, y_{G,it}^*)'$ is the G x 1vector of external spatially-lagged variables, $\mathbf{t}$ is the vector of the deterministic time trends, $\mathbf{\Lambda}_{ji}(j = 0,1)$, $\mathbf{\Gamma}_{ji}(j = 1, 2, \dots, p_i)$ and $\mathbf{\Phi}_{ji}(j = 0, 1, 2, \dots, q_i)$ are conformable matrices of parameters, and $\mathbf{u}_{it}$ is the G x 1 vector of shocks assumed to be serially uncorrelated with a zero mean and a non-singular covariance matrix, $\mathbf{\Sigma}_{ii} = Cov(u_{k,it}, u_{l,it}) = (\sigma_{ii,kl})$.

Expression [1] implies that each SpVAR can be seen as a spatially extended VAR model for the vector $\mathbf{Y}_{it} = (y_{1,it}, y_{2,it}, \dots, y_{G,it})'$. For each endogenous variable y_m of this vector (m = 1, 2,…, G), the SpVAR with N regions takes the form of the following system of equations:

$$\begin{cases} y_{m,1t} = \Lambda_{01,m} + \Lambda_{11,m} + \sum_{g=1}^{G} \Gamma_{11,mg} y_{g1,t-1} + \dots + \sum_{g=1}^{G} \Phi_{01,mg}\, y^*_{g1,t} + \sum_{g=1}^{G} \Phi_{11,mg}\, y^*_{g1,t-1} + \dots + u_{m,1t} \\ y_{m,2t} = \Lambda_{02,m} + \Lambda_{12,m} + \sum_{g=1}^{G} \Gamma_{12,mg} y_{g2,t-1} + \dots + \sum_{g=1}^{G} \Phi_{02,mg}\, y^*_{g2,t} + \sum_{g=1}^{G} \Phi_{12,mg}\, y^*_{g2,t-1} + \dots + u_{m,2t} \\ \vdots \\ y_{m,Nt} = \Lambda_{0N,m} + \Lambda_{1N,m} + \sum_{g=1}^{G} \Gamma_{1N,mg} y_{gN,t-1} + \dots + \sum_{g=1}^{G} \Phi_{0N,mg}\, y^*_{gN,t} + \sum_{g=1}^{G} \Phi_{1N,mg}\, y^*_{gN,t-1} + \dots + u_{m,Nt} \end{cases} \quad [2]$$

For each region, the vector of external variables is built as $Y_{it}^* = \sum_{j=1}^{N} w_{it} Y_{jt}$. The region specific weights w_{ij} form a row-standardized N x N connectivity matrix $\mathbf{W}$ with elements known a priori satisfying $w_{ii} = 0$ and $\sum_{j=1}^{N} w_{ij} = 1$. This matrix reflects the network of relationships in the regional system. Then, the spatially lagged vector Y_{it}^* summarizes the state of the economy in the neighboring regions, and their components, $y_{g,it}^* = \sum_{j=1}^{N} w_{ij} Y_{g,jt}$, are a weighted average of y_g in all regions except the i^{th}. The specification of the spatial weights matrix will be addressed in section 4.

To build the MultiREG-SpVAR model, first internal and external variables are grouped as $Z_{it} = (Y_{it}', Y_{it}^{'*})'$ in order to put all the regional models together as a system:

$$\begin{cases} \mathbf{A}_{01}\mathbf{Z}_{1t} = \mathbf{\Lambda}_{01} + \mathbf{\Lambda}_{11}\mathbf{t} + \mathbf{A}_{11}\mathbf{Z}_{1,t-1} + \cdots + \mathbf{A}_{r1}\mathbf{Z}_{1,t-r} + \mathbf{u}_{1t} \\ \mathbf{A}_{02}\mathbf{Z}_{2t} = \mathbf{\Lambda}_{02} + \mathbf{\Lambda}_{12}\mathbf{t} + \mathbf{A}_{12}\mathbf{Z}_{2,t-1} + \cdots + \mathbf{A}_{r2}\mathbf{Z}_{2,t-r} + \mathbf{u}_{2t} \\ \dots \\ \mathbf{A}_{0N}\mathbf{Z}_{Nt} = \mathbf{\Lambda}_{0N} + \mathbf{\Lambda}_{1N}\mathbf{t} + \mathbf{A}_{1N}\mathbf{Z}_{N,t-1} + \cdots + \mathbf{A}_{rN}\mathbf{Z}_{N,t-r} + \mathbf{u}_{Nt} \end{cases} \quad [3]$$

where $\mathbf{A}_{0i} = (\mathbf{I}_G, -\mathbf{\Phi}_{0i}), \mathbf{A}_{ki} = (\mathbf{\Gamma}_{ki}, -\mathbf{\Phi}_{ki})$ (i=1,…,N , k=1,…r) and r=max(p_i,q_i).

Secondly, link matrices $\mathbf{L}_i$ of order (2 x *G)* x *(N* x *G*) are constructed on the basis of the connection regional weights wij in order to obtain the identity $\mathbf{Z}_{it}= \mathbf{L}_i\mathbf{Y}_t$ that relates the region-specific variables $\mathbf{Z}_{it}$ to the 'global' variable $\mathbf{Y}_t = \left(\mathbf{Y}_{1t}^{'}, \mathbf{Y}_{2t}^{'} \ldots \mathbf{Y}_{Nt}^{'}\right)^{'}$, $\mathbf{Y}_t$ being a vector of order *(N* x *G*) x 1 containing all the endogenous variables of the multiregional model. Thus, the system of individual models [3] yields a compact specification in terms of $\mathbf{Y}_t$ given by:

$$\mathbf{G}_0\mathbf{Y}_t = \mathbf{\Lambda}_0 + \mathbf{\Lambda}_1\mathbf{t} + \mathbf{G}_1\mathbf{Y}_{t-1} + \cdots + \mathbf{G}_r\mathbf{Y}_{t-r} + \mathbf{u}_{1t} \quad [4]$$

where $\mathbf{G}_j = \left(\left(\mathbf{A}_{j1}\mathbf{L}_1\right)^{'}, \left(\mathbf{A}_{j2}\mathbf{L}_2\right)^{'}, \ldots, \left(\mathbf{A}_{jN}\mathbf{L}_N\right)^{'},\right)^{'}$ (*j*=0, 1,…,*r*), $\mathbf{\Lambda}_j = \left(\mathbf{\Lambda}_{j1}^{'}, \mathbf{\Lambda}_{j2}^{'}, \ldots, \mathbf{\Lambda}_{jN}^{'}\right)^{'}$

(*j*=0,1), and $\mathbf{u}_t = (\mathbf{u}_{1t}', \mathbf{u}_{2t}', \ldots, \mathbf{u}_{Nt}')'$ with $\sum_u = Cov\ (\mathbf{u}_t)$.

Finally, since can be shown that $\mathbf{G}_0$ is a (*N* x *G)* x *(N* x *G*) non-singular matrix if the global model is to be complete (that is, if it is possible to uniquely solve the state variables of all the regions), the following integrated reduced form can be obtained by premultiplying expression [4] by the matrix $\mathbf{G}_0^{-1}$

$$\mathbf{Y}_t = \mathbf{\Pi}_0^1 + \mathbf{\Pi}_0^2\mathbf{t} + \mathbf{\Pi}_1\mathbf{Y}_{t-1} + \cdots + \mathbf{\Pi}_r\mathbf{Y}_{t-r} + \mathbf{e}_t \quad [5]$$

where $\mathbf{\Pi}_0^j = \mathbf{G}_0^{-1}\mathbf{\Lambda}_j$ (j=0,1), $\mathbf{\Pi}_j = \mathbf{G}_0^{-1}\mathbf{G}_j$ (j=0,1,…,r) and $\mathbf{e}_t = \mathbf{G}_0^{-1}\mathbf{u}_t$ whit $\sum_e = Cov\ (\mathbf{e}_t)$, a non-restricted covariance matrix.

Having reparametrized the original system [3] as [5], the multiregional spatial vector autoregressive model can be seen as a reduced-form VAR model for the regional system vector $\mathbf{Y}_t = (\mathbf{Y}_{1t}', \mathbf{Y}_{2t}', \ldots, \mathbf{Y}_{Nt}')'$. This expression is the basis for the analysis of the dynamic properties of the multiregional model, and can be utilized among other things for the simulation of the response of the regional system to shocks in specific regions, as set out in section 4.

4. Empirical application: Crowding effects of public capital in the Spanish regional system

This section focuses on the estimation of both domestic and spillover crowding effects derived from the regional allocation of public capital in Spain. The effects derived from a hypothetical increase in the allocation of public capital investment in a Spanish region are identified in order to determine the response of regional private capital. The detection of these responses would contribute to improve the allocation of regional public investment. This paper goes beyond existing regional studies by considering the substitutability and complementarity hypothesis within a country. Effectively, to our knowledge, no studies can be found that allow the joint modeling of dynamic spatio-temporal interdependencies of regional economies within a regional system to analyze the spatial and temporal response of all regions to a temporary shock in the public capital of one specific region. Next, the characteristic of the data and the estimation results are presented.

4.1 The data and the properties of the time series

The database used in the empirical application consists of yearly time series for the 17 Spanish regions (Autonomous Communities) over the period 1964-2003 and for each region the macroeconomic variables used are the following: gross value added, *GVA*, measured at basic prices in thousands of year 2000 constant euros; total employment (*E*), in thousands of employed persons; and private (*KPR*) and public (*KPU*) net capital stocks[5], in thousands of year 2000 constant euros. The regional series for *GVA* and *E* have been drawn from the *BD.MORES* database (Bustos *et al*., 2008) and the time series for *KPR* and *KPU* have been taken from the *Fundación BBVA-Ivie* database (Mas *et al*., 2009).

The region-specific spatially-lagged variables used in the MultiREG-SpVAR model $\left(y^*_{it} = \sum_{j=0}^{N} w_{ij}\, y_{jt} \right)$ have been built using trade-based weights in order to capture the economic interaction of region *j* with the i^{th} region's economy and not only the geographic interaction. These weights w_{ij} were computed using data on interregional trade in Spain drawn from the *C-Intereg* database (Llanos *et al*., 2009, 2010).

Initially we used a full trade-share weight matrix based on the averages of regional goods trade flows in Spain. Mean trade shares, $\bar{s}_{ij}$, were computed as the proportion of region *j* in the total trade (exports plus imports) of region *i* over the period 2004-2007 (measured in millions of euros), and the spatial weights were defined as $w^*_{ij} = \bar{s}_{ij}$ The resulting multiregional model was not dynamically stable (some eigenvalues of the model were slightly above unity); as a result, the trade-share matrix was transformed into a more sparse matrix, trying at the same time to mitigate the potential endogeneity problem caused by using a weight matrix determined by one variable (trade) directly related with the phenomenon under study (regional economic growth).[6]

As a result, a binary trade-based spatial weight matrix was built defining non-normalized weights as $w^*_{ij} = \begin{cases} 0 \text{ if } i = j \\ 1 \text{ if } \bar{s}_{ij} \geq 0.1 \\ 0 \text{ if } \bar{s}_{ij} < 0.1 \end{cases}$ and then a W row-standardized weights matrix was defined as $w_{ij} = w^*_{ij} / \sum_j w^*_{ij}$. Thus, only trade-neighbors of region *i* that have a mean trade share above 10% of the total trade were used. This criterion is based on the idea that only 'relevant trader regions' have non-negligible spatio-temporal effects on their neighbors, the remaining regions being less important and assumed to have negligible individual impacts. The 10% critical cut-off point yields a set of 3 to 5 (not necessarily contiguous) neighbors. To check the robustness of our results, two other values (5% and 15%) were adopted, and the results were qualitatively similar to those presented in this paper, and thus were omitted for the sake of brevity.

[5] The regional public capital stock comprises productive public capital owned by the local, regional, and national administrations, including transport infrastructure (roads, ports, airports, and railways), water and sewage facilities, and urban structures.
[6] For details about the specification of the matrix of spatial weights, see Ramajo *et al.* (2013).

Table 1 presents the 17x17 weight matrix for the seventeen Spanish regions, where weights are displayed in row-normalized form by region, such that each row sums to one. The data in this table highlight the key role played by six regions (Andalusia, Catalonia, Castile-Leon, Madrid, the Basque Country and the Valencian Community), that are the more integrated with the rest of Spanish regional economies and thus could being catalogued as 'trade-centers' of the Spanish regional system.

Table 1

Spatial weights (w_{ij}) based on regional trade flows in Spain

	AND	ARA	AST	BAL	CAN	CANT	CAT	CLM	CYL	EXT	GAL	MAD	MUR	NAV	PV	RIO	VAL
AND	0	0	0	0	0	0	0.33	0	0	0	0	0.33	0	0	0	0	0.33
ARA	0	0	0	0	0	0	0.33	0	0	0	0	0	0	0	0.33	0	0.33
AST	0	0	0	0	0	0	0	0	0.25	0	0.25	0.25	0	0	0.25	0	0
BAL	0.33	0	0	0	0	0	0.33	0	0	0	0	0	0	0	0	0	0.33
CAN	0.33	0	0	0	0	0	0.33	0	0	0	0	0.33	0	0	0	0	0
CANT	0	0	0	0	0	0	0.33	0	0.33	0	0	0	0	0	0.33	0	0
CAT	0.25	0.25	0	0	0	0	0	0	0	0	0	0.25	0	0	0	0	0.25
CLM	0.25	0	0	0	0	0	0.25	0	0	0	0	0.25	0	0	0	0	0.25
CYL	0	0	0	0	0	0	0.25	0	0	0	0.25	0.25	0	0	0.25	0	0
EXT	0.25	0	0	0	0	0	0	0.25	0.25	0	0	0.25	0	0	0	0	0
GAL	0	0	0.20	0	0	0	0.20	0	0.20	0	0	0.20	0	0	0.20	0	0
MAD	0.20	0	0	0	0	0	0.20	0.20	0.20	0	0	0	0	0	0	0	0.20
MUR	0.33	0	0	0	0	0	0.33	0	0	0	0	0	0	0	0	0	0.33
NAV	0	0.33	0	0	0	0	0.33	0	0	0	0	0	0	0	0.33	0	0
PV	0	0	0	0	0	0	0.25	0	0.25	0	0	0.25	0	0.25	0	0	0
RIO	0	0	0	0	0	0	0.25	0	0.25	0	0	0	0	0	0.25	0	0.25
VAL	0.25	0	0	0	0	0	0.25	0	0	0	0	0.25	0.25	0	0	0	0

SOURCE: Own elaboration from *C-Intereg* database.

NOTE: Non-normalized spatial weights were computed as $w^*_{ij} = \begin{cases} 0 \text{ if } i = j \\ 1 \text{ if } \bar{s}_{ij} \geq 0.1 \\ 0 \text{ if } \bar{s}_{ij} < 0.1 \end{cases}$ and then a $W = (w_{ij})$ row-standardized weights matrix was defined as $w_{ij} = w^*_{ij}/\sum_j w^*_{ij}$

REGIONAL ABBREVIATIONS: Andalusia (AND), Aragón (ARA), Asturias (AST), Balearic Islands (BAL), Canary Islands (CAN), Cantabria (CANT), Catalonia (CAT), Castile-La Mancha (CLM), Castile-Leon (CYL), Extremadura (EXT), Galicia (GAL), Madrid (MAD), Murcia (MUR), Navarre (NAV), Basque Country (PV), La Rioja (RIO) and the Valencian Community (VAL).

As a step prior to the econometric analysis, the integration properties of all the variables have been examined in order to determine the existence of unit roots [I(1)] or stationarity [I(0)] in their time-series behavior, a crucial aspect of the VAR methodology. First, the order of integration of each variable (in logs) was investigated using the standard Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979) as well as the Weighted Symmetric Dickey-Fuller (WS) test (Park and Fuller, 1995) in order to increase the small-sample power performance of the unit root analysis. Both type of tests provided evidence favoring the hypothesis that the vast majority of the series under study behave as I(1) non-stationary variables. Further, some panel unit-root tests were used to test the presence of unit roots in the series (Breitung and Pesaran, 2008). These panel unit-root results provide again general evidence against rejecting the hypothesis that the variables in the database behave in a non-stationary manner[7]. Hence, all the regional SpVAR models that make up the multiregional specification have been estimated in (log) first differences, and not levels[8].

4.2 Empirical application: crowding effects of public capital

This section focuses on the estimation of both domestic and spillover crowding effects on private capital derived from a shock of the allocation of public capital in Spain. To do this, a MultiREG-SpVAR for the Spanish regional system has been estimated. Due to the very large number of regressions and intermediate results involved in the estimation, only the main estimation and specification test results are presented.

4.2.1 Conditions for the estimation of the MultiREG-SpVAR model

Because we are considering N=17 regions, seventeen individual SpVARX(p_i,q_i) models need to be estimated before the construction of the global model. All regional models contain the four domestic variables $Y_{it} = (y_{it}, e_{it}, kpr_{it}, kpu_{it})$, where $y_{it} = \log(GVA_{it})$ $e_{it} = \log(E_{it}), kpr_{it} = \log(KPR_{it})$ and $kpu_{it} = \log(KPU_{it})$, and the corresponding spatial lags Y^*_{it}. Due to data limitations, the maximum lag order of the domestic and external variables is set to two (p_i=2) and one (q_i=1), respectively. The optimum lag was chosen according to AIC choice criterion.

According to the Global VAR approach of Pesaran *et al*. (2004), three requirements need to be met for the validity of the methodology.[9] First, the global model must be dynamically stable, requiring examination of the eigenvalues of the model (5). In this case, the moduli of the 136 (17x8) eigenvalues of this model were all on or within the unit circle; specifically, the number of unit roots was 68. Secondly, the weights must be relatively small; as reported in Table 1, the binary trade-based weights are not close to one, the largest weight being 0.33 for some regions. Thirdly, the cross-dependence of the idiosyncratic shocks must be sufficiently small; in this application, several sets of average pairwise cross-section correlations were calculated, related to the endogenous variables in levels and in differences and to the SpVAR residuals obtained from each

[7] For the sake of brevity, we omit the details of this and other intermediate outputs. Complete results can be obtained on request from the authors.

[8] Although stationarity is not required, because vector error correction methods could be used for cointegrated series, due to the limited length of the time series we decided postpone such long-run analysis for future works.

[9] The weak exogeneity of the external variables is another key assumption of the Global VAR modeling approach. In our case, because no cointegrating relation between internal and external variables is assumed, this exogeneity hypothesis cannot be tested but automatically assured.

region-specific model, and very low cross-section correlations between residuals was observed, allowing us to simulate shocks that are mainly region-specific.

In summary, given that all the statistical conditions have been met, the estimation of the MultiREG-SpVAR is justified, and the dynamic properties of the model can be investigated.

4.2.2 Dynamic analysis: Generalized Impulse Response (GIR) functions

The dynamic analysis presented in this section follows the Generalized Impulse Response (GIR) approach proposed by Koop *et al*. (1996), and developed further in Pesaran and Shin (1998) for VAR models. This approach generalizes the traditional Orthogonalized Impulse Response method of Sims (1980), being invariant to the ordering of the variables in the SpVAR models, which makes the GIR functions a very useful tool to analyze the propagation of shocks across regions.

Thus, the GIR functions are used to simulate the response of the system to either a unitary (one standard error) shock in one internal variable in one specific region. Given the existence of trade links between regions that are incorporated in the model, other regions in the system will be (more or less) affected from the disturbance, providing relevant information about the degree of interregional spillovers in the Spanish regional system. In this application, both the domestic and spillover crowding effects of one-time innovations in the public capital installed in one region are estimated.

Tables 2, 3 and 4 show detailed estimates effects in the first, fifth and fifteenth years. In these tables, the rows display the region-specific shocks, where the shaded cells document the own-response of private capital to a domestic public capital shock (domestic crowding effect), and the non-shaded elements record the spillover crowding effects in the different regions of Spain. These results are new in the literature, since none of the previous studies has allowed spatio-temporal interdependencies between public and private capital of all the regions.

Table 2

Short-run effect of private capital to a positive unit shock in public capital

	Response (%) in:																
Shock in:	**AND**	**ARA**	**AST**	**BAL**	**CAN**	**CANT**	**CAT**	**CLM**	**CYL**	**EXT**	**GAL**	**MAD**	**MUR**	**NAV**	**PV**	**RIO**	**VAL**
AND	0.08	0.03	-0.02	0.08	0.04	-0.08	-0.01	-0.01	0.01	-0.02	-0.03	-0.03	-0.04	0.01	0.03	0.00	0.02
ARA	-0.03	0.07	0.02	-0.06	-0.11	0.00	-0.01	-0.06	0.02	-0.08	-0.01	0.00	-0.12	0.05	0.05	-0.02	-0.03
AST	0.00	0.01	0.04	-0.01	-0.04	0.06	0.06	0.03	0.03	0.01	-0.01	0.06	-0.06	0.06	0.08	-0.06	0.00
BAL	-0.04	-0.03	0.07	-0.04	-0.13	-0.01	0.00	-0.03	-0.04	0.03	0.00	0.01	0.00	-0.05	0.02	-0.02	-0.02
CAN	0.03	0.00	0.10	0.09	0.11	0.07	0.04	-0.01	0.06	0.08	0.03	0.04	0.07	0.05	0.12	0.06	0.09
CANT	0.02	-0.04	0.00	0.07	0.06	0.03	0.00	0.02	-0.03	-0.08	0.01	-0.11	0.02	0.07	-0.04	-0.02	-0.02
CAT	0.02	0.02	-0.01	-0.03	0.05	0.08	0.08	0.04	0.03	-0.03	0.02	0.10	0.00	0.03	0.01	-0.05	-0.01
CLM	-0.01	-0.02	-0.06	0.03	0.10	0.00	0.00	0.09	-0.05	0.10	-0.01	-0.01	0.00	-0.01	-0.10	-0.09	-0.01
CYL	-0.02	-0.01	-0.02	-0.05	-0.08	-0.01	-0.03	0.00	0.03	0.02	-0.04	-0.01	-0.08	0.03	0.11	-0.08	0.00
EXT	-0.07	0.03	0.05	-0.03	-0.05	0.03	-0.03	0.02	-0.02	0.05	-0.01	-0.02	-0.04	0.01	0.02	-0.02	-0.05
GAL	0.00	-0.03	0.02	0.02	0.04	0.10	-0.04	-0.04	0.04	0.01	0.10	-0.06	0.09	0.12	0.04	0.06	0.01
MAD	0.01	0.05	0.08	-0.03	-0.06	-0.02	0.05	0.00	-0.01	0.05	0.00	0.20	-0.02	-0.09	0.03	-0.11	0.01
MUR	0.04	0.00	0.11	0.04	0.03	0.04	0.00	0.03	-0.03	-0.04	0.02	-0.06	0.12	0.05	-0.01	-0.02	0.00
NAV	-0.02	0.03	0.02	-0.06	-0.11	-0.05	-0.05	0.00	0.03	-0.12	-0.02	-0.14	-0.02	0.09	0.04	0.00	-0.05
PV	0.04	0.05	0.05	0.04	0.02	0.01	0.08	0.01	0.02	0.06	0.04	0.11	0.06	-0.01	0.14	-0.02	0.03
RIO	0.00	0.01	-0.06	-0.07	-0.07	-0.05	-0.08	0.00	0.01	0.00	-0.03	-0.13	-0.01	-0.01	-0.04	0.13	-0.05
VAL	0.00	-0.07	-0.14	-0.08	-0.04	-0.02	-0.04	-0.03	0.05	-0.10	0.02	-0.09	0.02	0.07	0.02	0.06	0.00

Table 3

Medium-term effect of private capital to a positive unit shock in public capital

	Response (%) in:																
Shock in:	**AND**	**ARA**	**AST**	**BAL**	**CAN**	**CANT**	**CAT**	**CLM**	**CYL**	**EXT**	**GAL**	**MAD**	**MUR**	**NAV**	**PV**	**RIO**	**VAL**
AND	0.21	0.10	0.03	0.11	0.07	-0.23	0.53	-0.02	0.03	-0.26	-0.03	0.40	-0.31	0.14	0.53	-0.14	0.14
ARA	0.27	0.42	0.33	0.20	0.15	0.08	0.65	0.11	0.12	-0.37	0.10	0.56	-0.10	0.50	0.73	0.07	0.25
AST	0.32	0.33	0.43	0.35	0.25	0.33	0.51	0.27	0.22	0.19	0.17	0.47	0.18	0.38	0.58	0.16	0.37
BAL	0.13	0.07	0.29	0.13	0.04	0.12	0.16	0.12	-0.05	-0.08	0.10	0.18	0.17	0.07	0.20	0.13	0.09
CAN	-0.04	-0.02	0.11	0.03	0.03	0.03	0.01	-0.07	0.10	0.13	0.05	0.01	-0.06	0.10	0.29	0.04	0.04
CANT	0.55	0.27	0.51	0.60	0.49	0.28	0.78	0.42	0.18	-0.17	0.31	0.68	0.29	0.68	0.75	0.18	0.47
CAT	0.81	0.66	0.78	0.81	0.73	0.72	1.12	0.63	0.55	0.42	0.48	1.13	0.66	0.65	1.00	0.49	0.85
CLM	0.04	0.03	-0.04	0.13	0.16	0.06	-0.01	0.25	-0.09	0.16	0.04	0.03	0.10	0.06	-0.17	-0.13	0.05
CYL	0.06	0.04	0.05	-0.04	0.00	-0.09	0.31	0.05	-0.06	-0.31	-0.12	0.26	-0.21	0.21	0.51	-0.14	0.07
EXT	-0.36	-0.13	-0.19	-0.32	-0.26	-0.11	-0.62	-0.09	-0.24	-0.20	-0.12	-0.54	-0.12	-0.18	-0.48	-0.09	-0.41
GAL	0.09	0.01	0.08	0.12	0.10	0.08	0.16	-0.01	0.14	-0.02	0.17	0.14	0.10	0.41	0.36	0.14	0.12
MAD	0.42	0.44	0.52	0.44	0.29	0.25	0.73	0.30	0.22	0.15	0.23	0.81	0.27	0.08	0.57	0.10	0.49
MUR	0.42	0.22	0.48	0.40	0.32	0.17	0.51	0.33	0.11	-0.11	0.26	0.47	0.28	0.48	0.49	0.06	0.33
NAV	0.16	0.20	0.21	0.04	0.06	-0.03	0.34	0.16	0.06	-0.40	0.04	0.26	-0.05	0.56	0.58	-0.03	0.08
PV	0.04	0.10	0.00	0.05	-0.02	-0.01	0.13	-0.05	0.0	0.14	-0.01	0.09	0.04	-0.23	0.10	0.04	0.09
RIO	-0.27	-0.25	-0.38	-0.42	-0.30	-0.26	-0.50	-0.17	-0.17	-0.18	-0.21	-0.49	-0.23	-0.25	-0.47	0.19	-0.38
VAL	0.22	0.02	-0.06	0.06	0.11	0.02	0.48	0.04	0.18	-0.09	0.01	0.35	0.00	0.32	0.49	0.19	0.27

Table 4

Long-run effect of private capital to a positive unit shock in public capital

	Response (%) in:																
Shock in:	**AND**	**ARA**	**AST**	**BAL**	**CAN**	**CANT**	**CAT**	**CLM**	**CYL**	**EXT**	**GAL**	**MAD**	**MUR**	**NAV**	**PV**	**RIO**	**VAL**
AND	1.43	1.48	1.34	1.62	1.03	0.61	2.82	0.78	1.04	0.36	0.61	2.40	0.22	1.30	3.14	0.91	1.80
ARA	1.15	1.57	1.31	1.33	0.79	0.77	2.33	0.67	1.00	0.39	0.65	1.97	0.33	1.40	2.77	1.00	1.53
AST	0.16	0.35	0.27	0.24	0.08	0.25	0.40	0.11	0.27	0.41	0.10	0.31	0.05	0.26	0.57	0.15	0.29
BAL	0.12	0.16	0.30	0.17	0.01	0.14	0.21	0.10	0.02	0.13	0.13	0.20	0.18	0.06	0.27	0.21	0.16
CAN	0.26	0.22	0.41	0.35	0.26	0.21	0.53	0.12	0.26	0.15	0.17	0.49	0.09	0.39	0.82	0.25	0.38
CANT	1.08	1.15	1.13	1.36	0.82	0.79	1.87	0.70	0.86	0.64	0.67	1.58	0.53	1.19	2.19	0.88	1.39
CAT	0.43	0.78	0.55	0.69	0.38	0.69	0.80	0.29	0.79	1.19	0.43	0.68	0.46	0.31	0.85	0.61	0.75
CLM	-0.27	-0.28	-0.37	-0.21	-0.08	-0.16	-0.53	0.06	-0.35	0.02	-0.13	-0.45	-0.05	-0.20	-0.75	-0.39	-0.31
CYL	0.84	0.88	0.82	0.88	0.56	0.44	1.69	0.54	0.51	0.15	0.30	1.48	0.17	0.96	2.10	0.54	1.06
EXT	-0.78	-0.73	-0.67	-0.87	-0.54	-0.47	-1.45	-0.31	-0.73	-0.72	-0.37	-1.20	-0.27	-0.54	-1.53	-0.54	-1.03
GAL	0.22	0.22	0.26	0.31	0.20	0.19	0.47	0.07	0.31	0.12	0.20	0.39	0.15	0.56	0.82	0.32	0.32
MAD	0.34	0.61	0.51	0.48	0.19	0.30	0.74	0.18	0.39	0.54	0.25	0.74	0.20	-0.05	0.74	0.20	0.59
MUR	0.68	0.68	0.79	0.80	0.48	0.42	1.11	0.45	0.48	0.35	0.43	0.93	0.37	0.75	1.29	0.44	0.81
NAV	0.94	1.17	1.03	0.98	0.59	0.53	1.75	0.63	0.76	0.16	0.46	1.49	0.27	1.32	2.29	0.69	1.15
PV	-0.13	-0.11	-0.18	-0.15	-0.12	-0.13	-0.17	-0.16	-0.17	-0.03	-0.12	-0.17	-0.04	-0.43	-0.26	-0.10	-0.14
RIO	-0.16	-0.29	-0.29	-0.36	-0.20	-0.25	-0.42	-0.06	-0.28	-0.39	-0.18	-0.39	-0.14	-0.13	-0.46	022	-0.37
VAL	0.71	0.65	0.45	0.69	0.45	0.38	1.40	0.29	0.72	0.41	0.29	1.09	0.18	0.73	1.64	0.70	0.99

NOTE: Numbers reported are median estimates of responses of private capital to one standard error negative shock to public capital in the row region.

4.2.3 Discussion of the results (and policy implications)

From the estimates contained in tables 2, 3 and 4, the domestic and the spillover crowding effects display positive and negative signs, although positive effects prevail. As can be seen in table 2, initially all the domestic crowding effects are positive (except in the case of the Balearic Islands). After 5 years (see table 3) and 15 years (see table 4), only for two of the seventeen regions are the domestic crowding effects negative. This indicates that while public capital formation in a region will raise private capital within almost all the regions (public and private capital are complementary), the existence of negative domestic crowding effects points out to the production of countervailing crowding-out effects. This way, if increases of public capital imply negative effects on private capital (the substitution effects prevails for these regions), regional policy makers would have to analyze why this happens. Among the negative domestic effects, Extremadura is the region with the lowest value, being the most sensitive regional economy to a positive one-off shock in the public capital.

With respect to the spillover crowding effects shown in tables 2, 3 and 4, it is also possible to find positive and negative effects. From the responses, it is important to highlight the existence of asymmetric spillover crowding responses. For example, a positive unit shock in the public capital of Murcia has positive effects after 5 years on the private capital of Andalusia, while a positive shock in Andalusia has a negative effect after 5 years on the private capital of Murcia. In line with the applied methodology, these types of asymmetries are not easily explainable, since the results are derived from a complicated process involving the tracing of paths of influence throughout the regional economic system.

Our results about the effects of regional public capital on private capital contain mixed findings. Some results show crowding-in for certain regions, while some others show crowding-out in other regions. Nevertheless, crowding-in prevails. Any attempt at analyzing the results from tables 2, 3 and 4 would require the calculation of the average spillover crowding effects (average effects generated from increases in public capital of a region on the rest of regions). Thus, average spillover effects are computed from tables 2, 3 and 4 by rows as weighted averages considering the regional shares of national GVA. The results are shown in table 5. From table 5, the estimation results show evidence about the average spillover crowding effects, the domestic effects and the total effects within the regional economic system.

Table 5

Short, medium and long-run crowding effects on private capital to a positive unit shock in public capital

	SHORT RUN (0 YEARS)			MEDIUM RUN (5 YEARS)			LONG RUN (15 YEARS)		
Shock in:	**Spillover**	**Domestic**	**Total**	**Spillover**	**Domestic**	**Total**	**Spillover**	**Domestic**	**Total**
AND	0,00%	0,08%	0,08%	0,25%	0,21%	0,45%	1,91%	1,43%	3,34%
ARA	-0,02%	0,07%	0,05%	0,38%	0,42%	0,79%	1,58%	1,57%	3,15%
AST	0,03%	0,04%	0,07%	0,38%	0,43%	0,81%	0,28%	0,27%	0,55%
BAL	-0,01%	-0,04%	-0,06%	0,13%	0,13%	0,26%	0,16%	0,17%	0,33%
CAN	0,05%	0,11%	0,17%	0,03%	0,03%	0,07%	0,39%	0,26%	0,66%
CANT	-0,02%	0,03%	0,01%	0,55%	0,28%	0,83%	1,35%	0,79%	2,14%
CAT	0,03%	0,08%	0,11%	0,82%	1,12%	1,94%	0,62%	0,80%	1,42%
CLM	-0,01%	0,09%	0,08%	0,02%	0,25%	0,27%	-0,37%	0,06%	-0,30%
CYL	-0,01%	0,03%	0,01%	0,15%	-0,06%	0,08%	1,15%	0,51%	1,66%
EXT	-0,02%	0,05%	0,02%	-0,40%	-0,20%	-0,59%	-0,98%	-0,72%	-1,70%
GAL	-0,01%	0,10%	0,10%	0,14%	0,17%	0,31%	0,35%	0,20%	0,56%
MAD	0,01%	0,20%	0,22%	0,45%	0,81%	1,26%	0,48%	0,74%	1,22%
MUR	0,00%	0,12%	0,12%	0,39%	0,28%	0,67%	0,82%	0,37%	1,18%
NAV	-0,05%	0,09%	0,04%	0,20%	0,56%	0,75%	1,21%	1,32%	2,53%
PV	0,06%	0,14%	0,20%	0,06%	0,10%	0,16%	-0,15%	-0,26%	-0,41%
RIO	-0,05%	0,13%	0,08%	-0,37%	0,19%	-0,18%	-0,31%	0,22%	-0,09%
VAL	-0,03%	0,00%	-0,03%	0,26%	0,27%	0,53%	0,91%	0,99%	1,90%
Minimun	-0,05%	-0,04%	-0,06%	-0,40%	-0,20%	-0,59%	-0,98%	-0,72%	-1,70%
Maximun	0,06%	0,20%	0,22%	0,82%	1,12%	1,94%	1,91%	1,57%	3,34%
Difference	0,11%	0,25%	0,27%	1,22%	1,32%	2,54%	2,89%	2,28%	5,03%

First of all, for each region, and in the short run, the domestic crowding effects are more relevant than the spillover crowding effects. Nonetheless, in the medium run, this importance is not so clear, providing evidence of the relative importance for each region of the spillover effects versus the domestic effects. The total effects show that, in general, regional public investment in capital crowds in private capital on the short, medium and long-run. Nevertheless, empirical evidence of crowding out effects (substitution) is shown for some regions: Balearic Islands and the Valencian Community in the short-run, Extremadura and La Rioja in the medium-run, and Castile-La Mancha, Extremadura, the Basque Country and La Rioja in the long run.

With respect to the spillover effects, shocks in the public capital of the Spanish regions show that ten of the seventeen Spanish regions (59%) are generating in the short-run crowding out effects. These negative short run spillover effects lose force in the medium run (only Extremadura and La Rioja show negative effects). However, the number of negative spillover effects increase again in the long-run (Extremadura, La Rioja, Castile-La Mancha and the Basque Country). This could indicate the need for policy measures to coordinate or consolidate the positive effects of fiscal policies.

According to Buiter (1977), the crowding effects should not to be greater in the long-run than in the short-run. Nevertheless, from our results it is interesting to emphasize that the degree of crowding in/out is greater in the medium-run than in the short run. In the same way, the degree of crowding in/out is greater in the long-run than in the medium-run. We can interpret this result with the longer time it takes for the impacts for public capital to affect the regional system.

Finally, tables 6, 7 and 8 present different taxonomies of the Spanish regional economies in view of the range of values obtained by the domestic crowding effects (*X*-axis) and the spillover crowding effects (*Y*-axis). Centering our interest in the medium-run,[10] the lowest crowding-out effects can be found in Extremadura and La Rioja. Conversely, the highest crowding-in effects emanate from Catalonia and Madrid. From the foregoing analysis it is not a simple matter to suggest policy recommendation, although it is intuitive that an increase in the level of public capital in Madrid and Catalonia will generate important complementary effects in the private capital of these regions and, in addition in the private capital of different Spanish regions.

[10] For regional economic policy, the effects of changes in public capital over a longer time horizon is more relevant (Buiter, 1977).

Table 6

Regional taxonomy (Short run): Spillover crowding effects *vs.* Domestic crowding effects

Spillover Crowding Effects	(0.02, 0.06)		AST, CAT,	CAN, PV
	(-0.02, 0.02)		MUR	AND, MAD
	(-0.05, -0.02)	BAL, CANT, CYL, VAL	ARA, CLM, EXT, GAL, NAV	RIO
	Intervals	(-0.04, 0.04)	(0.04, 0.12)	(0.12, 0.20)
		Domestic Crowding Effects		

Table 7

Regional taxonomy (Medium run): Spillover crowding effects *vs.* Domestic crowding effects

Spillover Crowding Effects	(0.42, 0.82)		CANT	CAT, MAD
	(0.01, 0.42)	BAL, CAN, CYL, GAL, PV	AND, ARA, AST, CLM, MUR, NAV, VAL	
	(-0.40, 0.01)	EXT, RIO		
	Intervals	(-0.20, 0.24)	(0.24, 0.68)	(0.68, 1.12)
		Domestic Crowding Effects		

Table 8

Regional taxonomy (Long run): Spillover crowding effects *vs.* Domestic crowding effects

Spillover Crowding Effects	(0.95, 1.91)		CYL	AND, ARA, CANT, NAV
	(-0.02, 0.95)		AST, BAL, CAN, CAT, GAL, MAD, MUR	VAL
	(-0.98, -0.02)	EXT, PV	CLM, RIO	
	Intervals	(-0.72, 0.04)	(0.04, 0.81)	(0.81, 1.57)
		Domestic Crowding Effects		

For some regions, the relationship between public and private capital is complementary and public capital improves the productivity of private capital in production. On the other hand, the substitutability (crowding out) nature of public capital effect is in competition with private capital, reducing the ability of government to influence economic activities through public spending in other regions. Regional public capital investments can have asymmetrical crowding effects and this evidence may have far-reaching spatial planning implications.

With respect to the previous empirical work, and due to the fact that, to our knowledge, this is the first paper that considers crowding effects between regional economies within a regional economic system, no comparison with our results is possible. This is also the case of the Spanish regional economic system, where the previous empirical literature reveals conflicting results coming from different studies that analyze different time periods and use different methods (see Márquez *et al.*, 2011).

5. Conclusions

The central focus of this paper is on the question: does higher regional public capital accumulation crowd out regional private capital? As greater regional public capital accumulation induces a crowding out of private capital, and an increase in the public capital stock also crowds in private capital accumulation, empirical evidence on the net effect of these opposing forces is necessary. The purpose of this paper is to show new evidence about the relationship between public and private capital by formulating a Multiregional Spatial VAR model for the Spanish regional system. The work extends the class of VAR models applied in the recent works on the topic.

Our analysis takes the existing literature further in the following directions. It provides an empirical approach to measure both the domestic and spillover crowd effects from regional public capital allowing for spatio-temporal interdependencies of regional variables across all regions (previous studies have only been able to reveal a part of the complex spatio-temporal feedbacks across regional public and private capitals). The results confirm that the response of private capital to an increase in regional public capital can be substitution or complementary, and these responses can change over time. Finally, from the different regional taxonomies, the different Spanish regional economies are classified according to their responses.

In general, the key outcomes from the study presented in this paper indicate that investments in public capital could have different effects on private capital. Therefore, it is crucial for the government to consider these results in order to derive substantive conclusions, especially when the government is in the process of evaluating the impact of fiscal policy on regional private investment and regional output growth. In addition, the empirical results can be beneficial in both the regional macroeconomic area and regional policy analysis if the regional economic system is in the process of cutting expenditures to reduce the fiscal imbalances in the country. Even though the overall results from the empirical literature with respect to the impact of public capital investment on private capital investment are ambiguous, our study finds more positive effects of public capital on private capital growth. The key findings from this study are important, since it is not usual to estimate the substitution effects that regional public capital in a region can induce on regional private capital in other regions. In future work, we will attempt to find out some of the common features shared by the regions where public capital have been found to crowd out (crowd in) private capital at the different time horizons.

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