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A SPATIAL AUTOREGRESSIVE PANEL MODEL TO ANALYZE ROAD NETWORK SPILLOVERS ON PRODUCTION

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Abstract

The production function approach is used to introduce the effect of public infrastructure on economic growth focusing on its spillover effects. We improve the existing literature both from a conceptual and methodological perspective. As regressors we incorporate variables related to the new concepts of internal and imported transport infrastructure capital stocks, which are actually used in commercial flows, calculated by network analysis performed in GIS. The internally used capital stock represents own infrastructure that benefits accessing markets within the region itself, while the imported capital stock captures the spillover effect associated to the use of the infrastructure situated in neighboring regions. From a methodological perspective, we introduce spatial interdependence into these models, applying the most recent spatial econometric techniques based on instrumental variables estimation in spatial autoregressive panel models in comparison with Maximum Likelihood estimation methods. We illustrate the methodology with Spanish provincial panel data for the period 1980-2007. Results support the hypothesis that the imported capital has a positive spillover effect on production.

KEYWORDS: Transport spillovers; Production function; Panel Data Econometrics; GIS (Geographic Information Systems); Market access; Network analysis.

JEL CODES: E22, H54, R49

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1. Introduction

We analyze the impact (spillovers) of transport infrastructure on economic activity, following the production function approach, extended so as to account for spatial effects by way of an autoregressive panel data model. In the literature, numerous studies take into account the spillover effects understood as the benefits obtained by a region when using the infrastructures existing in other regions for trading (Pereira and Roca-Sagalés, 2003). Some of these studies evaluate the importance of spillovers differentiating by levels of territorial disaggregation, see García-Milá and McGuire (1992), Cantos et al. (2005), Delgado and Álvarez (2007). Following this thread, these studies usually quantify the spillover through a criterion of proximity, incorporating the public transport infrastructure capital stock corresponding only to adjacent neighbors. Based on this analytical framework, in this study we contribute to the literature in two distinctive ways.

Firstly, we consider a new concept of transport infrastructure capital stock used in commercial relations, qualified by network analysis in a Geographical Information System (GIS) environment, which correspond to the internally used and imported capital stocks as introduced by Álvarez et al. (2016). Given a geographical level of aggregation, e.g., countries, regions, provinces,… the internally used capital stock corresponds to the road infrastructure situated within an area, that is used in trade flows—exports and imports—to access markets. Complementing this internal stock, the imported capital stock represents the spillover effects derived from using the road network capital stock situated not only in neighboring areas as the existing literature does, but also in non-adjacent locations. Particularly, we consider that the spillover effects emanate from the road infrastructure existing in all provinces within Spain, distributed among provinces using commercial trade flows as weights.

Secondly, we apply novel estimation methods pertaining to the most recent spatial econometrics literature; specifically we employ a spatial autoregressive panel data model including a spatially lagged term in the dependent variable. Spatial econometric techniques allow us to capture the spatial interdependence in empirical analyses. In our empirical application, the estimation of the production function at the provincial level in Spain introducing road transport infrastructure—capital stocks—is performed by implementing fixed effects spatial two stage least squares (FES2SLS) in comparison with Maximum Likelihood (ML) estimation. In the spatial econometrics literature some authors, e.g., Gibbons and Overman (2012), remark that if correlated omitted variables were present, the spatially lagged dependent variable could be influenced by lagged regressors and disturbances. To leave that econometric limitation aside, in our empirical strategy we adopt the SAR panel data model with fixed effects, which also allows us to consider the internal and imported capital stocks as the direct and spillover effects of transport infrastructure, respectively.

The paper is structured as follows. In the next section, we briefly present the well-known methodological approach corresponding to the production function framework, extended so as to account for spatial effects. In section 3 we discuss the relevant variables, databases and statistical sources, and introduce the new definitions of internal and imported capital stocks. In section 4 we perform regression analyses, while in section 5 we calculate the direct and spillover effects of transport infrastructure on production. In the last section, we summarize and draw the main conclusions.

2. Methodological approach.

Following Álvarez and Delgado (2012) and Álvarez et al. (2016), we analyze the impact of transport infrastructure on regional production by embedding new stock variables within the existing regional production function models. We measure the magnitude of the spillovers between regions and compare these results with the ones obtained using spatial econometrics techniques. Particularly, this analysis is developed by applying the instrumental variable estimation in spatial autoregressive panel models introduced by Baltagi and Liu (2011) and maximum likelihood fixed effects estimator (ML-FE), following Millo and Piras (2012)[1].

Our analysis departs from the standard production function model for a regional panel data of N observations along T periods:

$$Y_{it} = f\left(X_{it};\beta\right)e^{\mu_i + v_{it}}, i = 1,...,N, t = 1,...,T, \qquad (1)$$

where Y_{it} is the output of the i-th province in the t-th period; X_{it} is a (1 x k) vector of explanatory variables, β is a (k x 1) vector of parameters to be estimated, μ_i is the vector of province effects and v_{it} is the remaining error term. It is assumed that μ_i and v_{it} are independent of each other and the regressor matrix X.

The usual input variables include the service flows from employment (L_{it}), private capital (K_{it}), and public capital stock incorporating the road network infrastructure. Using

[1] See Arbia (2014) for a recent literature review.

this structure, we consider the new concept of used capital stock to determine its effective contribution to production-discussed in the next section. The new concept differentiates between the internally used capital stock ($INTKP_{it}$) capturing direct effects from the infrastructure existing in a given location, and the imported capital stock from other locations ($IMPKP_{it}$) to which we associate the existence of spillover effects. The remaining public capital stock is also introduced as (KP_{it}). Incorporating all these factors, the production function (1) is extended as follows:

$$Y_{it} = f\left(L_{it}, K_{it}; \beta\right) g(KP_{it}, INTKP_{it}, IMPKP_{it}; \gamma) e^{\mu_{it} + v_{it}}. \qquad (2)$$

The empirical model to be estimated is based on the log-linear Cobb-Douglas (CD) aggregate production function:

$$\ln Y_{it} = \alpha + \beta_L \ln L_{it} + \beta_K \ln K_{it} + \gamma_{KP} \ln KP_{it} + \gamma_{INT} \ln INTKP_{it} + \gamma_{IMP} \ln IMPKP_{it} + \mu_i + v_{it}. \qquad (3)$$

Most studies use the production function approach to estimate the elasticity of inputs. Under the assumption of separability of the production function with a CD specification, the vector of coefficients γ includes the elasticities of the different public capital stocks of road infrastructure. The sign and magnitude of the γ_{INT} parameter represent the effect of a location's own road capital stock that is actually used in commercial relations within itself —i.e., the internal capital stock, while γ_{IMP} allows us to determine the importance of the spillover effects—i.e., the effect of other locations at the national, regional or provincial level constituting the imported capital stock. As for this latter concept, the nature of the transport infrastructure justifies its inclusion in (2), as it captures the benefits of infrastructure that transcend the borders of the locations where they are situated, and consequently the use of other locations's infrastructure by neighboring areas can be thought of as imports of capital stock, hence the name. These spillovers effects have been scarcely studied in the literature and, as far as we know, have not been analyzed in the context of a spatial autoregressive panel data model.

The majority of the research aimed at quantifying the effects of transport infrastructure on production is focused on the case of high capacity roads within the U.S. (see Cohen and Morrison (2002) and Pereira and Andraz (2004)). These studies not only showed the direct positive influence of road transport infrastructure following Aschauer (1989), i.e., that of a location's own capital stock, but also uncovered the relevant magnitude and significance of the spillover effects from other locations. For the Spanish case that we use to illustrate our new proposal and estimation methods, different studies confirm these results (García-Milá and McGuire (1992), Cantos et al. (2005), Delgado and Alvarez (2007) and Alvarez and Delgado (2012)).

However the concept of road infrastructure capital stock employed in all the previous studies so as to capture spillover effects is rather limited, as it only considers the capital stock of adjacent locations, instead of the comprehensive definition that we propose in what follows–imported–and that captures the real use that is made of the road network in commercial relationships in both adjacent and non-adjacent areas. This is not a trivial matter, as it is known since Tinbergen (1962) that the gravity equation, successfully explaining exports flows in terms of distance and markets sizes, postulates that a locations' trade flows are expected to take place not only in nearby areas (the closer the higher the volume of trade), but are also driven by the level of economic activity of locations that can be farther away (e.g., GDPs). Consequently, the exiting studies that overlook the trade enhancing accessibility role played by the road infrastructure located in all regions within a country, fail to capture the whole geographical breadth generating spillover effects on production.

Besides the previous conceptual limitation, another and even more important methodological drawback of the exiting literature is that it cannot rely on recent econometric techniques that allow capturing the spatial interdependence of the spillover effects. We introduce spatial interdependence by adopting methods based on the estimation of spatial autoregressive panel models. This allows us to control for spatial interdependence in the production function while retaining the nature of the spillover effects. According to Arbues et al. (2015), we define the capacity utilization rate of capital (*CU*) in terms of output increases in other provinces. Therefore, we can express this concept using a spatial specification as follows:

$$CU_{it} = e^{\lambda W \ln Y_{it} \varepsilon_{it}}, \tag{4}$$

where $W\ (NTxNT)$ is the spatial weight matrix which defines dependence across N provinces along the T periods. We refer to WY_{it} as the spatial lag of the dependent output variable.

Substituting the spatial specification (4) in (3) we obtain:

$$\ln Y_{it} = \alpha + \lambda W \ln Y_{it} + \beta_L \ln L_{it} + \beta_K \ln K_{it} + \gamma_{KP} \ln KP_{IT} + \gamma_{INT} \ln INTKP_{it} + \gamma_{IMP} \ln IMPKP_{it} + \mu_i + u_{it} \tag{5}$$

where $u_{it} = v_{it} + \varepsilon_{it}$. The common approach in the literature to capture and measure the spatial interdependence is based on the consideration of a physical contiguity matrix, whose elements would be one for two bordering provinces, and zero otherwise. These matrices are the main instrument to treat physical proximity as the main driver for the presence of spillovers. In our study each element of W corresponds to the inverse of the distance between provinces. As a result, the diagonal elements of W are null, while its off diagonal entries represent the bilateral spatial weights between locations. We perform the normalization $\hat{w}_{ij} = w_{ij} / w^*$, where $w^* = \sum_j w_{ij}$ is the row sum of the elements in W. [2]

The specification of the equation (5) leads to what has been labeled as the Spatial Autoregressive (SAR) model that includes the lagged dependent variable. The model can be extended to consider spatial dependence in the error term, which is called the Spatial Autoregressive model with Autoregressive disturbances (SARAR).

Regarding the econometric estimation of the model, in the SAR model we follow the panel data model extensions of the two-stage least square estimator (2SLS) proposed by Kelejian and Prucha (1998). In our empirical application, the estimation of the production function at the provincial level in Spain introducing transport infrastructure, we consider the fixed effects spatial two stage least squares (FE-S2SLS) for the SAR model, following Baltagi and Liu (2011), and a combination of instrumental variables (IV) and generalized method of moments (GMM) for the SARAR model, Kapoor et al. (2007).[3] For robustness, we employ other standard methods in the literature of spatial models, the ML procedure for fixed effects, Elhorst (2014a,b).[4]

Once the specification and estimation methods have been presented, we consider the issue of the spatial direct and indirect effects. This is relevant as parameter estimates per se are misleading elasticities, since they do not represent the real proportional change in the dependent variable for a change in a regressor. In our panel model with spatial dependence,

[2] When estimating the SAR model in the empirical section the simpler definition of the W matrix based on adjacency was also performed. The results obtained with W defined as a contiguity matrix are very similar to those reported considering the inverse of the bilateral distances, and the conclusions remain unchanged. These results, which are available upon request, confirm that the spillover effects emanating from adjacent provinces represent the highest impacts.

[3] These estimators have been implemented by Alvarez, Barbero and Zofío (2016) in the MATLAB environment – the routines are available at http://www.paneldatatoolbox.com

[4] These econometric techniques are available in the R package *splm* (Millo and Piras (2012))

changes to an explanatory variable in a given location have direct effects on itself, but also indirect effects on other regions' GDP. Specifically, the direct effects indicate how an increase in the explanatory variable in a specific province impact that province's GDP, while the indirect effect measures how an increase in an explanatory variable influences the GDP of other provinces—i.e., the true spillover effect corresponding to the partial derivative.

The total effect is the sum of the direct and indirect effect, quantifying the total effect on overall provincial GDP. Following LeSage and Pace (2009), the impact of each variable $\ln X_i$ on $\ln Y$ is computed through the following partial derivative:

$$\frac{\partial \ln Y}{\partial \ln X_j} = \left(I - \lambda W\right)^{-1} \beta_j , \tag{6}$$

which results into an NT by NT matrix for each explanatory variable. The direct effect is computed as the average of the diagonal elements of the matrix, while the total effect is the average of the row sums. The indirect effect is simply the difference between the total effect and the direct effect.[5]

3. Data: sources and description

The proposed production function was estimated using individual information on the Spanish provinces (NUTS-3 level) from 1980 to 2007 (in five years intervals except for the last two), and for the aggregate—total—economic activity. The period contemplated is of special interest given that it coincides with an increase in the decentralization of public functions as Spain joined the European Community. Both events gave rise to substantial growth in public investment intended to improve road infrastructure. It is worth highlighting the financial support provided by both the European Regional Development Fund and the Cohesion Fund, which are expected to result both in production growth and in the presence

[5] Finally, as the proposed spatial dependence specification does not correspond to a dynamic model including lagged values of the dependent variable in previous periods, all effects are interpreted as short-run elasticities, e.g., Baltagi et al. (2014), Fingleton (2015). Considering those values would yield equilibrium outcomes associated to changes in the regressors that are maintained indefinitely. While these results are interesting in their own right, it is unlikely that the regressors experience these unperturbed trends, particularly those corresponding to public capital stocks—including transportation infrastructure, whose values in Spain have come to a standstill with investment flows declining or halting after 2007 because of the financial crisis and the need to reduce public deficit.

of positive spillover effects from the existing and new transport infrastructure.[6] Indeed, road infrastructure investments transformed the topology of the network from a centralized—hub and spoke—lay out into a grid configuration, suggesting that the spillovers effects should be significant across the whole sample of Spanish provinces as they are more evenly distributed; i.e., the change in the road network tends to increase the accessibility of farther and less central locations along the period.

Data come from two main statistical sources. Gross Domestic Product (GDP) and private employment (number of employees, *L*) from the Spanish National Statistics Institute (*Instituto Nacional de Estadística*, INE). The series of productive (i.e., non-residential) private capital (*K*) and public capital (*KP*) are taken from the database compiled by Mas et al. (2011)[7] at the *Instituto Valenciano de Investigaciones Economicas* (IVIE). All variables are expressed in 2000 constant values.

As for the internal $INTKP_{it}$ and imported $IMPKP_{it}$ capital stocks we use new measures introduced by Álvarez et al. (2016). These authors proposed techniques based on GIS that allow differentiating the monetary value of the transport stocks of road infrastructure depending on their use by the different locations-provinces or regions- within a country. Particularly, and taking the transport infrastructure capital stock located within a given province as reference, they are able to distribute its value accounting for all trade flows crossing its individual roads (local, secondary, national and expressways) in the following way. First they value the share of the capital stock that is used within the province for internal commercial flows ($INTKP_{it}$). Secondly, and based on those flows originating in other provinces and passing through (or ending at) the provinces' network, they can value share of the transport infrastructure that is exported to the former ($EXPKP_{it}$). Thirdly and last, the counterpart for the latter is the capital stock that is imported ($IMPKP_{it}$) from other provinces, which is used by the reference province to export goods to all other locations in the country. Therefore, the exported and imported capital stocks represent outgoing and incoming spillover effects of the road infrastructures associated with commercial flows between provinces. As it has been defined in the previous section, since the dependent variable in the

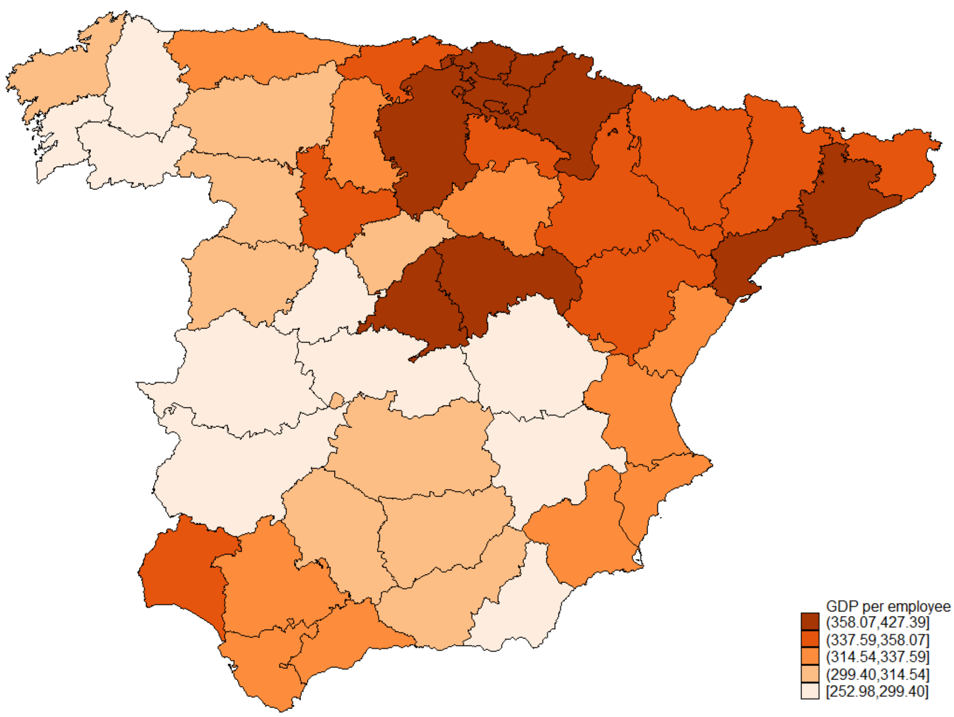
[6] One of the main objectives of the European structural and cohesion funds is to encourage economic and social cohesion across the European Union by supporting public investment in transport and communication networks.

[7] The public capital stock is net of the road network infrastructure, as this latter variable is used to compile the internal and imported stocks. The remaining capital stock *KP* includes the rest of non-transport related infrastructure and social capital (health and education public expending).

production function is a location's gross value added, it is assumed that it is its internal and imported capital stocks what has an effect on it, while its exported capital stock enters other provinces' production functions as their imported stock.

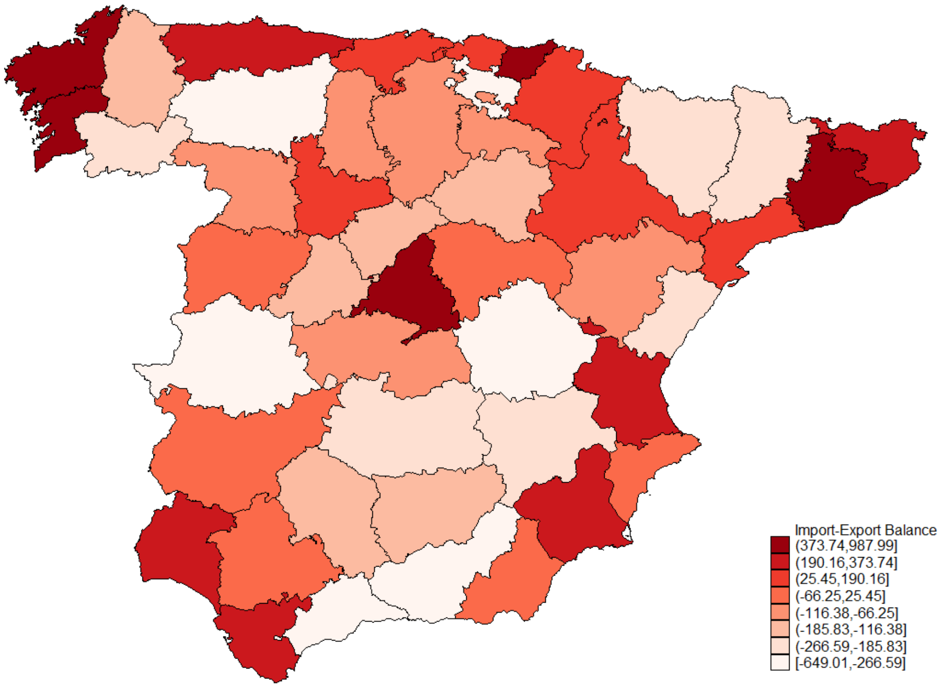
Figure 1 shows GDP per employee representing labor productivity (thousands of euros in 2000 constant prices, as the average for the whole period). Higher productivity levels are agglomerated during the period in the center and the northeast, as these are the provinces with higher economic activity. Therefore, these provinces with high productivity are large producers and net exporters of goods to the rest of provinces, and therefore those that benefits most from the existing public road capital stocks, both internally and imported from the rests of provinces.

Figure 1. GDP per employee, thousands Euro (1980-2007)



Source: Own elaboration

Figure 2. Imported-Exported capital balance, millions Euro (1980-2007)

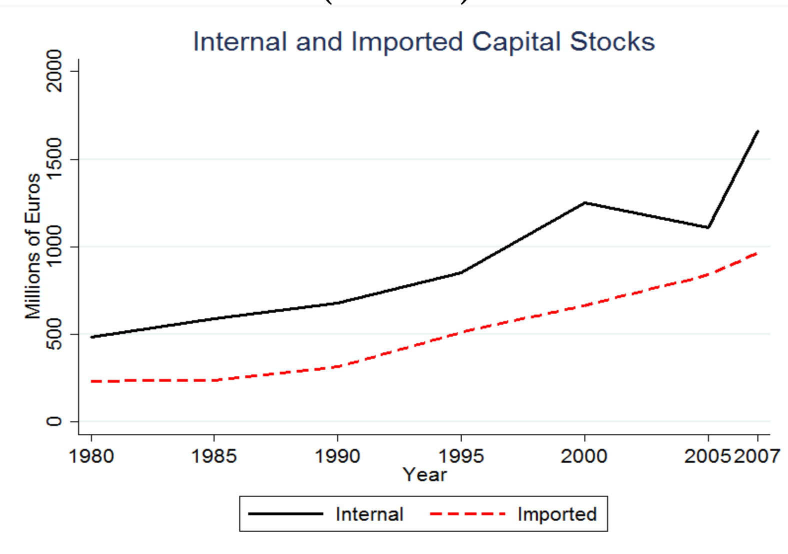


Source: Own elaboration

Figure 2 presents the difference between the imported and exported capital stocks: $IMPKP_{it}$ - $EXPKP_{it}$, i.e., a measure of net capital stock balance. Provinces in the upper range of the distribution are those with high economic activity and larger export flows: Madrid, Barcelona, Valencia, Zaragoza, etc… As a result, they make larger use of their neighbors' stock, which is allocated to them in larger proportions. Therefore, they use (import) the road network stock from all surrounding regions and main corridors when reaching all potential markets. The case of Madrid (the capital) is interesting, since it allows us to portrait two counterbalancing forces simultaneously. By locating in the center of the Iberian Peninsula, Madrid is a key corridor in all commercial flows, a situation that induces capital stock exports. But Madrid has grown also into an economic hub with a large share of the Spanish export flows, resulting in a demand for its neighbors' capital stocks (imports). In fact, Madrid is the province with the highest GDP in Spain, and accounts for the second largest share in the overall Spanish export flows second only to Barcelona (that in turn accounts for the second largest GDP).

In Figure 3 we observe that both the internally used and imported capital stocks at national level show an increasing and parallel evolution. The internal capital stock is characterized by higher values as normally a larger extent of trade takes place within provinces (and therefore road allocation to the internal capital stock tends to be larger than the imported stock). Nevertheless, the gap between the former and the latter gest smaller in the period, reflecting the increasing values of trade flows between provinces relative to within province shipments.

Figure 3. Internal and Imported capital stocks at national level, Millions Euro (1980-2007)



Regarding the rest of the variables, including the ancillary values of trade flows employed to estimate the used capital stock of infrastructure, we express the road network capital stock (both internal and imported) in monetary terms. Therefore, we estimate a production function introducing inputs on homogeneous monetary units. Table 1 shows the descriptive statistics corresponding to the variables used in the production function analysis.

Table 1 - Descriptive statistics (values in constant Euro, 2000)

Variable	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Gross Domestic Product (millions Euro)	11,031	18,185	830	145,712
Labour (thousands of employees)	312	448	30	3,465
Private Capital (millions Euro)	13,000	19,100	1,189	149,000
Public Capital (millions Euro)	3,491	4,579	0.001	40,300
Internal Used Capital Stock (thousands Euro)	947,420	899,359	94,691	6,753,727
Imported Capital Stock (thousands Euro)	538,692	569,339	34,917	3,573,256

Source: Own elaboration

4. Spillover effects of transport infrastructure in production:

4.1. The standard approach neglecting spatial dependence

We study first the contribution of the used internal and imported capital stocks as specified in the basic model corresponding to eq. (3); i.e., without considering spatial dependence. Results following panel data analysis techniques are shown in Table 2. *F* statistics of joint significance and R^2 show that the estimation is significant. Additionally, the model has been estimated by means of the fixed effects estimator so as to capture unobservable heterogeneity (Baltagi, 2008), because both the *F* test of individual effects and Hausman's test (Hausman, 1978) reject the null hypothesis for more efficient and consistent random effects. Looking at the results, the relative value of the coefficients for employment (0.294) and private capital (0.514) differ from those generally reported in studies researching the effect of infrastructure at the country level for developed economies—with labor elasticity exceeding that of private capital, thereby matching their share in aggregate output (GDP), Cohen and Morrison (2002), Pereira and Roca-Segalés (2003).[8] However, the lower values for labor concur with the results obtained in studies focused on regions and provinces within countries, and particularly Spain. Álvarez et al. (2016), Delgado and Alvarez (2007) and Nombela (2005) report similar values using standard panel data methods—with and without spatial spillovers.

Table 2: Production function with spatial spillovers (1980-2007)

Independent Variable (N = 329)	***Fixed Effects Model***
Fixed Effects Model	
Constant (c)	-1.017 (-3.15)***
Employment ($\ln L_{it}$)	0.294 (9.32)***
Private Capital ($\ln K_{it}$)	0.514 (14.87)***
Public Capital ($\ln KP_{it}$)	0.022 (5.94)***
Internal Capital Stock ($\ln INTKP_{it}$)	0.034 (2.33)**
Imported Capital Stock ($\ln IMPKP_{it}$)	0.125 (9.39)***
Joint Significance Test F	F(5,277) = 1,599.34
R^2	0.99
Individual Effects Test F	F(46,277) = 12.28
Hausman Test	$\chi^2(5) = 37.25$

*T-statistic in parenthesis. *** p<0.01, **p<0.05, *p<0.1*
Source: Own elaboration

[8] It is worth noting that in our database at provincial level the share of private capital on GDP exceeds that corresponding to labor. Therefore the reported elasticities tend to match these values, as it is usually the case in the production function literature.

As for the public capital coefficient, it is positive with a value of 0.022. Again, this result is similar to other estimations reported for the Spanish economy; e.g., Goerlich and Mas (2001) analyze the impact of productive public capital on private provincial production obtaining an elasticity value of 0.0205. However, when focusing on the new capital stock variables, the coefficient of the internally used capital stock is positive and significant, with a value of 0.034, whereas the elasticity of the imported capital is significant and considerably higher, 0.125. Therefore, we can initially conclude that with the standard specification the benefits of the internally used capital stock are less important than the spillover effects. So, the total economy benefits more of the road network in commercial relations. These results are in line with those obtained by Delgado and Álvarez (2007), who only considered spillover effects of high capacity road network between provinces with similar socio-demographics features, and are coherent with studies carried out on the Spanish industrial sector, which suggest broader measures for spillovers from public capital in the rest of the regions (Avilés et al., 2003; and Cantos et al., 2005).

4.2 The new approach accounting for the spatial effects of transport infrastructure

Next, we study the impact of the internal and imported capital stocks as additional inputs in the production function, but allowing for the possibility of spatial dependence, whose existence would render the standard regression model inconsistent. For this purpose, we rely on the spatial autoregressive panel model presented in eq. (5) that introduces lag spatial dependence in the dependent variable. The results obtained by alternative regressions are sequentially presented in Table 3; i.e., considering the fixed effect spatial 2SLS (FE-2SLS) estimator in comparison with the ML spatial fixed effects estimator (ML-FE). At the same time, we estimate the SAR and SARAR models corresponding to both estimators. Therefore, we compare the model with the lagged dependent variable with the extension introducing also spatial interdependence in the error term.

We observe that the coefficients associated to the different estimators are similar, while keeping the sign and significance for the totality of parameters. These results prove the robustness of the estimation applying the FE-S2SLS method with respect to the ML-FE estimator. Moreover, results are in general similar to those obtained in Table 2 for the standard econometric approach represented by eq. (3) following the literature on production functions—the only difference being the new internal and imported capital stock variables but not the estimation methods. Specifically, it is worth highlighting that these spatial estimators, both the FE-2SLS and the ML-FE, yield the set of results that most closely match the previous results, suggesting that the introduction of spatial interdependence does not qualify the effects of the different explanatory variables on production. Except made of the coefficients associated to the internally used and imported capital stocks. Indeed, including both the spatially lagged dependent variable and error term so as to account for their effect, is basically done at the expense of the internal capital stock, which losses significance. These results cast doubts about the predictive power and true impact in the variability of this aggregate when explaining provincial production.

Table 3: Estimates for production function with spatial spillover (1980-2007)

Independent Variable (N = 329)	***FE-S2SLS***		***ML-FE***	
	SAR	***SARAR***	***SAR***	***SARAR***
Spatially lagged depend. variable	0.496***	0.477***	0.484***	0.444***
($\ln WY_{it}$)	(14.20)	(12.57)	(15.31)	(11.46)
Employment	0.230***	0.286***	0.232***	0.318***
($\ln L_{it}$)	(9.43)	(10.45)	(9.97)	(11.87)
Private Capital	0.308***	0.280***	0.313***	0.273***
($\ln K_{it}$)	(10.26)	(9.31)	(11.93)	(10.02)
Public Capital	0.014***	0.013***	0.014***	0.012***
($\ln KP_{it}$)	(4.68)	(4.40)	(5.23)	(4.73)
Internal Capital Stock	0.010	0.010	0.010	0.010
($\ln INTKP_{it}$)	(0.86)	(0.81)	(1.00)	(0.89)
Imported Capital Stock	0.026**	0.034***	0.028**	0.042***
($\ln IMPKP_{it}$)	(2.10)	(2.60)	(2.46)	(3.33)
Spatially lagged error term		0.404***		0.623***
		(8.91)		(6.24)
Wald Joint Significance Test $\chi^2(6)$	13,951.11	5,533.07		
BSJK Test for serial and spatial autocorrelation and random effects $\chi^2(3)$		420.42		

Notes: *T-statistic in parenthesis. *** p<0.01, **p<0.05, *p<0.1.* FE-2SLS = Fixed Effects Spatial Two Stage Least Squares Estimator, Baltagi and Liu (2011) and Kapoor et al. (2007). ML-FE = Maximum Likelihood Fixed Effects Estimator, Millo and Piras (2012). BSJK = Baltagi, Song, Jung and Koh´s (2007) test for serial correlation, spatial autocorrelation and random effects.
Source: own elaboration

On the contrary, it seems that it is the relative proximity to the nearest provinces' GDPs through the spatially lagged dependent variable what better explains GDP levels and variations, rather than the internally use capital stock in infrastructure, along with the imported stock from other regions, with both seeing their influence reduced with respect to the previous model. We believe this result indicates that since most provinces are endowed with low amounts of internal capital stocks, as most of it is exported to the largest regions —see Figure 2, the effect of the internal capital stock is definitely lost on average. This fact prevents a strong correlation between this variable and provincial GDP, which in the spatial dependence model is precisely overshadowed by the spatially lagged GDP and error components. Nevertheless, the significance of the spillover effects associated to the imported road network stock is confirmed, and while it reduces its magnitude significantly with respect to the standard model without spatial dependence, it retains a positive value around 0.04.

These results on the relative magnitude and significance of the internal and imported capital stocks are in accordance with previous findings using Spanish data. When reporting regression results both at the regional (NUTS-2) and provincial (NUTS-3) levels, Álvarez et al. (2016) show that reducing the area of the spatial units increases the likelihood that a given location does not profit from its internal capital stock, simply because it is more likely that it is exported, as economic production (and trade, which is used to distribute capital stocks) is not averaged across space, resulting in many smaller units being devoid of production, which tends to agglomerate in few locations. That is, the smaller the area, the smallest the effect of the internal capital stock on average for the whole sample. We contend that this is the correct scale at which spillover effects can actually be observed and should be studied—i.e., overcoming the modifiable area unit problem present in estimates using large and/or uneven (in size) political boundaries (e.g., countries). Our results provide additional confirmation of the previous result on the diminishing effects of the internal capital stock on production as geographical disaggregation increases, in relation to the spillover effects associated to the imported stock. [9]

Contemporarily, and most remarkably, the coefficient accompanying the spatial lag of the dependent variable is positive and significant, with values around 0.5. Therefore, the output of the neighboring provinces weighted by the degree of proximity affects production positively, more intensively in adjacent provinces. This can be explained by the fact that the higher the GDP of neighboring locations, the higher the effect of all kind of bilateral economic flows on a region's activity. With the spillover effects materializing through trade in goods and services dependent on the transport infrastructure (e.g., freight shipments, tourism, etc.), and being more intense in open economies whose main sectors depend on

[9] The greater importance of the spillovers emanating from adjacent and non-neighboring locations over the internally endowed capital stock has been confirmed as early as Holtz-Eakin and Schwartz (1995) and Kelejian and Robinson (1997) using US data and a standard spatial specification. In the Spanish case, Delgado and Álvarez (2007) report it relying on a stochastic frontier approach, while Arbues et al. (2015) find strong evidence of the positive impact of transport spillovers adopting econometric models that apply the spatial lag to public capital, and relaying on maximum-likelihood estimators (Elhorst, 2014b). These authors highlight the existence of positive spillovers for the different types of transportation infrastructures, introducing spatial dependence in the dependent and explicative variables.

tradable goods and services. Again, in line with the results obtained by Arbues et al. (2015), this indicates that weighted average production in the nearest provinces positively affects the province under analysis.

Finally, as for the direct, indirect and total effects corresponding to eq. (6), these are positive and statistically significant for their corresponding variables in the spatial panel regression. As shown in Table 4, the indirect effect accounts for around a half of the total impact of an increase for all of the explanatory variables, corroborating the importance of accounting for both types of effects and the spatial spillovers themselves.

Table 4: Direct, indirect and total effects

	Direct, indirect and total effects		
FE-2SLS: SAR	***Direct***	***Indirect***	***Total***
Employment ($\ln L_{it}$)	0.234 (9.12)***	0.224 (6.01)***	0.458 (8.27)***
Private Capital ($\ln K_{it}$)	0.312 (10.01)***	0.300 (7.48)***	0.612 (10.68)***
Public Capital ($\ln KP_{it}$)	0.014 (4.82)***	0.013 (4.31)***	0.026 (4.82)***
Internal Capital Stock ($\ln INTKP_{it}$)	0.010 (0.87)	0.009 (0.85)	0.019 (0.86)
Imported Capital Stock ($\ln IMPKP_{it}$)	0.026 (2.02)**	0.025 (2.13)**	0.051 (2.09)**
FE-2SLS: SARAR	***Direct***	***Indirect***	***Total***
Employment ($\ln L_{it}$)	0.289 (10.54)***	0.257 (6.00)***	0.546 (9.10)***
Private Capital ($\ln K_{it}$)	0.283 (9.34)***	0.252 (6.71)***	0.535 (9.61)***
Public Capital ($\ln KP_{it}$)	0.013 (4.39)***	0.011 (3.79)***	0.024 (4.30)***
Internal Capital Stock ($\ln INTKP_{it}$)	0.010 (0.77)	0.009 (0.74)	0.019 (0.76)
Imported Capital Stock ($\ln IMPKP_{it}$)	0.035 (2.56)**	0.031 (2.88)***	0.066 (2.76)***
FE-ML: SAR	***Direct***	***Indirect***	***Total***
Employment ($\ln L_{it}$)	0.235 (10.10)***	0.215 (6.30)***	0.450 (8.67)***
Private Capital ($\ln K_{it}$)	0.317 (12.73)***	0.290 (6.73)***	0.607 (10.05)***
Public Capital ($\ln KP_{it}$)	0.014 (5.15)***	0.013 (4.27)***	0.027 (4.88)***
Internal Capital Stock ($\ln INTKP_{it}$)	0.010 (0.95)	0.009 (0.93)	0.020 (0.95)
Imported Capital Stock ($\ln IMPKP_{it}$)	0.029 (2.57)**	0.026 (2.44)**	0.055 (2.54)**
FE-ML: SARAR	***Direct***	***Indirect***	***Total***
Employment ($\ln L_{it}$)	0.322 (11.64)***	0.251 (5.68)***	0.573 (9.12)***
Private Capital ($\ln K_{it}$)	0.275 (9.82)***	0.215 (5.40)***	0.490 (8.14)***
Public Capital ($\ln KP_{it}$)	0.012 (4.67)***	0.010 (3.81)***	0.022 (4.46)***
Internal Capital Stock ($\ln INTKP_{it}$)	0.011 (0.87)	0.008 (0.85)	0.019 (0.87)
Imported Capital Stock ($\ln IMPKP_{it}$)	0.042 (3.30)***	0.033 (2.91)***	0.075 (3.21)***

*Notes: T-statistic in parenthesis. *** p<0.01, **p<0.05, *p<0.1. FE-2SLS = Fixed Effects Spatial Two Stage Least Squares Estimator, Baltagi and Liu (2011) and Kapoor et al. (2007). ML-FE = Maximum Likelihood Fixed Effects Estimator, Millo and Piras (2012).*
Source: Own elaboration

5. Summary and concluding remarks

The aim of this paper is to analyze the effects of road infrastructure on economic activity at a spatial level using a production function approach, and taking into account the spillover effects associated to the use of the public transport infrastructure situated in other locations. Given statistics availability, we employ Spanish data at the provincial level for the 1980 to 2007 period to illustrate our methodology. In doing so, we employ new concepts associated to the actual use of road network capital stock, differentiating in our specifications between that situated in a given location—internal, and the stock existing in the rest of locations—imported. Based on these concepts introduced by Álvarez et al. (2016), we include the corresponding stock variables as regressors, and consider as weight matrix the inverse of the distances between provinces, which is later employed to introduce spatial interdependence. Ultimately, this enables us to test the relative importance of the internally used capital stock effect on economic activity, in comparison to the elasticity of the spillover effects through the imported capital stock from other locations.

Additionally, from the perspective of the econometric methodology, our study departs from the traditional estimation of the production function based on standard panel data analysis in that we use recent spatial econometrics models. Particularly, in the second stage estimation we consider a spatial autoregressive panel model, following a specification that introduces spatial lag dependence in the dependent variable and in the error term. This allows us to analyze the impact of the nearest (in terms of trade flows) provinces' infrastructure on production. The spatial lag model is estimated considering different estimators; particularly the FE-2SLS following Baltagi and Liu (2011), and the ML-FE estimator from the *splm* package in R by Millo and Piras (2012).

There are several relevant findings. In the first place, in the spatial autoregressive panel model, labor and private capital are relevant production factors, while the contribution of the non-transport related public capital, which includes social capital and other infrastructure, is relatively low when compared to previous studies. The internally used capital stock of infrastructure has no effect on the production of the aggregate economy, while the imported capital stock effect is positive and significant, providing strong evidence of the spillover effects in road infrastructures—however, this effect is much lower that the spatial dependence from other locations GDPs. Nevertheless, the previous result confirming the relevance and significance of the spillovers effects is consistently obtained from a wide range of standard and spatial econometric specifications, which shows the robustness of these results.

Given the investment efforts made by Spanish and European administrations over the last three decades, the fact that they result in positive and significant spillovers effects at a very disaggregated geographical level (NUTS-3 level) is reassuring from an infrastructure policy perspective, as it confirms that accessibility in terms of trade flows distributes the positive effects of the road infrastructure across all locations; i.e., the main research hypothesis posed in this study is confirmed. Finally, we stress that when spatial interdependence through the dependent variable is introduced, we observe that economic activity in other provinces favors production for the economy of other locations to a larger extent, and contributes to improve the capacity utilization of capital.

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