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Spatial Productivity of Road Transportation Infrastructure

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Abstract

The empirical literature studying the effects of public capital on the performance of private enterprises remains inconclusive more than 20 years after the seminal paper from Aschauer. Although aggregated models have generated results that have shown significant effects of public capital on productivity, disaggregated applications have produced results that have only shown little or no significant effects. Traditionally, the differences in these results have been explained by the existence of regional spillovers and network effects caused by transportation and communication infrastructures. According to this view, the aggregate effect seems to be composed of the direct and indirect effects of public capital investment . We firmly believe that the results from these two types of studies might be made consistent by testing for the existence of spatial dependence among geographical units and by including variables for capital services in place of the traditional

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stock measures. This article pays special attention to the effects of road transportation infrastructure development on productivity in the Spanish economy. In particular, a classic production function is estimated that tests different spatial econometric models by using a road services variable and panel data from the 47 mainland Spanish provinces. We found that the services provided by the road transportation infrastructure had small but positive direct and spillover effects on productivity in these provinces.
Keywords: Spatial Econometrics, Transportation Infrastructure, Regional Productivity, Public capital

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1. Introduction

Measuring the economic effects of public infrastructure improvements on the productivity of private capital has been the center of academic debate for the last two decades [3]. The concept underlying these papers is that public capital plays a significant role as an input factor in the production process. The first empirical works addressing this issue appeared in the 1970s (Mera, 1973); however, it was only with the extraordinary results obtained by Aschauer (1989) that the research community showed a revived interest in the effects of public infrastructure improvements. In these early works, the authors found that public capital exerted a large and significant effect on output. Aschauer estimated an output elasticity of approximately 0.4,

[3] Different surveys on this topic compare different studies and focus on the methodologies adopted and the data used. For a detailed discussion, see: Gramlich (1994) and Pereira and Andraz (2011). Because of the high quality of the available data from Spain, many empirical works have recently been undertaken in Spain. de la Fuente (2010) and Álvarez et al. (2003) provide an exhaustive review of international research, including studies in Spain .

and the results in the study by Munnell and Cook (1990) ranged from 0.31 to 0.39. In an era when the productivity growth of most OECD-countries experienced a significant slowdown, policy administrators and scholars wondered whether this might be caused, at least in part, by insufficient public capital. In this context, Aschauers main findings were appealing because an increase in public investment in infrastructure seemed a straightforward solution to an alarming slowdown in productivity.

While there is little doubt that enterprises need a minimum level of public infrastructure to generate output to sell in markets, it should not be expected that the marginal output effect of extra public infrastructure will remain constant at every level. In the case of road transportation infrastructure, building one interstate network might cause a significant increase in productivity but building a second might not (Hulten, 2004). Following these articles, several methodological and conceptual objections on public capital productivity appeared in response. These critics pointed to problems involving spurious relationships (Garcia-Mila et al., 1996), reverse causation bias (Fernald, 1999; Chandra and Thompson, 2000), the use of aggregate data at the country and industry levels (Gramlich, 1994) and problems with taking into account dynamic feedbacks in the relationship between public capital and private-sector performance (Pereira and Andraz, 2011). Subsequent research failed to find the significant positive effects of public capital on private output (Holtz-Eakin and Schwartz, 1995). Notably, regional data were used in the articles with models that obtained low estimates of marginal productivity, while the early studies obtained large effects with national data.

Certain researchers suspected the existence of spillover effects (Cohen and Paul, 2004), which are also known as leakages; spillover effects indicate that the effects generated from public capital investment would not be confined to the region in which the infrastructure is located. If spillovers were present, part of the effect of public capital would be underestimated by using regional data. It should be noted that different categories of public capital may not have the identical spatial effects on private output, e.g., urban and water facilities projects may enhance economic activities that are confined to the local area, whereas communication and transportation infrastructure projects may cause important network effects. Transportation infrastructure projects are the public capital projects that generate the greatest interest. The spillover effects seem particularly relevant to these types of projects because public investments in a region may affect other geographical units connected by a transportation network in addition to affecting that particular region (Boarnet, 1998). In fact, state highway projects are natural laboratories to test these effects because the interstate highway system is designed with interstate linkages in mind (Holtz-Eakin and Schwartz, 1995). Despite recent developments, the nature of infrastructure spillovers also remains inconclusive; positive and negative spillovers have been found. Positive spillovers are explained by the connectivity that is characteristic of transportation infrastructure; any piece of a network is related and subordinate to the entire system, which increases the interrelationships between areas (Moreno and López-Bazo, 2007). If there were congestion, additional infrastructure development would enhance general economic activity (Cohen and Morrison Paul, 2003). Conversely, negative spillover might occur if migration processes arise that present evidence of leeching behavior; infrastructure improvements in neighboring areas enhance that location and enable the region to attract productive resources, assuming that such resources are mobile (Boarnet, 1998).

We attempt to overcome another caveat in the empirical literature that involves measuring both private and public capital with stock indicators instead of with flow variables. Measuring private capital as a stock fails to take into account utilization of the installed capacity. In the case of road transportation infrastructure, stock capital indicators are only a satisfactory measure of the quantitative properties of the infrastructure and not of the connective properties of the network. Using a Spatial Durbin Model, we attempt to correlate the use of private capital with business cycles studied in geographical units; stock measures of road infrastructure investment are replaced by the interaction of vehicles in a region with available road infrastructure, as proposed by Fernald (1999). By applying this framework, we aim to solve previous problems in the literature that might have caused the current ambiguity in the empirical results, as noted by Mikelbank and Jackson (2000). These authors argue that any tool that does not consider an adequate geographic scale, the correct measures and the interactions between them will not capture the true relationship between spatial economy and public capital.

The resulting model is applied to Spain, where road transportation infrastructure projects have been promoted through the implementation of the Infrastructure and Transport Strategic Plan that raised the quality of Spain's road transportation network to European standards in a short period of time. Delgado and Alvarez (2007) studied Spanish highways and underlined the effect of European Union funds assigned to finance infrastructure projects in less-developed areas to promote growth and cohesion within the entire European Union. Most studies conducted in Spain to date have focused on the Nomenclature of Territorial Units for Statistics 2 (NUTS-2) regional level [4]; however, following the recommendations of Rephann and Isserman (1994), we build a more disaggregated database using NUTS-3 level provinces in the Spanish territorial unit classification. In this context, the objective of this study is to measure the output effects of road transportation infrastructure projects in Spanish provinces in the period between 1986 and 2006. In particular, we aim to account for the marginal productivity effects of road transportation infrastructure services within a province and to document the existence of spillover effects outside the provincial boundaries through the use of spatial econometrics methodologies.

The structure of this paper is as follows. In the next section, we review the methodological issues of production function approach, the building of capital services variables and the treatment of the spillovers. In section 3, we describe the data used and the source of the variables. In section 4, the empirical models are discussed along with the econometric issues. In section 5, we present the estimation results. Finally, section 6 contains some conclusions and policy recommendations.

2. Theoretical background

In this paper, we focus on the changes in productivity that result from increased infrastructural investments by using a primal approach [5]. The main

[4] Several studies have utilized regional data to study this issue in Spain (for exhaustive information, see the recent survey by de la Fuente (2010)), whereas available papers using data on provinces are scarce, Álvarez et al. (2003), Delgado and Alvarez (2007) and Moreno and López-Bazo (2007)

[5] Other papers have previously addressed this issue using a dual approach. Cost function models rely on duality theory and allow for a richer analysis through the estimation of the optimal input demand equation. However, one of the shortcomings of this type

aim of this article consists of the estimation of the output elasticity of road infrastructures; to reach this objective, production function methodology is more useful than cost and profit function methodologies (Pfähler et al., 1996). We suppose that there is a conventional output production function that relates real physical output, Y, to the quantity of variable inputs, X, quasi-fixed private capital input, K, and external factors as different types of public transportation infrastructure projects, G.

$$Y = f(X, K, G) \tag{1}$$

In a log-linear Cobb-Douglas specification:

$$\ln Y = \alpha_0 + \alpha_1 \ln X + \alpha_2 \ln K + \alpha_3 \ln G + \upsilon \tag{2}$$

where $\mu \sim \mathcal{N}(0, \sigma_\upsilon^2 I_n)$.

Ideally, in (2), inputs should be measured in terms of service flows. When inputs such as capital, K, enter the production function as a stock, unbiased comparative-static effects are computed on the assumption that changes in input services are proportional to changes in input stocks. However, in the presence of positive adjustment costs, this assumption may not hold for capital, K. The non-proportional changes in private capital stock, K, and its flow of services, K^*, are represented as variations in the capacity

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of model is that information on factor prices is required. Estimating a profit function is an alternative that permits the estimation of unconditional demand effects, but it is even more extensive than the cost function approach in terms of data requirements. The information required by the cost and profit function approaches is not available at the NUTS-3 level in Spain.

utilization rate, (CU). In particular, we consider the following expression: $CU = \frac{K^*}{K}$ [6].

The lack of regional and provincial statistics for CU makes this variable an unobservable factor [7], and as a consequence the same happens to K^*. At this juncture, we suggest that CU depends on economic environment (Gajanan and Malhotra, 2007) or business cycles and besides we posit that this relationship would exhibit spatial dependence.

From a theoretical point of view, shocks in the production of *neighbor* units might increase the demand for products in the region under study. In international macroeconomics, when an economic boom produces an increase in the output of a country such as the United States of America, simultaneous increases in outputs in other countries are observed. Open economy models frequently have difficulty in explaining why business cycles are so closely related among countries. According to Baxter and Farr (2005), this fact frequently requires implausibly high cross-country correlations of productivity shocks. These authors show that variable capital utilization explains these events. Consequently, an alternative explanation would posit that the economic agents of one region might accommodate the utilization rate of capital to meet output increases in other regions (see Burnside and Eichenbaum (1996)).

Thus, we can formally express this using a spatial process as follows:

$$CU = \lambda + \phi WY + \nu \tag{3}$$

[6]Note that CU can also be expressed as the deviation of actual output from optimal output.

[7]Empirical regional measures of capacity utilization are described in Garofalo and Malhotra (2000)

where λ is a constant term and ν is distributed as a $\mathcal{N}(0, \sigma_\nu^2 I_n)$.

In (3), the n by n spatial weight matrix, W, reflects the connectivity of the provinces, and the scalar parameter, ϕ, reflects the strength of spatial dependence in Y. If the scalar dependence parameter, ϕ, is positive, then the CU rate in region i will be positively associated with the output of neighboring regions.

Substituting the spatial specification (3) in (2),

$$\begin{aligned} \ln Y &= \alpha_0 + \alpha_1 \ln X + \alpha_2(\ln CU + \ln K) + \alpha_3 \ln G + \upsilon \\ &= \alpha_0 + \alpha_2\lambda + \alpha_1 \ln X + \alpha_2\phi W \ln Y + \alpha_2 \ln K + \alpha_3 \ln G + \upsilon + \alpha_2\nu \\ &= \mu + \alpha_1 \ln X + \beta W \ln Y + \alpha_2 \ln K + \alpha_3 \ln G + \epsilon \end{aligned} \quad (4)$$

where the intercept $\mu = \alpha_0 + \alpha_2\lambda$ and $\upsilon + \alpha_2\nu = \epsilon \sim \mathcal{N}(0, \sigma_\nu^2 I_n)$

According to Manski (1993), the $W \ln Y$ variable in (4) denotes the endogenous interaction effects and $\beta = \alpha_2\phi$ is called the spatial autoregressive coefficient.

As discussed above, the effect of the different inputs on productivity should be measured in terms of service flows. Considered in terms of productivity changes, the significance of the role that the transportation infrastructure plays in the economy of a region is determined by the infrastructure services that it provides. Improvements in these services are expected to reduce generalized transportation costs as a result of shorter distances, less congestion and higher speeds that reduce fuel, capital and labor costs (Forkenbrock and Foster, 1990). However, transportation projects create other significant spatial location services in addition to reducing travel and logistics costs. They may enlarge the market potential of businesses by enabling them to serve broader markets more economically. In addition, improvements in the transportation system can provide firms with a greater variety of specialized labor skills and input products, making them more productive. (Rietveld, 1994) offers a description of the spatial development effects resulting from transportation infrastructure supply as a complete theoretical framework.

Measuring infrastructure as a stock fails to account for the actual supply of the services that determine its contributions to productivity (Oosterhaven and Knaap, 2003). Because the main purpose of this study is to compute the effect of road infrastructure projects on provincial output, public transportation infrastructure projects (G) were divided into two different variables, one for roads and the other for all other modes of transport. Despite the heavy dependence of Spanish companies on road transportation [8], investment in ports, airports and railways are also included to test for their possible effects. However, better information about road transportation infrastructure projects and vehicles is available, which allows a measurement model to be built that accounts for road services.

Following Fernald (1999), we suppose that road services, (RS), depend upon the flow of services provided by the aggregate stock of government roads ($ROAD$) and the stock of vehicles (VEH), as shown in (5),

$$RS_{it} = f(ROAD_{it} * VEH_{it}) \tag{5}$$

[8] According to the National Statistics Institute, road transportation was chosen in more than 77% of freight movements in Spain in year 2007.

2.1. Treatment of spillovers

Public capital is likely to produce spillovers in other provinces. Positive and negative spillovers have been detected and explained in the literature. To explain possible negative spillovers, we follow Boarnet (1998); if there were an increase in public capital in region A, there would be a rise in the price of labor and capital in the region, inducing resources to move from other regions to region A. This migration would yield a new output in region A, reducing the output in the rest of the regions. Therefore, total output in one region would depend positively on its infrastructure stock and negatively on the infrastructure stock of other regions as a result of negative output spillovers. These negative spillovers, called distributive effects by Rietveld (1994), might not arise in an analysis at a low spatial level. For instance, if we focus on an urban area, we might observe the building of offices or industrial facilities near a new highway; because these would have been built elsewhere, they would remain outside of our study.

Conversely, the foundations of the existence of positive spillovers rely on the network characteristics of transportation infrastructure in which every piece is subordinate to the entire system (Moreno and López-Bazo, 2007)[9]. Road network improvements in neighboring provinces might lead to a decrease in the transportation costs of moving inputs and final products for the economy of a particular province, which might translate into an increase in the demand for manufacturing goods and services. Congestion might also

[9] We are aware of Braesss paradox, which states that an increase in the capacity of a transportation network might reduce its overall performance. However, we assume that this phenomenon is less likely to be felt on an aggregate level than are the positive effects of network improvement.

play a significant role when explaining positive spillovers; new transportation infrastructures in regions in which bottlenecks exist might improve the performance of the entire network.

In (6), the provincial Cobb Douglas production function is augmented by including spillover effects using the spatial lag of the variable that contains information about transportation infrastructure projects, (G),

$$\ln Y = \mu + \alpha_1 \ln X + \beta W \ln Y + \alpha_2 \ln K + \alpha_3 \ln G + \theta W \ln G + \epsilon \quad (6)$$

where Y is the output of province, X is a matrix containing variable inputs, K contains quasifixed input private capital, and G contains public transportation infrastructure variables; α, β and θ are the parameters to be estimated. W is the row standardized N-by-N spatial weight matrix with $W_{ij} > 0$ when observation j is a spatial neighbor to observation i. To test for the consistency of the results, models are estimated using two different weighting matrices, W, that will be explained in the next section.

The specification of the Equation (6) leads to what has been labeled the Spatial Durbin Model (*SDM*) that includes both the lagged dependent variable and lagged independent variables. The *SDM* can be simplified to the spatial lag model and the spatial error model because these models are special cases of *SDM*. Our approach approximates a general to specific selection strategy after the recent contributions about model specifications in spatial econometrics (LeSage and Pace, 2009; Elhorst, 2010). The most general model may include three different types of spatial interactions, which were identified by Manski (1993) as the following: endogenous interaction effects, exogenous interaction effects and correlated effects. Elhorst (2010) found that the parameter estimates of the endogenous and exogenous interaction effects are biased when all interaction types are considered. To solve this problem, LeSage and Pace (2009) proposes the exclusion of the spatially autocorrelated error term, taking *SDM* as the departure from the general model. The alternatives, the exclusion of, or leading to, an omitted relevant variable problem at the cost of ignoring spatial dependence in the disturbances will only cause a loss of efficiency. Furthermore, the spatial Durbin model produces unbiased coefficient estimates when the true data-generation process is any spatial regression specification other than the Manski model.

Another advantage of the *SDM* is that it does not impose prior restrictions on the magnitude of indirect effects, e.g., the spatial spillovers; thus, this model is more appropriate for the aim of this study [10].

3. Description of data and variables

In this section, we discuss the data employed in the estimation of the model. Spain is a decentralized country made up of 2 autonomous cities (Ceuta and Melilla) and 17 autonomous communities, each with its own heritage and government. These autonomous communities correspond to NUTS-2 in the European territorial unit classification and are composed of 47 mainland provinces (NUTS-3). Both Autonomous Communities and provinces may be considered regional economies nested within a national system. The main property of this system is interdependence among the Spanish provinces because the evolution of each region depends on the be-

[10] These spatial spillovers are set to zero in a non-spatial model and in the spatial error model. In the spatial lag model, the spatial spillover effects in relation to the direct effects are identical for each explanatory variable.

havior of neighboring regions [11].

Table 1: Summary statistics of variables in logs

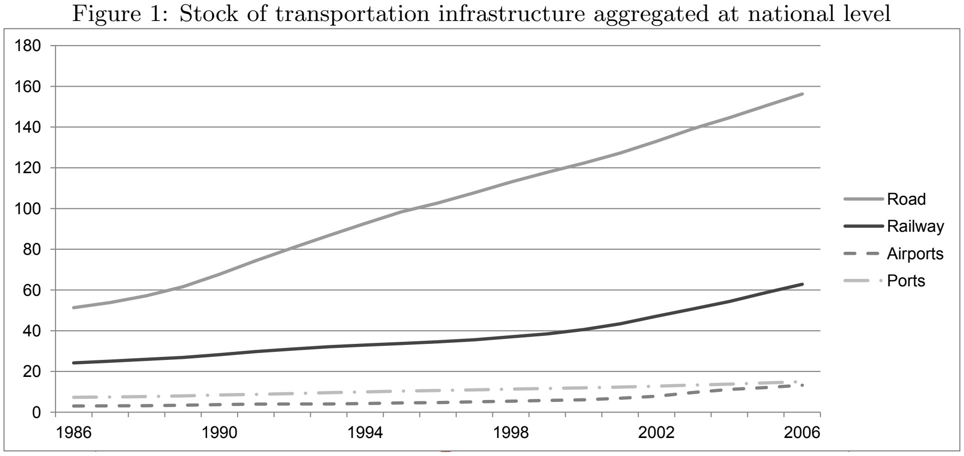
Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**
y	15.61	0.9	13.76	18.63
k	16.3	0.85	14.44	19.31
l	5.21	0.86	3.39	8
kh	-1.96	0.34	-3.14	-1.14
rs	27.57	1.49	24.15	32.88
trans	13.26	1.09	10.5	16.93
N		987		

We use a balanced panel dataset of 47 Spanish peninsular provinces covering the period from 1986 to 2006 that results in 987 observations, as shown in Table 1. The dependent variable, Gross Added Value, measured in thousands of 2000 Euros, came from the National Statistics Institute (INE). The source for the explicative variables, labor force, as measured in thousands of workers, and human capital, as measured by the share of total employment with higher level education (secondary school, technical college and university degrees), are INE and BBVA Foundation-Ivie, respectively.

The latest series of capital stock for the Spanish economy were also obtained from BBVA Foundation-Ivie (see Mas Ivars et al. (2012)), where net wealth and productive capital stock data are available for both public and private capital. Productive capital stock at constant pricing is a quantity factor that takes into account loss of efficiency as assets age and is the rele-

[11]Márquez and Hewings (2003), analyze regional competition between Spanish regions (NUTS-2).

Figure 1: Stock of transportation infrastructure aggregated at national level



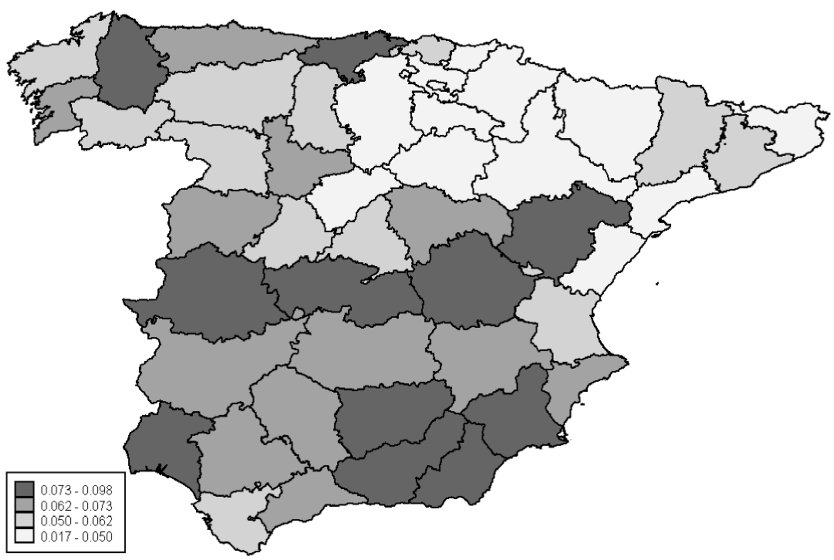
vant component for productivity analysis [12]. Transportation infrastructure projects, such as ports, airports and railways, have been collapsed into one single variable excluding the stock of roads because these were previously included in the road services variable. As explained in Section 2, this variable is the result of the product of the stock of road infrastructure and the stock of private vehicles in each province. The source for the required information to build road services is BBVA Foundation-Ivie.

Since the 1970s, there has been substantial development of road transportation infrastructure in Spain; during the 1990s, in particular, the implementation of the Infrastructure and Transport Strategic Plan caused a significant boost in investment into High Capacity Networks . Figure 1 represents the national stock of infrastructure for the different transportation

[12]The computations of the productivity of capital stock are obtained using a new methodology applied to Spanish capital stock estimates that is based on two OECD manuals (Schreyer, 2001; Schreyer et al., 2003).

modes for the period of 1986-2006. Figure 2 shows the spatial distribution of road infrastructure stock growth rates at the provincial level during that same period. Neighbor provinces share similar growth rates for this variable that display an uneven distribution far from a random spatial process.

Figure 2: Rate growth of road transportation infrastructure stock for the period of 1986-2006 at the provincial level



4. Econometric Model and Estimation Issues

4.1. Model specification

The empirical model we estimate is based on the log-linear Cobb-Douglas production function. Following the previous discussion about different spatial econometric models, we estimate a Spatial Durbin Model:

$$
\begin{aligned}
y_{it} &= \mu_i + \beta W y_{it} + \alpha_1 l_{it} + \alpha_2 hk_{it} + \alpha_3 k_{it} \\
&+ \alpha_4 rs_{it} + \alpha_5 trans_{it} + \theta_1 W l_{it} + \theta_2 W kh_{it} \\
&+ \theta_3 W k_{it} + \theta_4 W rs_{it} + \theta_5 W trans_{it} + \epsilon \qquad (7)
\end{aligned}
$$

where variables on both sides of the equations are in logarithms, ϵ is a well-behaved error term, and subscripts i and t denote provinces and time periods, respectively. Compared to Equation (6), this equation also includes human capital, hk, and public capital, G, separated into two variables, road services, rs, and other transportation modes infrastructure stock, $trans$. Finally, spatial fixed effects, μ_i, are introduced into the model to control for all time-invariant variables.

Moreover, as discussed above, these equations include the spatial lag of the dependent variable and the spatial lag of the explanatory variables. Two different criteria have been used to build W [13]. Wn stands for a physical contiguity matrix, in which its values would be 1 for two bordering provinces and 0 for all others. $Wd150$ is another binary weighting matrix with elements valued at 1 for those provinces within a radius of 150 kilometers from the centroid of the province of reference and 0 for provinces beyond that distance. These matrices treat physical proximity as the main driver for the presence of spillovers.

[13] The weighting matrices have been row normalized following standard practice in the spatial econometrics literature. After transformation, the sum of all elements in each row equals one. Note that the row elements of a spatial weighting matrix show the effect on a particular unit of all other units.

5. Results

5.1. Spatial Durbin Model interpretation

Before discussing the results, it is worth noting that the coefficient estimates must be interpreted carefully because they are dependent on model specifications. For example, if the estimated model had the form of the Spatial Error Model (*SEM*), the coefficient estimates in log-form can be directly interpreted as elasticities. However, the effect of the independent variables on the dependent variable in the *SDM* has no straightforward interpretation, and direct and indirect effects must be computed. LeSage and Pace (2009) shows that the partial derivates take the form of an N-by-N matrix for each k regressor and comments on their fundamental properties . For instance, the partial derivates matrix corresponding to the road services regressor (rs) from Equation (7) would have the following form,

$$\frac{\delta y_t}{\delta rs_t} = (I_N - \beta W)^{-1}(\alpha_4 I_N + \theta_4 W) \tag{8}$$

These authors propose scalar summary averages to increase the ease of reporting the effects associated with the regressors; thus, direct effects measure what effect changing an independent variable has on the dependent variable of a province. Direct effects, which appear in the main diagonal of the matrix shown in Equation (8), are their own partial derivatives and are summarized using the average of these elements of the matrix. This measure includes feedback effects, i.e., those affects passing through neighboring units and back to the unit that instigated the change. The cross-partial derivatives are named indirect effects, and they measure the effect of changing an independent variable in a province on the dependent variable of all the other provinces. Indirect effects appear as off-diagonal elements and are summarized as row sum averages. Finally, total effects are computed as the sum of direct and indirect effects.

5.2. Comments on the results

The results obtained through the estimation process are shown in Table 2, which contains the point estimates of the production function model using two alternative spatial weight matrices, as discussed above. In Table 3, direct, indirect and total effects computations are reported for the SDM.

Overall, the results are consistent with other production function studies and indicate the existence of transportation infrastructure spillovers. As discussed below, there are certain results shared by all the estimated models. All the specifications of the model yield similar results regarding the output point estimates of the coefficients accompanying the regressors. It is worth underlining the positive and highly significant effects of the spatial lag of the dependent variable that shows values of 0.297 and 0.251, depending on the W specification adopted. This result indicates that the weighted average of the output of neighbor provinces positively affects production in the geographic unit under analysis. According to the theoretical model that we developed in 2, changes in the business cycle in other provinces would significantly affect productivity in a particular province. In this case, because the sign of the parameter accompanying the spatial lag of the dependent variable is positive, economic agents in that province would increase the capacity utilization of quasifixed inputs when output in other provinces grows and would decrease the usage when output falls.

The Wald and Likelihood Ratio (LR) tests permit the determination of the validity of the hypothesis positing that the Spatial Durbin Model can be

Table 2: Spatial Durbin Model with Spatial Fixed Effects

	Wn		**Wd150**	
Variable	**Coef.**	**t-stat**	**Coef.**	**t-stat**
K	0.157***	7.98	0.178***	8.98
L	0.272***	15.19	0.268***	14.99
HK	0.016	1.63	0.020*	1.84
RS	0.060***	7.26	0.061***	7.38
Trans	-0.002	-0.47	-0.001	-0.13
W*K	0.039	1.12	-0.001	-0.04
W*L	-0.080***	-2.97	-0.058***	-2.24
W*HK	0.001	0.08	0.005	0.29
W*RS	0.001	0.06	0.011	0.87
W*Trans	-0.018**	-2.00	-0.017*	-1.96
W*Y	0.297***	7.34	0.251***	6.18
Corrected R^2	0.967		0.966	
Log-likelihood	2010.00		1995.10	
Wald Test Spatial Lag	20.117	$p = 0.001$	15.25	p =0.009
LR Spatial Lag	20.586	$p = 0.000$	15.276	$p = 0.009$
Wald Test Spatial Error	45.135	$p = 0.000$	32.63	p =0.000
LR Spatial Error	50.256	p =0.000	35.307	p =0.000
Observations	987		987	

Significance code: *p<.1, **p<.05, ***p<.01

Spatial fixed effects are not displayed, but are available under request.

simplified to the Spatial Lag Model. The results reported using the Wald test (20.12, p=0.001 for the contiguity matrix and 15.25, $p = 0.009$ for the W matrix, using neighbors within a distance of 150 km, respectively) or using the LR test (20.58, $p = 0.000$ and 15.28, p =0.000) indicate that the hypothesis must be rejected. Similarly, the hypothesis that the SDM can be simplified to the Spatial Error model must be rejected, according to the Wald tests (45.135, $p = 0.000$ and 32.63, p =0.000) and the LR tests (50.256, p =0.000 and 35.307, p =0.000). To investigate the null hypothesis that the spatial fixed effects are jointly insignificant, an LR test may be conducted. The results (3248.95,$p < 0.01$ and 3233.27, $p < 0.01$ both with 47 degrees of freedom) indicate that this hypothesis must be rejected and justify the extension of the model with spatial fixed effects.

However, as discussed above, inferences must be made about the effect of independent variables on the productivity of a province with regard to the direct, indirect and total effects displayed in Table 3. According to these results, the direct effects of labor and private capital on the aggregated output of a particular province are positive and significant. Moreover, these elasticities are stable. The elasticities of labor (approximately 0.27) and private capital (between 0.16 and 0.18) are positive and significant in all the models [14]. These coefficients are similar to those obtained in some of the latest applied studies in Spain (Márquez et al., 2010). Estimations of the

[14]Elhorst (2010) emphasize that empirical studies usually find significant differences among the coefficient estimates from models with and without spatial fixed effects. Models that include spatial fixed effects use time-series variations of the data, whereas models without controlling for spatial fixed effects utilize cross-sectional components of the data. Models of the first type tend to give short-term estimates, and models without controls for spatial fixed effects tend to give long-term estimates (Baltagi, 2008).

direct effects of other modes of transportation capital are also not significant, regardless of the empirical specification.

The estimated coefficients accompanying the variable of interest in this work, the road services variable, are positive and highly significant, and their sizes show little variation. On average, a 100% increase of the road services of a certain province causes a 6.1% increase in its productivity.

In the SDM, the indirect effects influence the existence and size of effects across boundaries. We find evidence of positive spatial spillovers for the road services variable with estimates of 0.025 and 0.034, which depend on the W matrix employed to define neighbors. According to these results, increases in the services provided by the road infrastructure of a province would yield positive effects for the productivity of its neighbor up to 3.4%. For the remaining modes of transportation, we found clear evidence of negative spillovers. The indirect effect coefficient is close to -0.02 in different settings. Following the interpretations presented in section 2.2, improvements in the services provided by the road infrastructure in one province would cause positive spillovers to other provinces by raising the quality of the road transportation network as a whole. Conversely, increased investment into ports, airports and railway infrastructure projects in a province would produce negative spillovers through the migration of productive factors to those regions with the larger levels of public capital investment.

These results offer evidence of spatial spillovers for the different types of transportation infrastructure projects consistent with most of the literature using Spanish provincial data. For instance, using a stochastic frontier approach, Delgado and Alvarez (2007) found positive and negative spillovers depending on the sector of the economy under review and the definition of the weighting matrix. Utilizing a production function, Moreno and López-

Table 3: Direct, Indirect and Total Effects

		Wn		Wd150	
	Variables	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**
Direct Effects					
	K	0.162***	8.47	0.180***	9.43
	L	0.272***	15.33	0.270***	16.01
	KH	0.016*	1.66	0.0191*	1.92
	RS	0.061***	7.76	0.062***	7.60
	Trans	-0.003	-0.69	-0.002	-0.42
Indirect Effects					
	K	0.114***	2.79	0.057	1.35
	L	0.002	0.05	0.011	0.41
	KH	0.009	0.38	0.013	0.59
	RS	0.025*	1.73	0.034**	2.28
	Trans	-0.025**	-2.09	-0.022**	-2.10
Total Effects					
	K	0.276***	6.67	0.234***	5.59
	L	0.274***	10.13	0.281***	11.77
	KH	0.025	0.95	0.032	1.35
	RS	0.086***	6.44	0.096***	6.78
	Trans	-0.028**	-2.19	-0.024**	-2.14

Significance code: *p<.1, **p<.05, ***p<.01

Bazo (2007) found the existence of negative spatial spillovers for transportation infrastructure development. By contrast, using Spanish provincial data, Álvarez et al. (2006) replicated the models used by Holtz-Eakin and Schwartz (1995) and Mas et al. (1996) and did not find either positive or negative spillovers.

Finally, we obtain the total effects of the variables in the productivity of a province by adding direct and indirect effects together. We find that all the variables included in the model are significant with the expected signs, except that the human capital variable does not appear to be statistically significant. As discussed above, the average total effect of road transportation services is positive and significant (ranging from 0.086 to 0.096). Conversely, the average total effect of investment into other modes of transport infrastructure appear to be dominated by negative spillovers, lowering the productivity of other provinces [15].

6. Conclusions

In this paper, we attempt to find the correct specifications for an aggregated production function to measure the effects of road infrastructure public investments on the economy of Spain. The main contribution of the work is twofold. First, we *revisit* Fernald (1999) using a variable that combines the stock of vehicles in a certain province with information about the road network to assess the effects of road transport infrastructure on productivity. Second, the empirical models include spatial lags of the in-

[15] We must remind ourselves that the estimated effects in Table 7 are computed as national average effects using the whole set of geographical units. Thus, the estimated effects for a particular province might be different from those results reported in 3.

dependent variables and of the dependent variable, which is not common in the literature. We empirically and theoretically justify the inclusion of the spatial lag as an explanatory variable. Primarily, we accommodate the private capital grade of utilization in the business cycles contained in the geographical units. In this fashion, we attempt to avoid shortcomings caused by the use of stock indicators of private and public capital while capturing the underlying spatial processes at work.

As our main empirical result, we find strong evidence of the positive effects of road infrastructure projects on the private economy of a province. Spillovers caused by investment in transportation infrastructure (i.e., the effects on one province of changes in the flows of road services in other provinces) are approximately half the size of the direct effects of such investment. Improvements in the road infrastructure of one spatial unit increases productivity in neighboring units by approximately half of the amount of the improvement in the spatial unit in which the infrastructure is located. According to the outcome of this model, specially the importance of spillover effects, seems to support the idea that road transport infrastructure investment effects are not confined within the territory where the infrastructure project is located. In the Spanish political context, this conclusion can have major consequences because both regional and provincial governments share with the national government the decision making about where to make infrastructure investments.

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