Road Investment and Productivity Growth: the Effects of Vehicle-Intensity and Congestion†

Daniel Montolio

Departament d’Hisenda Pública. Universitat de Barcelona
Av. Diagonal 690, Torre 4 Planta 2
08034 Barcelona (Spain)
Tel.: ++ 34 93 402 18 12
Fax: ++ 34 93 402 18 13

Institut d’Economia de Barcelona (IEB)

Albert Solé-Ollé‡
Departament d’Hisenda Pública. Universitat de Barcelona
Av. Diagonal 690, Torre 4 Planta 2
08034 Barcelona (Spain)
Tel.: ++ 34 93 402 18 12
Fax: ++ 34 93 402 18 13

Institut d’Economia de Barcelona (IEB)

Abstract. This paper presents a series of novelties with respect to previous studies of the effect of productive infrastructures on output growth. We study public investment in road infrastructures as a determinant of the Total Factor Productivity (TFP) growth for Spanish provinces (NUTS3) for the period 1984-1994. We allow the effect of road infrastructures to depend on the extent of the road use by provincial industries, proxied by these industries’ vehicle-intensity. Moreover, we consider the services provided by the stock of road infrastructures as an impure public good, that is, one that is subject to congestion. Finally, using the instrumental variables technique, we account for possible problems of endogeneity in the regressions.

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‡ Corresponding author: asole@ub.edu
1. INTRODUCTION

The inclusion of public infrastructures in a neoclassical production function is, broadly speaking, justified if it increases the productivity of the private factors of production (capital and labour). Empirically, since the seminal works by Aschauer (1989a,b), this has been one of the most frequently studied issues in economics because of the contradictory results reported and the important implications that the estimation of the effect of public investment on growth rates may have for policy decisions.

The debate on the productivity of public infrastructures has focussed on the size of its effect on output. This elasticity has been obtained, traditionally, from the empirical estimation of a production function (usually a Cobb-Douglas), in which output, private capital, labour and public infrastructures are contemporaneously related (see Gramlich, 1994 and Agell et al., 1997 for extensive reviews).\(^1\)

Another approach used in the literature to estimate this elasticity is the Total Factor Productivity (TFP hereafter) approach, also known as the Solow residual. Determinants of TFP growth have generally been studied using two kinds of approach. Studies using the first have focused on the breakdown of TFP growth into efficiency change and technological progress, usually through parametric stochastic and non-parametric production frontiers (Färe et al., 1994 and Perelman, 1995 among others). In this context, public infrastructures are considered to increase the productivity of private factors, inducing efficiency gains and, hence, productivity growth (see for the Spanish case, Salinas-Jimenez, 2003). The second is a regression estimation approach that relates TFP growth series to their possible determinants, among them public investment.

\(^1\) An alternative approach, in response to the criticism that the relation between infrastructures and economic growth is too complex to be simply embodied in a production function, is based on the cost function (see for instance, Berndt and Hansson, 1992, Seitz and Litch, 1995, or Morrison and Schwartz, 1996). This approach approximates all the aspects that influence the optimizing behaviour of a representative firm.
in infrastructures (see for instance, Hulten and Schwab, 1993 or Mas et al., 1998). In this paper we will use the latter approach to assess whether public investment in road infrastructures is a determinant of TFP growth across Spanish provinces (NUTS3) for the period 1984-1994.

Our work presents a series of novelties with respect to previous studies of the effect of public infrastructures on output growth. First, following the proposal of Fernald (1999), we allow the effect of road infrastructures to be higher in provinces with a sectoral structure that makes more intensive use of the services provided by the stock of road infrastructures. That is, if roads and highways are productive, then provinces with industries that make intensive use of these infrastructures should benefit more. The basic assumption is that changes in road growth are associated with larger changes in productivity growth in provinces that have more vehicle-intensive industries, given the complementarity between roads and vehicles.

Second, following Boarnet (1997) and Fernald (1999), we explore the empirical importance of congestion. We consider that services provided by the stock of road infrastructures are not a pure public good, but are subject to congestion. As variable that measures the congestion level of a provincial economy we use total kilometres driven by trucks and cars, which approximates aggregate road use. Given that we control for the road capital stock, the inclusion of kilometres driven allows us to capture the effect of congestion, as explained in Fernald (1999).

Finally, we deal with possible problems of causality between the variables used as proposed by Duffy-Deno and Eberts (1991) and Tatom (1991, 1993) or, more recently, by Roca and Pereira (1998), Pereira and Flores de Frutos (1999), Cadot et al. (1999), Fernald (1999) and Röller and Waverman (2000). We correct possible problems caused by the endogeneity of public investment in infrastructures by using instrumental
variables (IV hereafter) to estimate TFP growth equations. We distinguish between two types of instrumental variables: lagged values of the explanatory variables, and political variables. The use of political variables as instruments is justified if we consider that public investment decisions in Spanish provinces are taken by the central government. For Castells and Solé-Ollé (2004), decisions regarding public investment policies in Spain are based on a mixture of equity, efficiency and political arguments. Other variables that affect the territorial distribution of productive public investment are political and institutional factors such as the percentage of votes obtained or the margin of victory by the ruling party in each province. Once we quantify these political variables, we can use them as additional instruments in the regressions in order to analyse whether public infrastructures are a determinant of total factor productivity growth.

The paper is organized as follows. Section 2 presents the theoretical model which we use to derive the Solow residual equation including public investment in road infrastructures and which allows, at the same time, different effects of infrastructures across provinces depending on the intensity of use of private inputs and on the level of congestion of infrastructures in each province. Section 3 describes the data, the variables used, and the econometric techniques chosen. Section 4 presents the main results. Finally, section 5 concludes and summarizes the main findings.

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2 The central government has different objectives to fulfill with public investment policies. One, for instance, is to promote development in the poorer provinces. In this case, an increase in provincial income will be accompanied by a decrease in public resources devoted to infrastructures in that province (the equity argument). Alternatively, if the government wishes to maximize the overall national output, the relation between provincial growth and investment in infrastructures will be positive (the efficiency argument). See Castells and Solé-Ollé (2004).
2. THEORETICAL FRAMEWORK

2.1. The Production Function Approach

The model is based on a standard production function, which includes, apart from private inputs (labour and capital), the services derived from the public provision of road infrastructures:

\[ Y_{it} = A_{it} F(K_{it}, L_{it}, R_{it}), \]  

where \( Y_{it} \) is output in province \( i \) at time \( t \), \( A_{it} \) is the level of technology, which is considered neutral in a Hicks sense; \( K_{it} \) and \( L_{it} \) are the stock of private capital and labour respectively. Finally, following Fernald (1999), the effect of road infrastructures is introduced in the production function as a third input, \( R_{it} \):

\[ R_{it} = R^i(X_{it}, K_{it}^{g}). \]  

This third input of production is the result of the combination of an internal input (part of the private capital stock) of the firms in each region \( X_{it} \), and the flow of services provided by the stock of road infrastructures \( K_{it}^{g} \). Therefore, we can rewrite the production function as:

\[ Y_{it} = A_{it} F(K_{it}, L_{it}, R^i(X_{it}, K_{it}^{g})). \]  

We introduce additional assumptions that confer some important and useful properties on the production function presented in equations (1) and (3). We assume that firms produce under perfect competition and that they face constant returns to scale (CRTS hereafter) in private factors of production \( (K_{it}, L_{it} \text{ and } X_{it}) \), which adjust instantaneously. We denote by \( F_{J} \) the derivative of the production function \( F \) with

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3 Road services in province \( i \) \( (R^i) \) depend upon the flow of service provided by the aggregate stock of government roads and highways \( (K_{it}^{g}) \) as well as the stock of private vehicles in the province \( X_{it} \). Therefore, \( X_{it} \) is part of the private capital stock that directly uses the services provided by public capital stock of roads and highways; it is not an intermediate input of production.

4 This assumption implies that private factors’ prices are equal to their marginal productivities.
respect to input $J$. Cost minimization implies that the elasticity of output with respect to $J \Big( \varepsilon^{F,J}_u \Big)$ is equal to the share of input $J$ in production ($S^J_u$):

$$\varepsilon^{F,J}_u = F_j \frac{J}{F} = S^J_u \tag{4}$$

Moreover, the assumption of perfect competition and, therefore, the absence of profits for competitive firms implies that the sum of the shares of inputs on production ($S^J_u$) is equal to one. The main goal of this paper is to estimate the elasticity of output with respect to the services derived from road infrastructures ($\varepsilon^{F,K^g}_u$) at provincial level.

Given equation (3), we can observe this elasticity indirectly. We can express it in relative terms with respect to the private input $X_{it}$, given the share of this private input on production, ($S^X_u$):

$$\varepsilon^{F,K^g}_u = \frac{F_{K^g}}{F} \frac{K^g_u}{X_u} \left( \frac{F_X X_u}{F} \right) = \omega \cdot S^X_u \tag{5}$$

Parameter $\omega$ equals the relative elasticity of private and public inputs (for instance, trucks and roads respectively) with respect to production:

$$\omega = \frac{F_{K^g}}{F} \frac{K^g_u}{X_u} = \frac{\varepsilon^{F,K^g}_u}{\varepsilon^{F,X}_u} \tag{6}$$

We expect $\omega$ to be positive, which would indicate that provinces with a sectoral structure that is more intensive in the private input $X_{it}$ are also more intensive in the use of public inputs; therefore, public (road) infrastructures will be more productive for the economy.

Some further assumptions regarding technology greatly simplify the formal derivation and will help to interpret the result. The separability assumption implicit in

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5 Note from equation (3) that what we observe directly are road services ($R'$).
(1) and (3) allows us to re-write \( \omega_i \) as the relation between the elasticities of \( K_{it}^g \) and \( X_{it} \) in the production of road services (\( R_i \)) for the private firm:

\[
\omega_i = \frac{R_{g, it} K_{it}^g}{R_{X, X_{it}}}.
\] (7)

We assume that all Spanish provinces have the same Cobb-Douglas technology of production of road services: \( R_i(X_{it}, K_{it}^g) = R(X_{it}, K_{it}^g) \). Under this assumption, we obtain that \( \omega_i = \omega \). Of course, the rest of the production function remains equal and, then, the elasticity of output with respect to road infrastructures can vary across time and provinces if and only if it remains proportional to the share of input \( X_{it} \) in production, i.e., if and only if the elasticity is equal to:

\[
\varepsilon_{it}^{F, K^F} = \omega S_{it}^X.
\] (8)

Equation (8) shows how the elasticity of road infrastructures is defined in our model, and is estimated using a range of econometric techniques.

2.2. Total Factor Productivity

The effect of road infrastructures on economic growth is analysed by estimating TFP growth equations. In our case, and given that the production function chosen has a Cobb-Douglas form, TFP can easily be derived from the log-differentiation of the production function (1):

\[
\Delta \ln Y_{it} = \Delta \ln A_{it} + \frac{dF}{dK} \Delta \ln K_{it} + \frac{dF}{dL} \Delta \ln L_{it} + \frac{dF}{dR} \Delta \ln R_{it},
\] (9)

where \( \Delta \ln Y_{it} = \Delta \ln Y_{it} \cdot \Delta \ln Y_{it-1} \) is output growth. Solow (1956) defined the growth rate of TFP as a residual: the difference between output and the value given to the contribution of the inputs. Given our production function, equations (1) and (3),
reorganizing equation (9) and substituting the elasticities of inputs with respect to output by input shares in production, the Solow residual ($\Delta \ln A_{it}$) can be expressed as:

$$\Delta \ln A_{it} = \Delta \ln Y_{it} - S_{it}^K \Delta \ln K_{it} - S_{it}^L \Delta \ln L_{it} - S_{it}^R \Delta \ln R_{it}$$  \hspace{1cm} (10)

Introducing the aggregate road services function ($R$), with the Cobb-Douglas specification previously assumed, we obtain:6

$$\Delta \ln A_{it} = \Delta \ln Y_{it} - S_{it}^K \Delta \ln K_{it} - S_{it}^L \Delta \ln L_{it} - S_{it}^X \Delta \ln X_{it} - S_{it}^{Kg} \Delta \ln K_{it}^g,$$  \hspace{1cm} (11)

therefore, in our model TFP growth is defined as:7

$$TFP_{it} = \Delta \ln K_{it}^g + \Delta \ln A_{it},$$  \hspace{1cm} (12)

Substituting equation (8) in (12), this yields

$$TFP_{it} = \omega S_{it}^X \Delta \ln K_{it}^g + \Delta \ln A_{it}.$$  \hspace{1cm} (13)

Therefore, the productivity growth observed (output growth not produced by private inputs of production) depends on the contribution of government-provided road infrastructures and technology shocks, $\Delta \ln A_{it}$.

Note that, from equation (13), an increase in the infrastructures stock has a bigger impact on the productivity growth rate of provinces that are more intensive in the private input ($X_{it}$) that directly uses services derived from road infrastructures ($K_{it}^g$), i.e., in provinces with industries that make intensive use of the services provided by roads and highways ($S_{it}^X$).

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6 Note that $X_{it}$ is not an intermediate input; it is part of the private capital stock that directly uses the services provided by road infrastructures.

7 Equations (10) and (11) are obtained under the CRTS assumption. In the results section we discuss estimates obtained if we do not impose any restriction on the type of returns to scale of the production function following Hulten and Schawb (1993).
The main aim of this study is the estimation of $\omega$, once $S^X_i$ has been quantified for each province. Therefore, we estimate the “pure effect” ($\omega$) of public investment in infrastructures. By “pure effect” we mean the estimation of the effect of public road investment on output growth once we account for the positive (negative) effect on this elasticity in provinces with above (below) average vehicle-intensities.

2.3. Congestion

It seems reasonable to assume that the services per user provided by road infrastructures fall when the number of users rises. The explanation is that public infrastructures are subject to congestion. The impact of congestion becomes more important as increasing numbers of users “consume” the infrastructure’s services. Few empirical studies have introduced congestion when estimating the effects of public infrastructures on economic growth. With the exception of the works by Boarnet (1997) and Fernald (1999), previous empirical works have considered the services provided by public infrastructures as non-rival public goods.\(^8\) A simple way to model the average congestion level of an economy is to express the services derived from public infrastructures as:

$$\hat{K}_{it}^g = \frac{K_{it}^g}{U_{it}} \quad (14)$$

where $\hat{K}_{it}^g$ is the “effective” stock of road infrastructures that province $i$ can use in period $t$ once we have accounted for the level of usage ($U_{it}$) of the installed stock of

\(^8\) This assumption is in sharp contrast with the literature that deals with the estimation of the congestion costs of local public goods: see Borcherding and Deacon (1972), Bergstrom and Goodman (1973), Edwards (1990) or Means and Mehay (1995). For the estimation of costs of congestion in road and highways infrastructures see, for instance, Inman (1978). There are also some recent theoretical works by Glomm and Ravikumar (1994) and Eicher and Turnovsky (2000) on this issue.
public infrastructures \( (K_g^g) \). Therefore, \( \dot{K}_g^g \) depends on the stock of road infrastructures and a measure of usage of infrastructures (for instance, traffic intensity in roads and highways). Parameter \( \alpha \) captures the rate at which the services received by a firm decrease as the total number of users (firms) increases. If road infrastructures are a pure public good \( \alpha \) equals 0; if they are taken to be a pure private good \( \alpha \) equals 1.

Taking equations (3), (13) and (14), we can express TFP growth as:

\[
\frac{\Delta TFP}{TFP} = \phi S^X_u \Delta \ln K_g^g - \phi S^X_u \Delta \ln U_u + \Delta \ln A_u. \tag{15}
\]

where \( \phi = \omega \alpha \). In this case road infrastructure growth has a positive effect on productivity, but this may be offset by a simultaneous increase in the number of users of this infrastructure, the latter effect depending on the extent to which road infrastructures are public.

Equation (14) for congestion has been extensively used in the literature on local public good demand estimation (see for instance, Borcherding and Deacon, 1972). We denote this specification as the \textit{B-D Congestion model}. This model has the advantage of simplicity, allowing the estimation of the effects of congestion using a log-linear specification as in Fernald (1999). However, this functional form may be excessively restrictive, since it assumes a constant elasticity effect of users on TFP growth. Therefore, following Boarnet (1997) we also consider appropriate to use a more flexible approach to estimate the congestion effect. In order to derive the \textit{Flexible congestion model} we use a second-order translog expansion of the relationship \( \dot{K}_g^g = F(K_g^g, U_u) \), similar to the procedure used in Boarnet (1997):

\[
\Delta \ln \dot{K}_g^g = \beta_1 \Delta \ln K_g^g + \beta_2 \Delta \ln U_u + \beta_3 \Delta \ln (K_g^g)^2 + \beta_4 (\Delta \ln U_u)^2 + \beta_5 (\Delta \ln K_g^g \times \Delta \ln U_u). \tag{16}
\]

The use of this specification has two potential advantages. First, the translog expansion
includes an interaction term for $K_{it}^g$ and $U_{it}$. Since increases in road and highway stock should have the largest productive effect in the most congested provinces, a test for this interaction should be a part of the regression specification. Second, the translog specification allows the effect of $U_{it}$ to be non-linear. This may be necessary because an increase in the number of users may not cause any real congestion in totally uncongested roads. Both the B-D congestion model and the Flexible congestion model are estimated using a variety of econometric techniques.

3. DATA AND ECONOMETRIC ISSUES

3.1. Data

In this section, we describe the data-base used in the empirical estimations, its statistical sources and the procedures used to obtain the variables we are interested in. The estimations are conducted for the 50 Spanish provinces for the period 1984-1994. This time interval was chosen purely due to questions of data availability for some of the variables involved in the estimations, mainly road users (kilometres driven) and number of vehicles. Table 1 presents descriptive statistics of the variables used in the empirical analysis.

<Insert Table 1>

The Solow residual at sectoral level (firms) is defined from data on the capital-labour ratio, the intermediate inputs-labour ratio, and the share of each productive factor in production (see for instance, Estrada and López-Salido, 2001). At aggregate level, the use of Gross Domestic Product (GDP) as a measure of output of provincial economies would involve double accounting of intermediate inputs; therefore, it is better to use
Gross Value Added at factor costs (GVA f. c.) as a measure of output.\(^9\) The annual series of GVA f. c. used are at constant 1986 prices and are taken from the Spanish National Institute of Statistics (Instituto Nacional de Estadística, INE). The Solow residual takes the following form:\(^{10}\)

\[
\Delta \ln A_{it} = \Delta \ln Y_{it} - S^K_{it} \Delta \ln K_{it} - S^L_{it} \Delta \ln L_{it} - S^S_{it} X_{it} \Delta \ln X_{it} - S^{Kg}_{it} \Delta \ln K_{ig}.
\]

(11)

This depends on the growth rate of GVA (\(\Delta \ln Y_{it}\)), total private capital (\(\Delta \ln K_{it}\)) obtained from the Fundación BBVA (1999)\(^{11}\) covering the period 1964-1996 at constant 1986 prices, and, finally, employment (\(\Delta \ln L_{it}\)) obtained from the TEMPUS data base from INE, and covering our data span.\(^{12}\) Finally, \(\Delta \ln K_{ig}^g\) is the growth rate of public infrastructure stock devoted to roads and highways (series are at constant 1986 prices).\(^{13}\)

Data to quantify the share of private inputs on production directly using services derived by road infrastructures, \(S^X_{it}\), are very difficult to find for the Spanish provinces. To solve this problem we assume that \(S^X_{it}\) is proportional to the relation between a variable that indicates the use of services derived from road infrastructure (number of

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\(^9\) This variable excludes the consumption (by productive firms) of intermediate inputs.

\(^{10}\) Equation (11) presents private capital divided in \(K_{it}\) and \(X_{it}\), \(X_{it}\) being private capital from firms that directly use road infrastructures (i.e., trucks and industrial vehicles). We do not take this differentiation into account when calculating the TFP. We use data for overall private capital, which includes all types of private capital (except residential capital because it is not considered directly productive); among which is the capital that makes more intensive use of road infrastructures.

\(^{11}\) For more details on definitions and elaborations of the private and public capital stocks series for the Spanish case see Mas et al. (1996, 1998).

\(^{12}\) To obtain the TFP growth we need to establish the factor shares on total production of productive inputs. In our estimations we use \(S^K = 0.333\) and \(S^L = 0.666\), under the assumption that these parameters are constant across provinces \((i)\) and time \((t)\). These values are similar to those obtained for the Spanish economy by Boscá et al. (2003) and those used by Manzano (2002).

\(^{13}\) In the results section we also perform some regressions (not reported but available upon request) to check the robustness of the estimates for road infrastructures. We use two alternative variables: first, an aggregate measure of transport infrastructures including roads and highways, harbours, railways and airports, i.e., a measure of the public capital stock used in all types of transportation. Second, we use the total productive public infrastructure stock including roads and highways, water and sewer systems, urban structures, harbours, railways and airports.
industrial vehicles; $V_t$) and the GVA ($Y_t$):

$$S^X_t \approx \mu \left( \frac{V_t}{Y_t} \right).$$

(17)

Next, we compute $S^X_t$ for the whole of Spain as the mean for all provinces ($S^X_t$).

Dividing equation (17) by this mean, we obtain an index of relative intensity of the use of road infrastructures in each province, expressed as ratios of the Spanish mean (equal to 1):

$$\hat{S}_t = \frac{S^X_t}{S^X_t} = \frac{\mu \left( \frac{V_t}{Y_t} \right)}{\mu \left( \frac{V_t}{Y_t} \right)}.$$

(18)

Introducing (18) in (13), we obtain:

$$\dot{TFP}_t = \omega \hat{S}_t \Delta \ln K^g_t + \Delta \ln A_t.$$

(19)

where $\omega' = \omega S^X_t$.

The connection between our model and previous studies is based on a crucial assumption that simplifies the estimation of equation (19). If we assume $S^X_t = S^X_t$, and therefore $\hat{S}_t = 1$ for all provinces, we are implicitly assuming that the share in production by those private inputs that intensively use road infrastructures ($X_{it}$) is equal for all Spanish provinces and across years, and has an estimating equation of the following form:

$$\dot{TFP}_t = \omega' \Delta \ln K^g_t + \Delta \ln A_t.$$

(20)

Parameter $\omega'$ is, therefore, equivalent to the parameter derived from the “traditional” analysis of the effect of public infrastructures on TFP growth, which loses the “pure” effect of public capital presented above. From equation (19), for a province with an
intensity of utilization of the private input $X_{it}$ equal to the Spanish mean, the impact of public infrastructures is equal to $\omega \times 1$. In contrast, for two provinces with different levels of utilization of the private input that makes intensive use of road infrastructures, one 10% above and the other 10% below the Spanish average, the impact of public infrastructures is equal to $\omega \times 1.1$ and $\omega \times 0.9$ respectively. We estimate both equations: our *Vehicle-intensity model* of TFP growth in equation (19); and the *Basic model* presented in equation (20).

We approximate the share of the road factor on total production\(^{14}\) with an index of the share of the number of industrial vehicles ($V_{it}$) relative to the GVA f. c. in each province, all divided by the same ratio for the whole of Spain, and thus obtain a relative index (i.e., Spanish mean equal to one). Data for provincial industrial vehicle stock are taken from the *Anuario Estadístico de la Dirección General de Tráfico* for a number of years.

For the utilization variable in the case of roads and highways ($U_{it}$), following Fernald (1999), we use the total number of kilometres driven in each year and province (data provided by the *Anuario Estadístico de la Dirección General de Tráfico*). The inclusion of this variable of utilization of public infrastructures in our regressions may cause problems given the high correlation between this index of usage and the GVA growth and/or the variation in the sectoral composition of provinces. However, the coefficients of these variables can sometimes be useful to control for the congestion effects. Therefore, the effects of the usage variable are easier to identify when this usage comes from an external source of variation not controlled by the rest of variables.

\(^{14}\)According to Fernald’s (1999) proposal, to calculate this variable we should obtain it as the number of industrial vehicles multiplied by the utilization cost of the stock of vehicles (including depreciation rate and fiscal aspects) and divided by the value of production. The data required for the calculation proposed by Fernald (1999) are not available for Spanish provinces.
included in the model. For instance, in the case of roads and highways infrastructures, even if the total number of kilometres/year driven by industrial vehicles increases as provincial GDP increases and/or the sectoral structure becomes more intensive in transport services, the increase in the usage of public roads in the province could also be due to a considerable increase in the traffic that just passes through, a variable that is independent of the economic evolution of the province.

3.2. Econometric Issues

Studies that deal with the estimation of the effects of public investment on growth rates of income and TFP use different types of data and econometric approaches. We use a range of econometric techniques: Ordinary Least Squares (OLS), panel data techniques and instrumental variables. The aim is to show how, given the complexity of the issue, the choice of econometric technique produces different results.

The effect of the growth rate of road infrastructures on TFP growth is estimated for the 50 Spanish provinces \( (N = 50) \) for the period 1984-1994 \( (T = 10) \).\(^{15}\) The use of standard panel data techniques presents some notable advantages such as the possibility of controlling the effect of particular provincial circumstances, which cannot be accounted for appropriately using cross-section regressions. The technological shocks \( (\Delta \ln A_n) \) implied in our theoretical model can include, at least in theory, temporal and transversal variation. However, this variation is very difficult to quantify for the Spanish provinces. Omitting it from the regressions has a negative effect on the quality of the estimates: if it is correlated with the explanatory variables included then there is no guarantee that the parameters will be estimated consistently. Moreover, even when there

\(^{15}\) The variables are introduced in growth rates.
is no correlation the estimation will gain in efficiency if these effects can be accounted for. Panel data techniques allow us to deal with this problem through the specification of our technological shock as an additive combination of a temporal effect \((f_t, \text{ constant among provinces})\), an individual effect \((f_i, \text{ different for each province but constant for all the data span of our sample})\), and a specific error term \((e_{it})\):

\[
\Delta \ln A_{it} = f_t + f_i + e_{it}.
\] (21)

The time effect includes all the influences on TFP common to all provinces in a given year (for instance, the national economic cycle), while the individual effect includes the influences on the TFP specific to each province (for instance, climate and geographical factors). This individual effect does not account for the intrinsic effect on the level of production of each province but for the effect on its growth rate. The individual effects on the level of the series (possibly more important than that existent in the growth rates series) are eliminated when differentiating the series to compute the TFP growth rate.

There are two possible ways to estimate a specification with a disturbance term as presented in equation (21). One method is to treat the time and individual effects as fixed (and include them as regressors); the other is to consider them as part of the error term and, therefore, to consider them as random. The choice between the fixed effects model (FEM, hereafter) and the random effects model (REM, hereafter) depends on the existence of correlation between the individual effects and the variables included in the model. When this correlation is present, the estimation of the REM does not give us consistent estimators of the coefficients; consistency is only guaranteed with the FEM. In contrast, when there is no correlation, the REM present efficient estimates.16

16 In the final estimations reported we introduce, separately, individual fixed and random effects. Time fixed effects are included in all the estimations.
Since we estimate our models using OLS (or pooled estimation) and panel data techniques for both the FEM and the REM specifications of the error term, we use a series of test statistics to determine which specification is better suited. First, we perform a Wald test for joint significance specifically for the FEM (LSDV) estimation, that is, we test whether the individual and/or time dummies are jointly significant. Second, we use the Breusch-Pagan Lagrange Multiplier (B-P, hereafter) statistic for testing the FEM and the REM against the OLS (or pooled estimation).\(^\text{17}\) Third, we use a Hausman (1978) test, in which the null hypothesis is the absence of correlation between the time and/or individual effects and the variables included in the estimated equation; this test allows us to choose between the FEM and the REM. The Hausman statistic is distributed under the null as a chi-squared distribution; high values tend to reject the null hypothesis and, hence, indicate that the FEM model is the better choice.

One of the problems involved in estimating the effect of public investment on TFP growth is the possible existence of endogeneity of the explanatory variables included in the model, which may result in inconsistent estimators. In our model \(K^g_{it}\) may be endogenous, because an increase in the productivity of private factors in a given province may induce the government to invest more in public infrastructures in that province. Similarly, \(U_{it}\) may be considered as endogenous because an increase in TFP can induce more use of available public infrastructures. Therefore, to avoid problems related to reverse causality, we use a series of instrumental variables in a 2SLS estimation. We use lag values (in levels) of the \(a priori\) endogenous variables of each of the models estimated, their interaction terms, and political variables.

\(^{17}\) The null hypothesis of the B-P test is that the variance of the error term of the OLS residuals is constant.
In the case of lag values, the predicted values of $\Delta \ln K_{it}^g$ and $\Delta \ln U_{it}$ (\(\Delta \ln \hat{K}_{it}^g\) and $\Delta \ln \hat{U}_{it}$, respectively) from the first-stage regression are used as the explanatory variables for the growth rates of road infrastructures and utilization respectively in the estimation of the TFP growth equation (Basic model). Similarly, the interaction between $\hat{s}_{it}$ and the predicted values $\Delta \ln \hat{K}_{it}^g$ and $\Delta \ln \hat{U}_{it}$ are used as instrumental variables of $\hat{s}_{it} \Delta \ln K_{it}^g$ and $\hat{s}_{it} \Delta \ln U_{it}$ in the Vehicle-intensity model and B-D congestion model respectively. Finally, the square of the predicted value for $\Delta \ln K_{it}^g$, the predicted value for $\Delta \ln U_{it}$ and the interaction between the two predicted values are used as instrumental variables in the Flexible congestion model. In this latter estimation we make use of Non-linear 2SLS (see Bowden and Turkington, 1981).

The utilization variable, which accounts in our model for the effect of congestion on TFP growth, is also instrumented with the number of cars, as in Boarnet (1997).\(^{18}\) The argument is that provinces with more cars will have more congestion in roads and highways. However, provinces with high congestion might be undesirable places in which to drive, and residents might own fewer cars. Moreover, the number of cars may be linked to driving patterns and the propensity to drive (i.e., suburbanization). Of course, one may also think that the increase in the number of cars is not exogenous to provincial economic fluctuations. We experimented with this variable and with the increase in cars per capita, and found that both variables were valid instruments (i.e. they were not correlated with the error term). We also used other variables such as the percentage of the suburban population or the population growth rate; the first is a weak instrument and the second is endogenous.

\(^{18}\) Boarnet (1997) mentions the proportion of accidents that result in fatalities as a good instrument. Unfortunately we were unable to find data at provincial level and for our data span.
In addition, we used two political variables as instruments. In the literature there are studies on the evaluation of public policies that use political variables as instruments in regressions facing possible problems of endogeneity: see for instance Besley and Case (1995) or Levitt (1997). The first political variable approximates the probability of marginal wins/losses of parliament seats in the province at the last general elections ($\text{Margin}_{it-k}$). The idea behind this variable is that the central government’s commitment to invest in public infrastructures in a particular province may depend on its margin of victory there (see for instance, Case, 2001; Dahlberg and Johansson, 2002; or Johansson, 2003). Therefore, following Castells and Solé-Ollé (2004) $\text{Margin}_{it-k}$ is defined as the number of votes that the incumbent party in the central government would have needed in order to gain or lose one additional representative in the upper chamber (the Spanish Congreso) elected in each province at the last election. This variable is computed for every central legislative election\footnote{Given our data span, we have constructed this variable for the general elections held in Spain in 1982, 1988 and 1993.} through an algorithm that reproduces the d’Hondt method.

We also construct another variable that captures the idea that the central government can invest more in public infrastructures in provinces in which they obtained more political support (votes): see Cox and McCubbins (1986) and Dahlberg and Johansson (2002). In this case, the relevant variable is the overall number of votes obtained, rather than the margin of victory. To quantify this possible political influence on governmental decisions to invest in public infrastructures, we calculate the percentage of votes obtained in each province at the last general elections: $\text{Voteshare}_{it-k}$. 
4. RESULTS

The results obtained from our estimations are presented in Tables 2 to 5. Table 2 shows the results from the estimation of the Basic model (see equation 20), which includes only the growth rate of road infrastructures, and the Vehicle-intensity model (see equation 19), which includes the interaction of road infrastructures with \( \delta_h \). The columns in Table 2 present the results obtained using the different methodologies. The first column shows the OLS results (or “pooled estimation”); the second column presents the OLS estimation with fixed time effects (1-way FEM using LSDV). The third and fourth columns present the estimation of the random effects model (using Generalized Least Squares) with individual effects treated as random variables and time effects considered as fixed. Finally, the last column present the results obtained using IV in the regression, with 2SLS in the Basic model and Non-linear 2SLS in the Vehicle-intensity model.

Table 3 considers the effect of public road infrastructures and congestion on TFP growth. We present the two models for congestion: the B-D congestion model (see equation 13) and the Flexible congestion model (see equation 14). Each model is estimated using OLS (first column) and IV (second to fourth columns). Table 4 presents the results of the first-stage regression in the case of instrumentation of possible endogenous variables. The table has four columns. The first two columns refer to instruments for \( \Delta \ln K^g \): both lagged values of the endogenous variables and political variables. The last two columns present the instruments for the utilization variable (\( \Delta \ln U \)) used in the regressions addressed to study the effects of congestion on growth. Finally, Table 5 presents the effect of road infrastructures and congestion on TFP growth (using both the B-D and the Flexible congestion models) when we also account
for the vehicle-intensity of provinces.

All the estimations performed use the rate of TFP growth as a dependent variable, calculated with the values of the factor shares explained above (see footnote 12). The results are robust, and differ little in either size or significance using alternative sets of values for the shares of private capital and labour on total output. Finally, we present the results using White’s standard errors to avoid possible problems of heteroskedasticity in our regressions. We now summarize some of the main results obtained in these estimations.\(^{20}\)

The results presented in Table 2 for the Basic Model indicate a positive, significant effect of road infrastructures on TFP growth. The Hausman test indicates that the Random Effects Model performs better than the model that considers the individual and time effects as fixed. The GLS estimations offer elasticities around 9-12%. Using IV for the possible endogeneity of \(\Delta \ln K_{it}^{g}\) offers a higher point estimate, around 20%; moreover, the Sargan test indicates the validity of the instruments used in the first stage.

When the basic model is extended by incorporating the variable \(\hat{s}_{it}\) to account for the Vehicle-intensity of each province we obtain lower estimates: in the REM model (with and without fixed time effects) the elasticities are around 7-10%, and around 19% when we use IV. These results confirm our theoretical model. Given the construction of the model, we have to be precise when interpreting these results. To obtain the effect of road infrastructures in each province we should multiply each coefficient by the value of \(\hat{s}_{it}\) in each province. Thus, an elasticity of 7.2% (column 4 in Table 2) for roads and

\(^{20}\) The models finally estimated are derived under the CRTS assumption. Following Hulten and Schawb (1993) we perform all the estimation not imposing this restriction (results not reported but available upon request), i.e., introducing the term \((1-\rho)\Delta \ln K_{it}^{g}\) (private capital) in the regressions, where \(\rho\) indicates the type of returns to scale in private inputs implicit in the production function. All the results indicate that this additional variable is not significant in any of the regressions performed, indicating the existence of CRTS in the production function.
highways corresponds to a province with an intensity of use equal to the Spanish mean. In the case of a province with an intensity of use higher than 50% of the mean, the elasticity would be higher than 10%. Note that in the *Vehicle-intensity model* in Table 2 we estimate the effect of road infrastructures more precisely (smaller standard errors and higher $R^2$) than in the *Basic model*. Therefore, it seems that considering the different intensities of use of services derived from road infrastructures permits a more precise reflection of reality.

Comparing the estimates for road infrastructures and using the same econometric technique, it seems that the *Vehicle-intensity model* permits an estimation of the “pure” effect of road infrastructures, obtaining an elasticity that disembodies the effect of road infrastructures itself and the effect that arises from the productive structure of the province. The productive structure present in each province has an effect on the productivity of road infrastructures, which is greater in those provinces with a higher level of private inputs that make direct use of the services provided by roads and highways.

To check the robustness of the results obtained for road infrastructures we repeated the estimations for two other types of public infrastructures: transport and total infrastructures.\(^{21}\) The results were broadly similar to those presented above. It is worth mentioning that the elasticities of the public infrastructures variables increase with the level of aggregation of the variables.\(^{22}\)

\(^{21}\) For reasons of space the results are not presented here but are available upon request.
\(^{22}\) Transport infrastructures include roads and highways, harbours, airports and railways; total infrastructures include transport, water and sewer systems, and urban infrastructures. For the *Vehicle-intensity model* we apply $\hat{s}_w$ (index of industrial trucks in each province) to the case of transport infrastructures, assuming that firms that use more roads and highways infrastructures are very likely to use the rest of transport infrastructure, maybe because they provide private transport services, or for instance, they export they goods. We expect the same productive sectors that make more intensive use of roads and highways to be the sectors that also benefit more from a higher or better overall transport infrastructure.
Next, we study the effect of congestion on TFP growth, and analyse whether the level of the use of road infrastructures has an effect on productivity. Given the possible endogeneity of the variable of utilization of roads (and also of the road infrastructures) we use IV techniques to estimate the models with congestion. Table 3 presents the results for congestion considering two alternative models. In the B-D Congestion model when we instrument road infrastructures alone we obtain an elasticity of around 20% and a positive sign for our measure of congestion. In contrast, when we only instrument the utilization variable (the third column in Table 3) the elasticity of road infrastructures is around 10% but the sign for the congestion variables becomes negative (and the point estimate is not significant). These results suggest that we should use IV for both variables, and this is shown in the last column of Table 3. In this case we obtain a parameter for road infrastructures growth of around 27% and a negative, significant estimate for congestion.

Adopting the more Flexible congestion model, when the utilization variable is instrumented its sign is negative, as expected (we use non-linear 2SLS). The fact that the quadratic term is not significant in any of the regressions performed with the Flexible congestion model may indicate that the flexible specification does not capture more information than the B-D model; only the negative sign of the interaction term between road infrastructures and congestion indicates that congestion reduction and road building can be seen as substitute policy instruments. However, this interaction term is only statistically significant in the OLS regressions, i.e., the non-instrumented regressions.

At this point, it is worth checking the results from the first-stage regression in the
IV estimation used in Tables 2 and 3. Table 4 shows these results. The instruments used seem to be sound. First, the Sargan test for the validity of instruments indicates that in all the regressions the instruments are valid and, therefore, are not correlated with the error terms. Second, the instruments are significant in the first-stage regressions, in which we obtain acceptable adjusted $R^2$. Finally, note that, as expected, political variables seem to be better instruments for the road infrastructure growth (Castells and Solé-Ollé, 2004).

<Insert Table 4>

Note that the elasticity of roads infrastructures on TFP growth change from a initial 7.5% in the fixed effects regression (second column in Table 2) to 20.3% when this variable is instrumented (last column in Table 2), and to 27.6% when the utilization variable is also introduced in the regressions (fourth column in Table 3). Therefore, not using instrumental variables or omitting the congestion issue when analysing the effects of road infrastructures on growth has important consequences on the estimated elasticity of road infrastructures.

Finally, we estimate the two specifications of congestion taking into account the vehicle-intensity of each province (see Table 5). When we estimate the B-D Congestion model + Vehicle-intensity model using instruments for both endogenous variables (road infrastructures growth and utilization), we obtain an elasticity of around 25% for roads and a negative estimate for congestion (-19%), both significant and lower than in the model without the vehicle-intensity variable, confirming again the predictions of the theoretical model. In the estimations performed the Sargan test confirms the validity of the instruments used.

<Insert Table 5>

The Flexible congestion + Vehicle-intensity model shows negative estimates for the
utilization variable. Interestingly, the squared value of the utilization variable shows a positive (though not significant) estimate. This could indicate a non-linear structure of congestion: when an infrastructure is new, the first levels of utilization do not congest it (on the contrary: we would expect this initial level of usage to make the new infrastructure productive). It is when a certain level of utilization has been reached that the infrastructure is congested. However, the lack of significance of either the squared values of the regressors or the interaction variable indicates that the flexible model is poorly suited and that the \textit{B-D Congestion model} is a good approximation of the congestion inherent to any road infrastructure.

5. CONCLUSIONS

The results seem to support the null hypothesis that productive public investment in road infrastructures has, on average, affected relative provincial productivity performance in Spain for the period 1984-1994. In addition to the study of the existence of an effect \textit{per se} of road infrastructures on the TFP growth rate, this paper has addressed other important issues such as the effect of sectoral structure and the importance of congestion on the economic impact of public road infrastructures.

Our estimations were carried out using various economic model specifications and econometric techniques in order to analyse these crucial aspects in the public infrastructures debate. Of the econometric techniques, the IV technique seems to be the best in all the regressions performed, given the possible endogeneity of the regressors used. Moreover, political variables (a pure exogenous instrument), seem to be better instruments for public investment in road infrastructures, while the number of cars is adequate for the utilization variable in the congestion regressions. The Sargan test confirms the validity of the instruments used in all the IV regressions.
The first model estimated, the *Basic model*, shows positive and significant elasticities of road infrastructures – around 7-12% in the panel data case and around 20% in the IV estimation. This result suggests a high elasticity of public infrastructures devoted to road and highways, especially when compared with recent estimations of the effects of public infrastructures on growth (see for instance, Holtz-Eakin, 1994 or Pereira and Flores de Frutos, 1999) but in line with estimations of the effect of public infrastructures on TFP growth (see La Ferrara and Marcellino, 2000). We extend and complete the *Basic model* with the *Vehicle-intensity model*, which accounts for the utilization of public infrastructures by the firms (in each province) that make intensive use of road infrastructures. Comparing the results obtained in the *Vehicle-intensity model* with the results obtained in the *Basic model* highlights the effect of the sectoral structure of provinces on the elasticity of road infrastructures. The estimates obtained indicate that considering the different intensities of use, by private capital, of services derived from road infrastructures provides a more accurate reflection of the situation. It seems that the *Vehicle-intensity model* allows an estimation of the “pure” effect of public infrastructures, obtaining an elasticity that disembodies the effect of road infrastructures itself and the effect of the productive structure of the province: the productive structure has an effect on the productivity of road infrastructures, which is more productive in those provinces where there is a higher level of private inputs that directly use the services provided by road infrastructures. This result is robust whatever econometric technique is chosen, and the same results hold when comparing the *B-D congestion model* with and without vehicle-intensity. Our results, therefore, indicate the importance of providing more road infrastructures to provinces with a sectoral structure that makes more intensive use of services derived from road infrastructures. This conclusion seems to favour “efficiency” arguments when policy makers decide the
“optimal” allocation of public resources. In a similar vein, authors such as de la Fuente (2002) have recently argued that public capital policies have exceeded the optimal degree of redistribution in Spain and, therefore, considerations of efficiency should be prioritized in the regional allocation of investment in public infrastructure.

We analysed the effect of congestion using the *B-D congestion model* and the *Flexible congestion model*, which present competing models of congestion specification. The comparison indicates that the *B-D congestion model*, though simpler, captures the effect of congestion on productivity growth better than the *Flexible congestion model*. The congestion results for public infrastructures in roads and highways are interesting. First, the point estimates for the utilization variable used are negative, as expected, and statistically significant. This evidence seems to support our theoretical model: road use, once we control for the existing stock of road infrastructures, has a detrimental effect on the productivity of road infrastructures. As a result, one way to stimulate the productivity of private inputs could be to reduce congestion in roads and highways, by decreasing the number of users and by increasing the quantity/quality of existing roads. Note that from our analysis the point estimates for road infrastructures and utilization are very similar (although not equal), indicating that in Spain road infrastructures are close to being a private good.

Finally, the combination of vehicle intensity and congestion produces two models: the *B-D congestion model with vehicle-intensity* and the *Flexible congestion model with vehicle-intensity*. Again in these models we find that congestion of road infrastructures has a negative effect on the growth rate of TFP, and that this effect is stronger in provinces with a vehicle-intensive sectoral structure.
6. References


Technical Progress and Efficiency Gains in Industrialized Countries”, *American Economic Review*, 84, 1, 66-83.


**Tables**

Table 1: Descriptive statistics of the main variables used  
(Sample & period: Spanish provinces (NUTS 3) & 1984-94, N×T = 50×10 = 500)

<table>
<thead>
<tr>
<th>Name</th>
<th>Definition</th>
<th>Source</th>
<th>Mean</th>
<th>St. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\dot{TTP}_{it}$</td>
<td>Total Factor Productivity growth rate</td>
<td>o. c.</td>
<td>0.0114</td>
<td>0.0379</td>
</tr>
<tr>
<td>$Y_{it}$</td>
<td>Gross Value Added $^{(a)}$</td>
<td>INE</td>
<td>4,019.08</td>
<td>5,570.13</td>
</tr>
<tr>
<td>$\Delta \ln Y_{it}$</td>
<td>Gross Value Added growth rate</td>
<td>o. c.</td>
<td>0.0254</td>
<td>0.04063</td>
</tr>
<tr>
<td>$K_{it}$</td>
<td>Private capital stock $^{(a)}$</td>
<td>FBBVA</td>
<td>10,307.9</td>
<td>14,176.2</td>
</tr>
<tr>
<td>$\Delta \ln K_{it}$</td>
<td>Private capital stock growth rate</td>
<td>o. c.</td>
<td>0.0257</td>
<td>0.0181</td>
</tr>
<tr>
<td>$L_{it}$</td>
<td>Employment $^{(b)}$</td>
<td>INE</td>
<td>243</td>
<td>295.69</td>
</tr>
<tr>
<td>$\Delta \ln L_{it}$</td>
<td>Employment growth rate</td>
<td>o. c.</td>
<td>0.0024</td>
<td>0.0379</td>
</tr>
<tr>
<td>$K^g_{it}$</td>
<td>Road infrastructures stock $^{(a)}$</td>
<td>FBBVA</td>
<td>501.84</td>
<td>334.94</td>
</tr>
<tr>
<td>$\Delta \ln K^g_{it}$</td>
<td>Road infrastructures growth rate</td>
<td>o. c.</td>
<td>0.0612</td>
<td>0.0526</td>
</tr>
<tr>
<td>$U_{it}$</td>
<td>Kilometres driven in roads</td>
<td>DGT</td>
<td>3,718,631</td>
<td>3,690,496</td>
</tr>
<tr>
<td>$\Delta \ln U_{it}$</td>
<td>Kilometres driven growth rate</td>
<td>o. c.</td>
<td>0.0549</td>
<td>0.0498</td>
</tr>
<tr>
<td>$\hat{s}_{it}$</td>
<td>Vehicle-Intensity</td>
<td>o. c.</td>
<td>1.1411</td>
<td>0.2972</td>
</tr>
<tr>
<td>$V_{it}$</td>
<td>Number of industrial vehicles</td>
<td>DGT</td>
<td>42,940</td>
<td>48,708</td>
</tr>
<tr>
<td>$Cars_{it}$</td>
<td>Number of cars</td>
<td>DGT</td>
<td>218,657</td>
<td>313,766</td>
</tr>
<tr>
<td>$\Delta \ln Cars_{it}$</td>
<td>Number of cars growth rate</td>
<td>o. c.</td>
<td>0.045</td>
<td>0.0179</td>
</tr>
<tr>
<td>$\text{margin}_{it,k}$</td>
<td>Marginal probability of win/loss of Parliament seats $^{(c)}$</td>
<td>o. c.</td>
<td>0.0572</td>
<td>0.0471</td>
</tr>
<tr>
<td>$\text{voteshare}_{it,k}$</td>
<td>% of votes obtained by the ruling party$^{(c)}$</td>
<td>o. c.</td>
<td>0.4611</td>
<td>0.0948</td>
</tr>
</tbody>
</table>

Table 2: Estimation of the Basic and Vehicle-intensity models (without congestion). (Dependent variable: rate of growth of Total Factor Productivity. Sample & period: Spanish provinces (NUTS 3) & 1984-94, N×T =50×10=500)

<table>
<thead>
<tr>
<th>Individual effects included? (3)</th>
<th>NO</th>
<th>NO</th>
<th>RE</th>
<th>RE</th>
<th>NO</th>
</tr>
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<tbody>
<tr>
<td>Time effects included?</td>
<td>NO</td>
<td>FE</td>
<td>NO</td>
<td>FE</td>
<td>FE</td>
</tr>
</tbody>
</table>

i.- Basic model

<table>
<thead>
<tr>
<th>( \Delta \ln K_{it}^g )</th>
<th>(a) OLS</th>
<th>(b) OLS</th>
<th>(c) GLS(^{(2)})</th>
<th>(d) GLS</th>
<th>(e) IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \hat{\beta}_1 )</td>
<td>0.131</td>
<td>0.075</td>
<td>0.124</td>
<td>0.086</td>
<td>0.203</td>
</tr>
<tr>
<td>( t )</td>
<td>(6.410)**</td>
<td>(5.023)**</td>
<td>(5.073)**</td>
<td>(2.361)**</td>
<td>(2.106)**</td>
</tr>
<tr>
<td>( \bar{R}^2 )</td>
<td>0.059</td>
<td>0.125</td>
<td>0.060</td>
<td>0.120</td>
<td>0.145</td>
</tr>
<tr>
<td>Wald (Time effects) (4)</td>
<td>--.--</td>
<td>694.8***</td>
<td>--.--</td>
<td>--.--</td>
<td>--.--</td>
</tr>
<tr>
<td>Breusch-Pagan (Heterosk.) (5)</td>
<td>--.--</td>
<td>--.--</td>
<td>8.110**</td>
<td>43.265***</td>
<td>--.--</td>
</tr>
<tr>
<td>Hausman (FE vs. RE) (6)</td>
<td>--.--</td>
<td>--.--</td>
<td>0.001</td>
<td>0.035</td>
<td>--.--</td>
</tr>
<tr>
<td>Sargan (Instrument validity) (7)</td>
<td>--.--</td>
<td>--.--</td>
<td>--.--</td>
<td>--.--</td>
<td>0.012</td>
</tr>
</tbody>
</table>

ii.- Vehicle-intensity model

<table>
<thead>
<tr>
<th>( \hat{s}<em>{it} \times \Delta \ln K</em>{it}^g )</th>
<th>(a) OLS</th>
<th>(b) OLS</th>
<th>(c) GLS(^{(2)})</th>
<th>(d) GLS</th>
<th>(e) IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \hat{\beta}_1 )</td>
<td>0.110</td>
<td>0.061</td>
<td>0.098</td>
<td>0.072</td>
<td>0.191</td>
</tr>
<tr>
<td>( t )</td>
<td>(5.345)**</td>
<td>(4.598)**</td>
<td>(6.101)**</td>
<td>(3.481)**</td>
<td>(3.903)**</td>
</tr>
<tr>
<td>( \bar{R}^2 )</td>
<td>0.070</td>
<td>0.148</td>
<td>0.072</td>
<td>0.150</td>
<td>0.161</td>
</tr>
<tr>
<td>Wald (Time effects)</td>
<td>--.--</td>
<td>368.2***</td>
<td>--.--</td>
<td>--.--</td>
<td>--.--</td>
</tr>
<tr>
<td>Breusch-Pagan (Heterosk.)</td>
<td>--.--</td>
<td>--.--</td>
<td>9.063**</td>
<td>29.311***</td>
<td>--.--</td>
</tr>
<tr>
<td>Hausman (FE vs. RE)</td>
<td>--.--</td>
<td>--.--</td>
<td>0.034</td>
<td>0.050</td>
<td>--.--</td>
</tr>
<tr>
<td>Sargan (Instrument validity)</td>
<td>--.--</td>
<td>--.--</td>
<td>--.--</td>
<td>--.--</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Notes: (1) \( t \)-statistics are shown in brackets; ***, ** and * denote significance at the 1, 5 and 10 percent levels. (2) OLS = Ordinary Least Squares; GLS = Generalised Least Squares estimation of the Random Effects Model; IV = instrumental variables estimation (non-linear IV in the Vehicle-intensity model). (3) NO = individual or time effects not included; FE = individual or time effects treated as fixed effects, RE = individual or time effects treated as random effects. (4) Wald test of the joint significance of time effects. (5) Breusch-Pagan test for the presence of cross-section heteroskedasticity. (6) Hausman test for the correlation between individual effects and infrastructure growth. (7) Sargan test of instrument validity, distributed under the null of instrument validity as a \( \chi^2(K) \) with \( K \) = number of instruments; instruments used: lagged capital stock, incumbent’s vote margin at the last election, and incumbent’s vote-share at the last election; the value in tables at 95% of a \( \chi^2(3) \) is 0.35.
Table 3: Estimation of the B-D & Flexible Congestion models
(Dependent variable: rate of growth of Total Factor Productivity. Sample & period:
Spanish provinces (NUTS 3) & 1984-94, N×T =50×10=500)

<table>
<thead>
<tr>
<th></th>
<th>(a) OLS</th>
<th>(b) IV(2)</th>
<th>(c) IV</th>
<th>(d) IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual effects included? (3)</td>
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<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Time effects included?</td>
<td>FE</td>
<td>FE</td>
<td>FE</td>
<td>FE</td>
</tr>
<tr>
<td>Infrastructure growth instrumented? (4)</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>User growth instrumented?</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
</tbody>
</table>

i.- B-D congestion model

\[
\Delta \ln K_{it}^{g} = 0.085 \quad (2.586)^* \quad 0.231 \quad (2.701)^{**} \quad 0.093 \quad (2.341)^** \quad 0.276 \quad (2.777)^{***} \\
\Delta \ln U_{it} = 0.093 \quad (2.822)^{***} \quad 0.057 \quad (2.001)^** \quad -0.123 \quad (-1.439) \quad -0.255 \quad (-1.950)^* \\
\bar{R}^2 = 0.153 \quad 0.150 \quad 0.143 \quad 0.146 \\
Sargan (instrument validity) = --.-- \quad 0.031 \quad 0.025 \quad 0.001
\]

ii.- Flexible congestion model

\[
\Delta \ln K_{it}^{g} = 0.969 \quad (2.097)^{**} \quad 0.864 \quad (2.110)^{**} \quad 0.951 \quad (2.314)^** \quad 0.723 \quad (1.856)^* \\
\Delta \ln U_{it} = 0.940 \quad (2.417)^{**} \quad 0.621 \quad (2.140)^{**} \quad -1.201 \quad (-1.624) \quad -1.178 \quad (-1.887)^* \\
\Delta (\ln K_{it}^{g})^2 \times 100 = -0.028 \quad (-1.183) \quad -0.001 \quad (-0.161) \quad -0.020 \quad (-1.201) \quad -0.162 \quad (-1.289) \\
\Delta (\ln U_{it})^2 = 0.034 \quad (0.970) \quad 0.021 \quad (0.510) \quad 0.030 \quad (0.624) \quad 0.002 \quad (1.623) \\
\Delta (\ln K_{it}^{g} \times \ln U_{it}) = -0.122 \quad (-2.001)^{**} \quad -0.110 \quad (-1.236) \quad -0.161 \quad (-1.367) \quad -0.001 \quad (-1.313) \\
\bar{R}^2 = 0.164 \quad 0.158 \quad 0.155 \quad 0.144 \\
Sargan (instrument validity) = --.-- \quad 0.002 \quad 0.031 \quad 0.015
\]

Notes: (1) t-statistics are shown in brackets; ***, ** and * denote significance at the 1, 5 and 10 percent levels. (2) OLS = Ordinary Least Squares; IV = instrumental variables estimation (non-linear IV in the Flexible congestion model). (3) NO = individual or time effects not included; FE = individual or time effects treated as fixed effects, RE = individual or time effects treated as random effects. (4) NO= this variables has been considered exogenous; YES = endogenous variable. (5) Sargan test of instrument validity, distributed under the null of instrument validity as a $\chi^2(K)$ with $K$ = number of instruments; instruments used in equation (2): lagged capital stock, incumbent vote margin in the last election, and incumbent vote-share in the last election; instruments used in equation (3): lagged capital stock, lagged level of users, and growth of cars per capita; instruments used in equation (4): lagged capital stock, lagged level of users, growth of cars per capita, vote margin at the last election, and incumbent’s vote-share in the last election; the value in tables at 95% l of a $\chi^2(3)$ and $\chi^2(5)$ is 0.35 and 1.14, respectively.
### Table 4: Determinants of Road investment and Growth in road use.
(Dependent variable: rate of growth of road infrastructure and of km driven. Sample & period: Spanish provinces (NUTS 3) & 1984-94, N×T =50×10=500)

<table>
<thead>
<tr>
<th>Individual effects included?</th>
<th>Road investment: $\Delta \ln K_{it}$</th>
<th>Growth in road use: $\Delta \ln U_{it}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time effects included?</td>
<td>(a) OLS (2) NO NO</td>
<td>(c) OLS NO NO</td>
</tr>
<tr>
<td></td>
<td>(b) OLS FE FE</td>
<td>(d) OLS FE FE</td>
</tr>
<tr>
<td>$\ln K_{it-1}^g$</td>
<td>-0.027 (-7.104)**</td>
<td>-0.015 (-2.098)**</td>
</tr>
<tr>
<td>$\ln U_{it-1}$</td>
<td>-0.048 (-7.418)**</td>
<td>-0.014 (-2.149)**</td>
</tr>
<tr>
<td>$\text{margin}_{it-k}$</td>
<td>-0.412 (-8.933)**</td>
<td>-0.037 (-1.830)</td>
</tr>
<tr>
<td>$\text{voteshare}_{it-k}$</td>
<td>0.069 (3.088)**</td>
<td>0.001 (0.032)</td>
</tr>
<tr>
<td>$\Delta \ln \text{Cars}_{it}$</td>
<td>--.-- (2.249)**</td>
<td>0.271 (1.680)**</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.273 0.332</td>
<td>0.120 0.179</td>
</tr>
<tr>
<td>Wald (Time effects) (3)</td>
<td>21.61*** 19.15***</td>
<td>31.11*** 33.24***</td>
</tr>
</tbody>
</table>

Notes: (1) $t$-statistics are shown in brackets; ***, ** and * denote significance at the 1, 5 and 10 percent levels. (2) OLS = Ordinary Least Squares (3) Wald test of the joint significance of time effects.
Table 5: Estimation of the Vehicle intensity + Congestion models
(Dependent variable: rate of growth of Total Factor Productivity. Sample & period:
Spanish provinces (NUTS3) & 1984-94, N×T =50×10=500)

<table>
<thead>
<tr>
<th></th>
<th>(a) OLS</th>
<th>(b) IV(^{(2)})</th>
<th>(c) IV</th>
<th>(d) IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual effects included? (^{(3)})</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Time effects included?</td>
<td>FE</td>
<td>FE</td>
<td>FE</td>
<td>FE</td>
</tr>
<tr>
<td>Infrastructure growth instrumented? (^{(4)})</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>User growth instrumented?</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
</tbody>
</table>

** i.- B-D congestion + Vehicle intensity-model

\[ \hat{s}_i \times \Delta \ln K_{it} = 0.093 \quad 0.194 \quad 0.072 \quad 0.249 \]
\[ (2.920)^{***} \quad (2.500)^{**} \quad (2.800)^{***} \quad (3.101)^{***} \]

\[ \hat{s}_i \times \Delta \ln U_{it} = 0.085 \quad 0.073 \quad -0.103 \quad -0.197 \]
\[ (2.832)^{***} \quad (2.101)^{**} \quad (-1.440) \quad (-1.828)^* \]

\[ \bar{R}^2 = 0.155 \quad 0.147 \quad 0.153 \quad 0.157 \]

Sargan (instrument validity) --.-- 0.004 0.010 0.022

** ii.- Flexible congestion + Vehicle intensity-model

\[ \hat{s}_i \times \Delta \ln K_{it} = 0.998 \quad 0.871 \quad 0.984 \quad 0.821 \]
\[ (2.125)^{**} \quad (2.654)^{**} \quad (2.745)^{**} \quad (1.958)^* \]

\[ \hat{s}_i \times \Delta \ln U_{it} = 1.021 \quad 0.712 \quad -1.165 \quad -1.219 \]
\[ (2.320)^{**} \quad (2.014)^{**} \quad (-1.855)^* \quad (1.745)^* \]

\[ \hat{s}_i \times \Delta \left( \ln K_{it} \right)^2 = -0.055 \quad -0.022 \quad -0.031 \quad -0.151 \]
\[ (-1.159) \quad (-0.107) \quad (-1.248) \quad (-1.009) \]

\[ \hat{s}_i \times \Delta \left( \ln U_{it} \right)^2 = 0.042 \quad 0.036 \quad 0.055 \quad 0.015 \]
\[ (0.562) \quad (0.965) \quad (0.746) \quad (1.562) \]

\[ \hat{s}_i \times \Delta \left( \ln K_{it} \times \ln U_{it} \right) = -0.106 \quad -0.098 \quad -0.068 \quad -0.003 \]
\[ (-1.697)^* \quad (-1.026) \quad (-1.064) \quad (-1.268) \]

\[ \bar{R}^2 = 0.158 \quad 0.161 \quad 0.152 \quad 0.146 \]

Sargan (instrument validity) --.-- 0.013 0.026 0.005

Notes: See Table 2 and 3.