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International Center for Public Policy
Andrew Young School of Policy Studies
Georgia State University
Atlanta, Georgia 30303
United States of America

Phone: (404) 413-0235
Fax: (404) 651-4449
Email: paulbenson@gsu.edu
Website: <http://icepp.gsu.edu/>

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A General Model for the Distribution of Public Investment among Jurisdictions

Henry Aray¹ and Jorge Martínez-Vázquez²

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Abstract

This article proposes a comprehensive theoretical framework to bridge the gap between the theoretical and empirical literatures regarding the criteria followed by a policymaker to distribute public investment across jurisdictions. A social welfare function that considers, not only output per capita, but also output density, is proposed. We derive the optimal levels of public investment as a share of the total public capital stock, which turns out to be a function of the main criteria suggested by the previous empirical literature. A tractable equation for empirical and policy implementation is obtained. Furthermore, the model allows us to cast theoretical predictions to be tested empirically. For this purpose, we use data on the Spanish regions (autonomous communities) over the 1986-2010 period. Our findings show that most of the coefficients of the conventional criteria are significant and with the expected signs. In addition, the results provide the weights of the output measures in the social welfare function, and strongly suggest that output density should not be neglected, as has been often done in the previous literature. The results are quite robust across estimation methods, different alternate dependent variables and the inclusion of control variables.

JEL Codes: H40; H54; C23

Keywords: Public investment criteria, CES functions, Spain

¹ Department of Economic Theory and Economic History (University of Granada); email: haray@ugr.es.

² International Center for Public Policy (Georgia State University) and Governance and Economics Research Network (GEN); email: jorgemartinez@gsu.edu

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1. Introduction

The seminal work by Aschauer (1989) triggered a very active research on the relation between public capital stock and economic growth. Despite the absence of full consensus on the existence of an unambiguous relationship between public capital and economic growth, a fair assessment is that most of the empirical literature supports the presence of a positive relationship. Public investment provides the twofold “return” of increasing aggregate demand in the short run and increasing aggregate supply in the long run. In this regard, the stock of public capital becomes a crucial input for competitive and productivity gains, economic growth and general welfare, regionally and nationally.

Two of the most important issues regarding the stock of public capital are, first, reaching an adequate/optimal level, and second, achieving its right/fair geographical distribution. Regarding the first issue, most developed countries have been experiencing stagnation in the stock of public capital per capita,^{1,2} while most developing countries continue to struggle to reach adequate levels. In relation to the geographical distribution issue, the general principle in practice in developed countries has been to allocate public investment across jurisdiction (states, regions, municipalities, etc.) in order to reduce geographical income disparities and aiming at social cohesion, without neglecting national economic growth.³

This paper focuses on the second issue, and specifically, on the criteria that should be followed by policymakers to distribute public investments across country’s jurisdictions. Contributions to the literature on this topic are still limited. On the one hand, the relevant theoretical contributions have narrowly focused on the efficiency-equity trade-off neglecting other potential important criteria, like those accounting for spatial considerations. In fact, this literature has traditionally used an objective function exclusively based on total output or output per capita. On the other hand, although there have been numerous contributions to the empirical literature often proposing reasonable additional criteria for the allocation of public investment across jurisdictions, such contributions have been generally based on ad hoc equations which are not backed by any

¹ There has been awareness of this situation among many governments. Witness for example president Biden’s Bipartisan Infrastructure Law, the UK government’s infrastructure spending plan for the period 2020-2025, Germany’s 2030 FTIP (Federal Transport Infrastructure Plan), or France’s Relance recovery plan.

² OECD (2019, 2022).

³ A clear example of this is the European Regional Policy. For more information on it go to https://ec.europa.eu/regional_policy/home_en.

established theoretical economic model. In summary, neither the theoretical literature has provided a conceptually comprehensive framework, nor the empirical literature has offered operational rules derived from such a framework.

The main aim of this paper is to provide a framework that bridges the existing gap between the theoretical and the empirical literatures on the criteria for distribution of public investments across jurisdictions. This framework will be useful in addressing several interesting and unresolved research questions, including: How to possibly go beyond the traditional equity-efficiency trade off proposed by the existing theoretical literature. Where might the criteria used in the empirical literature come from? What should be the dependent variable used in empirical implementations? What are the expected signs of the coefficients for the criteria proposed in the empirical literature?

The primary contribution of the article is, therefore, to develop a quantitative general comprehensive theoretical framework that incorporates the economic and spatial dimension and can be applied to empirically evaluate the geographical distribution of public investments across jurisdictions.

Inspired by the new economic geography (NEG) literature and the literature on economic growth that considers the spatial dimension, we propose a theoretical framework in which the policymaker chooses the distribution of public investment across jurisdictions to maximize a social welfare function that considers not only output per capita, as done by previously theoretical literature, but also, output density. The maximization problem is subject to the jurisdictions' production functions and the laws of motion of public capital stock. CES functions for both social welfare and output are assumed. In addition, the law of motion of public capital stock accounts for diminishing marginal returns of the public investment instead of the traditional lineal form that assumes constant marginal returns. From the solution of the theoretical model, we can obtain a tractable equation for empirical implementation in which the public investment made by the central government, as a share of the total public capital stock, is a function of the main economic criteria proposed by the empirical literature. Hypotheses on the values and signs of the coefficients can be derived from the model. In addition, our model goes further by proposing two additional new criteria related to convergence in output per capita and regional economic size.

We then turn to the empirical implementation in order to shed light on the optimal allocation of public investment across jurisdiction and the criteria followed to such an end. Data of the Spanish regions (autonomous communities) over the 1986-2010 period are used. We carry out diagnostic

panel data tests and finally estimate with fixed effects accounting for heteroscedasticity, serial correlation and cross-sectional correlation.

The empirical results shows that most of the criteria are significant and with the expected signs. Furthermore, the goodness fit of the model is very large and results are quite robust across several estimation methods, alternate dependent variables, and the inclusion of control variables.

The rest of the paper is organized as follows. Section 2 reviews the literature. Section 3 describes the main variables that have been proposed in the previous empirical literature as guiding criteria for the allocation of public investment across jurisdictions. Section 4 develops the full theoretical framework. Section 5 lays out the empirical strategy. Section 6 discusses the estimation issues and presents the empirical results. Section 7 provides robustness checks, and section 8 concludes.

2. Review of the Literature

Academic interest in the distribution criteria for public investment dates to the 1950s, just after the Second World War. The reconstruction plan for Europe at the time entailed huge amounts of funds, and governments needed guidelines to allocate those resources. Considering this need, several scholars suggested criteria to optimize reconstruction and development. The works by Kahn (1951) and Chenery (1953) introduced the criterion of efficiency as a starting point for the allocation of resources.⁴ In this regard, Kahn (1951, page 38) warned of the "harmful consequences of elevating practical rules to the rank of absolute principles" and proposed the social marginal productivity, defined as the total net national contribution of a unit of capital to the national product, to capture the efficiency criterion. From that perspective, the objective function to be maximized was the national output. However, Galenson and Leibenstein (1955) questioned the appropriateness of maximizing the national product level, and instead proposed per capita output (income) as the objective function.

Interestingly, all those early works adopted a national or whole country perspective. To our knowledge, the first article to study the allocation of public funds across the states/regions of a country was Stewart (1967) who emphasized the marginal return of public investment as the

⁴ A slightly posterior related literature on the criteria for public investment allocation, including studies by Marglin (1963), Davisson (1964) and Mishan (1967A, 1967B), based the analysis on the projects' present discounted values of net benefits and the rate of returns to rank them. This is a very valid microeconomic approach to the problem, but in this paper, we are interested in the further development of the macroeconomic approach that started earlier.

criterion for the regional allocation of federal funds, and thus public investment should be concentrated in areas with the most significant growth potential, aiming to increase overall per capita income. Mera (1967; 1973) pointing out that policies aiming to improve interregional equity could conflict with the maximization of national output, which he called the goal of efficiency, and suggesting instead that regional policies should be formulated considering the balance between equity and efficiency, which has become the cornerstone of the theoretical literature.

One of the main criticisms addressed to those early contributions is that the objective functions, focused on maximizing the national GDP or per capita income, neglected social welfare. Although income per capita and social welfare are expected to be highly correlated, a model that considers social welfare as the objective function is more compelling, not only from the point of view of formal economic theory, but also for its socio-economic implications. Eckstein (1957; 1961) advanced models with social welfare functions that depended on per capita consumption and income. In the same vein, Freeman (1967) proposed a social welfare function model focused on income distribution as the target for the allocation of public investment. However, the Eckstein and Freeman's models also took a national perspective and did not consider the distribution of federal funds among jurisdictions (states/regions).

In an approach closer to the one developed in this paper, Behrman and Craig (1987) proposed a theoretical model with a social welfare function to allocate public funds for safety services across neighborhoods. Two other related papers by Caminal (2004) and De la Fuente (2004) proposed theoretical models in which the policymaker distributes funds for public infrastructure investment across regions in order to maximize a social welfare function. These studies were fundamentally theoretical contributions, including in some cases, some simple empirical applications. Perhaps an exception is Behrman and Craig (1987). However, their empirical analysis of the traditional efficiency-equity trade-off is reduced to the estimation of the inequality aversion parameter of the social welfare function.

On the side of the empirical literature, although most contributions have been based on ad hoc equations, overall, this literature has contributed some potential additional criteria for the allocation of public investment. A number of papers, including De la Fuente and Vives (1995), Yamano and Ohkawara (2000), Rodríguez-Oreggia and Rodríguez-Pose (2004), Kemmerling and Stephan (2010), Monastiriotis and Psycharis (2014), Aray (2019) and Fageda and Olivieri (2019) suggested the gross value added (GVA) per unit of public capital stock of the jurisdiction as the

efficiency criterion,⁵ and per capita GVA as the equity/redistribution criterion. The efficiency (equity/redistribution) indicator is expected to be positively (negatively) correlated with the public investment allocated to the jurisdiction.

Further potential refinements were introduced by Kemmerling and Stephan (2010) and Monastiriotis and Psycharis (2014), who argued that in the second criterion, it is necessary to differentiate between redistribution and equity. They proposed the per capita GVA for measuring redistribution and the ratio between the public capital stock of the jurisdiction and its geographical size (density of public capital stock) for measuring equity. Thus, the spatial dimension is captured by the evenness in the distribution of public capital stock across jurisdictions. The estimated coefficient for this variable is expected to be negative if equity is a goal for the allocation of public investment across jurisdictions. De la Fuente and Vives (1995) further contributed to the spatial dimension focus by proposing the feature of neutrality, which is calculated as the geometric mean between public capital stock per capita and the density of public capital stock. Notice that in this way, the equity criterion is nested into the neutrality criterion, meaning that differences in public capital stocks should not give any jurisdiction an unfair advantage or disadvantage. Along a similar line of thought, population density has been proposed to capture the criterion of special infrastructure needs. On the one hand, Rodríguez-Oreggia and Rodríguez-Pose (2004) and Lambrinidis, Psycharis and Rovolis (2005) argued that population density allows to account for the effects of agglomeration and congestion, and therefore, a positive correlation should be expected between public investment and population density. On the other hand, Mizutani and Tanaka (2010) and Rodríguez-Pose, Psycharis and Tselios (2016) posited that a negative correlation should be expected between public investment and population density provided the higher cost of delivering public goods in remote and low-density jurisdictions.

None of the aforementioned empirical articles has considered simultaneously the five criteria, perhaps, because of the high multicollinearity among them. All the criteria just discussed above can be grouped under the heading of “economic criteria,” on which, this paper will focus. There are other non-economic criteria, such as political factors, which are presumed to play also a role in explaining the actual distribution of public funds across jurisdictions (Cadot, Röller and

⁵ Because of the unavailability of data on public capital stock, the empirical implementations for some countries have been based on the ratio GVA to public investment as a proxy for the efficiency criterion.

Stephan, 2006; Castells and Solé-Ollé, 2005). Although, the solution of our theoretical model does not provide for an explicit role of the political criteria, the model is flexible to account for them.

3. Relevant economic criteria for the allocation of public investment across regions

For further use in our theoretical framework, in this section we restate the formal expressions for the allocation criteria that have been proposed by empirical literature reviewed in the previous section.

- **Efficiency**

The theoretical literature suggests that if the policymaker is only concerned about efficiency, then public investment among jurisdiction gets distributed so to maximize the total aggregate output of the economy. In this regard, the empirical literature reviewed above proposes an indicator based on the marginal productivity of the public capital stock to capture the efficiency criterion. More specifically, let us assume a production function for the jurisdiction j in time t as follows

$$Y_{jt} = F(K_{jt}, L_{jt}, G_{jt})$$

Where Y_{jt} is output, K_{jt} is the non-residential productive capital stock, L_{jt} is the number of workers (human capital) and G_{jt} is the stock of public capital.

The marginal productivity of the public capital stock is given by

$$\frac{\partial Y_{jt}}{\partial G_{jt}} = F_{G_{jt}}$$

Which is often proxied in empirical applications by the average productivity

$$\frac{Y_{jt}}{G_{jt}}$$

- **Redistribution**

The traditional measure to capture redistribution is the per capita (or per worker) output:

$$y_{jt} = \frac{Y_{jt}}{N_{jt}} \text{ or } \mathbf{y}_{jt} = \frac{Y_{jt}}{L_{jt}}$$

Where and N_{jt} is the total population of jurisdiction j .

- **Equity**

The idea behind this criterion is that jurisdictions converge to an equal ratio:

$$\frac{G_{jt}}{S_j}$$

Where S_j are the units of surface.

- **Neutrality**

This is expressed as:

$$\left(\frac{G_{jt}}{N_{jt}}\right)^{1-\gamma} \left(\frac{G_{jt}}{S_j}\right)^\gamma$$

With $0 \leq \gamma \leq 1$. Therefore, it is the geometric mean between the public capital stock per capita and the public capital stock per unit of surface. The objective is to equalize effective infrastructure endowments across regions. Notice that if $\gamma = 1$, then the neutrality criterion becomes the equity criterion.

- **Special infrastructure needs**

Population density is proposed to capture agglomeration and congestion:

$$\frac{N_{jt}}{S_j}$$

4. Theoretical model

The whole economy is composed by J jurisdictions. Let us consider that the representative jurisdiction's economy j produces in time t according to a CES production function as follows:

$$Y_{jt} = \left(\alpha_{jK}K_{jt}^{\omega_j} + \alpha_{jL}L_{jt}^{\omega_j} + \alpha_{jG}G_{jt}^{\omega_j}\right)^{\frac{1}{\omega_j}} \quad (1)$$

Where $\omega_j < 1$ is the substitution parameter and, α_{jK} , α_{jL} and α_{jG} are the share parameters.

In the spirit of Lucas and Prescott (1971), let us assume that public investment and the stock of public capital stock are non-linearly related. And, following Hercowitz and Sampson (1991), Kocherlakota and Yi (1997) and Cassou and Lansing (1998), let G_{jt} accumulate according to the following law:

$$G_{jt} = B_{jt} G_{jt-1}^{1-(\sigma_j+v_j)} C_{jt}^{\sigma_j} R_{jt}^{v_j}, \quad 0 < \sigma_j, v_j < 1; \quad 0 < \sigma_j + v_j < 1 \quad (2)$$

We consider that there are two agents providing public investment: the central government and the rest of the agents that includes regional and municipal governments, autonomous public entities, and private investors. Thus, C_{jt} is the public investments in jurisdiction j in period t made by the central government and R_{jt} is the public investment made by the rest of the agents.

As pointed out by Hercowitz and Sampson (1991), $1 - (\sigma_j + v_j)$ can be interpreted as the quality of old capital relative to the new investments. Moreover, as assumed by Hercowitz and Sampson (1991), capital accumulation is also generally subject to an exogenous shock, $B_{jt} > 0$. Note that B_{jt} , σ_j and v_j govern the relationship between new investment and the public capital stock in the next period. Thus, whenever $B_{jt} = 1$ and $\sigma_j + v_j = 1$, the stock of public capital depreciates fully after one period, while it is longer lasting if $0 < \sigma_j + v_j < 1$.

Cassou and Lansing (1998) also highlighted the advantage of the specification in equation (2) with respect to the standard linear equation at exhibiting decreasing returns of the investment, which can be interpreted as reflecting adjustment costs in increasing the volume of public capital stock or diminishing returns of the public investment. In addition, Cassou and Lansing (1998) also pointed out that equation (2) might also be viewed as capturing the behaviour of an aggregate stock that is measured by adding up different types of capital, which individually display different depreciation characteristics. This is an entirely appropriate assumption for the present paper because the public capital stock is composed of several types of infrastructures, including hard infrastructure stock (e.g., highways, roads, ports, airports, etc.) and soft infrastructure stock (e.g., schools, universities, hospitals, etc.).

Regarding the social welfare function, we note first that, as Freeman (1967) had already pointed out, the choice of the form is a value of judgement. Following Behrman and Craig (1987), in this paper, we adopt the CES specification, denoted by W_t^{BC} , allowing for varying degrees of relative jurisdictions' inequality aversion and the unequal treatment of jurisdictions with the same output levels:

$$W_t^{BC} = \left[\sum_{j=1}^J V_{jt} N_{jt} \left(\frac{Y_{jt}}{N_{jt}} \right)^\rho \right]^{\frac{1}{\rho}} \quad (3)$$

Where $\rho \in (-\infty, 1]$ is the parameter that quantifies the aversion to inequality in output (income) per capita among jurisdictions. As ρ becomes more negative, inequality aversion increases. When $\rho \rightarrow -\infty$, the planner only concerns itself with equity in output per capita. Conversely, if $\rho = 1$, the planner only concerns itself with the total output as a whole. Whenever $\rho < 1$, the planner is averse to inequality in output per capita.

In equation (3), V_{jt} addresses the equal versus unequal concerns across regions. If $V_{jt} = V_t$ means equal concern across jurisdictions but varying over time. V_{jt} can be also interpreted as weights. In this regard, Eckstein (1961) had pointed out that policymakers can attach any weights they wish to the national and regional groupings of income.⁶

The NEG, inspired by Krugman (1991), emphasizes the advantages of the spatial agglomeration of inputs for generating increasing returns and positive spillovers across firms. Furthermore, Hidalgo *et al.*, (2007) claim that output density plays a key role in determining the added value of products and pointed out that more-sophisticated products are located in densely connected areas whereas less-sophisticated products are produced in the less-connected peripheral areas.

From a regional perspective, the NEG literature shows that decreasing inter-regional transport costs, largely due to public infrastructure investment, would prompt firms and workers to agglomerate into the core regions. This results into increased spatial differences in production between the core and peripheral regions. This conclusion had been already reached in the early work by Hirschman (1958), who warned that investment in transport infrastructures at the national level could bring gains but also losses to regional economies, what he called the “leaking by linking” phenomenon.⁷ This is also interesting because many countries are struggling to avoid the depopulation of some regions, and often times, by building more transportation infrastructure.

From an economic growth viewpoint, Ciccone and Hall (1996) suggested that the spatial density of economic activity is a source of aggregate increasing returns, which could play a crucial role for explaining the large differences in average labor productivity and in long-term economic growth. They provided empirical evidence showing that the density of economic activity is positively related to labour productivity and total factor productivity and concluded that increasing

⁶ Behrman and Craig (1987) and Castells and Solé-Ollé (2005) collected in V_{jt} jurisdictions' specific characteristics.

⁷Puga (2002) also warned on the increased inequalities between regions within each EU Member State in spite of the large budget of the EU regional policy.

returns to density play a crucial role for explaining the large differences in average labour productivity across U.S. states. Thus, spatial externalities are driven by the density of production in a country/region (Ciccone, 2002). In addition, Davis, Fisher and Whited (2014), building on the work of Ciccone and Hall (1996), showed that output density is positively related to per capita consumption, i.e., to welfare.

Incorporating the insights from the NEG literature and the literature on economic growth that accounts for the spatial density of economic activity, we expand (3) to the fuller social welfare function:

$$W_t = \left[\sum_{j=1}^J V_{jt} N_{jt}^{1-\eta} S_j^\eta \left[\left(\frac{Y_{jt}}{N_{jt}} \right)^{1-\eta} \left(\frac{Y_{jt}}{S_j} \right)^\eta \right]^\rho \right]^{\frac{1}{\rho}} \quad (4)$$

Where $\eta \in [0,1]$. The expanded function in equation (4) is a social welfare function that considers as the main arguments output per capita and output per unit of surface (output density), instead of just output per capita. Note that if $\eta = 0$, then equation (4) is the Behrman and Craig's social welfare function in equation (3). If $\eta = 1$, the policymaker only cares about output density in the spirit of Ciccone and Hall (1996).

Last, let us rewrite equation (4) for the case in which $V_{jt} = \frac{N_{jt}}{N_t}$, where N_t is the total population of the whole economy, and thus, we obtain:

$$W_t = \left[\sum_{j=1}^J \left(\frac{N_{jt}}{N_t} \right) N_{jt}^{1-\eta} S_j^\eta \left[\frac{Y_{jt}}{N_{jt}^{1-\eta} S_j^\eta} \right]^\rho \right]^{\frac{1}{\rho}} \quad (5)$$

Notice that in the specification of the law of motion of capital, equation (2), we are considering two kinds of investors. Let us concentrate on the central government. Thus, the central government's objective is to allocate the public investment level in each jurisdiction (C_{jt}) that maximizes equation (5) subject to equations (1) and (2) and the resource constraint,

$$\sum_{j=1}^J C_{jt} \leq I_t^C$$

where I_t^C is assumed to be fixed for the sake of simplicity and in line with Behrman and Craig (1987).

This is a one-period model that allows us to benchmark empirical approaches studying the distribution of public investment funds across jurisdictions.

The solution of the model provides the optimal level of public investment as a share of the public capital stock^{8,9}

$$\frac{C_{jt}}{G_{jt}} = \frac{A\sigma_j\alpha_{jG}}{\lambda_t} \left(\frac{Y_{jt}}{G_{jt}}\right)^{-\omega_j} y_{jt}^\rho \left[\left(\frac{G_{jt}}{N_{jt}}\right)^{1-\eta} \left(\frac{G_{jt}}{S_j}\right)^\eta \right]^{-1} \left(\frac{N_{jt}}{S_j}\right)^{\eta\rho} \left(\frac{y_{jt}}{y_t}\right)^{-1} \frac{Y_{jt}}{Y_t} \quad (6)$$

Equation (6) becomes our benchmark equation. To note, all the economic criteria for public investment allocation among jurisdictions (described in the previous section) are collected in equation (6). Thus, $\frac{Y_{jt}}{G_{jt}}$ captures the efficiency criterion, which is positively (negatively) related to $\frac{C_{jt}}{G_{jt}}$ whenever $\omega_j < 0$ ($0 < \omega_j < 1$); meaning that inputs must be more biased to being complementary (substitutes) than substitutes (complementary).

The redistribution criterion is captured by y_{jt} if the central planner is output inequality averse, $\rho < 1$, which could become negative the higher the concern about income redistribution across jurisdictions.

Regarding space considerations, as suggested by De la Fuente and Vives (1995), the neutrality criterion, $\left(\frac{G_{jt}}{N_{jt}}\right)^{1-\eta} \left(\frac{G_{jt}}{S_j}\right)^\eta$, is negatively related to the share $\frac{C_{jt}}{G_{jt}}$. Notice that it becomes the equity criterion $\left(\frac{G_{jt}}{S_j}\right)$ if $\eta = 1$. The special infrastructure needs criterion, $\frac{N_{jt}}{S_j}$, would be positively (negatively) related to $\frac{C_{jt}}{G_{jt}}$ whenever the policymaker is (very) concerned about income redistribution, $0 < \rho < 1$ ($\rho < 0$), and $0 < \eta \leq 1$.

Last, notice that two new criteria are obtained from our model. First, $\frac{y_{jt}}{y_t}$, that we call convergence criterion, which is inversely related to $\frac{C_{jt}}{G_{jt}}$. The idea behind this criterion is to foster the catching up of lagged regions' GVA per capita to the national GVA per capita. Last, $\frac{Y_{jt}}{Y_t}$, the

⁸ The Appendix shows the details of the solution.

⁹ $\frac{C_{jt}}{G_{jt}}$ can be considered a measure of investment effort.

share of the GVA of jurisdiction j on the whole economy's GVA, which we call the economic size criterion and is positively related to $\frac{C_{jt}}{G_{jt}}$.

5. Empirical strategy

The model developed above is instrumental for bridging the existing gap between the theoretical and empirical literatures on the criteria to distribute public investment across jurisdictions. Thus, equation (6) can be used as a benchmark to perform empirical evaluations of the actual distributions of public investment across jurisdiction and the criteria considered for that. Furthermore, the model is general enough to explore the allocation of any publicly provided input, good and service by any government layer.

To be able to use equation (6) empirically, we need to make several further assumptions. First, randomness must be included. Second, as suggested by Castells and Solé-Ollé (2005), the best most recent information that the policymaker might have available to plan the allocation of public infrastructure is that from the previous period. Therefore, all the variables in the right-hand side in equation (6) are expressed in one lag.¹⁰ Thus, equation (6) is rewritten as follows

$$\frac{C_{jt}}{G_{jt}} = \frac{A\sigma_j\alpha_{jG}}{\lambda_t} \left(\frac{Y_{jt-1}}{G_{jt-1}}\right)^{-\omega_j} y_{jt-1}^\rho \left[\left(\frac{G_{jt-1}}{N_{jt-1}}\right)^{1-\eta} \left(\frac{G_{jt-1}}{S_j}\right)^\eta\right]^{-1} \left(\frac{N_{jt-1}}{S_j}\right)^{\eta\rho} \left(\frac{y_{jt-1}}{y_{t-1}}\right)^{-1} \frac{Y_{jt-1}}{Y_{t-1}} e^{\varepsilon_{jt}} \quad (7)$$

where ε_{jt} is the random disturbance and e is the exponential operator.

Third, the estimation of equation (7) in logs (Ln) could run into perfect multicollinearity between several variables. To avoid that, we could remove some variables, for example, the variables $Ln\left(\frac{G_{jt-1}}{N_{jt-1}}\right)$ and $Ln\left(\frac{G_{jt-1}}{S_j}\right)$. That has been probably the approach implicitly followed in some of the previous empirical literature. However, the drawback of removing variables from the equation to be estimated is that it might lead to misleading interpretations of some parameter estimates by assuming they remain the same after dropping variables. Instead of dropping variables $Ln\left(\frac{G_{jt-1}}{N_{jt-1}}\right)$ and $Ln\left(\frac{G_{jt-1}}{S_j}\right)$, we rewrite equation (7) as shown below,

$$\frac{C_{jt}}{G_{jt}} = \frac{A\sigma_j\alpha_{jG}}{\lambda_t} \left(\frac{Y_{jt-1}}{G_{jt-1}}\right)^{1-\omega_j} y_{jt-1}^{\rho-1} \left(\frac{N_{jt-1}}{S_j}\right)^{\eta(\rho-1)} \left(\frac{y_{jt-1}}{y_{t-1}}\right)^{-1} \frac{Y_{jt-1}}{Y_{t-1}} e^{\varepsilon_{jt}} \quad (8)$$

¹⁰Incidentally, this assumption also helps to avoid endogeneity issues.

It can be noticed in equation (8) that the parameters of $\frac{Y_{jt-1}}{G_{jt-1}}$, y_{t-1} and $\frac{N_{jt-1}}{S_j}$ have changed.

Taking logs in equation (8), we get

$$\begin{aligned} \text{Ln}\left(\frac{C_{jt}}{G_{jt}}\right) = & \delta_j + \tau_t + \beta_1^j \text{Ln}\left(\frac{Y_{jt-1}}{G_{jt-1}}\right) + \beta_2 \text{Ln}(y_{jt-1}) + \beta_3 \text{Ln}\left(\frac{N_{jt-1}}{S_j}\right) \\ & + \beta_4 \text{Ln}\left(\frac{y_{jt-1}}{y_{t-1}}\right) + \beta_5 \text{Ln}\left(\frac{Y_{jt-1}}{Y_{t-1}}\right) + \varepsilon_{jt} \end{aligned} \quad (9)$$

Where $\beta_1^j = 1 - \omega_j$, $\beta_2 = \rho - 1$, $\beta_3 = \eta(\rho - 1)$, $\beta_4 = -1$, $\beta_5 = 1$, $\delta_j = \text{Ln}(A\sigma_j\alpha_{jG})$, $\tau_t = -\text{Ln}(\lambda_t)$.

In line with the theoretical model, notice that according to equation (9), it is expected that $\beta_1^j > 0$, provide $\omega_j < 1$; $\beta_2 < 0$, whenever the policymaker is averse to output inequality ($\rho < 1$); $\beta_3 < 0$, provided that $0 < \eta \leq 1$ and that the policymaker is averse to output inequality ($\rho < 1$); $\beta_4 < 0$ with the objective of fostering the catching up of lagged regions; last, $\beta_5 > 0$, meaning that economic size matters for being favored with more investment.

Notice that the only criterion that is not explicitly collected in equation (9) is the neutrality criterion. However, we are able to get the implicit estimate and standard error of the parameter η from the estimation of equation (9) and show evidence on the neutrality criterion collected in equation (7). Finally, δ_j and τ_t account for the individual and time effects, respectively.

6. Data and Estimation Results

For the estimation, we use data for the seventeen Spanish autonomous communities (NUTS2) over the period 1986-2010.¹¹ Data on public investment and public capital stock with base year 2005 are from the BBVA Foundation and the Economic Research Institute of Valencia (Ivie). Hard infrastructure stock includes roads, hydraulic and water system infrastructures, railways, airports and ports, provided by all governments' layers, public firms, autonomous entities and firms that privately provide public infrastructure. Any other urban infrastructures provided by local governments and the rest of the agents are also included. Soft infrastructure stock includes infrastructure in education and health and other kind of infrastructures.¹² Data on central

¹¹ The smaller "Autonomous cities" of Ceuta and Melilla are excluded.

¹² It includes infrastructure related to water supply and sanitation, housing and community services, environmental protection, recreational, cultural and religious activities, social protection and public order and defense.

government's public investment in roads, hydraulic and water system and ports across autonomous communities are available. However, data on public investment in railways and airports are not explicitly disaggregated by government layers, but rather by public and private sectors. We can assume that the central government has made most of the public investment in railways and airports, because they are managed at the national level mainly through the public companies RENFE and AENA, respectively. Data on central government's public investment on education and health are also available.

Population data and surface are from the Spanish National Bureau of Statistics (INE), as well as the data used to construct constant GVA with base year 2005.

Table 1 shows correlation across the variables of the model. Since some explanatory variables are fairly correlated, multicollinearity diagnostics are carried out, and which show that no serious multicollinearity problems are faced.

Table 2 show the results obtained from estimating equation (9) assuming $\beta_1^1 = \beta_1^2 = \dots = \beta_1^{17} = \beta_1$ ($\omega_1 = \omega_2 = \dots = \omega_{17} = \omega$). In addition, Table 2 also shows the tests results for the hypotheses of the main problems faced dealing with the data at hand (p -values in parentheses). The Hausman test (H^{FR}) shows evidence in favor of fixed effects. The Green test (G test) rejected the null hypothesis of homoscedasticity, and the Wooldridge test (W^{SC}) rejected the null hypothesis of no serial correlation. Moreover, the Breusch-Pagan LM test (BP test) of independence shows evidence on cross-sectional correlation. Therefore, our estimation approach is to use panel corrected standard errors (Prais-Winsten, PW) and feasible general least square (FGLS) accounting for fixed effects (time and individual), heteroscedasticity, correlation across panels and autocorrelation with both, common and panel-specific AR(1) autocorrelation structures.¹³

It is striking in Table 2 the extraordinary explanatory capacity of the model, which is able to explain about 91 percent of the variability of the endogenous variable when a common autocorrelation structure (AR1) is considered. When a panel-specific autocorrelation structure (PSAR1) is accounted, the goodness-of-fit is better, since the model is able to explain about 93 percent of the variability of the endogenous variable. It is interesting because we are able to get

¹³ Beck and Katz (1995) provided evidence on the superiority of panel corrected standard errors (PW) estimate on FGLS. We provide both, anyway.

such an explanatory power using combinations of just four variables: GVA, population, public capital stock and surface.¹⁴

Regarding the parameter estimates, results are very robust across estimation methods. As expected, the efficiency criterion shows a positive and significant coefficient, which is significant at the 5% level with PW and at 1% with FGLS. The redistribution criterion also shows the expected negative coefficient ($\beta_2 < 0$) and it is significant at 1% in all cases, which also means that the hypothesis $\rho = 1$ is rejected. Therefore, this result suggests that the central government is averse to output inequality ($\rho < 1$), in fact, the estimated value of ρ is about 0.3-0.4.¹⁵ Therefore, the central government's public investment as a share of the total public capital stock is negatively correlated with the output per capita.

The spatial dimension also plays a role since the coefficient for population density shows a negative and significant coefficient at the 1% level in all cases. Notice that the estimated sign for population density is in line with the theoretical model prediction regarding the central government's aversion to output inequality, as found from the estimation of $\beta_2 < 0$ ($\rho < 1$). Therefore, the results show that the central government's public investment share is correlated negatively with population density.

Table 2 also shows the implicit estimate of η (β_3/β_2), which is positive and lower than one, as expected, and significant at 1% level in all cases. Therefore, it can be also checked in equation (7) that the neutrality criteria would have the expected sign in line with De La Fuente and Vives (1995).

Remember that η is also the parameter that weighs the two argument of the social welfare function in equation (4). The estimation results suggest that η is between 0.7-0.8, meaning that output per capita has been weighted 20%-30% in the social welfare function, while output density accounted for 70%-80%, which suggests that the central government has distributed public investment taking into account mainly spatial considerations. We go further and test the hypothesis $\eta = 1$ ($\beta_3 = \beta_2$), which, considering 10% (5%) significance level, it is rejected in three (two) out of the four estimation methods.

¹⁴ Castell and Sole-Olle (2005) with data for the Spanish autonomous communities for the 1987-1996 period, using a similar dependent variable and focusing mainly on the efficiency-equity trade-off (estimation ρ) and including additional explanatory variables of the transport sector, got at R^2 close to 60 percent.

¹⁵ Castell and Sole-Olle (2005) provided estimates for ρ about 0.3 and Sole-Olle (2013), using also data for the Spanish autonomous communities for 1978–2004 period, estimated ρ about 0.5.

Regarding the new criteria proposed by our theoretical model, we find that the convergence criterion exhibits the expected sign and is significant at 5% with PW(AR1) and at 10% with FGLS. Moreover, Table 2 also shows no rejection of the hypothesis $\beta_4 = -1$, as predicted by the theoretical model, and suggests that the central government allocates public investment to foster the catching up by lagging regions. However, no evidence was found for the economic size criteria.

As pointed out above, our model can be used either to distribute public investment or to assess the allocation of it. The empirical evidence for the Spanish central government allowed to test the theoretical predictions of the model, i.e., the expected signs were obtained and most of the coefficients of the criteria were significant. In addition, hypotheses testing on the value of the parameters provides further support to the theoretical model. The empirical results show that the Spanish central government has taken into account most of the criteria suggested by the empirical literature and formally derived from our theoretical model. Furthermore, it turns out the striking importance of the spatial considerations for the distribution of public investment among the Spanish regions, considering the fact that not only the criteria related to the space are highly significant, but also, because the high weight that output density seems to have had in the central government's social welfare function.

The empirical evidence is interesting because, the previous theoretical literature has traditionally considered social welfare functions exclusively based on the output per capita. Therefore, our approach, based on a more comprehensive theoretical framework, drives attention to the output density as a very relevant variable to be considered in social welfare functions dealing with the distribution of public funds across jurisdictions.

7. Robustness Checks

7.1. Alternate endogenous variable

Central government's public investment per capita

The previous empirical literature has also used public investment per capita as the dependent variable (Costa-Font, Rodríguez-Oreggia and Lunapla, 2003; Rodríguez-Oreggia and Rodríguez-Pose, 2004; Albalade, Bel and Fageda, 2012; Monastiriotis and Psycharis, 2014; Rodríguez-Pose *et al.*, 2016). We can rewrite our benchmark equation (6) so that we get,

$$\frac{C_{jt}}{N_{jt}} = \frac{A\sigma_j\alpha_{jG}}{\lambda_t} \left(\frac{Y_{jt}}{G_{jt}}\right)^{-\omega_j} y_{jt}^\rho \left(\frac{N_{jt}}{S_j}\right)^{\eta(\rho-1)} \left(\frac{y_{jt}}{Y_t}\right)^{-1} \frac{Y_{jt}}{Y_t}$$

Adding the error term, writing the right-hand side variables in one lag and taking logs, we finally get

$$\begin{aligned} \text{Ln}\left(\frac{C_{jt}}{N_{jt}}\right) &= \delta_j + \tau_t + \beta_1^j \text{Ln}\left(\frac{Y_{jt-1}}{G_{jt-1}}\right) + \beta_2 \text{Ln}(y_{jt-1}) + \beta_3 \text{Ln}\left(\frac{N_{jt-1}}{S_j}\right) \\ &+ \beta_4 \text{Ln}\left(\frac{y_{jt-1}}{y_{t-1}}\right) + \beta_5 \text{Ln}\left(\frac{Y_{jt-1}}{Y_{t-1}}\right) + \varepsilon_{jt} \end{aligned} \quad (10)$$

Where $\beta_1^j = -\omega_j$, $\beta_2 = \rho$, $\beta_3 = \eta(\rho - 1)$, $\beta_4 = -1$, $\beta_5 = 1$, $\delta_j = \text{Ln}(A\sigma_j\alpha_{jG})$, $\tau_t = -\text{Ln}(\lambda_t)$.

Notice in equation (10) that the parameters β_1^j and β_2 have now changed respect to those in equation (9). However, the former is still expected to be positive whenever inputs are more biased to be complementary than substitutes, while the latter could be positive, suggesting that public investment per capita might be positively correlated with income per capita, which, by no means implies that the central government is not averse to output inequality. Remember that whenever $\rho < 1$, the central government is output inequality averse.

Table 3 show the results of the estimation of equation (10) assuming equal coefficients for the efficiency criterion across jurisdictions, which shows the expected sign. However, it is not significant across most of the estimation methods. Now we get a positive correlation between central government's public investment per capita and income per capita, as expected. The coefficient is significant at 1% level in all cases. Notice, however that such a result is in line with that found in Table 2, since what is estimated is $\beta_2 = \rho$, the inequality-averse parameter, which is found positive but lower than one, and confirming the previous result that suggested that the central government is averse to output inequality. In fact, we find again that ρ is about 0.3-0.4.

The empirical studies listed above also found positive correlations between central government's public investment per capita and income per capita, or indicators based on the income per capita, and they concluded that the central government did not follow a redistribution criterion. This empirical literature might have inadvertently estimated the inequality-averse parameter of a social welfare function. Therefore, our model warns of the possibility of drawing misleading conclusions in empirical implementations when using public investment per capita as

the dependent variable. Thus, a positive correlation between the central government's public investment per capita and income per capita does not necessarily imply that the central government neglects the redistribution criterion.¹⁶

Again, the spatial dimension plays a role since the coefficient for population density shows a negative and significant coefficient at the 1% level in all cases, and in line with the theoretical model predictions whenever the central government is averse to output inequality ($\beta_2 = \rho < 1$). In addition, the implicit estimations of η are similar to those found in Table 2. The hypothesis $\eta = 1$ ($\beta_3 = \beta_2 - 1$) is rejected in three (two) out of the four estimation methods at 10% (5%) significant level.

Table 3 also shows that when the dependent variable is the log of the public investment per capita, stronger results for the convergence criterion are found, being significant across all the estimation methods (up to the 10% confidence level). Again, Table 3 shows no rejection of the hypothesis $\beta_4 = -1$, as predicted by the theoretical model, and no evidence was found for the economic size criteria.

Central government's public investment as a share of GVA

Theoretical and empirical literatures, and especially, literature on economic growth,¹⁷ have used public investment as a share of GDP, or GVA, as the dependent variable. We can rewrite our benchmark equation (6) so that we get

$$\frac{C_{jt}}{Y_{jt}} = \frac{A\sigma_j\alpha_{jG}}{\lambda_t} \left(\frac{Y_{jt}}{G_{jt}}\right)^{-\omega_j} y_{jt}^{\rho-1} \left(\frac{N_{jt}}{S_j}\right)^{\eta(\rho-1)} \left(\frac{y_{jt}}{y_t}\right)^{-1} \frac{Y_{jt}}{Y_t}$$

Adding the error term, writing the right-hand side variables in one lag and taking logs, we finally get

$$\begin{aligned} \ln\left(\frac{C_{jt}}{Y_{jt}}\right) = & \delta_j + \tau_t + \beta_1^j \ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right) + \beta_2 \ln(y_{jt-1}) + \beta_3 \ln\left(\frac{N_{jt-1}}{S_j}\right) \\ & + \beta_4 \ln\left(\frac{y_{jt-1}}{y_{t-1}}\right) + \beta_5 \ln\left(\frac{Y_{jt-1}}{Y_{t-1}}\right) + \varepsilon_{jt} \end{aligned} \quad (11)$$

¹⁶ In fact, Castell and Sole-Olle (2005) and Sole-Olle (2013) found positive correlations between GVA per capita and a dependent variable similar to ours in the benchmark model, precisely because they estimated the inequality averse parameter. However, they did not conclude that the policymaker neglected the redistribution criterion.

¹⁷ Check for instance Barro (1990; 1991).

Where $\beta_1^j = -\omega_j$, $\beta_2 = \rho - 1$, $\beta_3 = \eta(\rho - 1)$, $\beta_4 = -1$, $\beta_5 = 1$, $\delta_j = \text{Ln}(A\sigma_j\alpha_{jG})$, $\tau_t = -\text{Ln}(\lambda_t)$.

Again, β_1^j is expected to be positive whenever inputs are more biased to complementary than substitutes, while β_2 is expected to be negative whenever $\rho < 1$ as in equation (9).

Table 4 show the results of estimating equation (11) assuming equal coefficients for the efficiency criterion across jurisdictions, which shows the expected sign, but it is not significant across most of the estimation methods. Again, we get a negative correlation between central government's public investment as a share of GVA and income per capita. The coefficient is significant at 1% level in all cases and in line with the previous results since ρ is about 0.3-0.4.

Similar results to the previous main ones were also found for the criteria related to the spatial dimension. The coefficient for population density shows a negative and significant coefficient at the 1% level in all cases, and the implicit estimation of η is positive and significant at 1% in all cases and with similar values to those found previously. The hypothesis $\eta = 1$ ($\beta_3 = \beta_2$) is again rejected in three (two) out of the four estimation methods at 10% (5%) significant level.

Weaker evidence is found for the convergence criterion, although the expected sign is obtained. Nevertheless, Table 4 also shows the no rejection of the hypothesis $\beta_4 = -1$ in most of the cases, as predicted by the theoretical model.

Again, no evidence was found for the economic size criteria.

Central government's public investment per unit of surface (m^2)

Departing from our benchmark equation (6), rearranging terms, we get

$$\frac{C_{jt}}{S_j} = \frac{A\sigma_j\alpha_{jG}}{\lambda_t} \left(\frac{Y_{jt}}{G_{jt}}\right)^{-\omega_j} y_{jt}^\rho \left(\frac{N_{jt}}{S_j}\right)^{1+\eta(\rho-1)} \left(\frac{y_{jt}}{y_t}\right)^{-1} \frac{Y_{jt}}{Y_t}$$

Adding the error term, writing the right-hand side variables in one lag and taking logs, we finally get

$$\begin{aligned} \text{Ln}\left(\frac{C_{jt}}{S_j}\right) &= \delta_j + \tau_t + \beta_1^j \text{Ln}\left(\frac{Y_{jt-1}}{G_{jt-1}}\right) + \beta_2 \text{Ln}(y_{jt-1}) + \beta_3 \text{Ln}\left(\frac{N_{jt-1}}{S_j}\right) \\ &+ \beta_4 \text{Ln}\left(\frac{y_{jt-1}}{y_{t-1}}\right) + \beta_5 \text{Ln}\left(\frac{Y_{jt-1}}{Y_{t-1}}\right) + \varepsilon_{jt} \end{aligned} \quad (12)$$

Where $\beta_1^j = -\omega_j$, $\beta_2 = \rho$, $\beta_3 = 1 + \eta(\rho - 1)$, $\beta_4 = -1$, $\beta_5 = 1$, $\delta_j = \text{Ln}(A\sigma_j\alpha_{jG})$, $\tau_t = -\text{Ln}(\lambda_t)$.

Again, β_1^j is expected to be positive whenever inputs are more biased to complementary than substitutes, while β_2 is expected to be lower than one and, therefore, it could be positive. Furthermore, notice that β_3 could also be positive.

Table 5 shows the results of the estimation of equation (12) assuming equal coefficients for the efficiency criterion across jurisdictions, which again shows the expected sign. However, it is not significant across most of the estimation methods. As when we considered public investment per capita as dependent variable, we now get a positive correlation between central government's public investment per capita and income per capita. The coefficient is significant at 1% level in all cases and again confirming the value of ρ about 0.3-0.4.

In line with the prediction of the theoretical model, the coefficient for population density shows a positive and significant coefficient at the 1% level in all cases, and thus population density is positively correlated with public investment density. Again, the implicit estimation of η is positive and significant at 1% in all cases and with similar values to those found previously, while the hypothesis $\eta = 1$ ($\beta_3 = \beta_2$) is rejected in three (two) out of the four estimation methods at 10% (5%) significant level.

The coefficient of the convergence criterion shows again the expected sign and considering up to 10% significance level, it is significant in three out of the four estimation methods. Furthermore, Table 5 also shows the no rejection of the hypothesis $\beta_4 = -1$, as predicted by the theoretical model.

Again, no evidence was found for the economic size criteria.

7.2. Heterogeneous coefficients for the efficiency criteria

As suggested by the theoretical model, in Table 6 we show the results of estimating equation (9) considering heterogeneous coefficients for the efficiency criterion. Although there are both positive and negative coefficients, most of the statistically significant ones are positive, as expected. Stronger results are found for Cantabria, Castile-La Mancha, Valencia, Madrid and Murcia whose coefficients are positive and significant in at least three out the four estimation methods. It also noticeable the strong results for Navarre, and to a lesser extend for the Basque Country, whose coefficients are negative. These two regions (autonomous communities) have

different special financing regimes to the rest of the regional governments, which have a common regime known as general regime autonomous communities. Therefore, Navarre and the Basque Country have more revenue and expenditure autonomy than the rest of autonomous communities, i.e., more autonomy in public investment.¹⁸

Table 6 also shows tests of the hypotheses that all the coefficients are jointly to zero ($\beta_1^1 = \beta_1^2 = \dots = \beta_1^{17} = 0$) and equal coefficients across jurisdictions ($\beta_1^1 = \beta_1^2 = \dots = \beta_1^{17} = \beta_1$), both of which are rejected in all cases.

Regarding the coefficients of the rest of criteria, we find similar results to those in Table 2: ρ is estimated about 0.3-0.5; η is estimated between 0.6-0.8; and the hypothesis $\eta = 1$ ($\beta_3 = \beta_2$) is rejected at the 5% significance level across all the estimation methods. The major difference with respect to Table 2 is that the coefficient for the convergence criterion is not significant in all cases. Nevertheless, the hypothesis $\beta_4 = -1$ is not rejected in some cases.¹⁹

7.3. Introducing control variables

Political variables

Castells and Solé-Ollé (2005) included political variables in V_{jt} . Here we test this possibility by extending our initial V_{jt} including dummy variables to capture the impact of some political variables. Thus, we redefine $V_{jt} = \frac{N_{jt}}{N_t} e^{D'_{jt}\theta}$, where e is the exponential operator, and D_{jt} a vector of political variables including a dummy variable that takes on the value 1 whenever the same party is holding office simultaneously in the central and regional government, and zero otherwise, and a second dummy variable that takes on the value 1 in years in which the regional electoral processes are held, and zero otherwise; θ is a vector of parameters. We also include the first lag of these variables in the regression.

Table 7 shows the results of estimating equation (9) including the political variables. As can be noticed, the results for the economic criteria are very similar to those shown in Table 2. Regarding the political variables, weak evidence is provided. FGLS estimations shows a positive correlation between public investment allocation in jurisdictions in which the same party is holding office

¹⁸ For more details on the different financing system of the Spanish autonomous communities, see Aray (2018) and Lopez-Laborda, Martinez-Vazquez and Monasterio (2023).

¹⁹ Similar results were found using the alternate dependent variables. Results are available upon request.

simultaneously in both central and regional governments. Much weaker evidence is found for the years in which regional elections take place.^{20, 21}

Decentralization variables

Spain is a highly decentralized country, with the regional governments holding high but also different levels of autonomy. To explore the role such heterogeneity may play, we may assume that the central government considers fiscal decentralization indicators to distribute public investment. In this case we have that $V_{jt} = \frac{N_{jt}}{N_t} FA_{jt}^{\phi_1} IA_{jt}^{\phi_2}$, where FA_{jt} captures the level of financial autonomy, measured by the share of ceded taxes and other own taxes and fees on total revenues, excluding debt issuance in autonomous community j in time t . IA_{jt} captures the level of investment autonomy, measured by the share of investment in infrastructure of the subnational governments on total public investment in infrastructure in the autonomous community j in year t ;²² and where ϕ_1 and ϕ_2 are the parameters.

Table 8 shows the results of estimating equation (9) including the decentralization variables. The results for the economic criteria for distributing public investment remain very similar to the previous ones shown in Table 2, except for the negative and significant coefficients for the economic size criterion in three out of the four estimation methods. Regarding the decentralization variables, the results show that both, financial autonomy and investment autonomy are negatively related with public investment. The coefficients are statistically significant across all the estimation methods.²³

8. Conclusions

This article proposes a general model for the distribution of public investment across jurisdictions. We develop a theoretical model building on the insights of the New Economic Geography literature and the literature on economic growth that account for the spatial dimension. In the model, the policymaker maximizes a CES social welfare function whose arguments are the

²⁰ Castells and Solé-Ollé (2005) tested other more elaborate political variables based upon absolute values and shares of representatives and votes, turnover, dummies for coalition or support in regional and central governments, etc. However, they also found that the inclusion of such political variables does not affect the statistical significance of the economic variables.

²¹ Similar results were found using the alternate dependent variables. Results are available upon request.

²² FA_{jt} and IA_{jt} are constructed as Aray (2018).

²³ Similar results were found using the alternate dependent variables. Results are available upon request.

output per capita and the output density, subject to a CES production function, a nonlinear law of motion for the public capital stock, and an exogenous resource constraint. The model provides the ratio of the public investment to the total public capital stock as a function of the economic criteria that have been proposed in the past empirical literature on public investment distribution across jurisdictions. Thus, the paper bridges the theoretical and empirical literature on this topic. In addition, we propose two additional criteria related to convergence on output per capita and jurisdiction's economy size.

Our theoretical framework goes beyond the traditional equity-efficiency trade-off proposed in the past theoretical literature. In addition, the framework helps answer the questions, largely ignored by the past empirical literature, about where the criteria come from or how they could be justified, and what should be their parameters' expected signs. Furthermore, the theoretical model is flexible enough to support empirical implementations with different dependent variables and to account for control variables.

For the empirical implementation, we use data for the Spanish regional governments over the 1986-2010. Overall, the empirical evidence shows the expected signs of the estimated coefficients for the different criteria, and with most of the estimated coefficients being statistically significant. Perhaps most notoriously we find that output density plays a very important role as an argument of the social welfare function. This is important because the past theoretical literature had narrowly focused on output per capita as the only relevant argument of the social welfare function. These general conclusions are shown to be robust across estimation methods, different alternate definitions of the dependent variables and the introduction of control variables.

Future research could expand this work in several directions. First, we have assumed that the public investment made by other agents, specifically by regional governments, is exogenous. A natural extension of this paper would be to consider the case in which the central and regional governments interact, which would require to solve the problem simultaneously. This would lead to an empirical implementation with two equations to be estimated and allowing them to cast hypotheses on the equality of the parameters of the model across government layers and on the complementarity/substitutability of the investment provided by them. Second, it would be an interesting extension to introduce dynamics in the theoretical model.

Appendix: Obtaining equation (6)

The Central government's problem is to allocate the public investment level in each jurisdiction (C_{jt}) to maximize

$$\text{Max } W_t = \left[\sum_{j=1}^J \left(\frac{N_{jt}}{N_t} \right) N_{jt}^{1-\eta} S_j^\eta \left[\frac{Y_{jt}}{N_{jt}^{1-\eta} S_j^\eta} \right]^\rho \right]^{\frac{1}{\rho}}$$

St.

$$Y_{jt} = \left(\alpha_{jK} K_{jt}^{\omega_j} + \alpha_{jL} L_{jt}^{\omega_j} + \alpha_{jG} G_{jt}^{\omega_j} \right)^{\frac{1}{\omega_j}}$$

$$G_{jt} = B_{jt} G_{jt-1}^{1-(\sigma_j+v_j)} C_{jt}^{\sigma_j} R_{jt}^{v_j}$$

$$\sum_{j=1}^J C_{jt} \leq I_t^C$$

FOC:

$$\frac{\partial W_t}{\partial Y_{jt}} \cdot \frac{\partial Y_{jt}}{\partial G_{jt}} \cdot \frac{\partial G_{jt}}{\partial C_{jt}} - \lambda_t = 0, \quad \forall j$$

$$\begin{aligned} \frac{\partial W_t}{\partial Y_{jt}} &= \left[\sum_{j=1}^J \left(\frac{N_{jt}}{N_t} \right) N_{jt}^{1-\eta} S_j^\eta \left[\frac{Y_{jt}}{N_{jt}^{1-\eta} S_j^\eta} \right]^\rho \right]^{\frac{1}{\rho}-1} \left(\frac{N_{jt}}{N_t} \right) \frac{N_{jt}^{1-\eta} S_j^\eta}{\left(N_{jt}^{1-\eta} S_j^\eta \right)^\rho} Y_{jt}^{\rho-1} \\ &= \left[\sum_{j=1}^J \left(\frac{N_{jt}}{N_t} \right) N_{jt}^{1-\eta} S_j^\eta \left[\frac{Y_{jt}}{N_{jt}^{1-\eta} S_j^\eta} \right]^\rho \right]^{\frac{1}{\rho}-1} \left(\frac{N_{jt}}{N_t} \right) \frac{N_{jt} \left(\frac{S_j}{N_{jt}} \right)^\eta}{\left(N_{jt} \left(\frac{S_j}{N_{jt}} \right)^\eta \right)^\rho} Y_{jt}^{\rho-1} \\ &= \left[\sum_{j=1}^J \left(\frac{N_{jt}}{N_t} \right) N_{jt}^{1-\eta} S_j^\eta \left[\frac{Y_{jt}}{N_{jt}^{1-\eta} S_j^\eta} \right]^\rho \right]^{\frac{1}{\rho}-1} \left(\frac{N_{jt}}{N_t} \right) N_{jt}^{1-\rho} \left(\frac{S_j}{N_{jt}} \right)^{\eta(1-\rho)} Y_{jt}^{\rho-1} \\ &= A \left(\frac{N_{jt}}{N_t} \right) \left(\frac{S_j}{N_{jt}} \right)^{\eta(1-\rho)} y_{jt}^{\rho-1} \end{aligned}$$

$$\text{With } A = \frac{1}{\rho} \left[\sum_{j=1}^J \left(\frac{N_{jt}}{N_t} \right) N_{jt}^{1-\eta} S_j^\eta \left[\frac{Y_{jt}}{N_{jt}^{1-\eta} S_j^\eta} \right]^\rho \right]^{\frac{1}{\rho}-1} \text{ and } y_{jt} = \frac{Y_{jt}}{N_{jt}}$$

$$\begin{aligned}
\frac{\partial Y_{jt}}{\partial G_{jt}} &= \frac{\alpha_{jG}\omega_j}{\omega_j} \left(\alpha_{jK}K_{jt}^{\omega_j} + \alpha_{jL}L_{jt}^{\omega_j} + \alpha_{jG}G_{jt}^{\omega_j} \right)^{\frac{1}{\omega_j}-1} G_{jt}^{\omega_j-1} \\
&= \alpha_{jG} \left(\alpha_{jK}K_{jt}^{\omega_j} + \alpha_{jL}L_{jt}^{\omega_j} + \alpha_{jG}G_{jt}^{\omega_j} \right)^{\frac{1}{\omega_j}} \left(\alpha_{jK}K_{jt}^{\omega_j} + \alpha_{jL}L_{jt}^{\omega_j} + \alpha_{jG}G_{jt}^{\omega_j} \right)^{-1} G_{jt}^{\omega_j-1} \\
&= \alpha_{jG} Y_{jt} Y_{jt}^{-\omega_j} G_{jt}^{\omega_j-1} \\
&= \alpha_{jG} Y_{jt} \left(\frac{Y_{jt}}{G_{jt}} \right)^{-\omega_j} G_{jt}^{-1}
\end{aligned}$$

$$\begin{aligned}
\frac{\partial G_{jt}}{\partial C_{jt}} &= \sigma_j B_{jt} G_{jt-1}^{1-(\sigma_j+v_j)} C_{jt}^{\sigma_j-1} R_{jt}^{v_j} \\
&= \sigma_j G_{jt} C_{jt}^{-1}
\end{aligned}$$

The FOC becomes

$$\begin{aligned}
A\sigma_j\alpha_{jG} \left(\frac{N_{jt}}{N_t} \right) \left(\frac{S_j}{N_{jt}} \right)^{\eta(1-\rho)} y_{jt}^{\rho-1} Y_{jt} \left(\frac{Y_{jt}}{G_{jt}} \right)^{-\omega_j} C_{jt}^{-1} - \lambda_t &= 0 \\
A\sigma_j\alpha_{jG} \left(\frac{S_j}{N_{jt}} \right)^{\eta(1-\rho)} \left(\frac{N_{jt}Y_t}{N_tY_t} \right) y_{jt}^{\rho-1} Y_{jt} \left(\frac{Y_{jt}}{G_{jt}} \right)^{-\omega_j} C_{jt}^{-1} - \lambda_t &= 0 \\
A\sigma_j\alpha_{jG} \left(\frac{S_j}{N_{jt}} \right)^{\eta(1-\rho)} \left(\frac{y_{jt}}{y_t} \right)^{-1} \left(\frac{Y_{jt}}{Y_t} \right) y_{jt}^{\rho} \left(\frac{Y_{jt}}{G_{jt}} \right)^{-\omega_j} N_{jt} C_{jt}^{-1} - \lambda_t &= 0
\end{aligned}$$

The optimal level of public investment in jurisdiction j in period t is:

$$C_{jt} = \frac{A\sigma_j\alpha_{jG}}{\lambda_t} \left(\frac{Y_{jt}}{G_{jt}} \right)^{-\omega_j} y_{jt}^{\rho} N_{jt} \left(\frac{S_j}{N_{jt}} \right)^{\eta(1-\rho)} \left(\frac{y_{jt}}{y_t} \right)^{-1} \left(\frac{Y_{jt}}{Y_t} \right)$$

Dividing by G_{jt} in both sides and rearranging, we get

$$\begin{aligned}
\frac{C_{jt}}{G_{jt}} &= \frac{A\sigma_j\alpha_{jG}}{\lambda_t} \left(\frac{Y_{jt}}{G_{jt}} \right)^{-\omega_j} y_{jt}^{\rho} \frac{N_{jt}}{G_{jt}} \left(\frac{S_j}{N_{jt}} \right)^{\eta} \left(\frac{S_j}{N_{jt}} \right)^{-\eta\rho} \left(\frac{y_{jt}}{y_t} \right)^{-1} \left(\frac{Y_{jt}}{Y_t} \right) \\
\frac{C_{jt}}{G_{jt}} &= \frac{A\sigma_j\alpha_{jG}}{\lambda_t} \left(\frac{Y_{jt}}{G_{jt}} \right)^{-\omega_j} y_{jt}^{\rho} \frac{N_{jt}^{1-\eta} S_j^{\eta}}{G_{jt}^{1-\eta} G_{jt}^{\eta}} \left(\frac{S_j}{N_{jt}} \right)^{-\eta\rho} \left(\frac{y_{jt}}{y_t} \right)^{-1} \left(\frac{Y_{jt}}{Y_t} \right) \\
\frac{C_{jt}}{G_{jt}} &= \frac{A\sigma_j\alpha_{jG}}{\lambda_t} \left(\frac{Y_{jt}}{G_{jt}} \right)^{-\omega_j} y_{jt}^{\rho} \left[\left(\frac{G_{jt}}{N_{jt}} \right)^{1-\eta} \left(\frac{G_{jt}}{S_j} \right)^{\eta} \right]^{-1} \left(\frac{N_{jt}}{S_j} \right)^{\eta\rho} \left(\frac{y_{jt}}{y_t} \right)^{-1} \left(\frac{Y_{jt}}{Y_t} \right)
\end{aligned}$$

References

- Albalade, D., Bel, G., and Fageda, X. (2012). Beyond the efficiency-equity dilemma: Centralization as a determinant of government investment in infrastructure. *Papers in Regional Science* 91, 599–615.
- Aray, H. (2018). More on decentralization and economic growth. *Papers in Regional Science*, 97, 971–993.
- Aray, H. (2019). A New Approach to Test the Effects of Decentralization on Public Infrastructure Investment. *Regional Studies* 53, 1042–1057.
- Aschauer, D. A. (1989). Is public expenditure productive? *Journal of Monetary Economics* 23, 177–200.
- Barro, R. J. (1990). Government spending in a simple model of endogenous growth. *Journal of Political Economy* 98, 103–125.
- Barro, R. (1991). Economic Growth in a Cross Section of Countries. *The Quarterly Journal of Economics* 106, 407–443.
- Beck, N. and Katz, J. N. (1995). What to do (and not to do) with time-series cross-section data. *American Political Science Review* 89, 634–647.
- Behrman, J.R. and Craig, S.G. (1987). The distribution of public services: An exploration of local government preferences. *American Economic Review* 77, 315–332.
- Cadot, O., Röller L.H., and Stephan, A. (2006). Contribution to Productivity or Pork Barrel? The Two Faces of Infrastructure Investment. *Journal of Public Economics* 90, 1133–1153.
- Caminal, R. (2004). Personal redistribution and the regional allocation of public investment. *Regional Science and Urban Economics* 34, 55–69.
- Cassou, S. P. and Lansing, K. J. (1998). Optimal fiscal policy, public capital, and the productivity slowdown. *Journal of Economic Dynamics and Control*, 22, 911–935.
- Castells, A. and Solé-Ollé, A. (2005). The regional allocation of infrastructure investment: the role of equity, efficiency and political factors. *European Economic Review*, 49, 1165–1205.
- Chenery, H. B. (1953). The Application of Investment Criteria. *The Quarterly Journal of Economics* 67, 76–96.
- Ciccone, A. (2002) Agglomeration Effects in Europe. *European Economic Review* 46, 213–227.
- Ciccone, A. and Hall, R. E. (1996) Productivity and the Density of Economic Activity, *American Economic Review* 86, 54–70.

- Costa-Font, J., Rodríguez-Oreggia, E., and Lunapla, D. (2003). Political competition and pork-barrel politics in the allocation of public investment in Mexico. *Public Choice*, 116, 185–204.
- Davis, M. A., Fisher, J. D. M., and Whited, T. M. (2014). Macroeconomic Implications of Agglomeration. *Econometrica* 82, 731–764.
- Davisson, W. I. (1964). Public Investment Criteria. *Land Economics* 40, 153–162.
- De la Fuente, A. (2004). Second-best redistribution through public investment: a characterization, an empirical test and an application to the case of Spain. *Regional Science and Urban Economics* 34, 489–503.
- De la Fuente, A. and Vives, X. (1995). Infrastructure and education as instruments of regional policy: evidence from Spain. *Economic Policy* 10, 11–51.
- Eckstein, O. (1957). Investment Criteria for Economic Development and the Theory of Intertemporal Welfare Economics. *The Quarterly Journal of Economics* 71, 56–85.
- Eckstein, O. (1961). A Survey of the Theory of Public Expenditure Criteria. NBER Chapters, in: Public Finances: Needs, Sources, and Utilization, pages 439-504, National Bureau of Economic Research, Inc.
- Fageda X. and Olivieri C. (2019). Transport infrastructure and regional convergence: A spatial panel data approach. *Papers in Regional Science* 98, 1609–1631.
- Freeman, A. M., III. (1967). Income Distribution and Planning for Public Investment. *The American Economic Review* 57, 494–508.
- Galenson, W. and Leibenstein, H. (1955). Investment Criteria, Productivity, and Economic Development. *The Quarterly Journal of Economics* 69, 343–370.
- Hercowitz, Z., and Sampson, M. (1991). Output growth, the real wage, and employment fluctuations. *The American Economic Review*, 81, 1215–1237.
- Hidalgo, C. A., Klinger, B., Barabási, A.-L., and Hausmann, R. (2007). The Product Space Conditions the Development of Nations. *Science* 317, 482–487.
- Hirschman, A. (1958). The strategy of economic development. New Haven, Conn. Yale University Press.
- Kahn, A. E. (1951). Investment Criteria in Development Programs. *The Quarterly Journal of Economics* 65, 38–61.
- Kemmerling, A. and Stephan, A. (2010). Determinants of regional transport investment across Europe. In N. Bosch, M. Espasa, & A. Solé-Ollé (Eds.), The political economy of inter-regional

- fiscal flows: measurement, determinants, and effects on country stability. Cheltenham: Edward Elgar.
- Kocherlakota, N.R. and Yi, K-M. (1997). Is there endogenous long run growth? Evidence from the US and UK. *Journal of Money Credit and Banking*, 29, 235–262.
- Krugman, P. (1991). Increasing Returns and Economic Geography. *Journal of Political Economy* 3, 483–499.
- Lambrinidis, M., Psycharis, Y., and Rovolis, A. (2005). Regional allocation of public infrastructure investment: The case of Greece. *Regional Studies* 39, 1231–1244.
- Lopez-Laborda, J., Martinez-Vazquez, J., and Monasterio C. (2023). Fiscal Federalism: Comparative Experiences and Challenges, The Case of Spain, in J-F. Tremblay (ed.) *Fiscal Federalism: Comparative Experiences and Challenges*.
- Lucas, R. E., Jr. and Prescott, E. C. (1971). Investment under Uncertainty. *Econometrica* 39, 659–681.
- Marglin, S. A. (1963). The Opportunity Costs of Public Investment. *The Quarterly Journal of Economics* 77, 274–289
- Mera, K. (1967). Trade-off between Aggregate Efficiency and Interregional Equity: A Static Analysis. *The Quarterly Journal of Economics* 81, 658–674.
- Mera, K. (1973). Trade-off between Aggregate Efficiency and Interregional Equity: The case of Japan. *Regional Science and Urban Economics* 3, 273–300.
- Mishan, E. J. (1967A). Criteria for Public Investment: Some Simplifying Suggestions. *Journal of Political Economy* 75, 139–146.
- Mishan, E. J. (1967B). A Proposed Normalisation Procedure for Public Investment Criteria. *The Economic Journal* 77, 777–796.
- Mizutani, F. and Tanaka, T. (2010). Productivity effects and determinants of public infrastructure investment. *Annals of Regional Science* 44, 493–521.
- Monastiriotes, V. and Psycharis, Y. (2014). Between equity, efficiency and redistribution: An analysis of revealed allocation criteria of regional public investment in Greece. *European Urban and Regional Studies* 21, 445–462.
- OECD (2019). *Effective Multi-level Public Investment: OECD Principles in Action*, OECD Multi-level Governance Studies, OECD Publishing, Paris, <https://doi.org/10.1787/c3bc625b-en>.

- OECD (2022). Making the most of public investment to address regional inequalities, megatrends and future shocks. *OECD Regional Development Papers*, No. 29, OECD Publishing, Paris, <https://doi.org/10.1787/8a1fb523-en>.
- Puga, D. (2002). European regional policies in the light of recent location theories. *Journal of Economic Geography* 2, 373–406.
- Rodríguez-Oreggia, E. and Rodríguez-Pose, A. (2004). The Regional Returns of Public Investment Policies in Mexico. *World Development*, 32, 1545–1562.
- Rodríguez-Pose, A., Psycharis, Y., and Tselios, V. (2016). Politics and Investment: Examining the Territorial Allocation of Public Investment in Greece. *Regional Studies* 50, 1097–1112.
- Solé-Ollé, A. (2013). Inter-regional redistribution through infrastructure investment: tactical or programmatic? *Public Choice* 156, 229–252.
- Stewart, C. T. Jr. (1967). Regional Allocation of Public Funds for Economic Development. *Land Economics* 43, 421–433.
- Yamano, N. and Ohkawara, T. (2000). The regional allocation of public investment: Efficiency or equity? *Journal of Regional Science* 40, 205–229.

Table 1. Correlations and multicollinearity diagnostics

Correlations						
	$Ln\left(\frac{C_{jt}}{G_{jt}}\right)$	$Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$	$Ln(y_{jt-1})$	$Ln\left(\frac{N_{jt-1}}{S_j}\right)$	$Ln\left(\frac{y_{jt-1}}{y_{t-1}}\right)$	$Ln\left(\frac{Y_{jt-1}}{Y_{t-1}}\right)$
$Ln\left(\frac{C_{jt}}{G_{jt}}\right)$	1.0000					
$Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$	-0.0695	1.0000				
$Ln(y_{jt-1})$	-0.5888	0.2888	1.0000			
$Ln\left(\frac{N_{jt-1}}{S_j}\right)$	-0.3517	0.7121	0.4466	1.0000		
$Ln\left(\frac{y_{jt-1}}{y_{t-1}}\right)$	-0.3951	0.6342	0.7930	0.5101	1.0000	
$Ln\left(\frac{Y_{jt-1}}{Y_{t-1}}\right)$	-0.0803	0.4755	0.1145	0.1484	0.4957	1.0000
Multicollinearity diagnostics						
Condition number of the matrix (CNM): 12.5						
Varianza Inflation Factor (VIF)						
	VIF	1/VIF				
$Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$	6.49	0.1505				
$Ln(y_{jt-1})$	4.66	0.2145				
$Ln\left(\frac{y_{jt-1}}{y_{t-1}}\right)$	4.55	0.2199				
$Ln\left(\frac{N_{jt-1}}{S_j}\right)$	2.75	0.3637				
$Ln\left(\frac{Y_{jt-1}}{Y_{t-1}}\right)$	1.53	0.6227				
Mean VIF	4.00					

CNM > 30 indicates high multicollinearity.

VIF > 10 (1/VIF < 0.1) indicates that the variables are a linear combination of other variables.

Table 2. Estimation for the total public investment allocation of the central government

Dependent variable: Log of the public investment as a share of public capital stock								
	PW(AR1)		PW(PSAR1)		FGLS (AR1)		FGLS (PSAR1)	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
$\ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$	1.1609	0.4914 **	1.2299	0.5407 **	1.4436	0.3657 ***	1.5524	0.3372 ***
$\ln(y_{jt-1})$	-0.5997	0.0689 ***	-0.6133	0.0739 ***	-0.6573	0.0488 ***	-0.6630	0.0472 ***
$\ln\left(\frac{N_{jt-1}}{S_j}\right)$	-0.4074	0.1333 ***	-0.4145	0.1292 ***	-0.5157	0.1007 ***	-0.5350	0.0761 ***
$\ln\left(\frac{y_{jt-1}^j}{y_{t-1}}\right)$	-1.0023	0.4588 **	-0.6095	0.4001	-0.5514	0.3133 *	-0.4588	0.2453 *
$\ln\left(\frac{Y_{jt-1}}{Y_{t-1}}\right)$	0.0092	0.0942	-0.0235	0.0724	-0.0354	0.0782	-0.0137	0.0525
Implicit η	0.6793	0.2356 ***	0.6758	0.2259 ***	0.7846	0.1639 ***	0.8070	0.1284 ***
Individual effects	Yes		Yes		Yes		Yes	
Time effects	Yes		Yes		Yes		Yes	
R^2	0.9091		0.9265					
H^{FR}	27.5200	(0.0000)						
G test	155.9300	(0.0000)						
W^{SC} test	136.6170	(0.0000)						
BP test	377.9800	(0.0000)						
$\eta = \mathbf{1} (\beta_3 = \beta_2)$	3.7541	(0.0527)	5.9912	(0.0144)	2.4555	(0.1171)	6.8242	(0.0090)
$\beta_4 = -1$	0.0000	(0.9960)	0.9522	(0.3292)	2.0506	(0.1521)	4.8683	(0.0274)

Notes: Number of observations: 408. Number of groups: 17.

***, **, * significant at the 1%, 5% and 10% levels, respectively.

Table 3. Estimation for the total public investment allocation of the central government

Dependent variable: Log of public investment per capita								
	PW(AR1)		PW(PSAR1)		FGLS (AR1)		FGLS (PSAR1)	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
$Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$	0.2121	0.4945	0.3102	0.5415	0.4863	0.3701	0.6402	0.3399 *
$Ln(y_{jt-1})$	0.4014	0.0689 ***	0.3823	0.0742 ***	0.3450	0.0491 ***	0.3315	0.0477 ***
$Ln\left(\frac{N_{jt-1}}{S_j}\right)$	-0.4087	0.1339 ***	-0.4263	0.1307 ***	-0.5204	0.1015 ***	-0.5513	0.0775 ***
$Ln\left(\frac{Y_{jt-1}}{y_{t-1}}\right)$	-1.0796	0.4510 **	-0.6802	0.4012 *	-0.6185	0.3174 *	-0.5410	0.2450 **
$Ln\left(\frac{Y_{jt-1}}{Y_{t-1}}\right)$	0.0059	0.0949	-0.0297	0.0730	-0.0340	0.0789	-0.0182	0.0531
Implicit η	0.6828	0.2370 ***	0.6903	0.2273 ***	0.7945	0.1660 ***	0.8247	0.1300 ***
Individual effects	Yes		Yes		Yes		Yes	
Time effects	Yes		Yes		Yes		Yes	
R^2	0.9215		0.9460					
H^{FR}	27.5200 (0.0000)							
G test	155.9300 (0.0000)							
W^{SC} test	136.6170 (0.0000)							
BP test	377.9800 (0.0000)							
$\eta = 1 (\beta_3 = \beta_2 - 1)$	3.5859	(0.0583)	5.2850	(0.0215)	2.1777	(0.1400)	5.5045	(0.0190)
$\beta_4 = -1$	0.0311	(0.8600)	0.6352	(0.4255)	1.4450	(0.2293)	3.5107	(0.0610)

Notes: Number of observations: 408. Number of groups: 17.

***, **, * significant at the 1%, 5% and 10% levels, respectively.

Table 4. Estimation for the total public investment allocation of the central government

Dependent variable: Log of the public investment as a share of GVA								
	PW(AR1)		PW(PSAR1)		FGLS (AR1)		FGLS (PSAR1)	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
$Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$	0.2600	0.4992	0.3698	0.5373	0.5655	0.3721	0.7153	0.3374 **
$Ln(y_{jt-1})$	-0.6108	0.0704 ***	-0.6308	0.0740 ***	-0.6729	0.0497 ***	-0.6850	0.0476 ***
$Ln\left(\frac{N_{jt-1}}{S_j}\right)$	-0.4297	0.1352 ***	-0.4502	0.1306 ***	-0.5597	0.0998 ***	-0.5818	0.0762 ***
$Ln\left(\frac{y_{jt-1}}{y_{t-1}}\right)$	-0.9770	0.4576 **	-0.5806	0.4044	-0.4882	0.3122	-0.4193	0.2530 *
$Ln\left(\frac{Y_{jt-1}}{Y_{t-1}}\right)$	0.0099	0.0967	-0.0247	0.0743	-0.0278	0.0808	-0.0156	0.0540
Implicit η	0.7035	0.2357 ***	0.7137	0.2233 ***	0.8317	0.1605 ***	0.8494	0.1259 ***
Individual effects	Yes		Yes		Yes		Yes	
Time effects	Yes		Yes		Yes		Yes	
R^2	0.9176		0.9320					
H^{FR}	27.5200 (0.0000)							
G test	155.9300 (0.0000)							
W^{SC} test	136.6170 (0.0000)							
BP test	377.9800 (0.0000)							
$\eta = 1 (\beta_3 = \beta_2)$	3.2795	(0.0702)	4.6612	(0.0309)	1.5938	(0.2068)	4.3309	(0.0374)
$\beta_4 = -1$	0.0025	0.9598	1.0756	0.2997	2.6885	0.1011	5.2668	0.0217

Notes: Number of observations: 408. Number of groups: 17.

***, **, * significant at the 1%, 5% and 10% levels, respectively.

Table 5. Estimation for the total public investment allocation of the central government

Dependent variable: Log of the public investment per unit of surface								
	PW(AR1)		PW(PSAR1)		FGLS (AR1)		FGLS (PSAR1)	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
$\ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$	0.2241	0.4931	0.3192	0.5410	0.5032	0.3699	0.6521	0.3401 *
$\ln(y_{jt-1})$	0.4000	0.0689 ***	0.3817	0.0741 ***	0.3426	0.0492 ***	0.3307	0.0475 ***
$\ln\left(\frac{N_{jt-1}}{S_j}\right)$	0.5880	0.1336 ***	0.5719	0.1299 ***	0.4719	0.1023 ***	0.4467	0.0767 ***
$\ln\left(\frac{y_{jt-1}}{y_{t-1}}\right)$	-1.0592	0.4587 **	-0.6650	0.4053	-0.5860	0.3180 *	-0.5133	0.2496 **
$\ln\left(\frac{Y_{jt-1}}{Y_{t-1}}\right)$	0.0055	0.0949	-0.0298	0.0728	-0.0334	0.0800	-0.0183	0.0530
Implicit η	0.6866	0.2362 ***	0.6924	0.2258 ***	0.8034	0.1668 ***	0.8267	0.1288 ***
Individual effects	Yes		Yes		Yes		Yes	
Time effects	Yes		Yes		Yes		Yes	
R^2	0.7706		0.8056					
H^{FR}	27.5200 (0.0000)							
G test	155.9300 (0.0000)							
W^{SC} test	136.6170 (0.0000)							
BP test	377.9800 (0.0000)							
$\eta = \mathbf{1} (\beta_3 = \beta_2)$	3.5395	(0.0599)	5.3615	(0.0206)	1.9692	(0.1605)	5.5002	(0.0190)
$\beta_4 = -1$	0.0167	(0.8973)	0.6832	(0.4085)	1.6954	(0.1929)	3.8038	(0.0511)

Notes: Number of observations: 408. Number of groups: 17.

***, **, * significant at the 1%, 5% and 10% levels, respectively.

Table 6. Estimation for the total public investment allocation of the central government

Dependent variable: Log of public investment as a share of public capital stock								
	PW(AR1)		PW(PSAR1)		FGLS (AR1)		FGLS (PSAR1)	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
$\ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$								
Andalusia	-0.1831	0.7195	0.0821	0.6840	1.4393	0.3448 ***	0.2195	0.4644
Aragon	-1.4124	1.4682	-0.5576	1.5142	1.3155	0.9530	0.6963	1.1463
Asturias	0.1968	0.8007	0.6309	0.9124	2.2768	0.4278 ***	1.5457	0.6619 **
Balearic Islands	0.2252	0.4432	0.7729	0.5961	0.9667	0.2811 ***	0.6643	0.5151
Canary Islands	-0.9755	0.7641	-0.0773	0.9298	0.5107	0.4489	0.2384	0.7360
Cantabria	1.4785	0.7256 **	1.6410	0.9577 **	2.6917	0.4403 ***	2.4754	0.7551 ***
Castile and Leon	-0.2114	0.8459	-0.0858	0.6609	1.4513	0.4324 ***	0.0845	0.4241
Castile-La Mancha	1.5067	1.1000	1.8184	0.8699 **	2.6120	0.5833 ***	1.7332	0.5435 ***
Catalonia	-0.0013	0.5363	0.2626	0.5256	1.0486	0.1840 ***	0.2418	0.3822
Valencia	0.4304	0.5339	0.8481	0.4839 **	1.7012	0.1579 ***	0.8994	0.3051 ***
Extremadura	0.4899	0.7444	0.5326	0.6770	1.6912	0.3793 ***	0.4149	0.4546
Galicia	-1.1068	0.6546 **	-0.7202	0.5916	0.2067	0.4446	-0.7482	0.4672
Madrid	0.9497	0.6221	1.3957	0.5759 **	2.2949	0.1642 ***	1.4363	0.3822 ***
Murcia	0.8547	0.4494 **	1.2159	0.5551 **	1.8092	0.2946 ***	1.5137	0.4410 ***
Navarre	-3.5832	1.4047 **	-2.7219	1.3953 **	-2.1169	1.0750 **	-2.2346	1.2095 **
Basque Country	-2.1237	1.0138 **	-1.5244	0.9245 **	-0.1103	0.4488	-1.1095	0.6929
La Rioja	1.5020	2.0710	3.1299	2.0652	0.6007	1.3017	1.6376	1.2686
$\ln\left(y_{jt-1}\right)$	-0.4883	0.0748 ***	-0.5172	0.0695 ***	-0.6790	0.0142 ***	-0.5367	0.0444 ***
$\ln\left(\frac{N_{jt-1}}{S_j}\right)$	-0.3135	0.1100 ***	-0.3842	0.0974 ***	-0.5267	0.0424 ***	-0.4060	0.0648 ***
$\ln\left(\frac{y_{jt-1}}{y_{t-1}}\right)$	-0.2288	0.4056	-0.5183	0.3750	-0.3251	0.2363	-0.3165	0.2524
$\ln\left(\frac{Y_{jt-1}}{Y_{t-1}}\right)$	0.0446	0.0914	0.0935	0.0875	-0.1115	0.0559 **	0.0765	0.0632
Implicit η	0.6422	0.2459 ***	0.7430	0.2132 ***	0.7756	0.0645 ***	0.7565	0.1359 ***
Individual effects	Yes		Yes		Yes		Yes	
Time effects	Yes		Yes		Yes		Yes	
G test	122.72	(0.0000)						
W ^{SC} test	163.59	(0.0000)						
BP test	358.41	(0.0000)						
$\eta = 1 (\beta_3 = \beta_2)$	7.54	(0.0060)	6.55	(0.0105)	11.32	(0.0008)	11.2855	(0.0008)
$\beta_4 = -1$	3.62	(0.0572)	1.6499	(0.1990)	8.16	(0.0043)	7.3346	(0.0068)
$\beta_1^1 = \beta_1^2 = \dots = \beta_1^{17} = 0$	136.71	(0.0000)	185.44	(0.0000)	2439.57	(0.0000)	271.1560	(0.0000)
$\beta_1^1 = \beta_1^2 = \dots = \beta_1^{17} = \beta_1$	125.43	(0.0000)	146.98	(0.0000)	175.57	(0.0000)	202.6309	(0.0000)

Notes: Number of observations: 408. Number of groups: 17.

***, **, * significant at the 1%, 5% and 10% levels, respectively.

Table 7. Estimation for the total public investment allocation of the central government

Dependent variable: Log of the public investment as a share of public capital stock								
Including political variables								
	PW(AR1)		PW(PSAR1)		FGLS (AR1)		FGLS (PSAR1)	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
$\ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$	1.1311	0.4680 **	1.2792	0.5127 **	1.4117	0.3474 ***	1.6348	0.3297 ***
$\ln(y_{jt-1})$	-0.5995	0.0660 ***	-0.6269	0.0703 ***	-0.6563	0.0467 ***	-0.6843	0.0448 ***
$\ln\left(\frac{N_{jt-1}}{S_j}\right)$	-0.3936	0.1255 ***	-0.3859	0.1288 ***	-0.4806	0.0965 ***	-0.4778	0.0829 ***
$\ln\left(\frac{y_{jt-1}}{y_{t-1}}\right)$	-1.0123	0.4341 **	-0.7028	0.4051 *	-0.6418	0.3046 **	-0.6458	0.2534 **
$\ln\left(\frac{Y_{jt-1}}{Y_{t-1}}\right)$	0.0075	0.0885	-0.0588	0.0734	-0.0428	0.0742	-0.0805	0.0502
Implicit η	0.6565	0.2214 ***	0.6155	0.2167 ***	0.7323	0.1560 ***	0.6982	0.1295 ***
Oneparty	0.0131	0.0511	0.0133	0.0487	0.0647	0.0351 *	0.0618	0.0290 **
Lag oneparty	0.0271	0.0512	0.0245	0.0489	-0.0130	0.0350	-0.0183	0.0291
Election	0.0192	0.0360	0.0193	0.0340	0.0373	0.0234	0.0503	0.0219 **
Lag election	-0.0094	0.0351	-0.0014	0.0333	-0.0030	0.0228	0.0132	0.0214
Individual effects	Yes		Yes		Yes		Yes	
Time effects	Yes		Yes		Yes		Yes	
R^2	0.9185		0.9338					
H^{FR}	32.5969	(0.0000)						
G test	154.2500	(0.0000)						
W^{SC} test	195.3679	(0.0000)						
BP test	372.8340	(0.0000)						
$\eta = \mathbf{1} (\beta_3 = \beta_2)$	4.8734	(0.0273)	7.0318	(0.0080)	4.0735	(0.0436)	11.8248	0.0006
$\beta_4 = -1$	0.0008	(0.9774)	0.5384	(0.4631)	1.3828	(0.2396)	1.9529	(0.1623)

Notes: Number of observations: 408. Number of groups: 17.

***, **, * significant at the 1%, 5% and 10% levels, respectively.

Table 8. Estimation for the total public investment allocation of the central government

Dependent variable: Log of the public investment as a share of public capital stock									
Including decentralization variables									
	PW(AR1)		PW(PSAR1)		FGLS (AR1)		FGLS (PSAR1)		
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	
$\ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$	0.9155	0.3141 ***	1.0828	0.2908 ***	1.1219	0.2265 ***	1.3325	0.1896 ***	
$\ln(y_{jt-1})$	-0.6468	0.0430 ***	-0.6749	0.0408 ***	-0.6586	0.0324 ***	-0.6995	0.0281 ***	
$\ln\left(\frac{N_{jt-1}}{S_j}\right)$	-0.3115	0.0761 ***	-0.3628	0.0822 ***	-0.3825	0.0502 ***	-0.4508	0.0479 ***	
$\ln\left(\frac{y_{jt-1}}{y_{t-1}}\right)$	-0.5931	0.2621 **	-0.3674	0.2410	-0.5939	0.1763 ***	-0.3598	0.1216 ***	
$\ln\left(\frac{Y_{jt-1}}{Y_{t-1}}\right)$	-0.0711	0.0532	-0.0891	0.0373 **	-0.0786	0.0440 *	-0.0948	0.0241 ***	
Implicit η	0.4817	0.1219 ***	0.5376	0.1261 ***	0.5808	0.0813 ***	0.6444	0.0733 ***	
$\ln(FA_{jt-1})$	-0.1583	0.0846 *	-0.1663	0.0858 *	-0.1054	0.0399 ***	-0.1129	0.0301 ***	
$\ln(IA_{jt-1})$	-0.5259	0.1305 ***	-0.5179	0.1236 ***	-0.3297	0.0566 ***	-0.3994	0.0450 ***	
Individual effects	Yes		Yes		Yes		Yes		
Time effects	Yes		Yes		Yes		Yes		
R^2	0.9705		0.9753						
H^{FR}	89.5913	(0.0000)							
G test	153.2600	(0.0000)							
W^{SC} test	136.6173	(0.0000)							
BP test	319.1560	(0.0000)							
$\eta = \mathbf{1} (\beta_3 = \beta_2)$	30.5007	(0.0000)	27.5144	(0.0000)	60.5316	(0.0000)	80.1309	0.0000	
$\beta_4 = -1$	2.4103	(0.1205)	6.8930	(0.0087)	5.3087	(0.0212)	27.6999	(0.0000)	

Notes: Number of observations: 408. Number of groups: 17.

***, **, * significant at the 1%, 5% and 10% levels, respectively.