A Model for the Distribution of Public Investment among Jurisdictions

Henry Aray[⸸]
University of Granada

Jorge Martínez-Vázquez[†]
Georgia State University

April 2026

Abstract

This article proposes a theoretical framework to bridge the gap between theoretical and empirical literature on the criteria policymakers use to distribute public investment across jurisdictions. Policymakers maximize a social welfare function that accounts for both output per capita and output density, subject to relevant constraints. The resulting first-order conditions yield a tractable function for the ratio of public investment to the total public capital stock on the main economic criteria suggested by previous empirical literature, facilitating both estimation and policy interpretation. Using data for Spanish regions over the period 1986–2021, we find that the coefficients associated with these criteria are statistically significant and display the expected signs. We estimate the weights of the output measures in the social welfare function and suggest that output density should not be overlooked. The results are robust across estimation methods, the inclusion of control variables, and sensitivity analysis.

Keywords: Public investment criteria, CES functions, Output density, Output per capita.
JEL Codes: H40; H54; C23.

⸸ Corresponding author. Department of Economic Theory and Economic History (University of Granada); e-mail: haray@ugr.es.
† International Center for Public Policy (Georgia State University) and Governance and Economics Research Network (GEN); e-mail: jorgemartinez@gsu.edu

1. Introduction

Two critical issues concerning public capital stock are achieving an adequate or optimal level, and ensuring a fair geographical distribution. Regarding the first issue, many developed countries have been experiencing stagnation in public capital stock per capita,[1,2] whereas numerous developing countries continue to face challenges in reaching sufficient levels. In relation to the geographical distribution issue, the general principle in practice in developed countries has been to allocate public investment across jurisdictions (states, regions, municipalities, etc.) in order to reduce geographical per capita income disparities and aiming at social cohesion, without neglecting national economic growth.[3]

This paper focuses on the second issue, 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 equity-efficiency trade-off, often neglecting other potential important criteria, like those accounting for spatial considerations. In fact, this literature has traditionally relied on an objective function based on total output or output per capita. On the other hand, although numerous empirical studies have proposed 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 established theoretical economic model. In summary, neither the theoretical literature has provided a conceptually comprehensive framework, nor has the empirical literature 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 empirical literature regarding the criteria for distributing public investments across jurisdictions. This framework will be useful in addressing several interesting and unresolved research questions, including: How to possible go beyond the traditional equity-efficiency trade-off proposed by existing theoretical

[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.

literature. Where might the criteria used in empirical studies come from? What are the expected signs of the coefficients for the criteria proposed in the empirical literature?

The primary contribution of this article is therefore to develop a comprehensive quantitative theoretical framework that incorporates both economic and spatial dimensions, enabling empirical evaluations of the geographical distribution of public investment across jurisdictions.

Inspired by the new economic geography (NEG) and economic growth literature that considers the spatial dimension, as well as the more recent debate on place-based versus place-neutral regional economic development policies,[4] and the geography of discontent,[5] we propose a theoretical model 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 previous theoretical literature, but also output density. The maximization problem is constrained by the production functions, the laws of motion of public capital stocks of the jurisdictions, and a resource constrain.

The introduction of the output density in the social welfare function is a major novelty in urban and regional economic models. It allows us to move beyond the one-dimensional approach of considering per capita output as the sole driver of welfare. It recognizes that well-being depends on the richness of a jurisdiction as much as on the productivity of its territory. Therefore, the typical equity-efficiency trade-off for public investment distribution is not only limited to consider the output per capita, but also output density. In this scenario, the policymaker must deal with two key issues: the dispersion of output per capita and the dispersion of output density. These issues must be thoroughly considered when allocating public investment across different jurisdictions.

From the theoretical model, we can obtain a tractable equation for empirical implementation in which the public investment-to-public capital stock ratio is a function of the main criteria proposed by the empirical literature.

To the best of our knowledge, this is the first article that provides theoretical underpinnings for the economic criteria for allocating public investment across jurisdictions proposed by the empirical literature. Furthermore, our approach is sufficiently flexible to accommodate additional criteria and alternative outcome variables.

[4] This debate come from the analysis of a series of highly influential reports about regional development policy intervention in a globalized world (see Barca, et al., 2012).
[5] This literature posits that regional inequalities and the neglect of peripheral areas can generate significant economic and political risks (see Rodríguez-Pose, 2018 and Dijkstra, et al., 2020).

Derivations of hypotheses concerning the values and signs of the coefficients can be made from the model.

We then turn to empirical implementation to shed light on the optimal allocation of public investment across jurisdiction and the criteria followed to such an end. Data from the Spanish regions (autonomous communities) over the 1986-2021 period are used.

The empirical results shows that the criteria are significant and exhibit the expected signs. Furthermore, the findings highlight the importance of output density as a key variable to be considered in social welfare functions involving the distribution of public funds across jurisdictions. This is an intriguing development, as the existing theoretical literature has typically focused on functions based on output or output per capita. Additionally, the model demonstrates a strong goodness of fit, and the results remain robust across various estimation methods, the inclusion of control variables, and sensitivity analysis.

The remainder of this paper is organized as follows. Section 2 reviews the literature. Section 3 outlines the main variables proposed in previous empirical studies 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 estimation issues and presents the empirical results. Section 7 provides robustness checks, while Section 8 addresses policy implications, and Section 9 offers conclusions.

2. Related literature

Academic interest in the distribution criteria for public investment dates to the 1950s, just after World War II. The works by Kahn (1951) and Chenery (1953) introduced the criterion of efficiency as a starting point for the allocation of resources.[6] 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, as a measure of the efficiency criterion. From this perspective, the objective function to be maximized was the national output. However, Galenson and Leibenstein (1955)

[6] 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.

questioned the appropriateness of maximizing the national product level and instead proposed per capita output (income) as the objective function.

Interestingly, all these early works adopted a whole country perspective. To the best of our knowledge, the first articles to study the allocation of public funds across the states/regions of a country were Stewart (1967) and Mera (1967). Stewart (1967) emphasized the marginal return of public investment as the 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) pointed out that policies aiming to improve interregional equity could conflict with the maximization of national output, which he called the goal of efficiency, and suggested 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. Eckstein (1957; 1961) developed 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 that focused on income distribution as the target for the allocation of public investment. However, 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. However, their empirical analysis is limited to the traditional equity-efficiency trade-off and the estimation of the inequality aversion parameter of the social welfare function. Following Behrman and Craig (1987), Castells and Solé-Ollé (2005) introduced output per capita as the main argument of the social welfare function and further developed the equity-efficiency trade-off, providing evidence on the infrastructure needs of jurisdictions. Two other related papers by Caminal (2004) and De la Fuente (2004) developed theoretical models in which the policymaker distributes funds for public infrastructure investment across regions to maximize social welfare. These studies are fundamentally theoretical contributions, including in some cases, some simple empirical applications.

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 output per unit of public capital stock of the jurisdiction as the efficiency criterion, and per capita output 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 output to measure redistribution and the ratio between the public capital stock of the jurisdiction and its geographic size (density of public capital stock) to measure equity. This ratio aims to capture the degree of evenness of the public capital stock across different 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 by proposing the feature of neutrality, which is calculated as the weighted geometric mean between public capital stock per capita and the density of public capital stock. In this way, the equity criterion is nested into the neutrality criterion. Along a similar line of thought, population density has been proposed to capture special infrastructure needs. On the one hand, Rodríguez-Oreggia and Rodríguez-Pose (2004) and Lambrinidis et al. (2005) argued that population density accounts 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 et al. (2016) posited that a negative correlation between public investment and population density should be expected given the higher cost of delivering public goods in remote and low-density jurisdictions.

The aforementioned criteria can be classified under the umbrella term "economic criteria," which will be the primary focus of this paper. Other non-economic criteria, such as political factors, are presumed to play also a role in explaining the actual distribution

of public funds across jurisdictions (Cadot et al., 2006; Castells and Solé-Ollé, 2005). While our theoretical model does not explicitly account for the political criterion and others criteria, it is sufficiently flexible to accommodate variables capturing them.

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

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 jurisdiction *j* in time *t* as follows

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

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 the following:

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

Which is often proxied in empirical applications by the average productivity of the public capital stock:

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

- **Redistribution**

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

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

Being N_{jt} the total population of jurisdiction *j*.

- **Equity**

The criterion posits that jurisdictions converge to an equal ratio:

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

Being S_j 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 weighted 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, and the cost of delivering public goods in remote jurisdictions:

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

4. Theoretical model

The whole economy is composed of *J* jurisdictions. Let us consider the representative jurisdiction *j* produces in time *t* according to a CES production function with constant return 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.

The CES function production in equation (1) is much more flexible than the Cobb-Douglas production function with constant return, in fact, the former nests the latter if $\omega_j = 0$, in such a case the elasticity of substitution is equal to 1, what means that the shares of expenditures in inputs are constant regardless the inputs' prices variations. Instead, in equation (1) the shares of expenditures in inputs can increase or decrease as a

result of inputs' prices changes depending on the value of ω_j. Thus, equation (1) is able to capture different technology of production, including the polar cases of perfect substitution ($\omega_j \to 1$) and perfect complementarity ($\omega_j \to -\infty$) among inputs.

In regard to the public capital stock input, Dabla-Norris et al. (2012) pointed out that that only a fraction of the actual accounting cost of public investment passes into the value of public capital, and proposed a multidimensional public investment efficiency index covering project appraisal, selection, implementation, and evaluation. The empirical evidence provided by Dabla-Norris et al. (2012) shows that inefficiencies at any stage can undermine investment outcomes and warned of the fact that cross-national estimates of physical capital are based on the assumption of full efficiency of public investment.

In order to capture in our model the Dabla-Norris et al.'s concern, and in the spirit of Lucas and Prescott (1971), we assume that public investment and public capital stock are non-linearly related. Following Hercowitz and Sampson (1991), let that the public capital stock in jurisdiction j, G_{jt}, accumulate according to the following law:

$$G_{jt} = B_{jt} G_{jt-1}^{1-\sigma_j} C_{jt}^{\sigma_j}, \qquad 0 < \sigma_j < 1 \tag{2}$$

Where C_{jt} is the public investments made by the policymaker (the planner)[7] in jurisdiction *j* in period *t*.

One of the main advantages of equation (2) over the typical lineal approach for capital accumulation, is that investment does not translate into new capital one for one. The parameter σ_j measures the elasticity of public capital with respect to public investment, capturing the average efficiency with which spending is transformed into productive public capital. Low values of σ_j reflect institutional frictions, implementation delays, and efficiency losses, while high values of σ_j indicate a greater capacity to convert investment into effective capital. Therefore, σ_j affect the return of the public investment. This is also in line with the recent literature that shows that the quality of government institutions and the effectiveness of investment management are crucial determinants of both the allocation of public investment and its returns (Rodríguez-Pose and Ketterer, 2020, Balaguer-Coll et al., 2022).

[7] In the empirical implementation, the planner's aggregate investment encompasses investments from the central government, regional government, autonomous entities, and public and private firms. This approach enables the utilization of the most recent data.

Moreover, as assumed by Hercowitz and Sampson (1991), capital accumulation is generally subject to an exogenous shock, $B_{jt} > 0$,[8] which can be also interpreted as an efficiency shock capturing institutional quality.

According to Cassou and Lansing (1998), equation (2) reflects 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 behavior of an aggregate stock that is measured by adding up different types of capital, which individually display different depreciation characteristics. This assumption is appropriate 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 first note that, as Freeman (1967) had already pointed out, the choice of the form is a value of judgement. Following Behrman and Craig (1987), Castells and Solé-Ollé (2005) adopted the CES specification, denoted by W_t^{CS}, allowing for varying degrees of relative jurisdictions' inequality aversion and the unequal treatment of jurisdictions with the same output levels:

$$W_t^{CS} = \left[\sum_{j=1}^{J} \mathrm{V}_{jt} N_{jt} \left(\frac{Y_{jt}}{N_{jt}}\right)^{\rho}\right]^{\frac{1}{\rho}} \tag{3}$$

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

In equation (3), V_{jt} addresses the equal-versus-unequal concerns across regions and can be interpreted as weights. In this regard, Eckstein (1961) had pointed out that policymakers can attach any weights they wish to the jurisdictions.[9]

[8] Note that B_{jt} and σ_j govern the relationship between new investment and the public capital stock. Thus, whenever $B_{jt} = 1$ and $\sigma_j = 1$, the stock of public capital depreciates fully after one period, while it is long-lasting if $0 < \sigma_j < 1$.

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

Unless spatial variables are included in V_{jt}, using equation (3) as the objective function implies distributing public investment based on a spatially-blind strategy, that is, without explicit consideration of space, and focused exclusively on the equity-efficiency trade-off in output per capita.

The NEG (Krugman, 1991) emphasizes the benefits of the spatial clustering of inputs in promoting increasing returns and positive spillovers across firms, which affects the geographical distribution of economic activities.[10] Moreover, Martin and Rogers (1995) showed that a reduction in interregional transport costs, largely due to public infrastructure investment, would encourage firms and workers to agglomerate in core regions. As a result, spatial differences in production between core and peripheral regions would increase.[11] This conclusion had already been reached in the early work of Hirschman (1958), who warned that investment in transportation infrastructure at the national level could result in gains and losses for regional economies. This phenomenon, which he called "leaking by linking," underscores the potential trade-offs associated with such investments. It is also noteworthy that many countries are grappling with the challenge of preventing the depopulation of certain regions. In many cases, this is being addressed by building additional transport infrastructure. Martin and Rogers (1995) shed light on this issue by highlighting the positive effects of infrastructure that promotes internal trade in peripheral regions on the location of firms in such regions.

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 may be an important factor in economic growth. They provided empirical evidence showing that the density of economic activity is positively related to labor productivity and total factor productivity and concluded that increasing returns to density play a crucial role in explaining the large differences in average labor productivity across U.S. states. Thus, spatial externalities are driven by the density of production in a country/region (Ciccone, 2002). In addition, Davis et al. (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.

[10] Hidalgo *et al.* (2007) found that more sophisticated products are produced in densely connected areas, while less sophisticated products are produced in less connected peripheral regions.
[11] Puga (2002) also warned of the increased inequalities between regions within each EU Member State in spite of the large budget of the EU regional policy.

Linking the NEG and economic growth literature, Martin (1999) showed that public policies that attempt to influence economic geography through public infrastructure to achieve a more equal spatial distribution of economic activity could result in lower aggregate economic growth. Thus, there is a trade-off between spatial equity in industrial location and aggregate growth.

The insights of the NEG and spatial economic growth literature cross with the recent debate on regional policy implementation raised by Barca et al. (2012), Rodríguez-Pose (2018) and Dijkstra et al. (2020).

Barca et al. (2012) state that globalization is shaping economic geography of places, which must be taking into account by the regional policy. Therefore, a place-based approach for policy intervention should be implemented and accounting for the geographical context, which can be understood in terms of social, cultural and institutional characteristics. In fact, this literature posits that the clues for development lies in the interactions between geography and institutions. Moreover, Barca *et al*. (2012) suggest that aggregate output can be maximized by developing places of different sizes and densities rather than top urban places. Place-based regional policies could also be helpful in tackling the issue of the geography of discontent raised by Rodríguez-Pose (2018) and Dijkstra *et al*. (2020), who warned on the social and political consequences of limited employment opportunities and declining per-capita income in some regions relative to national average.

Incorporating the insights from the NEG literature and spatial economic growth, as well as, the suggestions by the place-based versus place-neutral approaches, and the geography of discontent for regional policy implementation, we expand equation (3) to the fuller social welfare function:

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

Where $\eta \in [0,1]$. The expanded function in equation (4) is a social welfare function that considers output per capita and output per unit of surface (output density). Note that if $\eta = 0$, then equation (4) is the Castells and Solé-Ollé'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).

The social welfare function in equation (4) is a sophisticated extension of traditional urban and regional economic models. Its main advantage is that it moves away from the one-dimensional approach of considering per capita income as the sole driver of welfare. It allows for a hybrid balance, recognising that well-being depends as much on the richness of a jurisdiction as on the productivity of its territory. This has hitherto been disregarded by models that exclusively consider output per capita. Indeed, as can be seen in equation (4), the policymaker is not only averse to output per capita inequality, but also to output density inequality Therefore, equation (4) also enables a trade-off between agglomerated jurisdictions that frequently experience congestion, and peripheral jurisdictions with limited infrastructure needs. This is a significant issue that must be given full consideration when allocating public investment.[12]

We rewrite equation (4) for the case in which $V_{jt} = 1$,[13] and thus, we obtain:

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

The policymaker'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,

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

where I_t 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 to study the distribution of public investment funds across jurisdictions.

The first order condition of the problem provides: [14]

$$\frac{C_{jt}}{G_{jt}} = A_{jt} \left(\frac{Y_{jt}}{G_{jt}}\right)^{-\omega_j} y_{jt}^{\rho} \left[\left(\frac{G_{jt}}{N_{jt}}\right)^{1-\eta} \left(\frac{G_{jt}}{S_j}\right)^{\eta}\right]^{-1} \left(\frac{N_{jt}}{S_j}\right)^{\eta\rho} \tag{6}$$

With $A_{jt} = \frac{W_t^{1-\rho} \sigma_j \alpha_{jG}}{\lambda_t}$.

[12] In a broader sense, our approach could also be useful for addressing megatrends, such as population aging, climate adaptation, digitalization, and migration. These megatrends clearly have spatial dimensions (see OECD, 2022).

[13] Empirical evidence for cases with variable V_{jt} will be provided in the robustness check section.

[14] The appendix shows the details.

Equation (6) becomes the benchmark equation. The left-hand side is the public investment-to-public capital stock ratio.[15] It should be noted that all economic criteria for public investment allocation among jurisdictions (described in the previous section) are obtained from our model. This is a significant contribution, as it bridges the theoretical and empirical literature. 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). If $\omega_j = 0$ (Cobb–Douglas production function), $\frac{Y_{jt}}{G_{jt}}$ disappears from the equation (6).

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.[16] If $\rho = 0$ (Cobb–Douglas social welfare function), y_{jt} disappears from the equation (6).

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 ratio $\frac{C_{jt}}{G_{jt}}$. Notice that it becomes the equity criterion $\left(\frac{G_{jt}}{S_j}\right)$ if $\eta = 1$. Moreover, 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, ($\rho < 0$) $0 < \rho < 1$, and $0 < \eta \leq 1$. If $\rho = 0$ (Cobb–Douglas social welfare function), $\frac{N_{jt}}{S_j}$ disappears from the equation (6). Furthermore, it should be noted that in the event that $\eta = 0$, $\eta = 0$, the spatial criteria will be eliminated from equation 6. Consequently, the criteria are constrained to the equity-efficiency trade-off in per capita output.

It is important to note that because the variables of the welfare function depend on a production function that uses public capital stock as an input, which is then modeled as a nonlinear function of public investment, the optimal investment levels obtained for the jurisdictions will be affected by the parameters that capture the efficiency in the

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

[16] Behrman and Craig (1987) pointed out that the curvature of the social welfare function depends on the parameter ρ. Thus, ρ captures the equity-efficiency trade-off, that is, it indicates the relative trade-off between equity and concern over maximizing of the aggregate output.

investment process to transform into effective public capital (B_{jt} and σ_j). It is also worth noting that the marginal product of public capital stock depends on the parameters α_{jG} and ω_j. Although the model does not explicitly distinguish the different stages of the public investment cycle, the multidimensional efficiency losses emphasized by Dabla-Norris et al. (2012) are embedded in the model.

5. Empirical strategy

The model developed above is instrumental for bridging the existing gap between the theoretical and empirical literature 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 jurisdictions 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 make several further assumptions. First, randomness must be considered. Second, as suggested by Castells and Solé-Ollé (2005), the most recent information that the policymaker might have available to plan the allocation of public infrastructure is that from the previous period. Therefore, all variables on the right-hand side in equation (6) are expressed in one lag.[17] Thus, equation (6) is rewritten as follows

$$\frac{C_{jt}}{G_{jt}} = A_{jt}\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)^{-\omega_j} y_{jt-1}^{\rho}\left[\left(\frac{G_{jt-1}}{N_{jt-1}}\right)^{1-\eta}\left(\frac{G_{jt-1}}{S_j}\right)^{\eta}\right]^{-1}\left(\frac{N_{jt-1}}{S_j}\right)^{\eta\rho} e^{\varepsilon_{jt}} \qquad (7)$$

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 this problem, we could remove some variables, for example, the variables $Ln\left(\frac{G_{jt-1}}{N_{jt-1}}\right)$ and $Ln\left(\frac{G_{jt-1}}{S_j}\right)$. Nevertheless, the disadvantage of eliminating variables from the equation to be estimated is that it may result in erroneous interpretations of certain parameter estimates by assuming they remain constant after the removal of 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,

[17]Incidentally, this assumption also helps to avoid endogeneity issues.

$$\frac{C_{jt}}{G_{jt}} = A_{jt}\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)^{1-\omega_j} y_{jt-1}^{\rho-1}\left(\frac{N_{jt-1}}{S_j}\right)^{\eta(\rho-1)} e^{\varepsilon_{jt}} \quad (8)$$

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.

By taking logs in equation (8), we get

$$Ln\left(\frac{C_{jt}}{G_{jt}}\right) = \delta_j + \tau_t + \beta_1^j Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right) + \beta_2 Ln\left(y_{jt-1}\right) + \beta_3 Ln\left(\frac{N_{jt-1}}{S_j}\right) + \varepsilon_{jt} \quad (9)$$

Where $\beta_1^j = 1 - \omega_j$, $\beta_2 = \rho - 1$, $\beta_3 = \eta(\rho - 1)$ and $\delta_j + \tau_t = Ln\left(A_{jt}\right)$.

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 ($\rho < 1$).

Notice that the only criterion that is not explicitly collected in equation (9) is the neutrality criterion. However, we can obtain the implicit estimate and standard error of the parameter η (β_3/β_2) 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 unobserved individual and time effects, respectively. In fact, it can be noticed that $\delta_j = Ln\left(\sigma_j \alpha_{jG}\right)$ and $\tau_t = Ln\left(\frac{W_t^{1-\rho}}{\lambda_t}\right)$. As previously stated, our model explicitly captures the warning noted by Dabla-Norris et al. (2012) through the individual effect δ_j. This is achieved by the parameters σ_j, which measures the average efficiency with which public investment is transformed into productive public capital stock in jurisdiction *j*, and α_{jG}, which serves as a measure of the technological importance or relative weight of input G_{jt} in generating output in jurisdiction *j*.

6. Data and Estimation results

For the estimation, we use data for the seventeen Spanish autonomous communities (NUTS2) over the period 1986-2021.[18] Data on public investment and capital stock in public infrastructure with base year 2020 are from the BBVA Foundation and the Economic Research Institute of Valencia (Ivie). We use data on productive capital stock

[18] The smaller "Autonomous cities" of Ceuta and Melilla are excluded.

in public infrastructure[19] instead of net public capital stock in public infrastructure. As outlined in section 3, the production process involves the use of various types of capital goods, each with its own characteristics. It is important to note that differences in characteristics also imply differences in the flow of services they provide. From a production theory perspective, the focus is on the flows of services that the public capital stock provides rather than its market value (net stock of public capital). Both, hard infrastructure and soft infrastructure are included. 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. Others 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.[20] Since constant value for productive public capital stock are not available, we use the volume index of productive capital stock in public infrastructure with base year 2020 to construct a series of constant productive capital stock in public infrastructure departing from the current value in 2020 of the net capital stock in public infrastructure.

With regard to public investment, the recently updated database by the BBVA Foundation-Ivie provides information on public investment by asset type and branch of activity. It does not, however, break this down by the main investing agent. Therefore, the investment data used corresponds to the total aggregate of the central government, the autonomous communities, autonomous entities and public and private firms.[21] This constitutes a limitation in the empirical implementation that would be offset by the availability of more up-to-date data.[22]

Population as well as the data used to construct the output variable (constant gross value added, GVA, with base year 2020) come from FEDEA.[23] Surface data are from the National Geographic Institute (ING).[24]

[19] Productive capital stock is a way of measuring the loss of efficiency that comes from ageing, and it is related to the cost of using capital.
[20] 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.
[21] Public investment in infrastructure by local governments are not included. On average, they were less than 10 percent of total public investment during the study period.
[22] Data can be found at https://www.fbbva.es/bd/el-stock-y-los-servicios-del-capital-en-espana/.
[23] Data can be found at https://fedea.net/datos/.
[24] Data can be found at https://www.ign.es/web/ign/portal/comunidades-autonomas.

The upper panel of Table 1 shows correlation across the variables of the model. Multicollinearity diagnostics are shown in the lower panel of Table 1, which show that no serious multicollinearity problems are faced.

Table 2 shows the results obtained from estimating equation (9) and test results for the hypotheses of the main problems faced dealing with the data at hand (p-values in parentheses). The Green test (G test) rejects the null hypothesis of homoscedasticity and the Wooldridge test (W^{SC}) rejects the null hypothesis of no serial correlation. In addition, the Breusch-Pagan test (BP test) of independence shows evidence on cross-sectional correlation. In such cases, the Hausman test for fixed and random effects is not valid. Therefore, we provide the Sargan-Hansen statistic of overidentifying restrictions (SH^{FR}) to test for fixed versus random effects, which shows evidence in favor of the fixed effects model.

Although, the introduction of the explanatory variables in one lag avoids endogeneity problems, there could still be suspicions of endogeneity of the variable $Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$. Table 2 also shows the Durbin–Wu–Hausman test (DHW test) robust to heteroscedasticity, autocorrelation and cross-correlation, which does not reject the hypothesis of exogeneity of the variable $Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$. The Sargan-Hansen statistic (SH^{IV}) supports cautiously the validity of the instruments.[25]

Given that our panel data violate standard OLS assumptions due to complex error structures, we provide results using the Driscoll and Kraay (DK) estimator and panel-corrected standard errors (PW-PCSE), taking into account heteroscedasticity, correlation across panels and autocorrelation, and assuming $\beta_1^1 = \beta_1^2 = \cdots = \beta_1^{17} = \beta_1$ ($\omega_1 = \omega_2 = \cdots = \omega_{17} = \omega$). DK estimator provides a nonparametric covariance matrix estimator robust to heteroskedasticity, contemporaneous cross-sectional dependence, and serial correlation of unknown form. PW-PCSE provides a covariance matrix estimator that explicitly accounts for panel-level heteroskedasticity and contemporaneous cross-sectional correlation across units, while serial correlation is addressed through the

[25] The second, third and fourth lags of the variables $Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$, $Ln(y_{jt-1})$ and $\frac{Y_{jt-1}}{G_{jt-1}}$ were used as instruments.

parametric assumption of a panel-specific first-order autoregressive error process AR(1).[26]

To further validate the empirical findings, we estimated a mixed-effects maximum likelihood model, which explicitly models multiple layers of dependence in the data (Multilevel estimation). The model has three components. First, we include a common year-level random effect that loads equally on all regions. This captures aggregate temporal shocks shared across units and accounts for contemporaneous cross-sectional dependence through a single latent time factor. Second, the model incorporates random intercepts and a random slope only for the regressor $Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$, allowing for region-specific unobserved heterogeneity, as specified by the theoretical model. It also incorporates an unstructured covariance matrix that freely estimates the variances of the intercepts and of the parameters β_1^j, as well as their covariance. It also allows the conditional variance of the outcome to differ across units through random coefficients without imposing unit-specific heteroskedasticity in the idiosyncratic error term. Third, we specify a parametric AR(1) process for the residuals to account for within-region serial correlation over time.

As can be seen in Table 2, the results from the three estimation methods provide strong evidence of robustness for the parameter estimates and strong goodness of fit. As expected, the efficiency criterion shows a positive coefficient, which is significant at the 1% level across all the estimation methods. We also provide in Table 2 test of the hypothesis $\beta_1 = 1$ ($\omega = 0$), which is not rejected across all the estimation methods (p-values in parentheses), and suggesting that, on average, the Spanish regions produce according to Cobb-Douglas production functions. The redistribution criterion also shows the expected negative coefficient ($\beta_2 < 0$), which is significant at the 1% level in all cases, and indicating that the hypothesis $\rho = 1$ is rejected. Therefore, the public investment-to-public capital stock ratio is negatively correlated with output per capita, which suggests that policymakers are averse to output inequality ($\rho < 1$).

The findings concerning the efficiency and redistributive criteria are consistent with those reported in earlier studies.

[26] Beck and Katz (1995) demonstrated the superiority of panel-corrected standard error estimates (PW-PCSE) in comparison to feasible general least squares (FGLS) estimates. The results obtained through the implementation of the FGLS method are available upon request.

Table 2 also shows test of the hypothesis $\beta_2 = -1$ ($\rho = 0$), which is not rejected across all the estimation methods (*p*-values in parentheses). Using data from the Spanish autonomous communities, Castells and Sole-Olle (2005) and Sole-Olle (2013) provided estimates for ρ of approximately 0.4 for the period 1987–1996 and 0.5 for the period 1978–2004, respectively. Our estimation of ρ close to zero may indicate that policymakers have become more output inequality averse over time.

The spatial dimension also plays a role, as the coefficient for population density shows a negative and significant coefficient at different confidence levels in all cases. Notice that the estimated sign for population density is in line with the theoretical model prediction regarding the policymakers' aversion to output inequality, as found from the estimation of $\beta_2 < 0$ ($\rho < 1$). Therefore, the results show that the public investment-to-public capital stock ratio is negatively correlated with population density as found by Lambrinidis et al. (2005), Mizutani and Tanaka (2010), Rodríguez-Pose et al. (2016) and Aray (2019).

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 the 1% level in all cases. It can also be checked in equation (7) that the neutrality criteria would have the expected sign in line with De La Fuente and Vives (1995). Thus, $\frac{G_{jt-1}}{N_{jt-1}}$ (public capital stock per capita) and $\frac{G_{jt-1}}{S_j}$ (density of the public capital stock) are negative correlate with the public investment-to-public capital stock ratio.

Remember that η is also the parameter that weighs the two arguments of the social welfare function in equation (4). The estimation results show that η is between 0.36 and 0.77, meaning that output per capita has been weighted 23%-64% in the social welfare function, while output density accounted for 36%-77%. We go further and test the hypothesis $\eta = 1$ ($\beta_3 = \beta_2$), which is not rejected in three (two) out of the four estimation methods (*p*-values in parentheses). This finding indicates that policymakers have allocated public investment based on both output per capita and output density, with a potential bias toward output density.

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

Our findings reveal an important role of the spatial dimension in the distribution of public investment that goes beyond the traditional equity-efficiency trade-off in per capita output. Policymakers are found to be averse not only to inequality in per capita output across jurisdiction, but also, to inequality in output density. This has significant implications for place-based policies as pointed out by Barca *et al*. (2012) and for spatial justice as warned by Rodríguez-Pose (2018) and Dijkstra et al. (2020).

Instead of supporting the simple argument of efficiency for investing in already dense areas (agglomerated jurisdictions), our estimates show that policymakers aim to balance investments between regions with low and high output density, similar to how they approach per capita output. This dual concern aligns with recent OECD (2022) recommendations that regional development strategies address multiple dimensions of spatial disparities simultaneously. Attention to output density reflects the recognition that the spatial concentration of economic activity itself represents a form of territorial inequality that generates distinct challenges. Sparse regions face higher per-unit costs for public services, limited access to markets and amenities, and population decline, while agglomerated regions have to deal with the issue of congestion.

However, the effectiveness of such redistributive investments is contingent on the institutional quality and governance capacity at the regional level. As demonstrated by Rodríguez-Pose and Ketterer (2020) and Balaguer-Coll et al. (2022), government quality and efficiency are central mediators of how public investment translates into regional development outcomes. Poor institutional quality can substantially erode the impact of infrastructure spending. Our theoretical framework is designed to account for these institutional dimensions. In the empirical implementation, jurisdiction-specific effects capture all time-invariant regional characteristics, including persistent differences in governance quality, administrative capacity, bureaucratic efficiency, and institutional frameworks across regions. While we do not observe time-varying governance indicators[27] that would allow us to directly test whether improvements in institutional

[27] The data from the European Quality of Government (QoG) is only available for the years 2010, 2013, 2017, 2021, and 2024. Due to the annual nature of the sample period, which spans from 1986 to 2021, it is not possible to utilise this data. Moreover, the index remains relatively stable across all Spanish regions during this period. See the data at https://www.gu.se/en/quality-government/qog-data. Secondly, we collected data from Spanish sources using the Regional Competitiveness Index (ICREG), published by the General Council of Economists of Spain. Specifically, the focus was on dimension 4 (Institutional Environment), yet once more, data was found to be scarce, limited to rankings, and exhibited minimal variability. Data is available at: https://catedracompetitividad.com/publicaciones/informe-competitividad-regional.

capacity translate into higher investment shares, our approach ensures that our key findings are not driven by permanent differences in government quality across regions.

7. Robustness Checks

7.1. Introducing control variables

Population share

It is reasonable to assume that policymakers assign weights to the jurisdictions in the social welfare function based on population shares. In this scenario, we can assume that $V_{jt} = \frac{N_{jt-1}}{N_{t-1}}$. As shown in columns 2 to 5 of Table 3, the results of PW-PCSE and multilevel estimations of equation (9) are presented.[28] This includes the estimate of the coefficient of the variable $Ln\left(\frac{N_{jt-1}}{N_{t-1}}\right)$, which is not significant. As can be seen, the results for the economic criteria are largely consistent with those shown in Table 2.

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 $V_{jt} = e^{D'_{jt}\theta}$, 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 holds office simultaneously in the central and regional governments, and zero otherwise (partisan alignment), and a second dummy variable that takes on the value 1 in years in which 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.[29]

Columns 6-11 of Table 3 shows the results of estimating equation (9) including the political variables. As can be observed, the results for the economic criteria are largely consistent with those shown in Table 2. Regarding the political variables, a positive and significant coefficient is obtained for the lag of the dummy variable that captures partisan alignment with the DK estimator.[30]

[28] The Driscoll-Kraay fixed-effects estimator does not yield a coefficient for $Ln(N_{jt-1}/N_{t-1})$ due to perfect multicollinearity among the regressors after the within-group transformation.
[29] Sources can be found in www.worldstatesmen.org and www.interior.gob.es.
[30] 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

Decentralization variables

Spain is a highly decentralized country, with regional governments maintaining high but also different levels of autonomy. To explore the role such heterogeneity may play, we may assume that decentralization indicators are taken into account to allocate public investment. In this case we assume that $V_{jt} = FA_{jt-1}^{\phi_1} NC_{jt-1}^{\phi_2}$, where FA_{jt-1} captures the level of financial autonomy, i.e. fiscal decentralization. It is 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. The variable NC_{jt-1} is a general indicator of the decision-making authority of the regions. It can be interpreted as a variable that captures the degree of administrative decentralization. The number of royal decrees of transfers of competencies are used to proxy the number of competencies actually transferred to the regions.[31] ϕ_1 and ϕ_2 are the parameters.

Columns 12-17 of Table 3 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 those in Table 2. Regarding the decentralization variables, the findings indicate that the coefficient of the variable measuring financial autonomy (fiscal decentralization) is positive and significant only with the DK estimator. However, stronger evidence was found for the indicator of administrative decentralization, which is positively correlated with the outcome variable. The coefficient is statistically significant at the 1% level when using DK and PW-PCSE estimations, and at the 10% level when using multilevel estimation.

While the results may appear descriptive, the distinction between fiscal and administrative decentralization provides a critical lens into the political economy of Spanish public investment. The stronger result found for administrative decentralization suggests that the "power to do" (competencies) outweighs the "power to fund" (financial autonomy) in the bargaining process for public investment.

The proxy for administrative decentralization can also be understood as an indicator of regional institutional maturity. As regions receive more competencies, they develop stronger technical bureaucracies and a clearer portfolio of infrastructure needs, enhancing their capacity to lobby for and execute national investment. Conversely, the lack of

governments, etc. However, they also found that the inclusion of such political variables does not affect the statistical significance of the economic variables.

[31] FA_{jt} and IA_{jt} were constructed as Aray (2018).

robustness in fiscal decentralization may be explained by the vertical fiscal imbalance inherent in the Spanish system. Since the central government still holds the primary "purse strings" for major national strategic investments (e.g., high-speed rail, airports and ports). Therefore, a region's internal financial capacity does not necessarily dictate the flow of state-led capital, which remains a tool for national territorial policy and political negotiation.

7.2. Model Validation: Ranking Comparison and Sensitivity Analysis

To further assess the validity of our estimates, we conducted a two-step robustness exercise. First, the observed average public investment-to-public capital stock ratios for all the Spanish autonomous communities during the sample period were computed. Subsequently, the autonomous communities were ranked according to this ratio, and the resulting ranking was then compared with the predicted ranking derived from the baseline model estimated with PW-PCSE. The results are displayed in the second and third columns of Table 4. The substantial degree of convergence between the two rankings validates the model's capacity to replicate the actual distribution logic, a finding that is further supported by the positive, high, and significant correlation coefficients of Spearman and Kendall. The model displays a high degree of accuracy in predicting the top five and bottom five positions, exhibiting a strong similarity with the observed rankings. Minor discrepancies are observed in the mid-range of the ranking.

Second, following the spirit of Dabla-Norris et al. (2012), we conducted a sensitivity analysis by simulating changes in the weights assigned to the efficiency, redistribution and spatial criteria. This allows us to observe how regional priorities shift under different policy frameworks.

In simulation 1, we impose $\beta_1^j = 1\ (\omega_j = 0)$ while holding the parameter estimates of $Ln\left(y_{jt-1}\right)$ and $Ln\left(\frac{N_{jt-1}}{S_j}\right)$ given by PW-PCSE, $(\hat{\beta}_2, \hat{\beta}_3)$. As illustrated in Table 4, simulation 1 generates a ranking that is strongly associated with the observed ranking, indicating that this particular weight structure is highly compatible with the underlying allocation logic of public investment. This result provides further evidence in support of the Cobb-Douglas production function.

Simulations 2, 3, and 4 show the ranking results using different values of the parameter capturing inequality aversion (ρ) and maintaining the parameter estimate of $Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$

given by PW-PCSE, ($\hat{\beta}_1$). These simulations demonstrate significant sensitivity; for instance, the case of allocating public investment focusing exclusively on efficiency criterion (simulation 2) shows no correlation with the observed ranking, which support the rejection of the hypothesis $\rho = 1$. However, simulations 3 and 4 indicate that the inequality-averse parameter could fall within the range of $\rho = -0.5$ to $\rho = 0$. As shown in Table 4, the result is stronger for simulation 4. Therefore, the evidence suggests that Spanish policymakers exhibit a strong aversion to inequality. Consequently, they have allocated public investment with the aim of balancing efficiency and redistribution.

Simulations 5, 6, and 7 provides the ranking results using different values of the parameter capturing the weight of output density in the social welfare function (η), while maintaining the parameter estimates of $Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$ and $Ln\left(y_{jt-1}\right)$ given by PW-PCSE ($\hat{\beta}_1$, $\hat{\beta}_2$). It is noteworthy that the ranking produced by simulation 5 (with η=0) does not align with the observed ranking. Furthermore, simulations 6 and 7, which exhibit rankings that are positively and significantly correlated with the observed, could be suggesting that the weight of output density in the social welfare function might be between η=0.6 and η=1.

8. Policy implications

Beyond its technical contributions, the findings of this article aim to enrich the debate on the future of regional policy, not only in Spain but also in the European Union. Cohesion policy is typically regarded as a compromise between two primary objectives: maximizing aggregate national growth (efficiency) and reducing disparities in per capita income (equity/redistribution). However, our analysis indicates that policymakers may adopt a more nuanced and "place-based" approach, as recommended by the Barca et al. (2012).

The present study identifies a significant aversion inequality not only to output per capita, but also to output density. These findings reveal that regional policy could be used to address the "geography of discontent." (Dijkstra et al., 2020).

The results for the Spanish case demonstrate that policymakers have not disregarded the equity-efficiency trade-off, suggesting that public investment has been allocated following a balance between regions with high and low per capita output, as well as between regions with high output density and regions with low output density. This indicates a prioritization of territorial cohesion over mere aggregate growth. Therefore,

our results unveil a policy aimed at prioritizing spatial justice. It appears that output density plays a more significant role in the social welfare function compared to output per capita. This suggests that the objective is not spatially neutral, but rather that investment is being used to address the structural disadvantages of low-density areas. In practical terms, this justifies the high per-capita cost of infrastructure in sparsely populated regions as a deliberate policy choice to ensure minimum service standards and prevent territorial abandonment, rather than an inefficient allocation.

Furthermore, our estimate for the inequality aversion parameter (ρ) lower than previous empirical evidence suggests a contemporary policy environment that is increasingly sensitive to regional disparities. It is consistent with a policy environment in which equity considerations are increasingly embedded in explicit spatial and social objectives, instead of being summarized by a single redistributive trade-off. This interpretation aligns with the multidimensional nature of EU place-based policies, where growth, cohesion, and territorial balance are pursued jointly.

Thus, our findings move beyond abstract theory to provide actionable insights for regional and national planning, providing a quantitative backing for the European Union's 'Do No Harm to Cohesion' principle. [32] By demonstrating that policymakers assign a high weight to output density and show aversion to spatial inequality, we show that public investment allocation in Spain has followed a cohesion-first logic.

In the context of EU policy instruments such as NextGenerationEU or the Cohesion Funds, these results suggest that evaluations based exclusively on a single "Return on Investment" (ROI) criterion may overlook relevant spatial and social dimensions. The model can be used to infer relative weights that are consistent with a multi-criteria perspective, in which economic growth, social returns, and spatial balance are jointly considered.

9. Conclusions

This article proposes a general model for the distribution of public investment across jurisdictions. In the model, the policymaker maximizes a CES social welfare function whose arguments are output per capita and output density, subject to a CES production

[32] The "do no harm to cohesion" principle, as articulated in the 8th Cohesion Report by the European Commission, underscores the imperative of enhancing the coherence between cohesion policy and other EU policies. Consequently, it establishes that no EU action or policy (whether in transport, digital, energy, or taxation) should increase regional disparities or undermine the process of convergence between territories.

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.

Our theoretical framework goes beyond the traditional equity-efficiency trade-off proposed in previous 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.

For the empirical implementation, we use data for the Spanish regions over the 1986-2021. Overall, the empirical evidence provides the expected signs of the estimated coefficients, which are 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 past theoretical literature has 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 and the introduction of control variables.

Future research could extend this work in several directions. A natural extension of this paper would be to consider the case in which the central and regional governments interact, which would require solving 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.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This project was supported by Consejería de Universidad, Investigación e Innovación and by ERDF Andalusia Program 2021-2027 (grant number C-SEJ-195-UGR23).

Appendix: Obtaining equation (6)

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

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

St.

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

$$G_{jt} = B_{jt} G_{jt-1}^{1-\sigma_j} C_{jt}^{\sigma_j}$$

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

FOC:

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

Where λ_t is the marginal cost of public revenues.

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

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

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

$$= W_t^{1-\rho} \left(\frac{S_j}{N_{jt}}\right)^{\eta(1-\rho)} y_{jt}^{\rho-1}$$

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

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

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

$$= \alpha_{jG}Y_{jt}Y_{jt}^{-\omega_j}G_{jt}^{\omega_j-1}$$

$$= \alpha_{jG}\left(\frac{Y_{jt}}{G_{jt}}\right)^{1-\omega_j}$$

$$\frac{\partial G_{jt}}{\partial C_{jt}} = \sigma_j B_{jt} G_{jt-1}^{1-\sigma_j} C_{jt}^{\sigma_j-1}$$

$$= \sigma_j G_{jt} C_{jt}^{-1}$$

The FOC becomes

$$W_t^{1-\rho}\sigma_j\alpha_{jG}\left(\frac{S_j}{N_{jt}}\right)^{\eta(1-\rho)} y_{jt}^{\rho-1}Y_{jt}\left(\frac{Y_{jt}}{G_{jt}}\right)^{-\omega_j} C_{jt}^{-1} - \lambda_t = 0$$

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

$$C_{jt} = A_{jt}\left(\frac{Y_{jt}}{G_{jt}}\right)^{-\omega_j} y_{jt}^{\rho-1}Y_{jt}\left(\frac{S_j}{N_{jt}}\right)^{\eta(1-\rho)}$$

With $A_{jt} = \frac{W_t^{1-\rho}\sigma_j\alpha_{jG}}{\lambda_t}$

Dividing by G_{jt} on both sides, multiplying the right hand-side by $\frac{N_{jt}}{N_{jt}}$ and rearranging, we obtain

$$\frac{C_{jt}}{G_{jt}} = A_{jt}\left(\frac{Y_{jt}}{G_{jt}}\right)^{-\omega_j} y_{jt}^{\rho-1}\frac{Y_{jt}}{N_{jt}}\frac{N_{jt}}{G_{jt}}\left(\frac{S_j}{N_{jt}}\right)^{\eta}\left(\frac{S_j}{N_{jt}}\right)^{-\eta\rho}$$

$$\frac{C_{jt}}{G_{jt}} = A_{jt}\left(\frac{Y_{jt}}{G_{jt}}\right)^{-\omega_j} y_{jt}^{\rho}\frac{N_{jt}^{1-\eta}}{G_{jt}^{1-\eta}}\frac{S_j^{\eta}}{G_{jt}^{\eta}}\left(\frac{S_j}{N_{jt}}\right)^{-\eta\rho}$$

$$\frac{C_{jt}}{G_{jt}} = A_{jt}\left(\frac{Y_{jt}}{G_{jt}}\right)^{-\omega_j} y_{jt}^{\rho}\left[\left(\frac{G_{jt}}{N_{jt}}\right)^{1-\eta}\left(\frac{G_{jt}}{S_j}\right)^{\eta}\right]^{-1}\left(\frac{N_{jt}}{S_j}\right)^{\eta\rho}$$

References

Albalate, 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.

Balaguer-Coll, M.T., Narbón-Perpiñá, I., Peiró-Palomino, J. and Tortosa-Ausina, E. (2022). Quality of government and economic growth at the municipal level: Evidence from Spain. *Journal of Regional Science*, 62, 96–124.

Barca, F., McCann, P. and Rodríguez-Pose, A. (2012). The Case for Regional Development Intervention: Place-Based Versus Place-Neutral Approaches. *Journal of Regional Science* 52, 134–152.

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, 91l–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.

Dabla-Norris, E., Brumby, J., Kyobe, A., Mills, Z. and Papageorgiou, C. (2012). Investing in public investment: an index of public investment efficiency. *Journal of Economic Growth*, 17(3), 235–266.

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.

Dijkstra, L., Poelman, H. and Rodríguez-Pose, A. (2020). The geography of EU discontent. *Regional Studies* 54, 737–753.

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, and A. Solé-Ollé (Eds.), The political economy of inter-regional fiscal flows: measurement, determinants, and effects on country stability. Cheltenham: Edward Elgar.

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.

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.

Martin, P. (1999). Public policies, regional inequalities and growth. *Journal of Public Economics* 73, 85–105.

Martin, P. and Rogers, C. A. (1995). Industrial location and public infrastructure. *Journal of International Economics* 39, 335–351.

Mera, K. (1967). Trade-off between Aggregate Efficiency and Interregional Equity: A Static Analysis. *The Quarterly Journal of Economics* 81, 658–674.

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.

Monastiriotis, 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. (2018). The revenge of the places that don't matter (and what to do about it). *Cambridge Journal of Regions, Economy and Society* 11, 189–209.

Rodríguez-Pose, A. and Ketterer, T. D. (2020). Institutional change and the development of lagging regions in Europe. *Regional Studies* 54, 974–986.

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				
	$Ln\left(\frac{C_{jt}}{G_{jt}}\right)$	$Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$	$Ln(y_{jt-1})$	$Ln\left(\frac{N_{jt-1}}{S_j}\right)$
$Ln\left(\frac{C_{jt}}{G_{jt}}\right)$	1.0000			
$Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$	0.3513	1.0000		
$Ln(y_{jt-1})$	-0.3639	0.2498	1.0000	
$Ln\left(\frac{N_{jt-1}}{S_j}\right)$	0.0262	0.7630	0.4256	1.0000

Multicollinearity diagnostics
Condition number of the matrix (CNM): 13.27

Varianza Inflation Factor (VIF)		
	VIF	1/VIF
$Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$	2.43	0.41
$Ln(y_{jt-1})$	1.24	0.81
$Ln\left(\frac{N_{jt-1}}{S_j}\right)$	2.79	0.36
Mean VIF	2.15	

CNM > 30 indicates high multicollinearity.

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

Table 2. Estimation for the total public investment

Dependent variable: Log of the public investment-to-public capital stock ratio						
	DK		PW-PCSE (AR1)		Multilevel (AR1)	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
$Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$	0.8112	0.1230 ***	1.1485	0.2463 ***	1.1933	0.1535 ***
$Ln(y_{jt-1})$	-1.1785	0.3342 ***	-1.3002	0.4843 ***	-0.8064	0.1778 ***
$Ln\left(\frac{N_{jt-1}}{S_j}\right)$	-0.8975	0.4302 **	-1.0052	0.5403 *	-0.2874	0.0699 ***
Implicit η	0.7615	0.2270 ***	0.7731	0.2859 ***	0.3564	0.1325 ***
Individual effects	Yes		Yes		Yes	
Time effects	Yes		Yes		Yes	
R^2	0.7856		0.7171		0.7359	
SH^{FR}	14.6333	(0.0022)				
G test	157.6740	(0.0000)				
W^{SC} test	115.6151	(0.0000)				
BP test	1534.8638	(0.0000)				
DWH test	1.6427	(0.2000)				
SH^{IV}	13.9630	(0.0827)				
$\beta_1 = 1\ (\omega = 0)$	2.3574	(0.1247)	0.3637	(0.5465)	1.5852	(0.2080)
$\beta_2 = -1\ (\rho = 0)$	0.2854	(0.5932)	0.3841	(0.5354)	1.1856	(0.2762)
$\eta = 1$	1.1036	(0.2935)	0.6297	(0.4275)	23.5796	(0.0000)

Notes: Number of observations: 595. Number of groups: 17.

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

Table 3. Estimation for the total public investment

Dependent variable: Log of public investment-to-public capital stock ratio																
	Including population share				Including political variables						Including decentralization variables					
	PW-PCSE (AR1)		Multilevel (AR1)		DK		PW-PCSE (AR1)		Multilevel (AR1)		DK		PW-PCSE (AR1)		Multilevel (AR1)	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
$Ln\left(\frac{Y_{jt-1}}{G_{jt-1}}\right)$	1.1485	0.2463 ***	1.1964	0.1535 ***	0.7930	0.1211 ***	1.1251	0.2407 ***	1.1805	0.1531 ***	0.9815	0.1274 ***	1.1284	0.2345 ***	1.3520	0.1791 ***
$Ln(y_{jt-1})$	-1.3002	0.4843 ***	-0.7923	0.1853 ***	-1.2059	0.3605 ***	-1.2909	0.4832 ***	-0.8020	0.1773 ***	-2.0439	0.4485 ***	-1.5527	0.5715 ***	-0.6217	0.2167 ***
$Ln\left(\frac{N_{jt-1}}{S_j}\right)$	-1.0796	0.5666 *	-0.2965	0.0767 ***	-0.8516	0.4352 *	-0.9596	0.5369 *	-0.2806	0.0696 ***	-1.9660	0.5373 ***	-1.5273	0.5728 ***	-0.3760	0.0839 ***
Implicit η	0.8303	0.3260 **	0.3742	0.1523 **	0.7063	0.2239 ***	0.7434	0.2842 ***	0.3499	0.1312 ***	0.9619	0.1127 ***	0.9837	0.2531 ***	0.6047	0.6047 **
$Ln\left(\frac{N_{jt}}{N_t}\right)$	0.0744	0.0662	0.0139	0.0534												
oneparty					0.0125	0.0271	-0.0018	0.0270	-0.0064	0.0249						
Lag oneparty					0.0616	0.0290 **	0.0435	0.0271	0.0399	0.0249						
election					-0.0005	0.0391	-0.0183	0.0210	-0.0225	0.0199						
Lag election					0.0191	0.0321	0.0070	0.0208	0.0013	0.0196						
$Ln(FA_{jt-1})$											0.1248	0.0434 ***	0.0486	0.0473	-0.0194	0.0470
$Ln(NC_{jt-1})$											0.8318	0.2005 ***	0.6322	0.2279 ***	0.2304	0.1290 *
Individual effects	Yes		Yes		Yes		Yes		Yes		Yes		Yes		Yes	
Time effects	Yes		Yes		Yes		Yes		Yes		Yes		Yes		Yes	
R^2	0.7169		0.7375		0.7885		0.8141		0.7405		0.7705		0.7990		0.6404	
SH^{FR}	64.6874	(0.0000)			39.7723	(0.0000)					47.3060	(0.0000)				
G test	1074.8413	(0.0000)			930.9477	(0.0000)					1852.1693	(0.0000)				
W^{SC} test	119.0028	(0.0000)			109.8237	(0.0000)					106.4845	(0.0000)				
BP test	1241.8917	(0.0000)			1502.9284	(0.0000)					1168.5140	(0.0000)				
$\beta_1 = 1\ (\omega = 0)$	0.3637	(0.5465)	1.6372	(0.2007)	2.9207	(0.0874)	0.2700	(0.6033)	1.3901	(0.2384)	0.0211	(0.8846)	0.3000	(0.5839)	3.8638	(0.0493)
$\beta_2 = -1\ (\rho = 0)$	0.3841	(0.5354)	1.2562	(0.2624)	0.3260	(0.5680)	0.3625	(0.5471)	1.2483	(0.2639)	5.4185	(0.0199)	0.9353	(0.3335)	3.0471	(0.0809)
$\eta = 1$	0.2709	(0.6027)	16.8776	(0.0000)	1.7216	(0.1895)	0.8153	(0.3666)	24.5396	(0.0000)	0.1145	(0.7350)	0.0042	(0.9485)	2.0350	(0.1537)

Notes: Number of observations: 595. Number of groups: 17.

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

Table 4. Ratio of public investment to the total public capital stock: Observed, predicted and simulated rankings of the Spanish Autonomous Communities

			Counterfactual Simulation						
			Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5	Simulation 6	Simulation 7
Autonomous Community	Observed ranking	Model prediction ranking	$\beta_1^j = 1\,(\omega_j = 0),\ \widehat{\beta}_2, \widehat{\beta}_3$	$\widehat{\beta}_1, \beta_2 = 0, \beta_3 = 0\,(\rho = 1)$	$\widehat{\beta}_1, \beta_2 = -1, \beta_3 = \widehat{\eta}\,(\rho = 0)$	$\widehat{\beta}_1, \beta_2 = -1.5, \beta_3 = -1.5\widehat{\eta}\,(\rho = -0.5)$	$\widehat{\beta}_1, \widehat{\beta}_2, \beta_3 = 0\,(\eta = 0)$	$\widehat{\beta}_1, \widehat{\beta}_2, \beta_3 = 0.6\,\widehat{\beta}_2\,(\eta = 0.6)$	$\widehat{\beta}_1, \widehat{\beta}_2, \beta_3 = \widehat{\beta}_2\,(\eta = 1)$
Galicia	1	2	1	9	6	4	8	4	4
Balearic Islands	2	1	2	3	2	6	4	2	8
Cantabria	3	4	5	7	9	7	9	9	7
Murcia	4	3	7	8	8	5	7	8	6
Castile and Leon	5	5	4	15	12	3	14	12	2
Castile-La Mancha	6	7	6	16	13	2	16	14	1
Catalonia	7	11	12	4	4	13	5	6	13
Canary Islands	8	8	11	5	5	12	3	3	14
Asturias	9	13	8	10	10	9	10	10	10
Extremadura	10	6	3	17	14	1	15	13	3
Valencian Community	11	10	10	6	7	11	6	7	12
Madrid	12	9	13	1	1	16	1	1	17
Andalusia	13	12	9	11	11	8	11	11	9
Basque Country	14	14	14	2	3	14	2	5	16
Aragon	15	15	15	14	16	10	17	16	5
Navarre	16	16	16	12	15	15	12	15	11
La Rioja	17	17	17	13	17	17	13	17	15
Spearman's rank correlation		0.9216 (0.0000)	0.8652 (0.0000)	0.1520 (0.5604)	0.4191 (0.0940)	0.6789 (0.0027)	0.1863 (0.4741)	0.4681 (0.0581)	0.5147 (0.0345)
Kendall's rank correlation		0.8088 (0.0000)	0.7206 (0.0000)	0.1324 (0.4896)	0.3235 (0.0762)	0.4559 (0.0103)	0.1324 (0.4896)	0.3382 (0.0630)	0.3235 (0.0762)

The predicted ranking are based on PW-PCSE estimates.

The counterfactual simulations are based on imputed values for a specific parameter and PW-PCSE estimates for the remaining parameters.

Correlation coefficients are calculated with respect to the observed ranking. *p*-values in parentheses.