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Jaime Alonso-Carrera
Universidad de Vigo

Maria Jesus Freire-Seren
Universidad de Vigo

Baltasar Manzano
Universidad de Vigo

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Macroeconomic effects from the regional allocation of public capital formation*

Jaime Alonso-Carrera
Departamento de Fundamentos del Análisis Económico and RGEA
Universidad de Vigo

María Jesús Freire-Serén
Departamento de Fundamentos del Análisis Económico and GRiEE
Universidad de Vigo

Baltasar Manzano
Departamento de Fundamentos del Análisis Económico and REDE
Universidad de Vigo

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Abstract

This paper proposes a multi-regional, general equilibrium model with capital accumulation to analyze the economic impact of the spatial distribution of public capital formation. This model is calibrated and solved by using data for the Spanish economy in order to simulate some comparative dynamic exercises of fiscal policy changes. These analyses illustrate the role that public investment plays in generating the existing imbalances in regional development. This is done by computing the spillover effects and the opportunity costs of regional distribution of public investment. Finally, two rankings of regional priorities in public investment can be derived: one based on the criterion of reducing regional disparities, and other based of an efficiency criterion.

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Correspondence address: María Jesús Freire-Serén, Facultad de Ciencias Económicas, Universidad de Vigo, Campus As Lagoas-Marcosende, 36310 Vigo, Spain. E-mail: mjfreire@uvigo.es

1 Introduction

Public investment in productive infrastructures is one of the fundamental responses of governments to the existing imbalances in regional development. This public intervention is based on the view that observed disparities in income per capita across regions primarily reflect differences in endowments of production factors and in total factor productivity (TFP, henceforth). Since this regional policy absorbs a lot of resources, recent literature has explored the effectiveness of public investment in reducing the observed differences in income levels across regions. In this line, this paper sets up a multi-regional, dynamic optimization model with capital accumulation as a tool to analyze the effects of public infrastructure investment on the regional economic performance.

The interest for evaluating the impact of public capital formation in private output was brought by Aschauer (1989), who concluded that public capital formation would have a meaningful positive effect on TFP. This conclusion, together with the observed differences in the endowments of public capital across regions, has inspired a subsequent research focusing in the regional dimension of public capital formation. This literature has found no clear evidence of a positive linkage between public capital and private output at the regional level.[1] The inconclusive nature of this literature may be partially explained by the fact that the majority of these works estimates the parameters of aggregate production functions, with the coefficient on public capital interpreted as the elasticity with respect to this variable. Thus, this methodology can only account for the direct effects of public capital on private output as a determinant of regional TFP. However, public capital formation can also affect the economic performance by changing saving, capital accumulation and/or time devoted to productive activities. To explore these indirect effects requires modeling explicitly the economic behavior of agents. In this paper, we propose a general equilibrium framework to characterize the impact of public capital on the regional differences in income levels. In particular, we use the Spanish experience from the process of fiscal decentralization during the last decades to assess the macroeconomic effects from the distribution of the public investment in infrastructures across regions. To our knowledge, the literature on dynamic macroeconomics did not deal with this issue. An exception is the study of Arcalean et al. (2007), which uses an endogenous growth model calibrated with data for the Portuguese economy to analyze the growth effects of regional redistribution policies.[2]

The evaluation of public capital formation as a tool of the regional policy should consider some specific issues in order to derive a complete cost-benefit analysis. On the one hand, the public infrastructure investment in a region may affect economic activity of the others regions because this investment can improve their accessibility and alter the terms of inter-regional trade. Thus, the evaluation of the regional impact of public capital formation should

[1] See, among many others, Evans and Karras (1994), Holtz-Eakin (1994) or Garcia-Milà et al. (1996).

[2] Other studies also use a general equilibrium approach to quantify the effects of public capital (see, e.g., Rioja, 1999 and 2005). However, these works only attend to the aggregate impact, without any consideration of regional effects.

include the study of the possible existence of regional spillover effects. However, this issue has received little attention in the literature. Munnell (1992) conjectures that the existence of these spillover effects explains the fact that the elasticities of output with respect to public capital obtained with regional data tend to be lower than those obtained with aggregate data.[3] Subsequent studies, such as those of Holtz-Eakin (1994), Holtz-Eakin and Schwartz (1995) or Boarnet (1998), address directly this issue and they find inconclusive evidence on the empirical relevance of regional spillover effects from public capital formation.[4]

In order to test the existence of regional spillover effects from public capital formation, the majority of research estimates either production or cost functions. The common procedure consists in augmenting the public capital of each region with some weighted sum of the stocks of the other regions. In this way, these works are testing whether a *technological spillover effect* exists, i.e., whether the public capital stock of a region directly affects the TFPs of other regions. This kind of spatial spillover effects comes from the fact that most of elements of public infrastructures, as can be the case of roads, telecommunications or railways, have network characteristics that improve the accessibility of regions. However, public infrastructure investment in one region may also affect indirectly the economic activity of the other regions because of the openness and the inter-regional competition.[5] This *non-technological* or *economic spillover effect* would have an impact on the regional accumulation of production factors, and so they could not be directly captured from the estimation of production and cost functions. Furthermore, these economic spillover effects also depend on the distortions associated with the tax financing of public investment. Hence, these spillover effects can only be computed by means of a dynamic general equilibrium analysis that explicitly models the individuals' decision margins and the economic relation among regions. One of the main objectives of this paper is to introduce this methodology to simulate how the public investment in one region affects the economic performance of the other regions.

On the other hand, public investment in one region also implies an opportunity cost given by the foregone increase in the private output of the region that exhibits the largest social profitability of public capital. The decision on the spatial allocation of public investment is subject to a standard trade off between regional equality and social efficiency.[6] Governments tend to devote large sums of public investment to improving the productivity capacity of their less development regions, and so to obtain a regional convergence in income per capita. However, the allocation of public resources in the poorest regions can sometimes

[3] Mundell (1990), Eisner (1991) and García-Milá and McGuire (1992) also find that output elasticity with respect to public capital is much smaller at the regional level than that at the aggregate level.

[4] For the Spanish case, Mas et al. (1996), Moreno et al. (1997), Pereira and Roca-Sagalés (2003) or Moreno and López-Bazo (2007), among others, have instead found evidence of the existence of positive spillover effects from public capital formation.

[5] In fact, this non-technological spillover effect from public capital formation may be negative. As Boarnet (1998) points out "public investments in one location can draw production from other locations" since "it enhances the comparative advantage of that location relative to the other places."

[6] See a detailed discussion in de la Fuente (2002b).

lead to sub-optimal levels of national income since those regions often exhibit the smallest profitability of public investment. De la Fuente (2003) estimates that the Spanish policy of regional redistribution through public infrastructure investment during the last decade exhibited a meaningful opportunity cost. Another main objective of this paper is to propose a theoretical framework that permits to compare the current spatial allocation of public investment in infrastructures with alternative distributions of this investment across regions.

This paper incorporates all these issues concerning to the economic impact of public infrastructure investment by using the theoretical foundations of those open economy macroeconomic analyses based on dynamic optimization. In particular, we use a multi-region, perfect-foresight, dynamic general equilibrium model with infinitely-lived representative consumers and capital accumulation. In the model a central or supra-regional government provides public infrastructures available to all firms with some congestion costs. Infrastructures in a region enhance the TFP of all regions. The central government collects revenue by taxing labor income, capital income and consumption uniformly across regions. Finally, there is a single supra-regional capital market in which equities are traded. Equities represent a claim to the capital stock of a region.

There exists a large tradition in macroeconomic literature in using this kind of models as a laboratory to analyze the international spillover effects of country-specific supply-side shocks. For example, Lipton and Sachs (1983), Bianconi (1995), Devereux and Shi (1991) or Ono and Shibata (1992), among others, investigate the response of each country's capital accumulation and terms of trade to tax policy and technological shocks in a two-country model. This type of theoretical frameworks is also used by the "open economy real business cycle" literature. Using a two-country, general equilibrium model, Bakus et al. (1992) or Baxter and Crucini (1995), among others, study the role of international financial markets in the international transmission of business cycles.[7]

In these multi-region dynamic-optimization models with capital accumulation, one needs the initial distribution of wealth across regions to characterize the competitive equilibrium. By following Kehoe et al. (1992), we then propose to compute the equilibrium path by means of a pseudo-social planning problem that maximizes a distorted social welfare function.[8] After that, we perform some numerical simulations in order to illustrate the kind of results that can be derived from the proposed framework. In particular, our model is calibrated and solved using data and estimates for the Spanish economy in order to simulate some comparative dynamic exercises of fiscal policy changes. We obtain that the current policy of public investment explains a meaningful fraction of the observed differences in output per capita across the Spanish regions. Furthermore, we also illustrate that the economic regional spillovers are a crucial determinant of the macroeconomic effects of the current public investment.

[7] See, for example, the surveys by Bakus et al. (1995) and Baxter (1995) for more details of this literature.

[8] Recently, Farmer and Lahiri (2005) also use this procedure to characterize the competititve equilibrium in a two-country model of endogenous growth with production externalities.

The paper is organized as follows. Section 2 describes the theoretical model and derives the conditions defining the interregional competitive equilibrium. In Section 3 we present the solution procedure based on the pseudo-social planning problem to compute the competitive equilibrium. Section 4 discusses the calibration of the model, whereas Section 5 presents the numerical experiments and interprets the results. Section 6 closes with some concluding remarks.

2 Model

We consider a national economy composed of N regions inhabited by infinitely lived individuals. Each region is populated by a constant number of individuals, which can differ across regions. We denote by π^i the fraction of national population located in region i and, without loss of generality, we normalize the whole population to unity, i.e., $\sum_{i=1}^{N} \pi^i = 1$. All regions produce a tradable homogenous commodity. Each region accumulates capital gradually over time, with the national market for capital being perfectly integrated. Hence, there exists a unified capital market where regions may borrow or lend by selling or buying equities from residents of the other regions. There is no asset other than equities. Finally, there is a national or central government that provides free productive services to the regions by means of a stock of infrastructures.

2.1 Firms

In each region there exists a large number of identical firms that operate under perfect competition. In the tradition introduced by Barro (1990), we assume that these firms use private capital, labor and free public infrastructures to produce an output, which can be either used for consumption, private investment or public expenditure. Thus, the production function of a firm in region i is given by

$$y_t^i = A^i \left(k_t^i\right)^{\alpha} \left[n_t^i \left(h_t^i\right)^{\phi}\right]^{1-\alpha} \left(\widetilde{I}_t^i\right)^{\gamma}, \tag{1}$$

where A^i is a region-specific technology parameter; k_t^i is the average stock of capital in region i; h_t^i is the average stock of human capital in region i; n_t^i is the average labor in region i; $\widetilde{I}_t^i$ denotes the services derived by a firm in region i from the use of the national stock of infrastructures. These public productive services are exogenous to the firm and only partly determined by public stock of infrastructures installed in region i. More specifically, the productive services derived by a firm in region i from public infrastructures are represented by

$$\widetilde{I}_t^i = \left[\frac{I_t^i}{\left(K_t^i\right)^{\upsilon}}\right] \left\{\prod_{i \neq j}^{N} \left[\frac{I_t^j}{d_{ij}\left(K_t^j\right)^{\upsilon}}\right]^{\frac{\varsigma}{\gamma}}\right\}, \tag{2}$$

where I_t^i is the aggregate stock of infrastructures installed in region i; K_t^i is the aggregate stock of capital in region i, so that $K_t^i = \pi^i k_t^i$; and d_{ij} denotes the distance between region

i and region j.

The specification (2) implies that the effective stock of infrastructures in one region differs from the observed stock installed in that region. Firstly, a firm in region i obtains services from the stock of infrastructures installed in this region, but also receives productive services from the stocks installed in the other regions because of the tradable nature of the final good. Firms in a region i use the stock of infrastructures installed in the other regions to transport their produced commodities to market places situated further away from the borders of region i. Following Holtz-Eakin and Schwartz (1995), among many others, we then assume that there exists a technological spillover effect of the regional public investment; i.e., the stock of infrastructures of a region i may affect positively the TFP of other regions. Thus, we incorporate the infrastructure stock of the other regions as a factor in the production function of region i, but with a weight that depends negatively on the distance between regions in order to introduce some heterogeneity in the interaction among regions. The parameter ζ determines the elasticity of output of a region with respect to the stock of infrastructures installed in the other regions.

Secondly, infrastructures are not a pure public good since their services to firms are subject to congestion costs. Following Barro and Sala-i-Martin (1992) or Fisher and Turnovsky (1998), among many others, we assume that the productive services derived by a firm from a given stock of public capital decrease when the aggregate stock of capital grows. The parameter υ measures the degree of congestion in the productive services that a firm can obtain from public capital.[9] Since we consider that the level of congestion depends on aggregate capital stock, then population also determines the congestion costs. Thus, the regional TFPs depend on the relative size of the regional population.

We impose that $\alpha - \gamma\upsilon > 0$ in order to guarantee that the marginal productivity of private capital will be strictly positive in each region at the aggregate level. Moreover, we consider that there is an exogenous process of labor augmenting technological progress that drives the growth of our economy. In particular, we assume that the stock of human capital grows at rate that is constant along time and across regions, i.e., $h_t^i = \xi^t h_0^i$. We also assume that $\xi > 1$ to obtain sustained growth.

The price of good y_t is the same across regions because the tradable nature and the absence of transportation cost. This price is taken as numerarie. Firms behave competitively by taking the infrastructures services $\widetilde{I}_t^i$ as given. Hence, the marginal product of private capital and labor are equal to their respective rental rate. Using the production function (1) factor prices at region i are then given by

$$r_t^i = \alpha A^i \left(k_t^i\right)^{\alpha-1} \left[n_t^i \left(h_t^i\right)^{\phi}\right]^{1-\alpha} \left(\widetilde{I}_t^i\right)^{\gamma} - \delta, \tag{3}$$

[9] Observe that we have assumed that the degree of congestion in the productive services obtained for a firm in region i is the same for the public capital installed in this region as that for the public capital installed in the other regions. In the estimations of production function (1) used to calibrate the model in next section we will not impose this restriction. However, we will obtain that estimated parameters of congestion are not significatively different one of each other.

$$w_t^i = (1-\alpha)A^i \left(k_t^i\right)^{\alpha-1} \left(h_t^i\right)^{\phi(1-\alpha)} \left(n_t^i\right)^{-\alpha} \left(\widetilde{I}_t^i\right)^{\gamma}, \tag{4}$$

where w_t^i and r_t^i are the wage rate and the rate of interest at region i, respectively; and δ denotes the depreciation rate of the stock of private capital.

2.2 Government

The government finances a path of public spending by taxing consumption at rate τ^c, labor income at rate τ^w and capital income at rate τ^k, and by means of a lump-sum tax with a payment per capita equal to τ_t at period t. Observe that the burden of the lump-sum taxation is equally distributed across individuals regardless their regional residences. We also assume that the government allocates this spending between public investment and public consumption, which we will denote by G_t and X_t, respectively. Finally, this government faces to the restriction of zero deficit in each period, where the lump-sum tax is the adjusting variable. Thus, the government is subject to the following budget constraint at period t:

$$X_t + G_t = \sum_{i=1}^{N} \pi^i \left(\tau^c c_t^i + \tau^w w_t^i n_t^i + \tau^k r_t a_t^i + \tau_t\right), \tag{5}$$

where a_t^i is the per capita stock of equities, and r_t is the instantaneous return on equities, which is set at the national market of these assets.

In order to maintain the size of public spending with respect to aggregate output, we assume that this public spending is a constant fraction of output at each period, i.e.,

$$G_t = \varphi \sum_{i=1}^{N} \left(\pi^i y_t^i\right) \quad \text{and} \quad X_t = \eta \sum_{i=1}^{N} \left(\pi^i y_t^i\right). \tag{6}$$

Moreover, government distributes public investment among regions by using weights that are constant over time, so that the public investment in region i at period t is given by

$$g_t^i = \varphi^i \sum_{i=1}^{N} \left(\pi^i y_t^i\right), \tag{7}$$

with

$$\sum_{i=1}^{N} \varphi^i = \varphi. \tag{8}$$

We assume that public consumption neither affects directly welfare nor participates in production, whereas public investment is accumulated in the stock of infrastructures. Therefore, the stock of infrastructures at region i evolves by means of the following law:

$$I_{t+1}^i = g_t^i + (1-\mu)\, I_t^i, \tag{9}$$

where μ is the depreciation rate of the stock of infrastructures.

2.3 Consumers

In each period, individuals hold a stock of equities a_t^i, which can be augmented by means of savings. Moreover, each individual is endowed with a unit of time in each period, which distributes between leisure and labor. All individuals have the same preferences. Thus, the utility function of a representative consumer in region i is given by

$$U^i = \sum_{t=0}^{\infty} \beta^t u\left(c_t^i, 1 - n_t^i\right) = \sum_{t=0}^{\infty} \beta^t \frac{\left[\left(c_t^i\right)^{1-\theta}(1 - n_t^i)^{\theta}\right]^{1-\sigma} - 1}{1 - \sigma}, \tag{10}$$

where c_t^i and n_t^i represent consumption and the fraction of time devoted to labor, respectively; $\beta \in (0, 1)$ is the subjective discount rate; θ is the share parameter for leisure in the composite commodity; and σ is the inverse of the elasticity of the intertemporal substitution of this composite commodity.

A representative consumer in region i maximizes her utility subject to the flow budget constraint given by

$$(1 - \tau^w)w_t^i n_t^i + \left[1 + (1 - \tau^k)r_t\right] a_t^i - \tau_t = (1 + \tau^c)c_t^i + a_{t+1}^i. \tag{11}$$

From the first order conditions of the previous maximization problem, we obtain that the optimality conditions for this problem are:

$$(1 + \tau^c)\left[\frac{u_2\left(c_t^i, 1 - n_t^i\right)}{u_1\left(c_t^i, 1 - n_t^i\right)}\right] + (1 - \tau^w)w_t^i = 0, \tag{12}$$

$$\frac{u_1\left(c_t^i, 1 - n_t^i\right)}{u_1\left(c_{t+1}^i, 1 - n_{t+1}^i\right)} = \beta\left[1 + (1 - \tau^k)r_{t+1}\right], \tag{13}$$

together with the budget constraint (11) and the transversality condition

$$\lim_{t \to \infty} \lambda_t a_t^i = 0, \tag{14}$$

where λ_t is the Lagrangian multiplier associated to the budget constraint (11), and $u_1()$ and $u_2()$ represents the marginal utilities of consumption and leisure, respectively.

2.4 The competitive equilibrium

In the competitive equilibrium of our economy with unified capital markets, regions may borrow or lend by selling or buying equities from residents of the other regions. Since equities are the only financial asset in this economy, we have that total wealth must add up to the national capital stock, so that

$$\sum_{i=1}^{N} \pi^i a_t^i = \sum_{i=1}^{N} \pi^i k_t^i. \tag{15}$$

Moreover, in a national perfectly integrated capital market, the arbitrage opportunities yield the following condition for an equilibrium to be viable:

$$r_t^i = r_t, \tag{16}$$

for all region i. Therefore, since the single good in this economy is tradable, and it can be either used for consumption, private investment or public expenditure, the following aggregate resource constraint holds at the equilibrium:

$$\sum_{i=1}^{N} \pi^i \left[c_t^i + k_{t+1}^i - (1-\delta)k_t^i\right] = (1-\eta-\varphi) \sum_{i=1}^{N} \left(\pi^i y_t^i\right). \tag{17}$$

Given the initial stocks of capital k_0, human capital h_0, infrastructures I_0 and equities a_0, as well as their distribution across regions, a competitive equilibrium under the fiscal policy $\left\{\varphi^i, \eta, \tau^c, \tau^w, \tau^k, \tau_t\right\}_{i=1}^{N}$ is defined as the time path of prices $\left\{w_t^i, r_t^i\right\}_{i=1}^{N}$ and of quantities allocations $\left\{c_t^i, n_t^i, a_t^i, k_t^i\right\}_{i=1}^{N}$ that satisfies: (i) utility maximization conditions (11), (12), (13) and (14) in each region i; (ii) profit maximization conditions (3) and (4) in each region i; (iii) government constraints (5), (6), (7) and (9); and (iv) market clearing conditions (15), (16) and (17).

Our economy exhibits a steady-state or balanced growth path (BGP, henceforth) equilibrium, along which the stock of capital, consumption and the stock of infrastructures at each region grow at a constant rate, whereas the time allocations, the relative prices and the ratio from output to private capital remain constant. Let us denote by ψ the stationary growth rate of output y_t^i. Since the ratio from public investment to output in each region is a constant, one obtains from the production function (1) that the stock of capital and the stock of infrastructures also grow at rate ψ and, moreover, this rate is given by

$$\psi = \xi^{\frac{\phi(1-\alpha)}{1-\alpha+\gamma(1-\upsilon)+\zeta(1-\upsilon)(N-1)}}. \tag{18}$$

Observe that scale effects exist since the growth rate depends on the number of interdependent regions, and this effect is generated through the technological spillover effects from infrastructures.[10] Finally, by dividing the budget constraint (11) by k_t^i, we obtain that consumption of all regions also grows at the rate ψ along the BGP.

In order to proceed with our analysis, we now normalized the variables to remove the consequences of the long-run growth. In particular, we introduce the following normalized variables:

$$\widehat{k}_t^i = \psi^{-t} k_t^i, \quad \widehat{c}_t^i = \psi^{-t} c_t^i, \quad \text{and} \quad \widehat{I}_t = \psi^{-t} I_t, \tag{19}$$

for all region i, which implies an identical normalization for output, wage rate, public investment, public consumption and the level of the lump-sum tax. Note that the normalized variables will remain constant along a BGP.

[10] A larger regional disaggregation may not necessarily lead to a larger growth rate. This disaggregation may imply a smaller intensity of the technological spillovers measured by ζ, which may offset the larger number of regions. In any case, this point should be estimated in each particular case.

3 Solution procedure

The distribution of assets across regions is a state variable in our model and, thus, the initial distribution determines the equilibrium path. Since it is not usually possible to obtain this distribution from data, we propose to follow the procedure of computing the competitive equilibrium by means of the first order conditions of a pseudo-social planner problem. As was proposed by Kehoe et al. (1992), this procedure consists in modifying the problem of a benevolent social planner, which maximizes the discounted sum of utilities of the regional representative consumers, to account for the fiscal policy distortions. More specifically, the pseudo-social planner faces to the following objective function:

$$\textstyle\sum_{i=1}^{N}\lambda^i\sum_{t=0}^{\infty}\beta^t U^i-\Omega_t, \tag{20}$$

with

$$\Omega_t=\textstyle\sum_{i=1}^{N}\pi^i\left(z_t^i c_t^i+s_t^i n_t^i+e_t^i k_t^i\right),$$

where z_t^i, s_t^i and e_t^i are variables describing tax distortions in region i, which are ignored by the planner; λ^i is the weight given to the welfare of the representative individual in region i, with $\sum_{i=1}^{N}\lambda^i=1$; and U^i is given by (10). The pseudo-social planner then chooses the time path of allocations $\left\{c_t^i,n_t^i,k_{t+1}^i\right\}_{i=1}^{N}$ to maximize the distorted social welfare function (20) subject to the following aggregate resource constraint:

$$\sum_{i=1}^{N}\pi^i\left[c_t^i+k_{t+1}^i-(1-\delta)k_t^i\right]=(1-\eta-\varphi)\sum_{i=1}^{N}\pi^i A^i\left(k_t^i\right)^{\alpha}\left[n_t^i\left(h_t^i\right)^{\phi}\right]^{1-\alpha}\left(\widetilde{I}_t^i\right)^{\gamma}, \tag{21}$$

where $\widetilde{I}_t^i$ is also taken as a given parameter. In the Appendix we derive the first order condition of the previous problem. The solution of this problem is indexed by the planner's weights λ^i and the exogenous variables z_t^i, s_t^i and e_t^i. As Kehoe et al. (1992) prove, any of these solutions can be decentralized as a competitive equilibrium by choosing a particular initial distribution of assets across regions. Therefore, given an initial distribution of assets, the competitive equilibrium of our economy can be characterized by the solution of the pseudo-social planning problem after setting the appropriate values for the weights λ^i and for the exogenous variables z_t^i, s_t^i and e_t^i describing the distortion from fiscal policy.

From the appendix we observe that, by following the previous procedure to characterize the competitive equilibrium, we are actually replacing the non arbitrage condition (16) in our definition of the competitive equilibrium with the following condition relating the marginal utilities of consumption across regions:

$$\left(\frac{\lambda^i}{\pi^i}\right)u_1\left(c_t^i,1-n_t^i\right)=\left(\frac{\lambda^j}{\pi^j}\right)u_1\left(c_t^j,1-n_t^j\right), \tag{22}$$

for any regions i and j, and for all t. Observe that this condition depends on the planner weights, which are implicit in the steady-state distribution of assets across regions. Thus, we will have to set these weights in the calibration exercise in order to obtain a particular solution.

In order to reduce the dimension of the previous distribution problem, we will also consider for simplicity that the national economy is composed of two regions: (i) the region that is target of our analysis, that we denote by *reference region*; and (ii) the *remainder region* that is artificially generated by taken the aggregate accounts of all regions except the *reference region.* In this way, we will analyze the effects of public infrastructure investment in each of the regions by changing sequentially the *reference region* from one region to other. Thus, we will independently analyze the effects of public investment in N different national economies, which will permit us to establish how the location of public investment across regions affects the economic activity.

4 Calibration

The model has to be solved and simulated in order to evaluate the dynamic, general equilibrium effects of changes in the policy of public investment. To this end, in this section we calibrate our economy by mapping its BGP equilibrium onto some facts derive from annual data of the Spanish economy during the period 1985-2001. Based on two empirical findings, we assume as a compromise solution that the Spanish economy is in a BGP since the 80s in order to follow a standard calibration procedure. On the one hand, Puch and Licandro (1997) show that the aggregate data for the Spanish economy from 1976 to 1994 are consistent with the required balanced growth conditions. On the other hand, some other authors show that the Spanish economy exhibits a very smooth convergence in GDP per capita across regions. For instance, de la Fuente (2002a) finds that the rate of convergence in output per capita across Spanish regions was equal to 0.38% from 1985 to 1995, which means that the regional composition of the Spanish GDP has experimented very small changes in this decade.[11]

The data comes from the Spanish National Accounts and from the series of private and public capital built by Mas et al. (2003). Tables 1 and 2 summarize the benchmark values of parameters used in this paper. Table 1 shows the parameters that are common for all regions, whereas Table 2 gives the values of the specific parameters that differentiate to each region.

[Insert Tables 1 and 2]

Following the procedure introduced in the previous section, we start from building the artificial national economies by considering sequentially the 17 Spanish regions as *reference*

[11] We have also checked that the regional dispersion of the Spanish GDP has experimented a very small decrease between 1985-2001. Moreover, the dynamic behavior of this output dispersion seems to obey basically the fluctuations in the economic activity. The dispersion increases in the sub-period 1985-1994 and decreases in the other sub-period.

regions. For each national economy, we denote by the superscript 1 to the variables and parameters of the *reference region* and by superscript 2 to the variables and parameters of the *remainder region*. We set the values of the weights λ^i such that the stationary solution of pseudo-social planning problem reproduces the relative consumptions per capita of regions observed in the data, which are given by Table 2 .

The parameters φ^1, φ^2 and η, which determine the paths of public investment in each region and the public consumption, are given by the respective average values of the ratios from regional public investments and from total public consumption to the aggregate GDP of the Spanish economy along the period of calibration. The calibrated values of φ^1 then reflects the patterns of the regional distribution of public investment observed in the data. We observe from Table 2 that this distribution does not obey any rule based on regional output per capita, even when we control for regional population. For the calibration of tax rates, we follow the methodology introduced by Mendoza et al. (1994), who derive the effective tax rates by comparing the before-tax prices and the after-tax prices. In this way, the calibrated rates of the consumption tax and the factor income taxes are consistent with the tax distortions which a representative individual faces to in a dynamic general equilibrium model.

We are now able to find the numerical values for parameters characterizing preferences and technologies. The private capital share in output, α, is calibrated to match the average share of labor income in the Spanish GDP. From data we can neither directly obtain the elasticities of output with respect to infrastructures, γ and ζ, nor the degree of congestion of the stock of infrastructures, υ. We can neither use previous estimations in the literature because they are based on parametric specifications that are not consistent with our model. Thus, we obtain the calibrated value of the parameters in technology by estimating the production function (1) with regional data after imposing the calibrated value for the capital share in output, α. In particular, the logarithmic specification of the production function in levels is estimated by ordinary least square, and using pooled aggregate data for the Spanish regions during the period 1964-2000. The results from this estimation are close to those previously obtained in the literature. The estimated elasticity of infrastructures, γ, is slightly small relative to the average of the previous estimations. However, as is usual, this is explained by the fact that the estimated value of the technological spillovers, ζ, is significatively positive.

Given the estimated parameters for the production function, we can compute the marginal productivity of effective infrastructures. The productivity of each region summarizes the effects that the endowments of infrastructures, the congestion costs and the technological spillovers from the infrastructures installed in the other regions have on the TFP of that region. The last two columns of Table 2 show the marginal productivities of effective infrastructures in the *reference* and the *remainder regions*, respectively. The regional ranking obtained from these marginal productivities meaningfully differs from the ranking in terms of output per capita. Moreover, the marginal productivity of effective infrastructures is always larger in the *reference region* that in *remainder* one. This a priory leads us to conclude that, given the current distribution of public investment across regions, the best strategy to maximize national output is to invest any additional unit in any region rather than to distribute it across all regions. However, by only attending to the marginal productivity of effective infrastructures, we would be skipping the effect that the public investment in a region may have in the economic decisions of the others regions. In the next section we will compute the economic relevance of these economic regional spillovers from the public investment in infrastructures.

The initial level of regional stocks of human capital h_0^i and the distance between the two regions d_{ij} are normalized to unit since they only determine the level of GDP.[12] The parameter σ is set to reproduce an inverse of the elasticity of intertemporal substitution on consumption c_t^i, given by $1-(1-\theta)(1-\sigma)$, equal to 2. The parameter ξ is selected from (18), such that ψ reproduces the annual average growth rate of the Spanish aggregate GDP. The population size of each region, π^1 and π^2, are selected to replicate the population participation of each region in the whole Spanish population. For simplicity we denote the population size of the *reference region* by π, so that $\pi^1=\pi$ and $\pi^2=1-\pi$. The technology parameters A^1 and A^2 are chosen such that the calibrated economy reproduces at the BGP the ratio between the gross added value of the two considered regions. In particular, we normalize A^2 to the unity, and we cover the differences in the gross added value by setting the level of A^1.[13] The second column of Table 2 shows the output of the *reference region* relative to the regional average observed from the data. We observe that Aragon, Baleares, Cataluña, Comunidad Valenciana, Madrid, Navarra, Pais Vasco and La Rioja exhibit a output per capita that is larger than the regional average. In the exposition of the results we will denote these regions as *rich regions*, whereas the other regions will be denoted as *poor regions* since their output per capita are smaller than the regional average.

We calibrate the remaining parameters by choosing them so that the BGP of our model matches the private capital-output ratio, the private investment-output ratio, the output-consumption ratio, the public capital-output ratio, the public investment-output ratio and the fraction of time devoted to market activities corresponding to the aggregate Spanish economy. First, the depreciation rate δ is calibrated from the law of motion for the capital

[12] In an economy with two regions, the distance between regions takes the same values in the production function of each region. Hence, this parameter does not introduce any kind of distributive effect in the allocation of resources.

[13] Observe from Table 2 that the values of A^1 for all regions, but Andalucía and Extremadura, are larger than unity, even when they exhibit a smaller per capita output than the *remainder region*. Note that the regional TFPs also depend on the relative size of population, on the stocks of infrastructures and on the externalities from aggregate capital stocks. The benchmark stocks of infrastructures in Andalucía and Extremadura are relatively large given their population sizes and their stocks of private capital, so that their relatively small levels of output are basically explained by a small regional-specific technological factor A^1.

stock at the BGP, which is given by

$$\frac{\widehat{i}}{\widehat{y}} = \psi \left(\frac{\widehat{k}}{\widehat{y}} \right) - (1 - \delta) \left(\frac{\widehat{k}}{\widehat{y}} \right),$$

where $\widehat{i}$ is the normalized level of private investment at the steady state. Second, the calibrated parameters θ and β are obtained from the conditions of the consumer's problem (12) and (13) at the BGP. Finally, the depreciation rate of stock of infrastructures μ is calibrated from the law of motion (9) at the BGP.

The numerical method used to solve the model is that proposed by Sims (2002), which is explained in detail by Novales et al. (1999). This method consists on analyzing the stability of the first order approximation of the dynamic system defining the competitive equilibrium around the BGP. For our numerical computations of the dynamics we simulate the economy for 2000 periods.

5 Experiments and results

This section describes the consequences of changing the benchmark policy of public investment. For that purpose, we will assume that the economy is initially at the steady state associated to the benchmark fiscal policy, and then government introduces unannounced reforms of this policy. In particular, we will carry out two types of experiments. First, we will investigate the effects of balanced budget reforms where the rate of public investment φ is augmented from its benchmark level. We will analyze two different regional distributions of this increase in public investment: (i) when the increase is allocated according to the current distribution of public investment; and (ii) when the increase is fully allocated to either the *reference region* or the *remainder region*. From the former reform we will then obtain the marginal effects of the current policy of public investment, whereas from the later reforms we will characterize the marginal regional spillover effects of public investment. Second, we will study the impact of redistributing public infrastructure investment across regions by maintaining the aggregate rate of public investment, φ, constant. The following subsections show the details and results of these experiments.

5.1 Marginal effects of current public investment

In this subsection we analyze the marginal effects of the current policy of public investment, which is determined by both its aggregate level and its regional allocation. Our strategy consists on increasing the aggregate rate of public investment. In order to isolate the effect of public investment from the tax distortion, we accommodate the reform by means of the lump-sun taxation, which is equally distributed across all individuals in the national economy. In particular, we study the effect of increasing permanently the public investment by 0.01% of aggregate output, i.e., we rise φ by 0.0001. Moreover, we allocate this increase across regions by using the same regional shares in public investment as in the benchmark model. More precisely, we consider that the public investment in the *reference region* and in the *remainder region* increases by the following proportions of aggregate output:

$$\triangle\varphi^i = 0.0001 \left(\frac{\varphi^i}{\varphi^1 + \varphi^2} \right), \tag{23}$$

for $i = 1, 2$. The effects of this reform are determined by the interaction among the distortions arising from the level and the regional distribution of public investment, from the taxation, from the interregional spillover effects and from the congestion costs. We next study these effects for each of the national economies obtained by taken alternatively each of the Spanish regions as *reference region*.

We first compute the accumulated variation of output per capita with respect to its before-reform steady-state level along the transition to the new steady-state. In particular, we calculate the discounted sum of the variation of regional output in each period as percentage of the discounted sum of aggregate output of the national economy associated to the new fiscal policy. Table 3 shows the results from this analysis. The first column of this table determines which of the Spanish regions is taken as *reference region*. Both the *reference regions* and the *remainder regions* experiment an accumulated increase in the output per capita for all the counterfactual national economies. For instance, if government raises public investment every period by 0.01% of national GDP, and he maintains the benchmark patterns of the regional allocation of this investment, then the accumulated increase in the output per capita of Madrid accounts for 0.0525% of the present value of national GDP associated to the new fiscal policy, whereas the rest of the regions accounts for 0.0416%.

[Insert Table 3]

Obviously, the reform also generates an accumulated increase in the output per capita of the national economy. However, at this point we must make the following clarification. Given the nature of the reform, one should expect the 17 national economies considered in Table 3 to be identical. However, these national economies are built by following different regional aggregations, so that they are dissimilar approximations of the actual national economy. Thus, the minor differences among the figures in the last column of Table 3 come from the errors derived from the aggregation that we have used to create each of the artificial *remainder regions*. These differences can then be used to derive the bias of the results obtained along the paper. In this sense, we can conclude that this bias is in general of small magnitude and, moreover, it does not affect to the qualitative conclusions of the paper.[14]

If we compare the accumulated increase in the output per capita for the *reference regions* with the accumulated increase for the *remainder* ones, the result depends on whether the output per capita of the former regions is larger or smaller than the regional average. Except

[14] In particular, the standard deviation of the results in the third column of Table 3 is 0.0009.

for the case of Canarias, we observe that this figure is larger (smaller) for the rich (poor) *reference regions* than for the *remainder regions*. However, the economic explanation of this result is not in the relative position of each region in terms of output per capita, but in the marginal productivity of the effective infrastructures in each region and in the pattern of the regional distribution of infrastructures at the benchmark fiscal policy. The latter two variables jointly determine the impact that the increase in the rate of public investment has on the regional TFP and, thus, on the regional output per capita. These two forces act in the same direction for some regions and in the opposite direction for other ones (see Table 2). For instance, while Andalucía receives a large fraction of the increase in the public investment, this region exhibits a relatively small marginal productivity of effective infrastructures. The small effect of the reform in the output per capita of this region is then explained by the fact that the small productivity of infrastructures dominates. By the contrary the large productivity of infrastructures explains the large impact of the reform in regions that exhibit a relatively small participation in public investment like, for instance, Baleares. Finally, the exceptional result for Canarias is explained by its relatively large participation in public investment in per capita terms and by its large marginal productivity of effective infrastructures.

In any case, since the impact of public investment in regional output per capita is generally larger in the richest regions, we can conclude that the current policy of public investment in infrastructures goes against of reducing the regional disparities in output per capita. An effective policy to reduce the regional differences would require in general to redistribute public investment from rich to poor regions to compensate the smaller impact that the latter regions receive from infrastructures. By the contrary, a public policy based on the efficiency criterion would obviously select the richest regions as the target of public investment since they exhibit in general the largest impact from infrastructures.

Evidently, the impact of the proposed reform also depends on the tax burden derived from the corresponding increase in public revenues. The results in Table 3 indicate that the regional cost of public funds used to finance the reform is dominated by the positive impact in the regional TFP. Moreover, the impact from the tax distortions does not introduce any discrimination across regions in terms of the accumulated increase in the output per capita experimented after the reform. The reason of this result is that the taxation policy is uniform across regions. On the one hand, the marginal cost of public funds is given by the marginal tax rates, which are the same for all regions. On the other hand, the lump-sum taxation is distributed uniformly across individuals regardless the region of their residence. The marginal cost per capita of the increase in public revenue is then constant across regions. Therefore, the relative differences in the overall impact of the reform on the regional output per capita is then exclusively driven by the effects that the increase in public investment has on the regional TFPs.

The results in Table 3 come from the dynamic adjustment of the regional economies to the reform. This adjustment also differs from rich to poor regions. On the one hand, the poor regions devote in the benchmark situation a relatively small fraction of time to work, so that the substitution effect derived from the increase in the marginal productivity of labor associated with the reform dominates in the short run. Hence, in these regions the number of hours worked and the output per capita jumps up instantaneously with the reform, and then they increase monotonously towards the new stationary level. On the other hand, in the case of the rich regions, the income effect derived from the increase in the marginal productivity of labor associated with the reform dominates in the short run because these regions devote a relatively large fraction of time to work before the reform. Thus, both the number of hours worked and the output per capita decrease instantaneously in these regions with the reform, and then they goes up monotonously to the new stationary levels, which are larger than the old ones. In any case, the long run effects always dominate, so that the accumulated increase in output per capita is positive in both poor and rich regions.

The differences between rich and poor economies in the dynamic adjustment advise us to analyze the welfare effects of the fiscal reform considered in this subsection. The short run effects may lead the reform to generate welfare losses. We next analyze the variation of the utility per capita in each region. For that purpose, we use the procedure introduced by Lucas (1987), which consists in computing the time-invariant change in consumption required to restore an individual to the level of utility obtained under the benchmark fiscal policy.[15] Table 4 reports the discounted sum of the required changes in consumption as percentage of the present value of aggregate output of the national economy associated to the new fiscal policy. A negative sign in this table means that the reform increases the utility of the representative consumer, since one must reduce her consumption in order to restore her initial level of utility. For instance, if the government raises public investment every period by 0.01% of national GDP, and he maintains the benchmark patterns of the regional allocation of this investment, then a representative consumer of Madrid is willing to reduce the discounted sum of her consumption by an amount that accounts for almost 0.0078% of the present value of national GDP associated to the new fiscal policy.

[Insert Table 4]

For all of the artificial national economies, the proposed increase in the aggregate public investment drives the welfare per capita of both the *reference* and *remainder* regions up. We can then conclude that the long-run behavior of leisure and consumption dominates, so that the reform of public investment policy generates an accumulated increase in welfare. Therefore, the current level of the aggregate public investment is socially suboptimal given its current pattern of regional allocation.

As was pointed out before, the impact that the reform proposed in this subsection has on a region is generated by two forces: (i) the effect of the increase in the stock of infrastructures installed in this region (*direct effect*); (ii) and the economic spillovers generated by the

[15] See Cooley and Hansen (1992) for a detailed explanation of this procedure of computing welfare effects of fiscal policy.

increase in the stock of infrastructures installed in the other regions (*spillover effect*). In the following subsection we decompose the overall impact of the reform reported here by computing the regional spillover effects associated with that reform.

5.2 The marginal interregional spillover effects of public investment

In this subsection we first analyze the effects of increasing the rate of public investment corresponding to the *reference region.* We maintain the rate of public investment in the *remainder region,* and we accommodate the reforms with the lump-sum taxation, which is equally distributed across individuals in the national economy. Remember that the first objective of this experiment is to isolate how much of the regional impact from the current public investment policy is due to the interregional spillovers generated by this investment. For that reason, we now study the effect of increasing permanently the public investment in the *reference region* by the same proportion of the aggregate national output as the one considered in the reform studied in Subsection 5.1. More precisely, we consider that $\Delta\varphi^1$ is given by (23) with $i = 1$, and that $\Delta\varphi^2 = 0$. This exercise of balanced budget incidence then characterizes numerically the regional spillover effects generated by the current public investment allocated to each region. We will focus on the effects on the output per capita, which are presented in Table 5.

[Insert Table 5]

We observe from the first column of Table 5 that the *reference regions* (i.e., those regions where government decides to increase public investment) experiment an accumulated increase in output per capita. As a consequence the *reference region* always improves its relative position. Furthermore, the results in the first column of Table 5 correspond to the *direct effect* derived from the experiment considered in Subsection 5.1. Therefore, we conclude that the current policy of public investment in infrastructures has a positive *direct effect* in all the Spanish regions. We also observe that the accumulated increases in the output per capita are also in this case generally larger for the initially richest regions, which is also now explained by the regional distribution of public investment and the marginal productivity of infrastructures in each region. Therefore, this confirms that public investment in productive infrastructures increases the differences in output per capita across Spanish regions, even when we omit the interregional spillover effects.

The second column of Table 5 shows the accumulated effects of the reform on the output per capita of the *remainder region.* Thus, this column summarizes the regional spillover effects generated by the public infrastructure investment in each of the Spanish regions. We observe that the investment in any region exhibits positive spillover effects in the artificial region derived from the aggregation of the other regions. Obviously, this implies that the government always drives the national output per capita up by increasing the public infrastructure investment in any region, as is illustrated by the third column in Table 5. The public investment in a region increases the TFP of the *remainder region* and, moreover, this investment also expands the business opportunities of the latter region in the region that is the target of public investment. These changes in the economic performance of the *remainder region* explain the positive spillover effect. However, at this point we can only conclude that the public investment in a region affects positively the output per capita of the aggregation of the other regions. We cannot then rule out the possibility that this investment in the *reference region* decreases the output per capita of some of those regions composing the *remainder region*.

In order to fully characterize the interregional spillover effects, we have to analyze the effects of increasing the public investment of the *remainder region* on the output per capita of the *reference region*. Observe that we can now isolate the spillover effects of the reform considered in Subsection 5.1 by comparing the figures in Table 5 with those in Table 3. Remember that this reform consisted on increasing the aggregate public investment by maintaining the benchmark patterns of its regional allocation. From that comparison, we observe that the direct effect given by the first column of Table 5 is larger than the overall effect given by the first column of Table 3. Hence, under the current policy of public investment a region receives negative spillover effects from the investment in the rest of the regions. This conclusion seems to contradict the estimations of the interregional spillovers effects given by the literature for the Spanish economy. However, we must clarify two points regarding our result. On the one hand, while the literature only estimates the existence of technological spillover effects (given by ζ in this paper), the difference between Table 5 and 3 is instead illustrating the economic spillover effects. In this sense, we observe that the economic spillover effects are always negative even when we have also estimated a positive technological spillover effect. While the investment in the *remainder region* increases the TFP of the *reference region*, this investment still reduces the relative position of the latter region because the larger increase in the TFP of the former region.

On the other hand, from this comparison between Tables 5 and 3, we can only derive that the aggregate investment in the *remainder region* has a negative spillover effect in the *reference region*. However, remember that the *remainder region* is an artificial region created by the aggregation of the rest of the regions. Hence, we can say nothing about how the public investment in each of the regions in this aggregation affects the *reference region*. We cannot then rule out the possibility that the investment in some of those regions composing the *remainder region* separately generates positive spillover effects in the *reference region*.

5.3 Effects from redistributing the current rate of public investment

In this subsection we analyze the effects of redistributing the benchmark level of public investment from the *remainder* to the *reference region*, i.e., $\Delta\varphi^1 = -\Delta\varphi^2$. In particular, we simultaneously increase the public investment in the *reference region* and reduce the public investment in the *remainder region* by a proportion of the aggregate output equal to the left-hand side of (23). The results derived from this differential incidence analysis are qualitatively similar to those from the exercise of balanced-budget incidence presented in Subsection 5.2.[16] This confirms that the current distribution of public infrastructure investment is also suboptimal under any of the criteria considered in this paper: reduction of the regional disparities in output per capita or maximization of national aggregate output.

Table 6 presents the accumulated variation of regional output per capita as a percentage of the discounted sum of national GDP. We present the results from this table by remarking the differences and similarities with the results from the exercise in the previous subsection (see Table 5). For notational convenience we denote the present reform as *differential reform* and the reform of the previous subsection as *balanced reform.* By comparing the numbers from Tables 5 and 7 we observe that the variation obtained by the *reference region* with the *differential reform* is much larger than the obtained with the *balanced reform.* This difference is caused by the positive spillover effects that the *reference region* receives from the *remainder region* under the *differential reform.* From the analysis in Subsection 5.2, we know that the reduction in the public investment allocated to the *remainder region* generates positive spillover effects.

[Insert Table 6]

The second column of Table 6 reports the variation of output per capita of the *remainder region.* The sign of these effects coincides with those given in Table 5 for the case of the *balanced reform.* Hence, the spillover effects from increasing the rate at which public investment is allocated to the *reference regions* dominates the negative effect from the reduction of the rate at which public investment is allocated to the *remainder region.* Evidently, the net variations in the output per capita of the *remainder region* are smaller in the *differential reform* than in the *balanced reform* because, while in the later reform the rate of public investment in the *remainder region* does not change, this rate is reduced in the former reform. This implies that the accumulated variation in the national output per capita is smaller under the *differential reform*, as can be seen from the third column of Table 6. Therefore, the redistribution of current public investment is a less effective tool to rise the national aggregate output than the increase in the current level of public investment.

Nevertheless, given the positive impact of the *differential reform* in the national output, we also conclude that the current regional allocation of public investment is suboptimal. A more concentrated regional distribution of public investment would lead to a larger level of national output with independence of the regions in which the public investment is concentrated. However, we cannot elaborate at this point a regional ranking of priorities in the allocation of public investment based on a efficiency criterion. To this end, we need to implement an alternative differential reform where the level of public investment redistributed from the *remainder* to the *reference region* is the same for all the national economies considered in our quantitative analysis. For that reason, we have simulated a

[16] Observe that both reforms imply the same relative increase in public investment for the *reference region.* The difference between the two reforms is the way as the government accommodates the increase in public investment in order to maintain the balanced-budget constraint.

reform in which $\Delta\varphi^1 = 0.000001$ and $\Delta\varphi^2 = -0.000001$. We omit the numerical results of this new reform because they are qualitatively identical to those reported by Table 6. The relevant point of this reform is the comparison between the impact in the aggregate output of the different national economies. From this exercise we derive that the ranking of regional priorities in the distribution of public investment based on the efficiency criterion is as follows: La Rioja, Baleares, Navarra, Cantabria, Murcia, Canarias, Asturias, Aragón, Extremadura, Castilla-La Mancha, País Vasco, Madrid, Castilla-León, Galicia, Comunidad Valenciana, Cataluña and Andalucía. This ranking widely differs from those rankings previously derived in the literature by studies like, for instance, de la Fuente and Vives (1995). These preceding rankings were exclusively based on the marginal productivity of infrastructures given by an estimated production function without technological spillovers. Our ranking is not only determined by the marginal productivity of infrastructures, but also by the economic interregional spillovers.

5.4 A sensitivity analysis

In this subsection we report how our main findings are affected by changing some of the benchmark parameters. In particular, we will focus in the parameters determining the productive role of the infrastructures: the elasticity of output with respect to effective infrastructures γ; the intensity of the technological spillovers ζ; and the degree of congestion in the productive services from infrastructures υ. While the benchmark values of the other parameters are very similar to those used in the literature, there are some controversy about the estimated values of the three aforementioned parameters.

Elasticity of infrastructures. The qualitative conclusions obtained in the experiments analyzed in this section are robust to changes in the value of γ. However, we still derive some important information from this sensitivity analysis. Firstly, a decrease in γ reduces the relative increase in output per capita and the welfare gain obtained by the *reference region* from an increase in the public investment in this region. The increase in public investment even reduces the welfare per capita for sufficiently small values of γ. While the marginal cost of public investment (the tax distortion) does not depend on γ, the marginal benefit derived from the public investment does because that parameter determines the marginal productivity of infrastructures and the interregional spillovers. On the one hand, an increase in γ raises the marginal productivity of effective infrastructures. On the other hand, we obtain that the negative spillover that the *reference region* receives from the public investment in the *remainder region* is an increasing function of γ in absolute terms. However, the effect of γ on the marginal productivity of infrastructures dominates the effect on regional spillovers. Secondly, we also obtain that the sensitivity of the negative spillovers received by the *reference region* from the *remainder* one is larger for the richest *reference regions*. Finally, the positive spillover effects that the public investment in the *reference region* generates in the *remainder region* are an increasing (decreasing) function of γ when the former region is a poor (rich) region. The increase in γ raises the productivity advantage of the rich regions, whereas this increase basically pushes the demand of the poor regions up and, thus, the business opportunities of the *remainder region* grow up.

Technological spillovers. We obtain expected results from the sensitivity analysis with respect to the parameter ζ. Firstly, the impact on output and welfare per capita from increasing the aggregate public investment depends positively on the value of ζ. This dependence is determined by the fact that an increase in ζ drives the marginal productivity of effective infrastructures up. Secondly, the absolute value of the negative economic spillovers from the public investment in the *remainder region* is evidently a decreasing function of ζ. In the absence of technological spillovers, the public investment in a region has not positive effects on the aggregate productivity of the other regions, so that the economic spillovers in these regions are only driven by the derived decrease in their relative economic position. Finally, a reduction in the value of ζ increases (reduces) the impact that the redistribution of the current public investment has on the output per capita of the *reference* (*remainder*) *region*. This result is explained by the reduction in the absolute value of the economic spillovers that the *reference* (*remainder*) *region* receives from the reduction (increase) in the public investment allocated in the *remainder* (*reference*) *region*.

Congestion costs. The changes in value of the parameter υ have a very small effect on the main findings from our fiscal policy analysis. For instance, if we consider the case $\upsilon = 0$, we obtain that the impact of increasing the aggregate public investment on output and welfare per capita is slightly larger than in the benchmark case $\upsilon = 0.36$. This is also the conclusion with respect to the impact of the redistributive reform on the output per capita in the *reference region*. Finally, the interregional spillover effects are almost the same under these two values of υ.

6 Conclusions and extensions

In this paper we have proposed a multi-regional, general equilibrium model with capital accumulation to investigate the economic impact of the spatial distribution of public capital formation. This model was solved and calibrated by using data for the Spanish economy in order to make a comparative dynamic analysis of the current public investment policy. For that purpose, we have simulated two reforms of this investment policy: an increase in the national public investment and a change in the distribution of the current level of public investment across regions. These analyses showed that public investment plays an important role in generating the existing imbalances in regional development. This was shown by means of a cost-benefit analysis, where we have computed the spillover effects and the opportunity costs of the regional distribution of public investment.

The present paper is subject to be extended in several ways in order to enrich the analytical tool that we have proposed to study the regional effects of public investment. We could first remove the assumption of immobile labor, such that the population size of each region would be endogenously determined. Regional immobile labor is not an unrealistic assumption for capturing the short effects of regional policy. Moreover, this is a standard assumption in the applied studies of the Spanish economy since regional migration seems to be subject to large costs. However, over long periods of time there has been substantial migration from poorer to richer regions. In a recent paper, Arcalean et al. (2007) show that labor mobility is a crucial assumption in determining the growth effects of public expenditure. Therefore, regional migration may also be a mechanism determining, at least in the long run, the regional spillover effects of public investment.

The present paper could also be extended to introduce explicitly the role of public infrastructures in reducing the transportation costs in the economic relation between regions. This extension introduces a new dimension in the economic role of public capital since this assumption affects directly the economic relations between regions. This seems a natural way of incorporating explicitly the microfoundations of the technological spillover effects considered in this paper.

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Appendix: The pseudo planning solution

The first order conditions of the pseudo-social planning problem are:

$$\lambda^i u_1(c_t^i, 1 - n_t^i) = \pi^i \left(\mu_t + z_t^i\right), \tag{A.1}$$

$$\lambda^i u_2(c_t^i, 1 - n_t^i) = \pi^i \left[\mu_t \left(1 - \alpha\right) \left(\frac{y_t^i}{n_t^i}\right) - s_t^i\right], \tag{A.2}$$

$$\mu_t = \beta \left\{\mu_{t+1} \left[1 + \alpha \left(\frac{y_{t+1}^i}{k_{t+1}^i}\right) - \delta\right] - e_t^i\right\}, \tag{A.3}$$

for $i = 1, 2..., N$, and the aggregate resource constraint (21), where μ_t is the Lagrangian multiplier associated to this maximization problem. These conditions characterize an equilibrium path of our economy if the following *side conditions* hold:

$$z_t^i = \tau^c \mu_t, \tag{A.4}$$

$$s_t^i = \tau^w \mu_t \left(1 - \alpha\right) \left(\frac{y_t^i}{n_t^i}\right), \tag{A.5}$$

$$e_t^i = \tau^k \mu_{t+1} \left[\alpha \left(\frac{y_{t+1}^i}{k_{t+1}^i}\right) - \delta\right], \tag{A.6}$$

for $i = 1, 2..., N$, and the government's constrains (5) to (9) are satisfied. Combining these side conditions with the first order conditions from above, we obtain the set of conditions given in Sub-section 2.4 to characterize the national economy equilibrium, where the condition (16) was replaced by the condition (22).[17] Note that the later condition results from combining (A.1) for any two regions i and j with the side condition (A.4). Therefore, given an initial distribution of assets, the equilibrium path of our national economy can be characterized by the solution of the pseudo-social planning problem by imposing the side conditions and by setting the appropriate value of the weights λ^i.

[17] However, by combaining (22) with the Euler equations given by (13) for $i = 1, 2..., N$, we obtain that the pseudo-social planning solution also satisfies the non-arbitrage condition (16).

Table 1. Values of common parameters in the benchmark model

	Parameter	Value
Preferences		
Fraction of national population in region 1	π	(*)
Subjective discount factor	β	$0,9731$
Share parameter for leisure	θ	$0,6539$
Intertemporal elasticity of substitution	$\frac{1}{\sigma}$	0.2571
Technology		
Gross growth rate of human capital	ξ	$1,0527$
Technology parameter of region 1	A^1	(*)
Technology parameter of region 2	A^2	1
Initial stock of human capital in region 1	h_0^1	1
Initial stock of human capital in region 2	h_0^2	1
Share of private capital	α	$0,33$
Share of human capital	ϕ	$0,5339$
Output elasticity of infrastructures	γ	$0,0978$
Technological spillovers from infrastructures	ζ	$0,0036$
Degree of congestion in infrastructures	υ	$0,36$
Depreciation rate of private capital	δ	$0,10$
Depreciation rate of infrastructures	μ	$0,0462$
Distance between regions	d_{12}	1
Fiscal policy		
Ratio public investment in region 1-national output	φ^1	(*)
Ratio public investment in region2-national output	φ^2	(*)
Ratio public consumption-national output	η	$0,1706$
Rate of consumption tax	τ^c	$0,1316$
Rate of labor income tax	τ^w	$0,3109$
Rate of capital income tax	τ^k	$0,1633$

(*) See Table 2

Table 2. Values of particular parameters in the benchmark model

Regions	Data		Calibrated parameters				Model	
	$\frac{y^1}{y}$	$\frac{c^1}{c}$	A^1	π	φ^1 (1)	λ	PI^1_{ef} (2)	PI^2_{ef} (2)
Andalucía	0.7850	0.8713	0.9510	0.1724	0.00613	0.1374	0.3434	0.1994
Aragón	1.0545	1.0517	1.2440	0.0318	0.00141	0.0351	1.2278	0.1790
Asturias	0.8730	0.9653	1.1651	0.0293	0.00113	0.0287	1.1494	0.1796
Baleares	1.2556	1.1830	1.4654	0.0184	0.00058	0.0249	3.1072	0.1798
Canarias	0.9950	0.9173	1.1514	0.0382	0.00144	0.0308	1.1852	0.1791
Cantabria	0.9471	0.9747	1.2399	0.0137	0.00057	0.0132	1.9333	0.1799
Castilla-León	0.8969	0.9309	1.0831	0.0673	0.00272	0.0594	0.6675	0.1826
Castilla-Mancha	0.8249	0.8384	1.0292	0.0435	0.00192	0.0308	0.7206	0.1809
Cataluña	1.1903	1.1195	1.2630	0.1576	0.00449	0.1909	0.8171	0.1772
C. Valenciana	0.9901	1.0135	1.1606	0.0982	0.00306	0.1021	0.7796	0.1816
Extremadura	0.6651	0.7482	0.9550	0.0277	0.00125	0.0164	0.7018	0.1799
Galicia	0.7661	0.8669	1.0215	0.0726	0.00243	0.0579	0.6181	0.1833
Madrid	1.2802	1.1838	1.3570	0.1275	0.00327	0.1708	1.1497	0.1733
Murcia	0.9225	0.9255	1.1818	0.0262	0.00085	0.0225	1.5816	0.1796
Navarra	1.2363	1.1632	1.4192	0.0137	0.00064	0.0179	2.4795	0.1793
País Vasco	1.1731	1.1134	1.2787	0.0553	0.00227	0.0667	1.0791	0.1789
La Rioja	1.1121	1.0132	1.3832	0.0068	0.00025	0.0067	4.2730	0.1824

(1) Ratio of public investmentent in region 2 to national output is given by $\varphi^2 = 0.0344 - \varphi^1$.

(2) Marginal productivity of effective infrastructures: $PI^i_{ef} = \gamma \left(y^i / \widetilde{I}^i \right)$.

Table 3

Accumulated variation in output per capita generated by increasing aggregate public investment and maintaining its patterns of regional distribution

(as a percentage of discounted sum of national GDP per capita)

Reference regions	*Reference region*	*Remainder region*	*National economy*
Andalucía	0.0336	0.0432	0.0415
Aragón	0.0440	0.0424	0.0425
Asturias	0.0374	0.0425	0.0424
Baleares	0.0517	0.0429	0.0431
Canarias	0.0406	0.0404	0.0404
Cantabria	0.0398	0.0421	0.0421
Castilla-León	0.0378	0.0420	0.0417
Castilla-La Mancha	0.0345	0.0407	0.0405
Cataluña	0.0490	0.0415	0.0426
ComunidadValenciana	0.0416	0.0424	0.0423
Extremadura	0.0286	0.0404	0.0401
Galicia	0.0330	0.0423	0.0416
Madrid	0.0525	0.0416	0.0430
Murcia	0.0385	0.0415	0.0414
Navarra	0.0509	0.0428	0.0430
PaísVasco	0.0484	0.0423	0.0427
LaRioja	0.0453	0.0414	0.0414

Table 4

Welfare cost per capita from increasing aggregated public investment, and maintaining its patterns of regional distribution

(as a percentage of discounted sum of national GDP per capita)

Reference regions	*Reference region*	*Remainder region*	*National economy*
Andalucía	−0.0042	−0.0052	−0.0051
Aragón	−0.0063	−0.0050	−0.0050
Asturias	−0.0056	−0.0050	−0.0050
Baleares	−0.0079	−0.0049	−0.0050
Canarias	−0.0032	−0.0052	−0.0051
Cantabria	−0.0053	−0.0050	−0.0050
Castilla-León	−0.0047	−0.0051	−0.0050
Castilla-Mancha	−0.0030	−0.0052	−0.0051
Cataluña	−0.0069	−0.0046	−0.0050
Com.Valenciana	−0.0059	−0.0049	−0.0050
Extremadura	−0.0024	−0.0052	−0.0051
Galicia	−0.0043	−0.0051	−0.0051
Madrid	−0.0078	−0.0046	−0.0050
Murcia	−0.0044	−0.0051	−0.0051
Navarra	−0.0076	−0.0049	−0.0050
País Vasco	−0.0069	−0.0049	−0.0050
La Rioja	−0.0048	−0.0051	−0.0050

Table 5
Accumulated variation in output per capita generated by increasing public investment in the reference region
(as a percentage of discounted sum of national GDP per capita)

Reference regions	*Reference region*	*Remainder region*	*National economy*
Andalucía	0.0512	0.0085	0.0159
Aragón	0.0682	0.0125	0.0142
Asturias	0.0591	0.0103	0.0117
Baleares	0.0796	0.0140	0.0152
Canarias	0.0626	0.0170	0.0185
Cantabria	0.0625	0.0123	0.0130
Castilla-León	0.0585	0.0114	0.0145
Castilla-La Mancha	0.0539	0.0133	0.0150
Cataluña	0.0703	0.0096	0.0191
Comunidad Valenciana	0.0629	0.0101	0.0153
Extremadura	0.0456	0.0114	0.0123
Galicia	0.0518	0.0096	0.0127
Madrid	0.0758	0.0104	0.0187
Murcia	0.0600	0.0131	0.0144
Navarra	0.0783	0.0143	0.0152
País Vasco	0.0736	0.0131	0.0164
La Rioja	0.0694	0.0169	0.0173

Table 6
Accumulated variation in output per capita generated by redistributing public investment towards the reference region
(as a percentage of discounted sum of national GDP per capita)

Reference regions	*Reference region*	*Remainder region*	*National economy*
Andalucía	0.0550	0.0010	0.0103
Aragón	0.0693	0.0112	0.0130
Asturias	0.0599	0.0092	0.0107
Baleares	0.0797	0.0134	0.0146
Canarias	0.0636	0.0157	0.0175
Cantabria	0.0627	0.0118	0.0124
Castilla-León	0.0602	0.0087	0.0122
Castilla-La Mancha	0.0550	0.0117	0.0135
Cataluña	0.0735	0.0048	0.0156
Comunidad Valenciana	0.0650	0.0069	0.0126
Extremadura	0.0463	0.0103	0.0113
Galicia	0.0533	0.0071	0.0105
Madrid	0.0782	0.0071	0.0161
Murcia	0.0605	0.0124	0.0137
Navarra	0.0788	0.0138	0.0147
País Vasco	0.0754	0.0110	0.0146
La Rioja	0.0698	0.0168	0.0172