Macroeconomic effects from the regional allocation of public capital formation*

Jaime Alonso-Carrera
Departamento de Economía Aplicada and RGEA
Universidade de Vigo

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

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

February 2007

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 solved and calibrated by using data for 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.

JEL Classification: E62, H20, O40.
Keywords: Infrastructures, Dynamic General Equilibrium, Regional Economics.

*This paper is part of a project cofinanced by FEDER and Fundación CaixaGalicia. We wish to thank Ángel de la Fuente, Gerhard Glomm, Carlos de Miguel, Farshid Vahid and the participants in presentations at the Australasian Workshop in Macroeconomic Dynamics in Canberra, Australian National University and Spanish Ministry of Economy for their useful comments. Of course, they should not bear any responsibility for the remaining errors. Additional financial support from the Spanish Ministry of Education and FEDER through grants SEJ2005-03753, PR2006-0148 and PR2006-0149; and the Xunta de Galicia through grant PGIDIT06PXIC300011PN are also gratefully acknowledged. Finally, Alonso-Carrera and Freire-Serén thank the School of Economics at the Australian National University for its hospitality during a visit where part of this research was undertaken.

Correspondence address: María Jesús Freire-Serén, Facultade de Ciencias Económicas, Universidade 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 factors of production 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 regional output and welfare.

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 infrastructure stocks interpreted as the productivity of public capital. 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 explore 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 two decades to assess the macroeconomic effects of 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), who 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 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 output and welfare 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 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) or Pereira and Roca-Sagalés (2003), 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 intial distribution of wealth across regions to characterize the competive equilibrium. By following Kehoe et al. (1992), we then propose to compute the equilibrium path by means of the 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. Our model is solved and calibrated using data and estimates for Spanish economy in order to simulate some comparative dynamic exercises of fiscal policy changes. In particular, given the benchmark fiscal policy obtained from the calibration, we consider two types of numerical experiments. First, we carry out balanced-budget incidence analyses, where we investigate the effects of increasing the aggregate rate of the public infrastructure investment. In this case, we alternatively consider that the shock in public investment either alters or

[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.

maintains the current patterns in the regional distribution of public investment. Second, we develop a differential incidence analysis, where we study the impact of redistributing public infrastructure investment across regions by maintaining total public expenditure constant. In all these experiments, we numerically compute the impacts on output and welfare of the fiscal policy changes, focusing on the induced changes on the regional dispersion of these macroeconomic variables.

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 a brief summary and some concluding remarks.

2 Model

We consider a national economy composed of N regions inhabited by infinitely lived individuals. Whole population remains constant and, without loss of generality, we normalize its size to unity. However, the population of each region can be different. We denote by π^i the fraction of national population located in region i, where $\sum_{i=1}^{N} \pi^i = 1$. All regions produce a tradeable homogenous commodity by using labor and capital as inputs. Each region accumulates capital gradually over time, with the national market for capital being perfectly integrated, so that 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 collects revenues from interregional uniform taxes and decides to allocate this revenue between public investment and public consumption. This government also distributes public investment among regions in order to increase their TFPs.

2.1 Firms

In each region there exists a large number of identical firms. They operate under perfect competition and use private capital, labor and 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 the efficient level of technology in region i, which depends on exogenous regional factors; 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 its use of the national stock of infrastructures.

The productive services derived by a firm in region i from public infrastructures are represented by

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

where I_t^i is the aggregate stock of infrastructures 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. First, 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 tradeable 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_{ij} determines the elasticity of output of region i with respect to the stock of infrastructures installed in region j.

Second, infrastructures are not a pure public good since their services to firms are subject to congestion costs. Following Fisher and Turnovsky (1998), among many others, we assume that the productive services derived by a firm from a given stock of public capital decreases 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 congestions 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 assume that the stock of human capital grows at a rate that is constant along time and across regions, i.e., $h_t^i = \xi^t h_0^i$, where ξ denotes the gross rate of growth. We also assume that $\xi > 1$ to obtain sustained growth. Finally, in order to ensure that output grows

[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.

asymptotically at the same rate in all regions, we impose that $\zeta_{ij} = \zeta$ for all i and j. The equalization of growth rate across regions ensures that the gross added value of each region to national output will not tend to zero.

The price of good y_t is the same across regions because the tradeable nature and the absence of transportation cost. This price is taken as numerarie. Since firms behave competitively, the value of marginal productivity of private capital and labor are equal to their respective rental rate. Hence, using the production function (1) factor prices at region i is given by

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

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

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. Furthermore, we assume that this 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 $\left(c_t^i\right)^{1-\theta}(1-n_t^i)^{\theta}$; and σ is the inverse of the elasticity of the intertemporal substitution of this composite commodity. In this economy with endogenous labor supply, the inverse of the elasticity of the intertemporal substitution of consumption c_t^i is given by $1-(1-\theta)(1-\sigma)$.

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 tradeable, 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

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

Observe that scale effects exist since the growth rate depends on the number of inter-dependent regions, and this effect is generated through the technological spillover effects from infrastructures. 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 we have used the growth rate in the BGP as the discounting parameter. Hence, the normalized variables $\widehat{k}_t^i$, $\widehat{c}_t^i$ and $\widehat{I}_t$ will remain constant along a BGP for all i, and $\widehat{k}^i$, $\widehat{c}^i$ and $\widehat{I}$ will denote the respective stationary values of these variables.

3 Solution procedure

In the kind of models like the one considered in this paper, the distribution of assets across regions is a state variable 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:

$$\sum_{t=0}^{\infty} \beta^t \left[\left(\sum_{i=1}^{N} \lambda^i U^i \right) - \Omega_t \right], \tag{20}$$

with

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

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:

$$\sum_{i=1}^{N} \left\{ \pi^i \left[c_t^i + k_{t+1}^i - (1-\delta) k_t^i \right] \right\} + X_t + G_t = \sum_{i=1}^{N} \left(\pi^i y_t^i \right), \tag{21}$$

where y_t^i is given by (1). 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 initial distribution of assets 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 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. More specifically, we will have to impose some calibration target like, for instance, the relative consumption per capita of regions observed in the data.

In the next sections we will illustrate this solution procedure by specializing the model to the Spanish economy. In order to reduce the dimension of the previous distribution problem, we will 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

In this section we find the numerical values of the parameters by mapping the BGP equilibrium of the general model onto some facts derive from annual data of Spanish economy during the period 1985-1995. 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 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 have experimented very small changes in this decade.

The data was obtained from the Spanish National Accounts and from the series of private and public capital built by BBVA Foundation. Tables 1 and 2 summarize our calibrated parameters. 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 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*. Moreover, we consider that the planner weights are equal to the relative size of regional population, i.e., $\lambda^i = \pi^i$ for all region i. Under this assumption, the condition (22) imposes that the marginal utility of consumption is constant across regions as an equilibrium condition. We think this is a reasonable assumption since, with these weights, our model reproduces relative consumptions per capita of regions at the BGP that are very close to those observed in the data.

The parameters φ^1, φ^2 and η, which determine the paths of public investment in each regions 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 GDP of the artificial national economy along the period of calibration. 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 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 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.[10] 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) to reproduce the average growth rate of Spanish GDP from 1985 to 1995. Following, Corrales and Taguas (1991), we fix the annual depreciation rate of the stock of infrastructures μ to 5%. The population size of each region, π^1 and π^2, are selected to replicate the population

[10] 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.

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 efficient levels of technologies 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 the efficient level of technology for the *remainder region,* A^2, to the unity and, thus, cover the differences in the gross added value by the efficient level of the *reference region*, A^1.[11] 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, 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.

Finally, we calibrate the remaining parameters by choosing them so that the BGP of our model matches the capital-output ratio, the private investment-output ratio, the output-consumption ratio and the fraction of time devoted to market activities corresponding to the aggregate Spanish economy. On the one hand, the depreciation rate δ is calibrated from the law of motion for the capital stock at 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. On the other hand, the calibrated parameters θ and β is obtained from the first order conditions of the consumer's problem (12) and (13) at the BGP:

$$(1 + \tau^c) \left(\frac{\theta}{1 - \theta} \right) \left(\frac{n}{1 - n} \right) = (1 - \tau^w)(1 - \alpha) \left(\frac{\widehat{y}}{\widehat{c}} \right),$$

$$\frac{\psi}{\beta} = 1 + (1 - \tau^k) \left[\alpha \left(\frac{\widehat{y}}{\widehat{k}} \right) - \delta \right].$$

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

In order to give a complete characterization of the macroeconomic effects of the spatial allocation of public infrastructure investment across Spanish regions, we will analyze the

[11] Observe from Table 2 that the values of A^1 for all regions, but Andalucía, is larger than unity, even when they exhibit a smaller per capita output than the *remainder region.* However, note that the regional TFPs also depend on the relative size of population and on the externalities from public infrastructures and from aggregate capital stocks.

impact of alternative reforms of the benchmark fiscal policy. More precisely, 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 is augmented from its benchmark level by increasing taxes. 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 two types of exercises.

5.1 Marginal effects of current public investment

In this subsection we analyze the marginal effects of the current policy of public investment, that is determined by both its aggregate level and its regional allocation. Our strategy consists on increasing the aggregate rate of public investment, so that the reform is financed by increasing taxes. In order to isolate the effect of public investment from the tax distortion, we use the lump-sum tax to accommodate the reform. 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 weights 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* increase respectively by the following proportions of aggregate output:

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

and

$$\triangle\varphi^2 = 0.0001\left(\frac{\varphi^2}{\varphi^1+\varphi^2}\right).$$

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 regional 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 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*. We observe that the results are the same for all the counterfactual national economies except for the case when the Comunidad Valenciana is the *reference region*. Both the *reference regions* and the *remainder regions* in general experiment an accumulated increase in the output per capita. 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 rise in the output per capita of Madrid accounts for almost 0.05% of present value of national GDP associated to the new fiscal policy, whereas the rest of the regions accounts for almost 0.03%. We also observe that the accumulated increase in output per capita is always larger in the *reference regions* than in the *remainder* ones.

[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 real national economy. Thus, the minor differences among the figures in the third 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.[12]

These results in Table 3 come from the dynamic adjustment of the regional output per capita. Except for the case of the Comunidad Valenciana, this macroeconomic variable goes up instantaneously with the policy shock, and then it increases monotonously to the new steady-state level. However, the output per capita of the Comunidad Valenciana goes down instantaneously, and then it increases monotonously to a new steady-state level that is smaller than the one associated to the benchmark model. The differentiated behavior of the Comunidad Valenciana may derive from the fact that this region covers a large proportion of the tax revenues and receives a small productivity effect from the stock of infrastructures. Effectively, we observe from Table 2 that this is a large populated region with a labor productivity below the regional average. Moreover, we also see that this region is endowed with a stock of infrastructures relatively much smaller than others regions with a large population. For instance, Andalucia, that is also a poor and large populated region, obtains a large proportion of the increase in public investment (18.57%), whereas Comunidad Valenciana obtains a much smaller proportion (8.57%). Thus, unlike in the case

[12] In particular, the standard deviation of the results in the third column of Table 3 is 0.00451.

of Comunidad Valenciana, the marginal effect of public investment on output per capita is positive in Andalucia.

We also analyze the welfare effects of the fiscal reform considered in this subsection. More precisely, we 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.[13] 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 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 0.005% of the present value of national GDP associated to the new fiscal policy.

[Insert Table 4]

The first column of Table 4 shows that, except Asturias, Canarias and Cantabria, all the regions obtain a welfare gain from the proposed increase in aggregate public investment. Moreover, the reform increases the welfare of the national economy. Effectively, we observe that the welfare effect in the *remainder regions* is always larger than the one obtained in the *reference regions.* Evidently, these marginal effects on welfare is the result of the interaction of the different distortions existing in our economy: public expenditure, taxes, congestion costs and regional spillover effects. However, given the general equilibrium nature of the model, we can not derive the contribution of each of these distortions to the overall effect. In the next subsection we compute the marginal spillover effects of public investment since this was one of the main purposes of this study.

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 by increasing the lump-sum taxes. In particular, we study the effect of increasing permanently the public investment in the *reference region* by 0.001% of aggregate national output, i.e., we rise φ^1 by 0.00001.[14] This

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

[14] The algorithm used to solve the model does not converge to an interior stationary solution when we introduce this policy shock in Asturias, Canarias, Cantabria and Comunidad Valenciana. To avoid this problem, we consider smaller shocks in these regions: 10 times smaller in Asturias and Comunidad Valenciana and 100 times smaller in Canarias and Cantabria.

exercise of balanced budget incidence then characterizes numerically the regional spillover effects generated by the public investment in each region. Moreover, as a by-product of our analysis, we also derive some rankings of regional priorities in public investment. 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, except Aragon, Comunidad Valenciana, Pais Vasco and La Rioja, the *reference regions* (i.e., those regions where government decides to the increase public investment) experiment an accumulated increase in output per capita. As a consequence the *reference region* always improves its relative position, except when public investment is raised in Aragon, Comunidad Valenciana and La Rioja. We also observe that the accumulated increases in the output per capita are generally larger for the initially poor regions. Therefore, this confirms that public investment in productive infrastructures can be an effective tool to reduce the differences in output per capita across Spanish regions.

To understand the results of Table 5, it seems convenient to check how the output per capita adjusts to the new steady-state value after the fiscal reform. Figures 1 and 2 illustrates this dynamic adjustment by sketching the shape of the deviation of output per capita after the reform with respect the stationary level corresponding to the benchmark policy. On the one hand, Figure 1 shows the dynamic adjustment of Galicia, which would be a representative region of those regions with an initial output per capita below the regional average. On the other hand, Figure 2 shows the dynamic adjustment of Cataluña as a representative region of those regions with an initial output per capita above the regional average. By comparing the two figures, we observe that the dynamic adjustment in the poor regions differs from the dynamic adjustment in the rich regions. The output per capita of the former group of regions jumps up instantaneously with the policy shock, and then it increases monotonously to the new steady-state level. By the contrary, the output per capita of the rich regions goes down instantaneously with the policy shock, and then it increases monotonously to the new steady-state level. In any case, in all regions, except Aragon, Comunidad Valenciana and La Rioja the final steady-state value of the output per capita is larger than the initial one.

The accumulated losses of output obtained by Aragon, Comunidad Valenciana, Pais Vasco and La Rioja, as *reference regions*, then reflect the patterns of dynamic adjustment induced by the fiscal reform. In all of these regions the output per capita goes down instantaneously. After this initial change, the output per capita of Aragon and La Rioja increases to the new steady-state level that is slightly smaller than the old one, whereas the output per capita of Comunidad Valenciana decreases monotonously to the new steady-state. On the contrary, the output per capita in Pais Vasco increases monotonously to a new stationary level that is larger than the initial one. However, for the later region the dynamics in the periods where output decreases with respect to the initial level dominate to the dynamics in the periods where output increases. In any case, the dynamic pattern in the output is driven in all regions by the reaction of labor supply and savings to the shock, which reflects the equilibrium between the income and the substitution effects of increasing public investment.

[Insert Figure 1and 2]

The second column of Table 5 shows the accumulated effects of the reforms on the output per capita of the *remainder region*. Thus, this column summarizes the regional spillover effects of the public infrastructure investment in each of the Spanish regions. We observe that the investment in the poor regions exhibits negative spillover effects at the margin, whereas the investment in the rich regions generates positive spillover effects. Given this result, one should check the impact of the reform on the aggregate output per capita of the national economy. The third column of Table 5 shows that the government always drives the national output per capita up by increasing the public infrastructure investment in any region, except in the case of Asturias, Canarias and Cantabria. From this third column we can derive a ranking of regional priorities in public infrastructure investment in terms of maximizing Spanish aggregate output. We obtain that this ranking differs from the obtained by focusing on the effects on the *reference region*. In particular, these two rankings have opposite regional priorities in the public investment. This result reflects the traditional conflict between the redistribution and the efficiency criteria in the spatial allocation of public investment. The former criterion takes the poorest regions as the optimal allocation of public investment in infrastructures. On the contrary, the efficiency criterion selects the richest regions as the optimal destination of public investment since they are the most productive regions.

In order to fully characterize the interregional spillover effects, we next analyze the effects of increasing the public investment of the *remainder region* on the output per capita of the *reference region*. We maintain the rate of public investment in the later region and accommodate the reforms by increasing the lump-sum taxes. In particular, we study the effect of increasing permanently the public investment in the *remainder region* by 0.001% of aggregate national output, i.e., we rise φ^2 by 0.00001. The results from this exercise of balanced-budget incidence are reported in Table 6.

[Insert Table 6]

The first column of Table 6 confirms two conclusions obtained in the previous exercises: (i) on the one hand, the results can be basically stated by attending to whether the *reference region* is rich or poor; (ii) on the other hand, Comunidad Valenciana has a specific behavior that differs from the general patterns. The investment in the *remainder region* increases marginally the output per capita of the *reference regions* that are relatively rich, whereas it drives the output per capita of poor *reference regions* down. After the fiscal shock, the output per capita of the rich regions jumps up instantaneously, and then it decreases to a new stationary level that is larger than the initial one. On the contrary, the output per capita of the poor regions goes down instantaneously, and then it decreases to the new steady-state level. The proposed reform enhances the comparative advantage of the rich *reference regions*, which offsets the fact that they finance a large part of the increase in the public investment allocated in the other regions. Obviously, this reform then increases the economic disadvantage of poor *reference regions* with respect to the counterfactual average region.

Finally, Comunidad Valenciana departs from this general result because it behaves as a rich region even when its initial output per capita is smaller than the regional average. The stark point is that the fiscal reform reduces the output per capita of the *remainder region* when Comunidad Valenciana is taken as *reference region*.

5.3 Effects from redistributing the current rate of public investment

In this subsection we analyze the effects of distributing the benchmark level of public investment from the *remainder* to the *reference region*. In particular, we simultaneously increase the public investment in the *reference region* and reduce the public investment in the *remainder region* by 0.001% of the aggregate output, i.e., we rise φ^1 and reduce φ^2 by 0.00001.[15] The results derived from this differential incidence analysis are qualitatively similar to those from the first exercise of balanced-budget incidence presented in the previous subsection.[16] This confirms that the current distribution of public infrastructure investment is not optimal under any of the criteria considered in this paper: reduction of the regional disparities in output per capita, maximization of national aggregate output or maximization of national aggregate welfare.

Table 7 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 first exercise in the previous subsection. 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 larger than the obtained with the *balanced reform* when this region is the poorest one, whereas the opposite conclusion is obtained in the case of the richest regions. Therefore, the redistribution of actual public investment is a more effective tool to reduce the regional differences in output per capita than increase the actual level of public investment given priority to the poorest regions. In any case, the ranking of regional priorities based on this need criterion are identical for these two policy strategies.

[Insert table 7]

[15] We consider the same exception pointed out in footnote 14.

[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.

The second column of Table 7 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 rich *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 former reform the rate of public investment in the *remainder region* does not change, this rate is reduced in the later 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 7, the accumulated variation of national output is positive when public investment is redistributed towards rich regions, whereas is negative when investment is redistributed towards poor regions, except in the case of Extremadura and Galicia. Therefore, the redistribution of current public investment is a less effective tool to rise the national aggregate output than increase the current level of public investment. In any case, the ranking of regional priorities based on this efficiency criterion are identical for these two policy strategies.

Table 8 shows the welfare effects of the regional redistribution of public investment considered in this subsection. We first observe that the welfare effects obtained by the *reference regions* depends on whether or not they have a output per capita larger than the regional average. The *reference region* obtains a welfare gain when it exhibits an advantageous relative position in output per capita. On the contrary, except for the case of Extremadura and Galicia, the reform reduces the welfare of the *reference region* when it is a poor region. Secondly, the second column of Table 8 shows that the reform improves the welfare of the *remainder region*, except for the case of Cantabria. Finally, the welfare effects on the national economy mimic the welfare results obtained for the *reference region*.

[Insert Table 8]

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 Spanish economy in order to simulate the comparative dynamic analysis of two reforms of benchmark fiscal 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. Finally, from the analysis we have derived two rankings of regional priorities in public investment: one based on the criterion of reducing regional disparities, and other based of an efficiency criterion.

The comparison of these two rankings has reflected the traditional conflict between the redistribution and the efficiency criteria in the spatial allocation of public investment. The former criterion gives priority to the investment in the poorest regions, whereas the later criterion outweighs the richest economies.

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. Firstly, we could 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.

Secondly, a natural extension would be to endogenize the process of human capital accumulation. In this way, we would introduce a new margin in the individuals' problem of decision that would be affected by the public capital formation. In particular, it would be interesting to introduce public capital as a factor in the technology of human capital accumulation. In this way, one could evaluate the effects from the composition of public capital at a regional level. In other words, one could determine which type of public capital, productive infrastructures or educative infrastructures, should be outweighed in each region by attending to different criteria.

Finally, the present paper could 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 of 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:

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

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

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

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:

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

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

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

and the government's constrains (5) to (9). 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 equilbrium increased by the condition (22). Note that the later condition results from combining (A.1) for two any 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.

Table 1. Values of common parameters in the benchmark model

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	$1,0527$
Efficiency level of technology in region 1	A^1	(*)
Efficiency level of technology in 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	$0,0036$
Depreciation rate of private capital	δ	$0,10$
Depreciation rate of infrastructures	μ	$0,05$
Degree of congestion in infrastructures	υ	$0,36$
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	$0,15$
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	$\frac{y^1}{y}$	A^1	π	φ^1	φ^2
Andalucía	0.745	0.9855	0.1782	0.0065	0.0285
Aragón	1.112	1.2514	0.0308	0.0013	0.0337
Asturias	0.955	1.2078	0.0285	0.0011	0.0339
Baleares	1.254	1.3780	0.0181	0.0006	0.0344
Canarias	0.965	1.1957	0.0383	0.0014	0.0336
Cantabria	0.964	1.2520	0.0136	0.0006	0.0344
Castilla-León	0.912	1.1211	0.0662	0.0027	0.0323
Castilla-La Mancha	0.830	1.1013	0.0430	0.0021	0.0329
Cataluña	1.189	1.2085	0.1563	0.0045	0.0305
Comunidad Valenciana	0.977	1.1506	0.0991	0.0030	0.0320
Extremadura	0.682	1.0697	0.0277	0.0014	0.0336
Galicia	0.774	1.0817	0.0711	0.0024	0.0326
Madrid	1.215	1.2587	0.1273	0.0030	0.0320
Murcia	0.903	1.2079	0.0268	0.0009	0.0341
Navarra	1.228	1.3337	0.0134	0.0007	0.0343
País Vasco	1.187	1.2254	0.0548	0.0025	0.0325
La Rioja	1.108	1.3650	0.0068	0.0003	0.0347

The regional average of output coincides with the aggregate output since total population is one.

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	0.03823241	0.02881565	0.03049372
Aragón	0.04203874	0.02989625	0.03027024
Asturias	0.10050420	0.02779347	0.02986573
Baleares	0.04987601	0.02988227	0.03024415
Canarias	0.23521771	0.02900652	0.02900652
Cantabria	0.20381614	0.02672821	0.02913660
Castilla-León	0.05531325	0.02841699	0.03019752
Castilla-La Mancha	0.04425187	0.02960724	0.03023695
Cataluña	0.04634501	0.02716781	0.03016520
Comunidad Valenciana	−0.08425448	0.04361345	0.03094174
Extremadura	0.03606842	0.03008039	0.03024626
Galicia	0.04041213	0.02952373	0.03029789
Madrid	0.04772414	0.02760579	0.03016685
Murcia	0.05344025	0.02952642	0.03016731
Navarra	0.04871127	0.03000064	0.03025137
País Vasco	0.04658136	0.02928586	0.03023365
La Rioja	0.04180041	0.03019811	0.03027700

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	−0.00375724	−0.00636249	−0.00589823
Aragón	−0.00497196	−0.00591536	−0.00588631
Asturias	0.00304762	−0.00601074	−0.00575258
Baleares	−0.00468091	−0.00590197	−0.00587987
Canarias	0.01961010	−0.00647447	−0.00547543
Cantabria	0.01579590	−0.00582182	−0.00552782
Castilla-León	−0.00237297	−0.00609697	−0.00585044
Castilla-La Mancha	−0.00334033	−0.00597768	−0.00597768
Cataluña	−0.00477267	−0.00607996	−0.00587563
Comunidad Valenciana	−0.01993154	−0.00459081	−0.00611107
Extremadura	−0.00362327	−0.00593123	−0.00586730
Galicia	−0.00355927	−0.00605059	−0.00587346
Madrid	−0.00472890	−0.00604189	−0.00587474
Murcia	−0.00254435	−0.00593869	−0.00584772
Navarra	−0.00470306	−0.00589683	−0.00588083
País Vasco	−0.00476151	−0.00594536	−0.00588048
La Rioja	−0.00498593	−0.00589303	−0.00588686

Table 5

Accumulated variation in output per capita generated by increasing public investment in the reference region by $0.00001y_t$

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

Reference regions	*Reference Region*	*Remainder region*	*National economy*
Andalucía	0.04756995	−0.00662610	0.00303163
Aragón	−0.09921492	0.01116943	0.00776959
Asturias (1)	0.30691184	−0.01029849	−0.00125800
Baleares	0.07108662	0.01234381	0.01343381
Canarias (2)	0.06682850	−0.00303716	−0.00036130
Cantabria (2)	0.14211603	−0.00282877	−0.00085752
Castilla-León	0.34034659	−0.02155930	0.00239886
Castilla-La Mancha	0.22441790	−0.00705390	0.00289938
Cataluña	0.00463808	0.00596999	0.00576181
Comunidad Valenciana (1)	−0.21567833	0.02554672	0.00164131
Extremadura	0.20730689	−0.00198000	0.00381729
Galicia	0.15162148	−0.00717136	0.00411881
Madrid	0.01188310	0.00709176	0.00770170
Murcia	0.96148660	−0.02353937	0.00285933
Navarra	0.03256456	0.01012129	0.01042203
País Vasco	−0.00217675	0.00527209	0.00486389
La Rioja	−0.47145941	0.02839914	0.02500010

(1) The increase in public investment is 10 times smaller to ensure convergence.

(2) The increase in public investment is 100 times smaller to ensure convergence.

Table 6
Accumulated variation in output per capita generated by increasing public investment in the remainder region by $0.00001 y_t$
(as a percentage of discounted sum of national GDP per capita)

Reference regions	*Reference Region*	*Remainder region*	*National economy*
Andalucía	−0.00614951	0.00505884	0.00306152
Aragón	0.00824507	0.00267770	0.00284917
Asturias	−0.08327402	0.00599422	0.00345008
Baleares	0.00387252	0.00282843	0.00284733
Canarias	−0.22476541	0.01344285	0.00431945
Cantabria	−0.19999027	0.00708624	0.00426999
Castilla-León	−0.02199097	0.00484913	0.00307231
Castilla-La Mancha	−0.00957275	0.00360458	0.00303795
Cataluña	0.00464503	0.00224266	0.00261815
Comunidad Valenciana	0.16672986	−0.01621637	0.00191361
Extremadura	−0.00488407	0.00322283	0.00299827
Galicia	−0.00681358	0.00370410	0.00295629
Madrid	0.00411793	0.00235962	0.00258345
Murcia	−0.01896253	0.00362294	0.00301765
Navarra	0.00434695	0.00285932	0.00287926
País Vasco	0.00520258	0.00275404	0.00288822
La Rioja	0.00851152	0.00280029	0.00283913

Table 7
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	0.05373589	−0.01169056	$-3.16e-005$
Aragón	−0.10741972	0.00848710	0.00491717
Asturias (1)	0.31611383	−0.01092912	−0.00160840
Baleares	0.06726402	0.00953975	0.01058456
Canarias (2)	0.06944140	−0.00318820	−0.00040649
Cantabria (2)	0.14456777	−0.00290839	−0.00090272
Castilla-León	0.36331221	−0.02649219	−0.00068714
Castilla-La Mancha	0.23412682	−0.01066744	−0.00014128
Cataluña	$-1.87e-006$	0.00372344	0.00314118
Comunidad Valenciana (1)	−0.23710362	0.02770756	0.00146477
Extremadura	0.21223083	−0.00520547	0.00081752
Galicia	0.15848767	−0.01088135	0.00116079
Madrid	0.00777302	0.00472826	0.00511586
Murcia	0.98250326	−0.02723964	−0.00017853
Navarra	0.02826664	0.00725935	0.00754084
País Vasco	−0.00733644	0.00251478	0.00197340
La Rioja	−0.47977624	0.02559403	0.02215752

(1) The increase in public investment is 10 times smaller to ensure convergence.

(2) The increase in public investment is 100 times smaller to ensure convergence.

Table 8
Welfare cost per capita from 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	0.00644903	−0.00110653	0.00023987
Aragón	−0.01887294	−0.00109243	−0.00164007
Asturias (1)	0.03837526	−0.00060630	0.00050467
Baleares	−0.00680588	−0.00363858	−0.00369584
Canarias (2)	0.00839035	−0.00020081	0.00012823
Cantabria (2)	0.01744588	$3.82e-005$	0.00027497
Castilla-León	0.04342930	−0.00272656	0.00032896
Castilla-La Mancha	0.02761700	−0.00109091	0.00014353
Cataluña	−0.00267298	−0.00078564	−0.00108063
Comunidad Valenciana (1)	−0.02918084	0.00265848	−0.00049680
Extremadura	0.02505484	−0.00088413	−0.00016562
Galicia	0.01823539	−0.00163584	−0.00022299
Madrid	−0.00335592	−0.00155828	−0.00178712
Murcia	0.11623254	−0.00319505	$5.60e-006$
Navarra	−0.00828806	−0.00252706	−0.00260426
País Vasco	−0.00393746	−0.00046867	−0.00065876
La Rioja	−0.08482936	−0.00704877	−0.00757767

(1) The increase in public investment is 10 times smaller to ensure convergence.

(2) The increase in public investment is 100 times smaller to ensure convergence.

Figure 1: Adjustment path after an increase in public investment in Galicia

(% Deviations from the initial steady state)

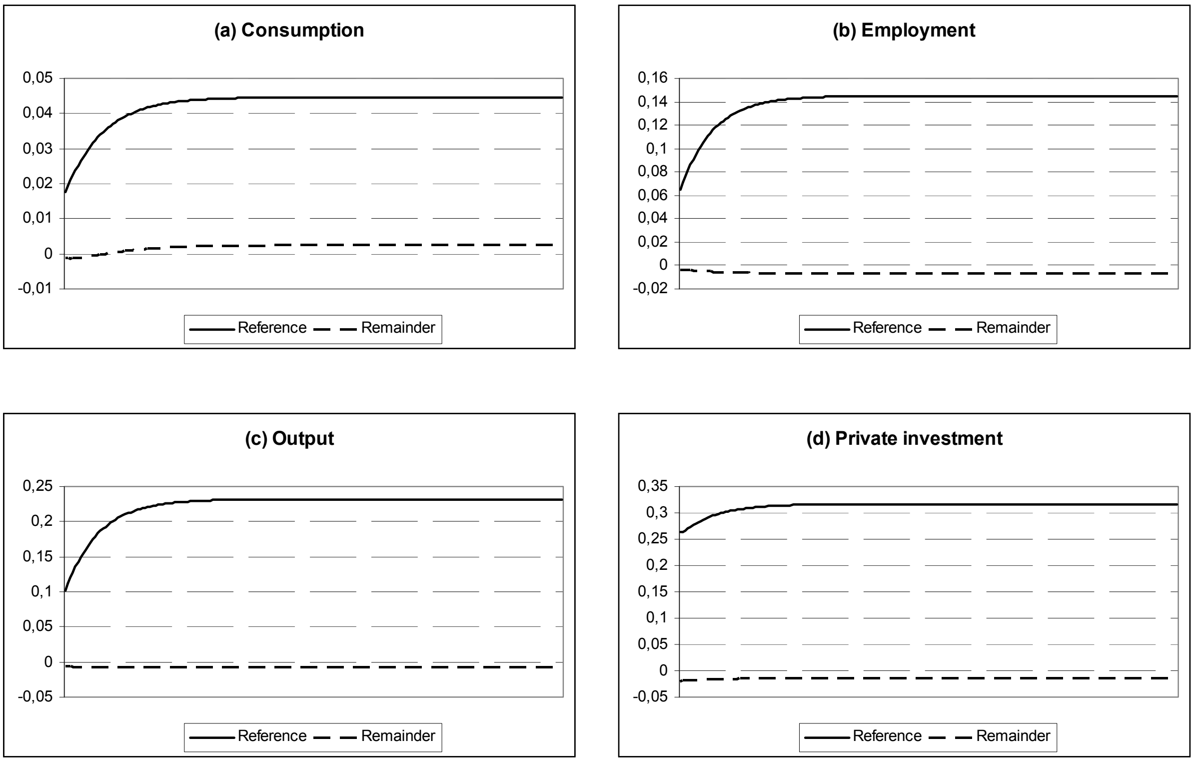

Figure 2: Adjustment path after an increase in public investment in Cataluña

(% Deviations from the initial steady state)