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CESIFO WORKING PAPER NO. 3728
CATEGORY 1: PUBLIC FINANCE
FEBRUARY 2012

CESifo *Working Paper No. 3728*

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Abstract

Regional income disparities have increased in many European countries recently, even as national and supra-national policy instruments were created to correct them. To explain these evolutions, we develop a two-region, two-sector model with migration and public investment in infrastructure and education. Accumulation and creation of new ideas and technologies as well as migration are at the core of differential regional growth. In this framework, we assess the effectiveness of structural funds, modelled on the EU policy. In a numerical example calibrated to Portugal, we find that, to diminish the initial gap in income per capita, the backward region needs to receive over 8% of its own GDP in structural funds, while the actual disbursements were around 4%. We also find that maximizing innovation in the backward region conflicts in the short run with the goal of maximizing its income per capita. Moreover, the rich region has an incentive to bias the allocation of structural funds towards human capital formation.

JEL-Code: O100, H700, R580, R120.

Keywords: two-region economy, structural change, migration, regional policy, European Union.

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December 2011
We thank Dan Knudsen, Jens Suedekum and participants at the conference on Subsidiarity and economic reform in Europe, Brussels, 2006 for helpful comments. We also thank Christoph Helbach and participants at the International Workshop on The Economics of Education at the University of Duisburg for insightful comments. Glomm acknowledges financial support for this research through a Faculty Summer Grant by the West European Studies at Indiana University. Arcalean and Schiopu acknowledge financial support from Banc Sabadell. Arcalean acknowledges support from the Spanish Ministry of Education and Science under the grant ECO2011-2492. All remaining errors are our own.

1 Introduction

In many developed countries balanced regional growth is a major goal for policy makers at all administrative levels. Two things distinguish the case of the European Union (EU). First, policies are designed and applied by a multi-layered governance structure with both national and European institutions being concerned with various measures of regional growth and inter-regional inequality. Second, the regional development policies have increased in importance as the EU continued to enlarge towards countries with large differences in terms of output per capita. The view of the European Commission is that "Imbalances do not just imply a poorer quality of life for the most disadvantaged regions and the lack of life-chances open to their citizens, but indicate an under-utilization of human potential and the failure to take advantage of economic opportunities which could benefit the Union as a whole[1]." Thus, given recent EU enlargement, regional development policies[2] are called for to fulfill an even bigger role. This brings into sharper focus the question of how effective these funds have been in reducing the inter-regional inequality and other imbalances, like long-term unemployment and a presumed lack of innovation.

Figure 1 summarizes the markedly different evolutions of regional disparities across European countries, from some degree of convergence (Greece, Italy) or stability (United Kingdom, Spain) to significant divergence (Portugal, Germany). However, it shows unambiguously that during the last three decades regional income levels have drifted further apart in most countries, despite sustained redistribution at both national and supranational level[3].

It is straightforward to argue that a trade-off between aggregate growth and regional equality arises whenever agglomeration forces are strong and resources are mobile. The literature has documented the existence of this type of trade-off[4] and studied the nature of the underlying agglomeration forces[5]. However, the dynamic interactions between agglom-

[1] First Report on Economic and Social Cohesion, European Commission (1996)

[2] These policies include the Structural Funds – ERDF, EAGGF Guidance Section, ESF, and FIFG – as well as the Cohesion Fund. In this paper we shall reffer generically to structural funds.

[3] In the mid-1980s, the European Regional Development Fund accounted for only 7.5% of the Community budget. In the 2007-2013 period, by contrast, the Structural and Cohesion Funds will comprise 36% of planned Community spending.

[4] See for example, Crozet and Koenig (2008), Bräuninger and Niebuhr (2008) and Boldrin and Canova (2001), among many others.

[5] Papers focused on long run economic growth, like Glomm (1992), Lucas (2004) or Tamura (2002) , study the drivers of the urbanization process that leads to divergent evolutions of the "traditional" (agricultural) country-side compared to the "modern" (industrialized) city. On the other hand, new economic geography papers, starting with Krugman (1991) (also see Baldwin and Krugman (2004), Suedekum (2005), Pflueger (2003), Forslid and Ottaviano (2003), Ottaviano and Thisse (2002), Martin and Ottaviano (2001) or Robert-Nicoud (2002)) study the inputs' localization pattern in a symmetric two-region economy. Market size and

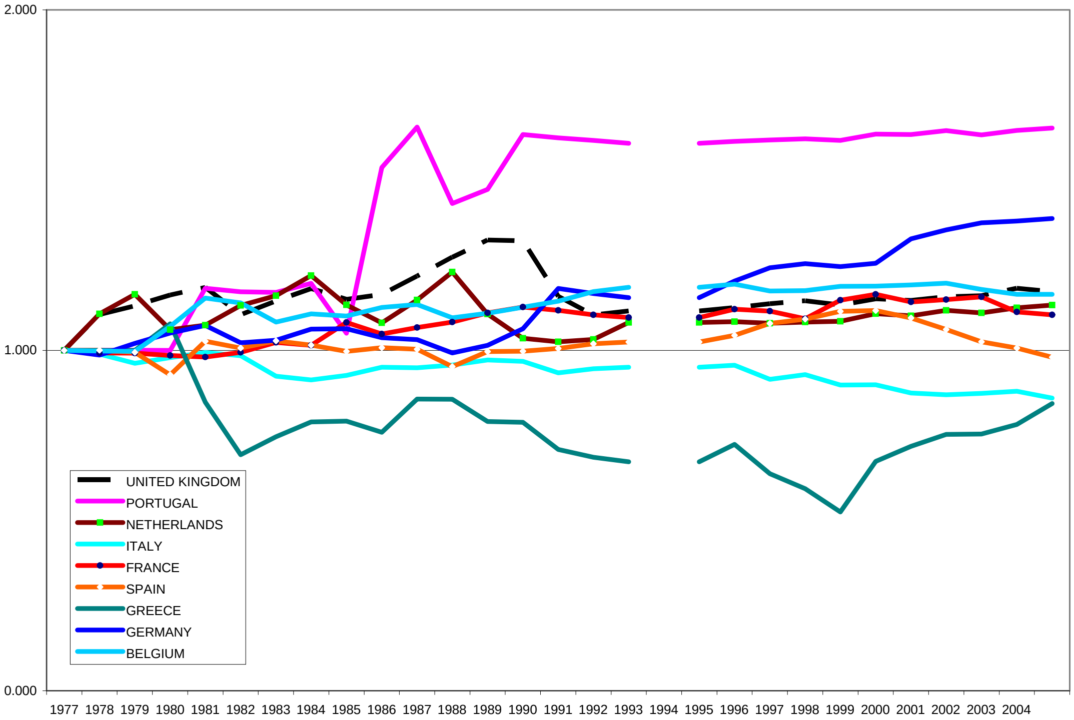

Figure 1: Coefficient of variation (CV) in regional output per capita (mil. PPS, constant prices) for NUTS 2 level regions. The values in 1977 have been normalized to one for all countries. There is a break in the series in 1994. While the values of the CV have been normalized for smoothness, the underlying definition of regions has changed. Only regions of the former West Germany have been included. Source: Regio-EU, Eurostat

erative processes and supranational redistribution policies have received relatively little attention[6].

In this paper, we develop a two-sector, two-region endogenous growth model to study spatial redistribution policies, similar to those employed in the EU. In this model, creation and accumulation of new ideas and technologies drive regional growth and disparities. We incorporate investment in infrastructure and human capital development as the two main outlays of public spending. Moreover, we allow for capital market integration and labor mobility both across sectors and across regions.

The model uses the link between income and innovation at regional level to provide a

the cost of trade are essential for generating economic disparities.

[6]Suedekum (2005) looks at regional education policies while Brakman et al. (2002) consider the role of government spending in locational competition.

novel explanation of the increasing trend in the *aggregate* employment in science and engineering (S&E) jobs. While in Kortum (1997) and Segerstrom (2007) the increasing cost of innovations requires an increase in the labor input in research, in our paper, inter-regional migration increases the population density. This in turn facilitates potential interactions amongst researchers, increasing their productivity and hence induces the share of labor employed in research to increase. As regional disparities are reinforced, national employment in innovation related sectors increases if agglomeration forces are strong enough.

In our model, regional dynamics are the joint result of endogenous forces - technological change and inter-regional migration, as well as exogenous forces - the national and supranational policies. We use the theoretical framework to provide quantitative and qualitative assessments of these policies. Specifically, we go beyond analyzing the size of supra-national transfers to consider the shares of such transfers allocated to infrastructure and skills improvement (education), respectively. The two outlays - public capital investments and human capital formation - represent the main usages of structural funds, allowing for comparative dynamics exercises with regard to changes in both their size and composition.

In a numerical example calibrated to Portugal, we find that the structural funds, modelled on EU policy, can improve the growth rate of the lagging region and slightly reduce the regional inequality, without necessarily producing convergence. In order to diminish the initial gap in income per capita, the backward region needs to receive over 8% of its own GDP while the actual disbursements amounted to only 4%. We also find that maximizing innovation related employment in the backward region conflicts in the short run with the goal of maximizing its income per capita. Moreover, the rich region has an incentive to bias the allocation of structural funds towards human capital formation, since infrastructure investment in the poor region depresses migration, which in turn reduces innovation in the rich region. The model links the regional income differences to empirical differences in the industrial structure of each economy and generates optimal patterns of public expenditures that can be used as a benchmark when assessing the performance of actual policies. As a consequence, we show how supra-national transfers can improve on the national allocations, when growth maximizing policies are pursued.

We add to a sizeable literature on regional convergence initiated by Barro and Sala-i Martin (1992) and applied to the European regional context by de la Fuente et al. (1995), Sala- i-Martin (1996), Boldrin and Canova (2001), Di Liberto et al. (2008), Ramajo et al. (2008) and others. The consensus that seems to emerge from this literature is that while there has been some substantial convergence early on, convergence may have slowed down since about late 70s and that the role of the cohesion policies in bringing about or contributing to convergence has been rather limited. Ramajo et al. (2008) provide some evidence that convergence was faster in the cohesion countries (Greece, Spain, Portugal and Ireland) than in non-cohesion countries.

Our paper contributes to this literature by providing an explicit model of regional convergence that takes into account the amount and the composition of the cohesion funds. Di Liberto et al. (2008) finds a significant role for public education expenditure in the regional convergence in Italy. Similarly, de la Fuente et al. (1995) use an econometric approach to assess the success of infrastructure and education policies in promoting regional convergence in Spain. They find the actual impact of these policies to be small. This is comparable to a claim in Boldrin and Canova (2001) that, even in the presence of structural funds policies, convergence among European regions has been limited. Our calibrated model yields similar implications by connecting growth performance to innovation processes.

The structure of the paper is the following. Section 2 presents the model of a two region economy and defines the competitive equilibrium. Section 3 solves it and analyzes its properties. Section 4 describes the calibration and the main dynamic implications of the model. Section 5 includes policy experiments. The final section concludes and the appendix contains sensitivity analyses.

2 A two-region economy with internal migration

Consider an economy composed of two regions, denoted p for poor and r for rich. Each region is inhabited by overlapping generation of two-period lived agents. Production consists of a competitive final good sector and a monopolistically competitive intermediate good sector, called research. We model the two regions as small open economies i.e. they take the interest rate r as given. Each region is characterized by area L_j and population stock $N_{j,t}$, $j = \{p, r\}$. The final good is assumed to be homogenous across regions and its price is normalized to 1. Therefore, no trade occurs in equilibrium and the final good markets clear in each region. There is no trade in intermediate goods.

In this economy, initial differences of per capita incomes in the two regions generate migration from the "poor" to the "rich" region and potentially divergence both in output levels and in growth rates. National and supra-national transfers directly affect economic growth in the receiving region through productive public investments in infrastructure and public education. Moreover, these public investments indirectly influence the growth in the rich region as well, by altering the migration patterns.

To ease notation, in the following we drop the region subscript whenever possible.

2.1 Households

In each region there is initially a large number of residents, N_t. Individuals live for two periods, youth and old age, derive utility from consumption in both periods and dislike congestion from population density in their region. Similar to Casella (2005) and Ciccone and Hall (1996), this congestion depends on population density in the region in which they reside. One can think of this disutility from congestion as deriving from increased housing costs or longer commuting time. Individuals earn wages and save when young, get the return on their savings when old, and consume in both periods. At the beginning of their youth, consumers also decide whether to migrate or not. The utility of a typical agent from generation t is

$$U(c_t, c_{t+1}, a_t) = \log c_t + \beta \log c_{t+1} - a_t, \tag{1}$$

where c_s is consumption in periods s, where $s = t, t+1$ and a_t is a congestion cost that sets in once the density N_t/L in that region exceeds a certain level $\widetilde{N}/L$. For simplicity, the congestion cost accrues in the first period of life, but results do not depend on this assumption.

Formally, congestion costs are given by

$$a_t = \omega \max\left(0, \frac{N_t - \widetilde{N}}{L}\right)^{\eta}. \tag{2}$$

We assume $\omega > 0$ and $\eta > 1$, so that congestion costs are increasing and convex in population density.

2.2 Production

2.2.1 The final good sector

The final good is produced using physical capital K_t, a fraction ϕ_t of the labor force available in the region, N_t, a continuum of differentiated intermediate goods h_{it} and services flowing from a publicly provided good, $\widehat{X}_{G,t-1}$, that is financed by tax revenues from the previous period. The price of the final good is normalized to one. The production function is given by

$$Y_t = \widehat{X}^{\varepsilon}_{G,t-1}\ K_t^{\alpha_1}\ (\phi_t N_t)^{\alpha_2} \int_0^{A_t} h_{it}^{\alpha_3} di. \tag{3}$$

Constant returns to scale in hired factors implies $\alpha_1 + \alpha_2 + \alpha_3 = 1$. The public good can be thought of as infrastructure such as roads, utilities, contract enforcement, etc. It is made available to all firms at a zero price. However, the service flow it provides depends on the area of the region:

$$\widehat{X}_{G,t-1} = \frac{X_{G,t-1}}{L}. \tag{4}$$

This formalizes the idea that equal public spending benefits more a smaller region, since agents have better access to the above mentioned amenities. For example, the effective flow of transportation services - in terms of distance, transportation time or congestion at peak hours, depends on the density of the (rail)road network, measured in miles of road/tracks per square mile.

As each region is a small open economy, the capital is available at an exogenous and fixed interest rate r. Capital depreciates at a constant rate, δ_k. This also implies that the stock of physical capital is composed of local (S_t) and out-of-region (S_t^f) aggregate savings, such that:

$$K_t = S_{t-1} + S_{t-1}^f. \tag{5}$$

2.2.2 The research sector

Production in the research sector is similar to Romer (1987, 1990). A fraction $1 - \phi_t$ of the workforce decides to specialize in producing differentiated goods. One interpretation for these differentiated goods is the creation of new skills, technologies or ideas that are used in the production of the final good. In our model, the range of technologies available in each region plays a critical role for the income convergence as well as for migration between regions.

The *range* of technologies available in period t comprises the undepreciated technologies from the previous period and the ones newly produced. The fraction of the labor force that specializes in producing the intermediate goods also contributes to the expansion of the set of available varieties, according to the following law of motion.

$$A_t = A_{t-1}(1-\delta) + B\left[\frac{(1-\phi_t)\ N_t}{L}\right]^{\lambda}\ \left(\widehat{X}_{E,t-1}\right)^{\theta}\ , \tag{6}$$

where $0 < \delta < 1$, $0 < \theta < 1$, $0 < \lambda < 1$, $B > 0$. The productivity of research increases with the *density of innovators,* $(1-\phi_t)\ N_t/L$ and the effective quality of the education system in that region, $\widehat{X}_{E,t-1}$. Glomm (1992) and Lucas (2004) develop a model in which output is produced by coalitions of agents who access each other's experience, hence density is crucial for productivity. Ciccone and Hall (1996) show that in the US, the density of economic activity explains more than half of the variance in output per worker. Furthermore, Carlino et al. (2007) document a strong positive correlation between employment density and the per capita patent count.

Publicly financed education has been extensively used in models of human capital accumulation by Loury (1981), Glomm and Ravikumar (1992), Fernandez and Rogerson (1998) or Blankenau and Simpson (2004). In this model, the new varieties that are developed by a researcher are akin to human capital, hence it is natural to consider the role of education in stimulating the productivity of research. The overall education quality available to researchers increases with the funds available for education and decreases with the number of people that engage in creative activities.

$$\widehat{X}_{E,t-1} = \frac{X_{E,t-1}}{(1-\phi_t)N_t}. \tag{7}$$

Here $X_{E,t-1}$ is public education expenditures which are financed from the previous period tax revenues and $1-\phi_t$ is the fraction of labor force in the research sector. Notice that the public expenditure in period t depends on the tax revenues in the previous period and thus on the level of technology at $t-1$. This dependence indirectly introduces a "standing on the shoulders of giants effect" as in Jones (2005) and Romer (1990), albeit in a congestible manner.

Notice that in our model, the same agents invent and commercialize the intermediate goods, hence they combine innovation and entrepreneurship functions. For simplicity we label them researchers. Moreover, we assume that the previously invented technologies that are still viable become "common knowledge" and thus cannot be sold at a profit. This is a reasonable assumption given a period in this model is 30 years, while maximum patent protection does not exceed 20 years. Previously invented technologies are produced and sold competitively.

Each researcher contributes $\partial A_t/\partial((1-\phi_t)\,N_t)$ new goods over which she has monopoly power. Intermediate goods of all varieties are produced one for one from the consumption good. Since the final good is the numéraire, the marginal cost of an intermediate good is constant and equal to one. Denote the price of the i^{th} variety of intermediate good as p_{it} and by Π_t the total profit of a researcher.

In equilibrium, agents are indifferent between providing labor services in the final goods sector or engaging in research. Since agents have the same preferences, the indifference condition boils down to life-time income equalization,

$$w_t = \Pi_t. \tag{8}$$

This condition determines the fraction of the labor force engaged in creating and selling intermediate goods $1 - \phi_t$.

An important issue that arises in a two-region economy is the presence of knowledge spillovers between regions. Rodriguez-Pose and Crescenzi (2006) find that in the European Union this type of spillovers decrease very fast with distance, becoming insignificant in locations farther than 3-hour drive time. In a related study, Varga (2000) finds that in the US the cut-off distance for knowledge spillovers is between 50 and 75 miles. A second factor found by Rodriguez-Pose and Crescenzi (2006) to drastically limit the capacity of regions to assimilate knowledge spillovers is the size of agricultural employment. In this case "relying on knowledge spillovers is no substitute of local investment in R&D"[7].

While the distance argument is inherently weaker in the case of a small country (such as Portugal, in our calibration exercise), significant differences in agricultural employment across Portuguese regions (see table 1) motivate us to exclude knowledge spillovers from the model. Moreover, we indirectly capture the idea of inter-regional spillovers, by incorporating national redistribution into our calibration. Since public spending is productive in our model, increasing the budget of the poor region by reallocating resources from the rich region achieves a similar effect to knowledge spillovers.

2.3 Migration

By the non-arbitrage condition (8), the wage earned by labor is equal in equilibrium to the profit earned by researchers. Thus, the utility level of all agents in a given region is the same. There are no monetary migration costs. However, increased population density in a region induces welfare losses through congestion. An agent in the poor region migrates if the overall utility level she gets in the rich region exceeds that of staying. In each period, equilibrium migration m_t, between the two regions is given implicitly by the equality

$$U\left(c_{p,t}, c_{p,t+1}, a_{p,t}\left(\frac{N_{p,t} - m_t}{L_p}\right)\right) = U\left(c_{r,t}, c_{r,t+1}, a_{r,t}\left(\frac{N_{r,t} + m_t}{L_r}\right)\right), \tag{9}$$

where U denotes the utility enjoyed in each region and $c_{j,t}$, $c_{j,t+1}$, $a_{j,t}$, $N_{j,t}$, L_j refer respectively to consumption flows, congestion costs, population and area in region j, where $j = \{p, r\}$.

[7] Rodriguez-Pose and Crescenzi (2006), p.17

Given initial differences in population and/or technology, the regional economy dynamics is characterized by sustained migration and divergence in output. Given sufficient spatial redistribution, convergence can also obtain. The migration pattern depends on the congestion parameters specified in the utility function: ω, η and $\widetilde{N}$, which capture the scale effect, the rate of growth and the threshold at which congestion becomes positive. Both national and supranational transfers alter the migration pattern. Moreover, the effect of both types of transfers depends on the shares allocated to infrastructure and human capital formation.

2.4 Government

Each region has its own government that taxes income uniformly at rate τ which is assumed constant over time and uses the proceeds of period t to finance the public goods described above at period $t+1$ such that a balanced budget is maintained each period. The government budget constraint is

$$X_{E,t} + X_{G,t} \leqslant R_t = \tau(w_t \phi_t N_t + \Pi_t(1-\phi_t)N_t + r_t S_{t-1} + r_t S^f_{t-1}), \tag{10}$$

where $X_{E,t}$, $X_{G,t}$ are the two expenditure outlays, public education and infrastructure respectively and R_t is the total tax revenue.

Since we have assumed each region is a small open economy, the stock of capital used each period will not generally be equal to the savings from that region. For simplicity, we assume that both local and out-of-region savings are taxed in the region where the capital was used.

2.5 Regional transfers

In addition to national investment, we incorporate supra-national policies in the form of structural funds. Expenditures on each of these outlays is assumed to be a fixed proportion κ_E or κ_G of the budget size R_t of the recipient region

$$X_{E,t} = \kappa_E R_t, \; \kappa_E > 0 \tag{11}$$

$$X_{G,t} = \kappa_G R_t, \; \kappa_G > 0, \; \kappa_G + \kappa_E \leqslant 1. \tag{12}$$

We model the structural funds as a fraction of the poor region's GDP accruing to its public budget.

$$SF_t = \Delta^{SF} Y_{p,t} = \Sigma \ R_{p,t}$$

where Δ^{SF} and Σ are the fractions of structural funds in total output and total tax revenue of the lagging region, respectively. Thus, the amounts invested in education and infrastructure in the poor region are given by the following expressions:

$$\begin{aligned} X_{E,p,t} &= (\kappa_E + \kappa_E^{SF}) R_{p,t} = \Delta_E Y_{p,t}, \\ X_{G,p,t} &= (\kappa_G + \kappa_G^{SF}) R_{p,t} = \Delta_G Y_{p,t}, \end{aligned} \tag{13}$$

where κ_E^{SF} and κ_G^{SF} are the shares devoted to education and infrastructure, respectively.

Notice that the structural funds enter the government budget constraint (10) only on the expenditure and not on the revenue side. Our modelling of these structural funds corresponds to what Chatterjee et al. (2003) call "productive transfer". This implies that all structural funds are used in their entirety to augment the productive government expenditures; there is no unproductive expenditure or waste.

In addition to structural funds, which accrue to a region's budget without diminishing the resources in the other region, in our quantitative exercise we also allow for national level redistribution of tax proceeds from the rich region to the poor region.

2.6 Equilibrium

A *competitive equilibrium* in a two-region economy $j = \{p, r\}$ is a set of sequences of *allocations* $\left\{c_{j,t}, c_{j,t+1}, s_{j,t}, \phi_{j,t}, h_{j,it}, k_{j,t}\right\}_{t=0}^{\infty}$, *prices* $\{p_{j,t}, w_{j,t}, q_{j,t}\}_{t=0}^{\infty}$ and migration flows $\{m_t\}_{t=0}^{\infty}$ such that, in each region, for a given set of government *policies* $\{\tau_j, X_{G,j,t}, X_{E,j,t}\}_{t=0}^{\infty}$:

1) Given the *prices,* the allocations $\{c_{j,t}, c_{j,t+1}, s_{j,t}\}_{t=0}^{\infty}$ solve the household's problem;

2) Given the *prices*, the allocations $\left\{\phi_{j,t}, h_{j,it}\right\}_{t=0}^{\infty}$ solve the firm's problems in both sectors;

3) The sequence $\left\{\phi_{j,t}\right\}_{t=0}^{\infty}$ satisfies the intersectoral labor allocation condition (8);

4) The migration flow $\{m_t\}_{t=0}^{\infty}$ solves the utility indifference condition given by (9) each period;

5) Prices are determined by marginal conditions;

6) Final goods markets clear so that

$$C_{j,t,t} + C_{j,t-1,t} + S_{j,t} + R_{j,t} + \int_0^{(1-\delta)A_{j,t-1}} h_{j,it}^c di + \int_{(1-\delta)A_{j,t-1}}^{A_{j,t}} h_{j,it}^m di = Y_{j,t}; \tag{14}$$

7) Government budget is balanced.

The last two terms in (14) represent the demand for final good stemming from the intermediate goods producers. In the following section we state and solve the problems solved by households and firms.

3 Solving the model

3.1 The household problem

Here we specify the household's maximization problem. Strictly speaking, there are two different problems, one problem for a production worker and one problem for a worker in the research sector. A simple arbitrage condition requires that workers in both sectors receive the same income. Apart from this difference, the two problems are the same. We therefore only state one problem, namely the problem for a worker in the production sector.

$$\max_{c_t, c_{t+1}, s_t} \log c_t + \beta \log c_{t+1} - a_t \tag{15a}$$

$$\text{s.t. } c_t + s_t \leqslant w_t(1-\tau) \tag{15b}$$

$$c_{t+1} \leqslant (1 + (1-\tau) r_{t+1}) s_t. \tag{15c}$$

$$\text{given } \{w_t, r_{t+1}, \tau\}.$$

3.2 Firm's problem in final good sector

Production of the consumption good is standard. Firms take prices and the level of public spending as given and maximize profits by choosing raw labor $\phi_t N_t$, the quantities of intermediate goods h_{it} and capital K_t:

$$\max_{\phi_t N_t, h_{it}, K_t} \; Y_t - w_t \; (\phi_t N_t) - p_{it} \int_0^{A_t} h_{it} di - q_t K_t \tag{16}$$

$$\text{s.t. } Y_t \;=\; \widehat{X}^{\varepsilon}_{G,t-1} \; K_t^{\alpha_1} \; (\phi_t N_t)^{\alpha_2} \int_0^{A_t} h_{it}^{\alpha_3} di.$$

$$\text{given } \{\widehat{X}^{\varepsilon}_{G,t-1}, w_t, p_{it}, q_t\}.$$

In equilibrium, due to symmetry of the intermediate goods in the final good production, their prices are identical. Hence,

$$p_t = p_{it} = \frac{\partial Y_t}{\partial h_{it}} = \alpha_3 \ \widehat{X}^{\varepsilon}_{G,t-1} \ K_t^{\alpha_1} \ (\phi_t N_t)^{\alpha_2} \ h_t^{\alpha_3 - 1}. \tag{17}$$

Usually, in models of technological change à la Romer (1987), due to the above-mentioned symmetry, all intermediate goods are produced in the same quantity. In this model however, we have assumed that only new varieties can be sold at a profit. Hence, goods produced using previous vintage varieties are symmetrical and sold in quantity h_t^c, at a price equal to the marginal cost. On the other hand, all newly invented varieties will be sold at monopoly prices in identical quantity h_t^m to maximize profits. Therefore (3) becomes

$$Y_t = \widehat{X}^{\varepsilon}_{G,t-1} \ K_t^{\alpha_1} \ (\phi_t N_t)^{\alpha_2} \left[\int_0^{(1-\delta)A_{t-1}} (h_{it}^c)^{\alpha_3} di + \int_{(1-\delta)A_{t-1}}^{A_t} (h_{it}^m)^{\alpha_3} di \right].$$

Labor and capital are paid competitive prices, i.e.

$$w_t = \alpha_2 \frac{Y_t}{\phi_t N_t}, \tag{18}$$

$$q_t = q = \alpha_1 \frac{Y_t}{K_t}. \tag{19}$$

Since r is exogenous and fixed over time, the firm's choice for K will also be fixed so that capital is paid its marginal value. Factoring in the depreciation, we get $q_t = q = r + \delta_k$.

3.3 Firm's problem in the research sector

For each new variety, producers of the intermediate differentiated goods face the demand derived from the final good production and solve the following problem:

$$\max_{h_{it}} \ \pi_t = p(h_{it}^m) h_{it}^m - h_{it}^m, \tag{20}$$

where $p(h_{it}^m)$ is the demand function derived from the production function of the firm in the final goods sector in (17) and the last term is the total cost of producing h_{it}^m units (at unit marginal cost, in terms of the final good). Having monopoly power, the producers set the price at a markup over the marginal cost, where the markup is inversely proportional to the elasticity of the demand curve. Together with the profit definition in (20), this implies a constant price. Recall that, since the final good is the numéraire, the marginal cost is constant and equal to one.

$$p_t^m = p = \frac{1}{\alpha_3}. \tag{21}$$

Consequently, each new variety will generate the profit

$$\pi_t = h_t^m \left(\frac{1-\alpha_3}{\alpha_3} \right), \tag{22}$$

while old, undepreciated varieties are produced competitively and sold at marginal cost, implying

$$p_t^c = 1. \tag{23}$$

Equations (21) and (23) yield the equilibrium quantities of each new and old variety, h_t^m and h_t^c. Thus, total profits per researcher are given by

$$\Pi_t = n^m \pi_t, \tag{24}$$

where n^m is the number of varieties each researcher sells at a profit

$$n^m = \lambda \frac{B}{L^\lambda} \widehat{X}_{E,t-1}^{\theta} \left[(1-\phi_t) N_t \right]^{\lambda-1}.$$

3.4 Dynamics

In the following, we first focus on characterizing the dynamics of output and technology for each of these regions in the absence of migration, taking the population size as given. Then, we calibrate the model and endogenize the regional market size, by allowing inter-regional migration.

Using (17), (21) and (23) to solve for h_t^m and h_t^c gives:

$$h_t^m = \left(\alpha_3^2 \; \widehat{X}_{G,t-1}^{\varepsilon} \; K_t^{\alpha_1} \; (\phi_t N_t)^{\alpha_2} \right)^{\frac{1}{1-\alpha_3}}. \tag{25}$$

$$h_t^c = \left(\alpha_3 \; \widehat{X}_{G,t-1}^{\varepsilon} \; K_t^{\alpha_1} \; (\phi_t N_t)^{\alpha_2} \right)^{\frac{1}{1-\alpha_3}} \tag{26}$$

Comparing (25) and (26) the following intermediate result follows.

Remark 1 *New varieties are produced in lower quantities than old varieties:* $h_t^m = \alpha_3^{\frac{1}{1-\alpha_3}} h_t^c$.

Using (25), (26) as well as and (24) in (8) we can rewrite the indifference condition of becoming a researcher:

$$\lambda \frac{B}{L^{\lambda}} \widehat{X}^{\theta}_{E,t-1} \left[(1-\phi_t)N_t\right]^{\lambda-1} h^m_{it} \left(\frac{1-\alpha_3}{\alpha_3}\right) = \tag{27}$$

$$= \alpha_2 \widehat{X}^{\epsilon}_{G,t-1} K_t^{\alpha_1} \frac{(\phi_t N_t)^{\alpha_2}}{\phi_t N_t} \left\{(1-\delta)A_{t-1}\left(h^c_{it}\right)^{\alpha_3} + \frac{B}{L^{\lambda}} \widehat{X}^{\theta}_{E,t-1}\left[(1-\phi_t)N_t\right]^{\lambda}\left(h^m_{it}\right)^{\alpha_3}\right\}$$

Manipulating (27) yields

$$\phi_t \left[\lambda\alpha_3(1-\alpha_3)+\alpha_2\right] - \alpha_2 = \frac{\alpha_2(1-\delta)A_{t-1}N_t^{\theta}}{B\left(\frac{N_t}{L}\right)^{\lambda} X^{\theta}_{E,t-1}\alpha_3^{\frac{\alpha_3}{1-\alpha_3}}}(1-\phi_t)^{1+\theta-\lambda}. \tag{28}$$

The equilibrium labor allocation ϕ_t solves the nonlinear equation (28). Higher education budgets or increased market size (e.g., due to migration) increase the fraction of employment in research $(1-\phi_t)$ along the transition[8]. Thus, as the calibration section makes clear, the model accommodates the empirical evidence[9] on the steady increase in the S&E employment share in the developed world.

Proposition 2 *Given public education quality $X_{E,t-1}$ and previous period technology A_{t-1}, there is a unique and interior equilibrium allocation of people between final good sector (ϕ_t) and research $(1-\phi_t)$. Moreover, ceteris paribus*

1. *Higher education quality in a region raises the share of researchers in the labor force: $\partial(1-\phi_t)/\partial X_{E,t-1} > 0$;*

2. *Better previous period technologies decrease the incentive to become a researcher: $\partial\phi_t/\partial A_{t-1} > 0$;*

3. *Larger markets (in terms of density) display a higher share of researchers in total labor force: $\partial\phi_t/\partial N_t < 0$ if $\lambda > \theta$;*

Proof. Denote $f(\phi_t) = \phi_t\left[\lambda\alpha_3(1-\alpha_3)+\alpha_2\right] - \alpha_2$ and $g(\phi_t) = \alpha_2(1-\delta)A_{t-1}N_t^{\theta}(1-\phi_t)^{1+\theta-\lambda}/(B\left(N_t/L\right)^{\lambda} X^{\theta}_{E,t-1}\alpha_3^{\frac{\alpha_3}{1-\alpha_3}})$.

Uniqueness and interiority follow from $f(0) < 0; f(1) \geqslant 0$ (> 0 if $\lambda > 0$), $f' > 0$ together with $g(0) > 0; g(1) = 0$ and $g' < 0$ if $1+\theta > \lambda$. Increased education quality shifts g down, decreasing the equilibrium ϕ_t. A higher population density has a similar effect. On the

[8] On the other hand, the increase in the technology level, A_t implies a decrease in ϕ_t. However, a high depreciation rate for intermediate goods varieties can make this effect negligible.

[9] See Kortum (1994) and Kortum (1997).

contrary, a higher technology index in the previous period (or a lower depreciation rate of these technologies) shifts g, thus increasing ϕ_t. ∎

Using (25) and (26) in the production function (3), we get:

$$Y_t = \alpha_3^{\frac{\alpha_3}{1-\alpha_3}} \left[(1-\delta)A_{t-1} + \frac{B}{L^\lambda}\widehat{X}_{E,t-1}^{\theta}\left((1-\phi_t)N_t\right)^\lambda \alpha_3^{\frac{1}{1-\alpha_3}}\right] \left[\widehat{X}_{G,t-1}^{\varepsilon} K_t^{\alpha_1} (\phi_t N_t)^{\alpha_2}\right]^{\frac{1}{1-\alpha_3}}$$

We now use the expression for (19) to solve for Y_t

$$Y_t = F^{\frac{1}{\Gamma}} \left(\widehat{X}_{G,t-1}\right)^{\frac{\epsilon}{\Gamma}} (\phi_t N_t)^{\frac{\alpha_2}{\Gamma}} \left[(1-\delta)A_{t-1} + \frac{B}{L^\lambda} X_{E,t-1}^{\theta}\left((1-\phi_t)N_t\right)^{\lambda-\theta} \alpha_3^{\frac{1}{1-\alpha_3}}\right]^{\frac{1-\alpha_3}{\Gamma}} \tag{29}$$

where

$$F = \alpha_3^{\alpha_3}\left(\frac{\alpha_1}{q}\right)^{\alpha_1}$$

$$\Gamma = 1 - \alpha_3 - \alpha_1.$$

Thus, output, innovation and technological level at period t depend only on parameters, previous period technologies and policy allocations. Note that the expression in square parentheses is just the current range of intermediate goods A_t, adjusted for the quantity difference between new and old varieties.

The output of a region depends positively on the infrastructure quality $X_{G,t-1}$. There are two channels through which the quality of public education $X_{E,t-1}$ affects output - directly, through the current technology (see the second term in the square bracketed expression) and indirectly, through the labor allocation ϕ_t, since $\partial\phi_t/\partial X_{E,t-1} < 0$ as established in Proposition 2.

Proposition 3 *Given a total public budget R_{t-1} and a technology level, A_{t-1}, there exists an optimal allocation between public education and infrastructure such that the current output Y_t is maximized. This allocation also maximizes the growth rate of the economy from $t-1$ to t.*

While in general the optimal allocation cannot be found analytically, it is useful for generating some intuition to focus on the special case of an economy that starts from $A_{t-1} = 0$[10]. Here, (28) becomes a first order equation that yields a constant labor allocation ϕ_t:

$$\phi_t = \frac{\alpha_2}{\lambda\alpha_3(1-\alpha_3)+\alpha_2}.$$

[10] Clearly, this would also imply no production in the previous period and hence a zero budget. However, for the purpose of this exercise, we assume an exogenous budget R_t.

Moreover, (29) simplifies to

$$Y_t = D\left(X_{G,t-1}\right)^{\frac{\epsilon}{\Gamma}}\left(X_{E,t-1}\right)^{\frac{\theta(1-\alpha_3)}{\Gamma}} N_t^{\frac{\alpha_2}{\Gamma}+\frac{(\lambda-\theta)(1-\alpha_3)}{\Gamma}}$$

where

$$D = \left(\frac{F}{L^{\varepsilon}}\right)^{\frac{1}{\Gamma}}\left(\frac{\alpha_2}{\lambda\alpha_3(1-\alpha_3)+\alpha_2}\right)^{\frac{\alpha_2}{\Gamma}}\left(\frac{B\lambda\alpha_3(1-\alpha_3)}{L^{\lambda}\lambda\alpha_3(1-\alpha_3)+\alpha_2}\right)^{\frac{(\lambda-\theta)(1-\alpha_3)}{\Gamma}}\alpha_3^{\frac{1}{1-\alpha_3}}.$$

Using the notation $X_{G,t} = \kappa_G R_t$ and $X_{E,t} = \kappa_E R_t = (1-\kappa_G)R_t$, the output maximizing allocation is then given by solving

$$\frac{\partial Y_t}{\partial \kappa_G} = 0,$$

which further yields

$$\kappa_G^* = \frac{\varepsilon}{\varepsilon + \theta(1-\alpha_3)} \in (0,1).$$

The growth maximizing share of infrastructure κ_G^* is smaller than in Barro (1990) because of the presence of the additional government spending on education.

As expected, the optimal share of infrastructure spending increases with the elasticity of infrastructure ε and decreases with the elasticity of education quality, θ which affects the range of new varieties invented. However, κ_G increases with the elasticity of intermediate goods, α_3. This is because a higher α_3 increases the quantity demanded of each variety which in turn increases the weight of infrastructure in output, since $h_{i,t}$ depends only on $X_{G,t-1}$. At the same time a higher α_3 implies a more elastic demand for intermediate goods in the final good sector which has two effects on the profitability of a newly invented variety. On the one hand, it erodes the markup so profit per unit sold goes down. On the other hand, it increases the quantity sold of each variety, so total profit per variety can go up or down. Consequently, the net effect on the fraction of people working in the intermediate goods sector, ϕ_t is ambiguous

$$\frac{\partial \phi_t}{\partial \alpha_3} = \begin{cases} \geqslant 0, & \alpha_3 \leqslant 1/2 \\ < 0, & \alpha_3 > 1/2 \end{cases}.$$

In the general case, ϕ_t also depends on policies and the market size. Nonetheless the existence of an optimal policy allocation carries through. It is easy to see that κ_G^* is always bounded away from zero, since some infrastructure spending is essential for output, while this is not true for investment in education, mainly because previous period technologies ensure some intermediate goods can be produced without any investment in education quality.

In this section we have characterized the dynamics and the industrial structure of a regional economy in the presence of public investment in education and infrastructure, taking as given the market size. A notable result is that the market size, more specifically the population density, determines the extent of specialization, in the form of increased capacity to produce differentiated goods. Since the *range* of technologies enters linearly in the final output production, our model displays scale effects. There is ample evidence for the absence of such scale effects at the country level (for a discussion of these scale effects see, for example Jones (1999)). Nonetheless, our model applies to the level of relatively small regions such as the metropolitan area of Lisbon. While there is some evidence of negative scale effects at the city level due to a well known paper by Glaeser et al. (1992), Cingano and Schivardi (2004) for example argue that this result may be due to an identification problem and provide evidence for positive scale effects at the city level. They summarize their results as follows: "....the productivity regressions show substantial positive effects of both specialization and city size on local TFP growth."

4 Calibration

We calibrate the model to the case of Portugal. As shown in Figure 1, the regional dispersion has increased steadily over the last three decades. As the present model contains only two regions, we divide the country in two groups (rich and poor) of NUTS 2 regions. The rich group includes regions with GDP per capita greater than 75% of the EU average (only *Lisabona e Vale do Tejo* makes the cut) while the poor group consists of the regions whose GDP per capita is under this cut-off. Thus, the second group includes the regions eligible to receive structural funds.

We calibrate the model to match key moments of regional level data for Portugal in two different years which are 25 years apart, namely 1977 and 2002, as detailed below. We obtain regional output and labor force data in 1977 from the Euregio[11] dataset and use Eurostat data for 2002[12] values. In both cases, regional GDP per capita is expressed in purchasing power parities and the cluster averages are weighted by population.

The first subscript denotes the region (p for poor, r for rich) and the second subscript denotes the time (1 for the first period of the model, $1977-2002$). The labor force in the

[11] For more details on the CRENOS data on European regions, see Paci and Pigliaru (1999).

[12] The use of 2001 data has been conditioned by a change in the definition of NUTS classification system for Portugal that took effect in 2003. Data consistent with the 1977 definition are taken from The Third Report on Economic and Social Cohesion.

Region	Labor force ('000) 1977	Agric. empl. (%) 1977	GDP in 1977 (mil PPS*/cap.)	Below 75% of EU average	$\frac{GDP}{capita}$	Average growth rates 1977-2001
Lisboa e Vale do Tejo	866.2	6	8018	no	8018	1.95%
Norte	1591.0	33	5136	yes	5163**	1.48%
Centro	516.6	24	4945	yes		
Alentejo	143.5	40	5768	yes		
Algarve	83.2	33	5604	yes		

*Purchasing Power Standard **population weighted

Table 1: Portuguese regions

poor region in 1977 is normalized $N_{p,1} = 1$ so that $N_{r,1} = 0.37$. The land area of the poor region L_p is set to 1. The area of the rich region is, in relative terms, $L_r = 0.156$.

We calculate average annual growth rates of the labor force at regional level between 1980 and 2002 using data from Cambridge Econometrics' Regional Database. Extrapolating to the entire period of interest ($1977 - 2002$), we obtain the population growth factors of 1.055 and 1.145 in the rich and poor region, respectively (and an average growth factor of 1.112). The same data source provide labor force estimates for $2002 - 2013$ by regions. We use these figures to compute growth factors of 1.047 and 1.073 for the second period of the model. In our simulations, we also apply these growth factors to all subsequent periods.

Using data for Portugal between $1965 - 1995$, Ligthart (2000) obtains an overall labor share of 0.67, implying a capital share of 0.33.[13] We set $\alpha_1 = 0.3$, in line with estimates used by Blanchard (1998) and Conesa and Kehoe (2003) for European countries. We calibrate α_3 as described below and use the assumption of constant returns to scale in the hired factors to back out $\alpha_2 = 1 - \alpha_1 - \alpha_3$. The capital depreciation rate δ_k is set to a fairly standard value of 6% annually. The discount factor is 0.99 annually, corresponding to $\beta = 0.78$ and the exogenous world-wide interest rate is set to 4% per year.

Estimates of public capital elasticity vary in the empirical literature depending on the type of data and the econometric methodology used. While time series studies obtain estimates as high as 0.4, panel data studies with fixed effects find much lower values[14]. Since the elasticities of the two public investment types determine the optimal mix of

[13] Gollin (2002) estimates the share of employee compensation in GDP, adjusted for the income earned by self-employed and proprietors. In the case of Portugal, that share ranges between 0.62 and 0.82 in 1990, while the unadjusted share in 1981 is 0.476.

[14] Romp & de Haan (2005) provide a comprehensive review on estimates for public capital elasticity.

public policies, in the benchmark model we want to ensure that the two elasticities are equal in order to keep the results unbiased. We set both ε and θ to 0.1 and perform sensitivity analysis on these values in the appendix. We also set the depreciation rate of ideas to $\delta = 0$. In the appendix we also present the results for $\delta = 0.05$ and $\delta = 0.1$.

To calibrate the migration process, we normalize the scale parameter ω to one. We set $\eta = 2$ so that congestion costs are quadratic. We calibrate the break-in point for congestion $\widetilde{N}$ to match migration flows, as described below. This calibrated value is allowed to grow at the rate of population growth in the rich region. The migration pattern is determined by using these values in the indifference condition (9).

In this model outcomes at period t depend on the size and allocation of the public budget, which is financed by tax revenues in the previous period. Thus, in order to match regional dynamics for Portugal from period $t = 1$ onward, we need the initial ($t = 0$) technologies $A_{p,0}, A_{r,0}$ and output values $Y_{r,0}, Y_{p,0}$. We normalize the output level in the poor region $Y_{p,0} = 1$ and use 1970 regional output[15] to compute the relative output in the rich region $Y_{r,0} = 0.8$.

We are left with six unknown parameters: initial technology levels $A_{p,0}, A_{r,0}$, the elasticity of output with respect to skills $\alpha_{3,}$ the productivity of new skills production B, the elasticity of technology with respect to researchers λ, and the break-in point for congestion $\widetilde{N}$. To identify them, we target the following moments:

1. Per capita output ratio rich/poor 1977, $(Y_{r,1}/N_{r,1}) / (Y_{p,1}/N_{p,1})$
2. Per capita output ratio rich/poor 2002, $(Y_{r,2}/N_{r,2}) / (Y_{p,2}/N_{p,2})$
3. Average annual growth real output - rich, '77-'02 (%), $g_{Yr} = (Y_{r,2}/Y_{r,1})^{1/25} - 1$
4. Migration, '77-'02 (% of labor force), m_1
5. S&E share in labor force rich region, $1 - \phi_{r,1}$
6. S&E share in labor force poor region, $1 - \phi_{p,1}$

The first three moments were computed using data from the Regio and CRENOS datasets.

Using inter-regional migration data for the periods 1979-81 and 1989-91 reported in Rees et al. (1999), we estimate a net immigration rate into Lisabona e Vale do Tejo of 1.81% of the total labor force.

[15] To our knowledge this is the earliest regional output data available for Portugal. We use information on regional GDP from Table III from National Institute of Statistics - Portugal (1970).

The share of scientists and engineers (S&E) in total population has been used in the literature as a proxy for the innovative class (see Kortum (1994)). In the case of Portugal, the average share of S&E in total degrees awarded between 1979-1984 and 1985-1990 is 22% (OECD (1992), Table 3, page 12). Absent data on the distribution of S&E across our regions of interest, we use the spatial distribution of college graduates as a proxy. During the above-mentioned intervals, 66% of college graduates originate in the Lisbon area (OECD (1992), page 16). Assuming graduates are uniformly distributed in space, we use NUTS3 population stocks to adjust this proportion to the boundaries of Lisabona e Vale do Tejo, obtaining a share of 69.9%. Using an average higher education attainment of 2.5% of active population in 1975, we compute the initial labor force share of the creative class in the rich and poor region to be 1.423% and 0.226% respectively.

To complete the calibration, we incorporate the actual national and supranational regional policies.

Parameter		Value	Parameter		Value
Discount factor	β	0.78	Tax rate	τ	0.352
Production					
physical cap. share	α_1	0.3			
total labor share	$\alpha_2 + \alpha_3$	0.7	Nat. budget shares		
			Public capital	κ_G	0.114
public capital share	ε	0.1	Public education	κ_E	0.171
public educ. share	θ	0.1			
Area	L_p	1	Initial population	N_p	1
	L_r	0.156		N_r	0.37
Annual interest rate	r	4%	Agglomeration	η	2
Annual K deprec.	δ_K	6%		ω	1

Table 2: Calibration of the benchmark model

4.1 Government Policies

According to OECD (1992), the ratio of total tax revenue to GDP is 35.2% in 1990, so $\tau = 0.352$. We proxy Δ_G by the average gross public capital formation as a fraction of GDP. According to OECD (2005), this figure is approximately 4% for Portugal for the period $1977 - 2004$. This value should be considered an upper bound since public capital in OECD (2005) includes types of capital that do not enter directly in the production function, such as public recreational facilities and the public capital in the judicial system. Data on the share of education spending in GDP (Δ_E) is available only from 1995 on and it is approximately 6%. Expressed as public budget shares, infrastructure represents

$\kappa_G = 0.114$ and education $\kappa_E = 0.171$. Table 2 summarizes the parametrization.

4.1.1 Supra-national redistribution (Structural funds)

Rodriguez-Pose and Fratesi (2004) estimate that the total development support under the structural funds has never exceeded 4% of the GDP in the poorest areas. Given the tax rate of 35.2%, this corresponds to a share of 11.36% of the region's budget. We take this value to be the benchmark and later examine the changes in this percentage. Thus, the budget of the poor region increases by 11.36%, while the rich region's budget remains unchanged. In terms of composition of the structural funds, Gelauff and Ederveen (2006) suggest that around 20% of all available funds are spent on infrastructure projects. Suedekum (2005) reports that 30% of the funds are directed to improvements in human capital in the lagging regions. Since we only model the two main outlays of the EU regional policy, we use these numbers as relative weights: 0.4 and 0.6, respectively.

To incorporate the transitory nature of the structural funds, we study the case when they add to the national public budget outlays in period 1 only. Thus, economic activity in period 2 is the result of infrastructure and education investments made during the previous period, enhanced with the external contributions.

4.1.2 National redistribution

While the focus of the model is on supra-national policies, we cannot overlook the amount of national level redistribution that has an effect on reducing the gap between rich and poor regions. To capture this effect, we use Eurostat data on government transfers to households and tax revenues collected in each of the five regions in the years of 1999 and 2001. The corresponding figures for 1999 are presented in Table 3 below. However, data on transfers to households provide an incomplete picture of national redistribution. To get a better estimate of total government transfers we need to add resources transferred from the central budget to the local governments through the national redistribution programs[16]. Dias and Silva (2004) report the central government transfers to municipalities as percentage of each region's GDP. We use them to calculate the transfers received by each region through the equalization funds. Then we add these numbers to the households transfers to get the total government transfers. The difference between the total amount of taxes and contributions collected and the government transfers represents the government consumption. This makes up about 8% of the total tax revenues. Consequently, we adjust

[16] These programs include the Financial Balance Fund, Municipalities' General Fund, Municipal Cohesion Fund and Parish Financing Fund. The resouces under these programs are trasferred in the form of grants from the State to the local governments (municipalities and parishes).

Region name	Social transfers	Regional redistribution	Total received	Total contributed (adjusted for government consumption)	Redistribution (% of contributions)
Lisboa e Vale do Tejo	6,415	230	6,645	8,018	- 24%
Norte	6,486	417	14,517	12,377	+ 17%
Centro	4,858	382			
Alentejo	1,426	213			
Algarve	675	60			

*numbers are in million euros

Table 3: National level redistribution, 1999

the total taxes paid in each region for the government consumption to get an estimate of the amount contributed towards redistribution purposes.

Next, the degree of redistribution is given by the ratio of receipts by region to total funds distributed. As shown in Table 3, we get a ratio of 0.17 for the poor region and 0.24 for the rich one, meaning that the poor region gets 17% more than it paid in taxes while the rich region gets only 76% of what it contributed. We do the same calculations for 2001 and we get 0.19 and 0.26 for the poor and rich, respectively. Taking the mean values for those two years, we set the redistribution shares to 18% and 25% of the tax revenues in the poor and rich regions.

4.2 The benchmark model

Table 2 summarizes the data moments and their model analogues in the benchmark model as well as the values of the calibrated parameters.

To assess the calibration, we compare additional data moments against the model predictions. Thus, the average output growth in the poor region during the first period is 1.48 in the data, close to the value generated by the model, 1.65. We also compute the ratio of average annual growth rate in the S&E share in the two regions. We use Eurostat higher education data and NUTS3 population counts to compute shares of S&E in the labor force in 2002 of 3.29% and 1.11% in the rich and poor region respectively. These figures imply a ratio of average annual growth rates of S&E employment of 0.51. The model counterpart of this statistic is 0.55.

Figure 2 shows the evolution of the economy over five periods or about 130 years. The period 1977-2002 corresponds to the first time period in the model.

Targeted moments		Data	Model	Param.	Values
Per capita output ratio rich/poor 1977	$\frac{Y_{r,1}/N_{r,1}}{Y_{p,1}/N_{p,1}}$	1.550	1.550	B	57.69
Per capita output ratio rich/poor 2002	$\frac{Y_{r,2}/N_{r,2}}{Y_{p,2}/N_{p,2}}$	1.636	1.636	$A_{r,0}$	68.57
Real output growth - rich, '77-'02 (%)	g_{Yr}	1.950	1.950	$A_{p,0}$	63.96
Migration, '77-'02 (% of labor force)	m_2	1.810	1.810	λ	0.779
S&E share in labor force - rich	$1-\phi_{r,1}$	1.423	1.423	$\widetilde{N}$	0.253
S&E share in labor force - poor	$1-\phi_{p,1}$	0.226	0.226	α_3	0.220

Check moments		Data	Model
Real output growth - poor, '77-'02 (%)	g_{Yp}	1.480	1.65
Relative growth of S&E share	$\left(\frac{\frac{1-\phi_{r,2}}{1-\phi_{r,1}}}{\frac{1-\phi_{p,2}}{1-\phi_{p,1}}}\right)^{\frac{1}{25}}-1$	0.51	0.55

Table 4: Benchmark model outcomes and calibrated parameters. Last two rows provide untargeted moments in the data and the model.

The model predicts that the rich region is able to sustain an increasing share of employment in the knowledge sector for the first two periods. This happens despite the technological advance, which, per se, would imply lower profitability from further innovation and is essentially driven by higher education spending (due to the higher budget) but also by the migration from the poor region as well as exogenous population increase (a market size effect).

The increase in innovation related employment in the poor region is driven by public spending, including the additional funding in the form of structural funds. As supranational funding stops in the second period, the growth of the S&E share slows down. However, lower initial technologies together with the exogenous increase in population generate a steady increase in the share of creative employment. Output growth rates diverge at first and then converge at a very slow pace.

In the long run, the share of labor force in research starts decreasing, even in the rich region (after period three), despite an ever increasing market size. The main reason for this is the presence of "common knowledge" varieties, that cannot be sold at a profit. Over time their measure increases in total technologies, lowering the incentive to become a researcher. This channel is also driven by the depreciation rate of ideas, which was set to zero in the benchmark calibration. However, the sensitivity analysis included in the appendix shows that positive depreciation rates induce only modest changes of employment in research.

The equilibrium exhibited in Figure 2 is consistent with the rising employment allocated

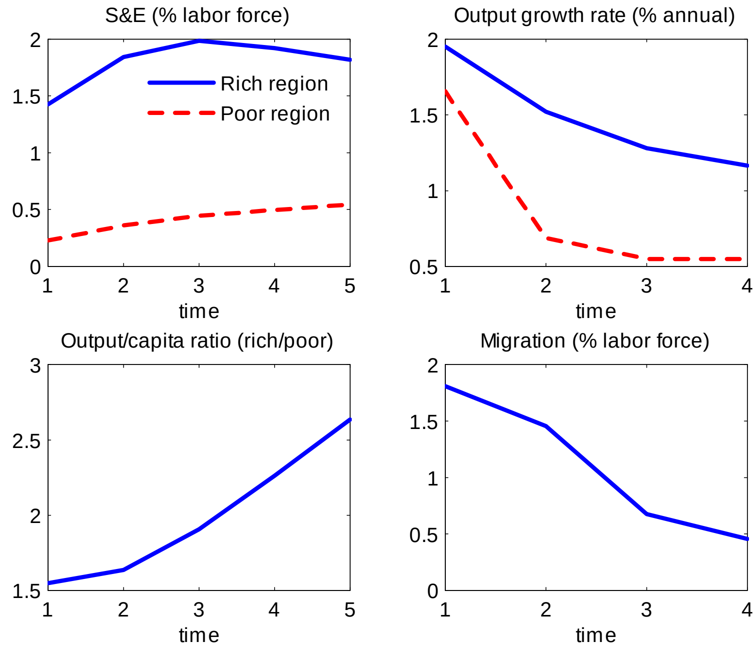

Figure 2: Time paths in a two-region economy with migration

to the creation of new goods in the rich region. Unlike Kortum (1997) and Segerstrom (2007) where the rising share of time allocated to R&D is explained by innovation becoming more and more difficult as time progresses, in our model the share of time allocated to creating new ideas in the rich area rises because over time higher education quality and internal migration creates more favorable conditions for R&D. Moreover, if the poor region is depopulating fast enough, the increase in the S&E employment share in the rich region dominates the corresponding decrease of innovation related employment in the poor region.

In the next sections we perform various counterfactual exercises to separate the effects of the structural funds.

5 Policy experiments

The effects of development funds can now be assessed along several dimensions. We first look at the effect of varying the *size* of structural funds while keeping their structure i.e. the budget shares the same. Second, we allow the *composition* of funding to change. We need to keep in mind that the regions' budget shares for infrastructure and human capital investment also matters for the effectiveness of the structural funds in as much as they differ from the optimal shares predicted by the model. Moreover, the optimal shares vary with the *size* of the budget, hence both the quantity and composition of structural funds will alter the way local funds are best spent.

The data suggests that national level public investment in education and infrastructure account for 15% and respectively 10% of total revenues, which translates into 60% and respectively 40% of total public investment. Comparing the observed shares against those obtained in the model, one can use the direction and the size of the bias to derive normative implications for the optimal allocations of the supplementary resources available through structural funds.

Proposition 4 *Denote the observed shares of the regional budget going to infrastructure and educations before structural funds are disbursed, as κ_E and κ_G and the total structural funds expressed as a share in the regional budget of the poor region with Σ. Denote the output maximizing shares for the two outlays κ_E^* and κ_G^*. Also, denote the output maximizing shares of the the structural funds disbursements as κ_E^{SF} and κ_G^{SF}. Then,*

1. *If $\kappa_E > \kappa_E^*$ and $\kappa_E - \kappa_E^* \geqslant \Sigma$, then $\kappa_E^{SF} = 0$ ($\kappa_G^{SF} = 100$);*
2. *If $\kappa_E < \kappa_E^*$ and $\kappa_E^* - \kappa_E \geqslant \Sigma$, then $\kappa_E^{SF} = 100$ ($\kappa_G^{SF} = 0$);*
3. *If $\kappa_E < \kappa_E^*$ and $\kappa_E^* - \kappa_E < \Sigma$, then $0 < \kappa_E^{SF} < 100$ ($0 < \kappa_G^{SF} < 100$);*

It is straightforward to see that if the actual budget shares in the poor region are relatively far from the optimal budget shares, structural funds should be entirely allocated either to infrastructure or education, depending on which is underfunded. If regional shares are close to optimal values, then structural funds should be split such that the *after-redistribution* shares are optimal.

The changes in the size and the allocation of the structural funds are done under the assumption that the structural funds are available only in period 1. Finally, we study the effects of a change in *duration* of structural funds.

5.1 Changes in the size of structural funds

First, we study the effects of changing the *size* of structural funds disbursed in period 1 in the poor region keeping the allocation across education and infrastructure constant (60% and 40%, respectively). Recall that in the benchmark calibration we used a share of structural funds in the poor region's budget of 4% of its GDP. The structural funds are available only in period 1.

In the counterfactual experiments we set the size of structural funds to 0%, 8%, and 12% and study the dynamics of the share of the creative class, per capita output of the two regions, as well as the migration between them. Figure 3 shows the time paths of these variables under different magnitudes of structural funds.

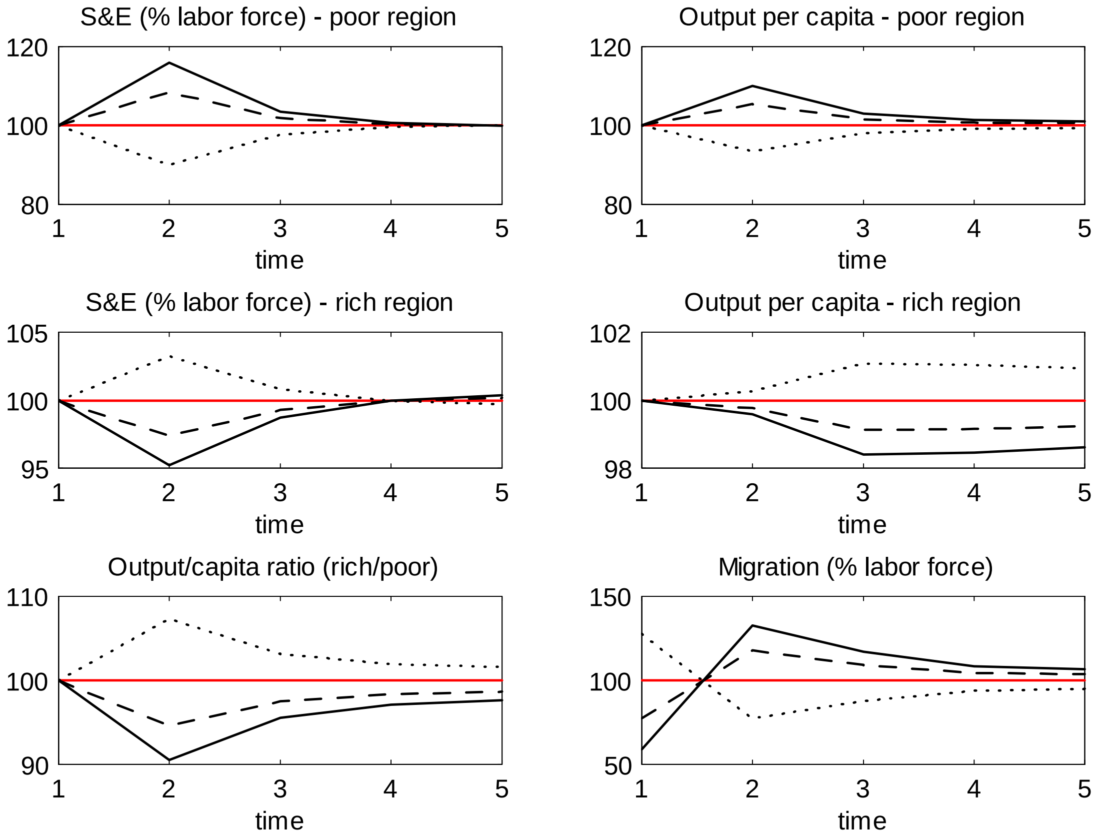

Figure 3: Changes in the size of the structural funds. The benchmark (normalized to 100) is the case of structural funds worth 4% of the poor region's GDP. The other cases are: 0% (dotted line), 8% (dashed line) and 12% (solid dark line). Migration is defined as the share of total labor force that moves from the poor to the rich region.

Higher spending by doubling (tripling) the structural funds to 8% (12%) of the poor region's GDP increases its employment in the research sector by around 8% (15%) relative to the benchmark. In the rich region there is a corresponding fall in research employment of about 2.6% (4.8%). On the other hand, removing structural funds would cut employment in research by 10% in the poor region but would increase it by 3.25% in the rich region relative to the benchmark.

There is a corresponding movement in output per person in the two regions. While the increase in output per person in the poor regions is short lived, the drop in output per person in the rich region is much more persistent.

These movements in research employment and in output per capita can easily be explained by (i) the direct effect of increased infrastructure and education expenditures and (ii) the more indirect effects of the migration induced by this policy reform. Increasing infrastructure and education spending in period 1 increases output in the poor region in period 2. This effect is of course absent in the rich region.

The direct and the indirect effect combine to increase output per capita in the poor region by about 5.4% when structural funds are doubled and by almost 10% when they are tripled. Conversely, removing structural funds lowers the income per capita in the poor region by around 6.4%.

Higher structural fund spending in the poor region increases living standards in the poor region, slows down migration, decreases the market size for innovative activity in the rich region, decreases the fraction of the labor force in innovative activity, which in turn decreases the growth rate of rich region output. Increasing the structural funds to 12% decreases rich region output in period 3 by around 1.75%.

To assess the role of external funding for regional convergence, we compare the *output per capita ratio* between the rich and the poor region. In the absence of structural funds, this ratio increases by more than 7.3%, while doubling (tripling) the size of structural funds diminishes the ratio in output per capita by 5.4% (9.5%) relative to the benchmark. These large changes are short lived since structural funds and only paid out in period 1.

It is also interesting to notice the time-varying behavior of migration under the funding schemes considered. A higher spending reduces migration at first but once structural funds are phased out, migration from the poor region continues at higher levels.

The largest migration in the first period takes place when no structural funds are disbursed (2.31% of the labor force). This is due to both population growth and divergence in per capita income.

The rich region has higher output per capita under less generous structural funds. This is easy to understand for the first period, since higher migration under no structural funds boosts innovation, through the market size effect. However, in the long run, in the absence of external funding, migration is permanently lower. So what explains the higher income per capita in the subsequent periods? This is due to the following two reasons. First, migration - and hence the population stock - is lowest under no structural funds, thus lowering the denominator of the per capita income. Second, in the benchmark calibration, we have set the skills depreciation to zero, which preserves the gain in technologies realized in the first period. In the appendix we examine the sensitivity of our results to this assumption. The long run effect discussed above survives even when skills depreciate at a similar rate with physical capital (5%). Moreover, there is little change in the output ratios between the two regions.

In this section we have studied the effects of changing the size of structural funds on both the recipient economy and the rich region in the presence of inter-regional migration. While the economy of the poor region benefits in the short run from larger external funding of infrastructure and education, the possibility to migrate mitigates these benefits in the long run.

In terms of income convergence, the analysis has revealed that much higher disbursements than those observed in reality would be needed to achieve this goal. Between 1977 and 2001 the income ratio between rich and poor regions increased from about 1.55 to about 1.64, or a change of around 6%. Doubling the structural funds to account for 8% of the output in the poor region would keep the per capita output ratio constant. A threefold increase of external funds generates a per capita output ratio of 1.4, or a change of around 9.5%.

5.2 Changes in the composition of structural funds

In this section, we study how the composition of structural funds expenditure (infrastructure vs. human capital formation) influence the equilibrium outcomes in the two regions. Proposition 3 establishes the existence of an output (growth) maximizing allocation of infrastructure and public education investment. If, due to various reasons, the allocations from the national government are not optimal, structural funds can adjust the mix in the right direction, provided they are used optimally.

To see how these objectives depend on the composition of structural funds, we consider alternative budget shares while keeping the size of structural funds to 4% of poor region's GDP, as shown in Figure 4. National spending size and structure is kept constant. The horizontal axis shows the share of infrastructure in total structural funds disbursed in period 1. As the composition of structural funds available in period 1 has dynamic effects, we present the outcomes associated with the first two periods.

Changing the structural funds composition has different effects on the employment in the knowledge creating sector in the short and the long run. Under the benchmark calibration, to maximize first period research employment in the poor region, all funds should go to public education (zero infrastructure share).

At the same time, this allocation lowers output per capita in the poor region since it pushes the investment mix further away from the optimal level. This explains why funding education exclusively generates the largest flow of migrants to the rich region in period 1,

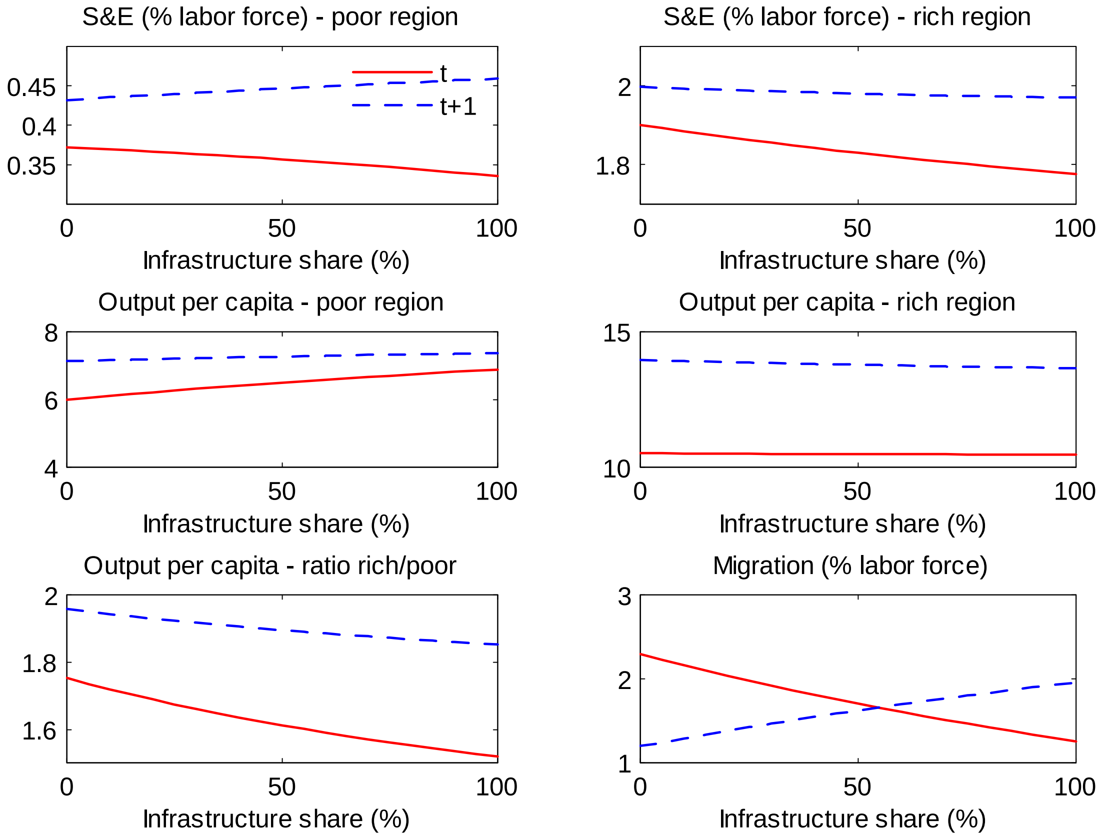

Figure 4: Changes in the composition of structural funds. The benchmark infrastructure share is 40%. Migration is defined as the share of total labor force that moves from the poor to the rich region.

hence augmenting the disparities between regions. However, allocating all funds towards education in period 1 reduces migration in the long run (second period and onward). This obtains because the high rate of migration in period 1 produces higher congestion and thus discourages further migration. In turn, low migration dilutes the effective productivity of researchers, leading to the lowest share of employment in this sector. This happens due to the fact that public education quality displays congestion effects so, at a given budget size, lower migration implies lower per capita effective education quality.

Besides the direct effects in the poor region, altering the composition of structural funds impacts the economy of the rich region as well. Higher migration in the first period, associated with directing structural funds exclusively toward education finance, increases the market size and thus increases employment in the differentiated goods sector. This increases the aggregate output. In per capita terms, however, the changes are marginal.

Our results are consistent with the brain-drain literature that shows that excessive education investment can result in increased outmigration (see Suedekum (2005)). However, in this model, the productivity of innovators increases if the resources available in the education system are spread over a smaller number of people, so outmigration can be a channel of industrial diversification in backward regions. Our benchmark calibration suggests that focusing on infrastructure investments is the most effective way to narrow regional income differences.

Another aspect that is worth pointing out is the fact that altering public spending patterns in the backward region affects the rich region as well. When migration is a channel for growth, policies that reduce migration from the poor regions to rich regions, will necessarily make the latter worse off, suggesting that whenever the allocation of structural funds is decided at the national level, rich regions will favor a high share of investment in public education.

The finding raises some questions with regard to the mechanisms used to allocate structural funds. Brakman et al. (2005) and Gelauff and Ederveen (2006) report that regional policy is biased towards infrastructure, while other studies, like Midelfart-Knarvik and Overman (2002), point out that investments in human capital formation can be undesirable, since they may counteract the comparative advantage of the lagging regions. In this model, the optimal shares of supranational funding depend not only on the relative productivities of infrastructure and public education, but also on the timing of such funding. Thus, the regions may have different preferences over the allocations of structural funds, even in the long run. This preference difference can lead to political economy problems and biases in the cohesion policy implementation, if the eligibility of projects financed by supranational money is partly decided at national level. This can be true even when the mix of local policies is set optimally, since the composition of the structural funds may still depart from it.

5.3 Changes in the duration of structural funds

In this section we study the following cases: no transfers, transfers for two and three periods relative to the benchmark case (structural funding available only one period) keeping the size and the allocation of funding constant (as in the benchmark calibration). The results are displayed in figure 5. As expected, the lowest output gap between the rich and the poor region is obtained when the funding has the longest duration. The share of the labor force involved in knowledge creation mirrors the evolution of output. As established in the first experiment, the structural funds lower the migration for the period for which they are available. Migration increases once the supra-national funding is no longer in place. Interestingly, the strongest increase in migration in the long-run is obtained in the case when the structural funds are available for three periods. This obtains because in this case there are more periods with low migration and thus lower congestion in the rich region.

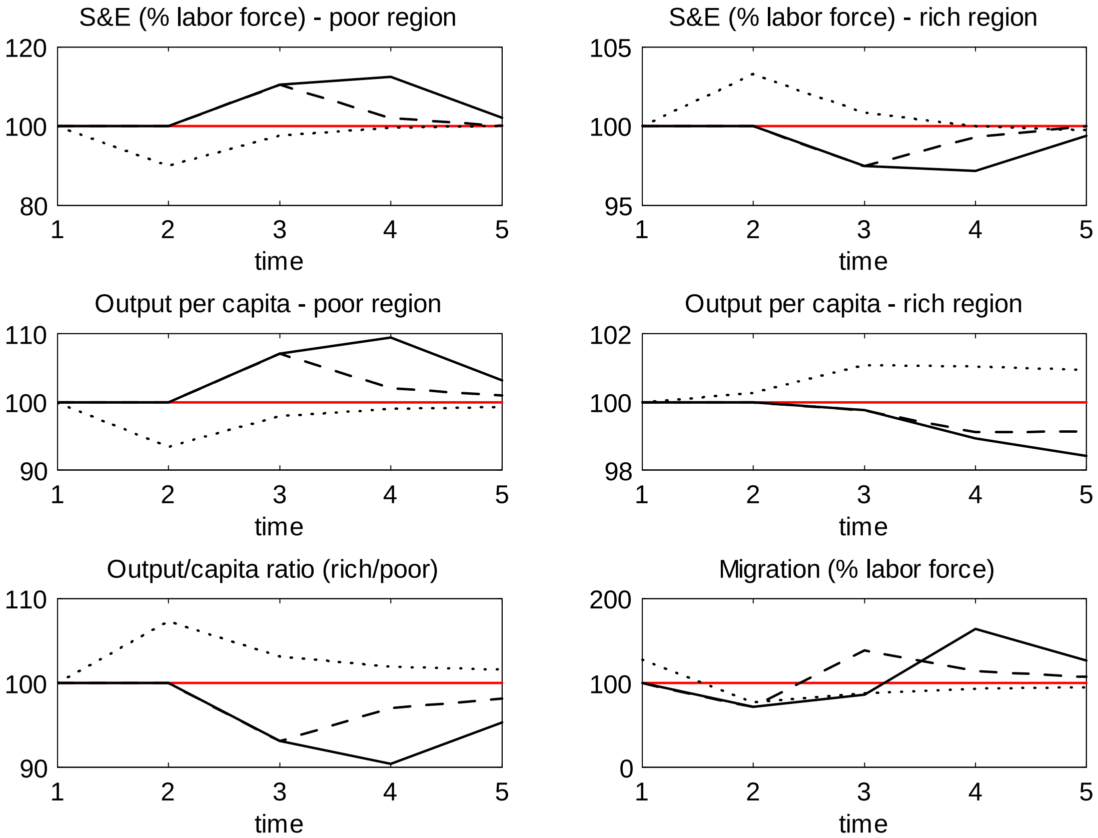

Figure 5: Changing the duration of structural funds transfers. The benchmark (normalized to 100) is the case of structural funds worth 4% of the poor region's GDP for one period. The other cases are: no transfers (dotted line), transfers for two (dashed line) and three (solid dark line) periods. Migration is defined as the share of total labor force that moves from the poor to the rich region.

5.4 The role of migration

In this section we examine the importance of migration for the dynamics of the two regions. Figure 6 shows the no migration case relative to the benchmark model, which incorporates both structural funds and migration.

As explained above, if due to some reason (e.g. structural funds) inter-regional migration stops, the market size for research activities in the rich region increases at a lower rate. This diminishes the innovation in that region and its output growth rate. Opposing effects arise in the poor region. This mechanism is amplified by population growth.

Based on our calibration, stopping migration would generate an increase of output per capita in the poor region of around 2% in period 4 and a simultaneous decline of almost 10% in the rich region. Migration thus has a substantial divergence effect.

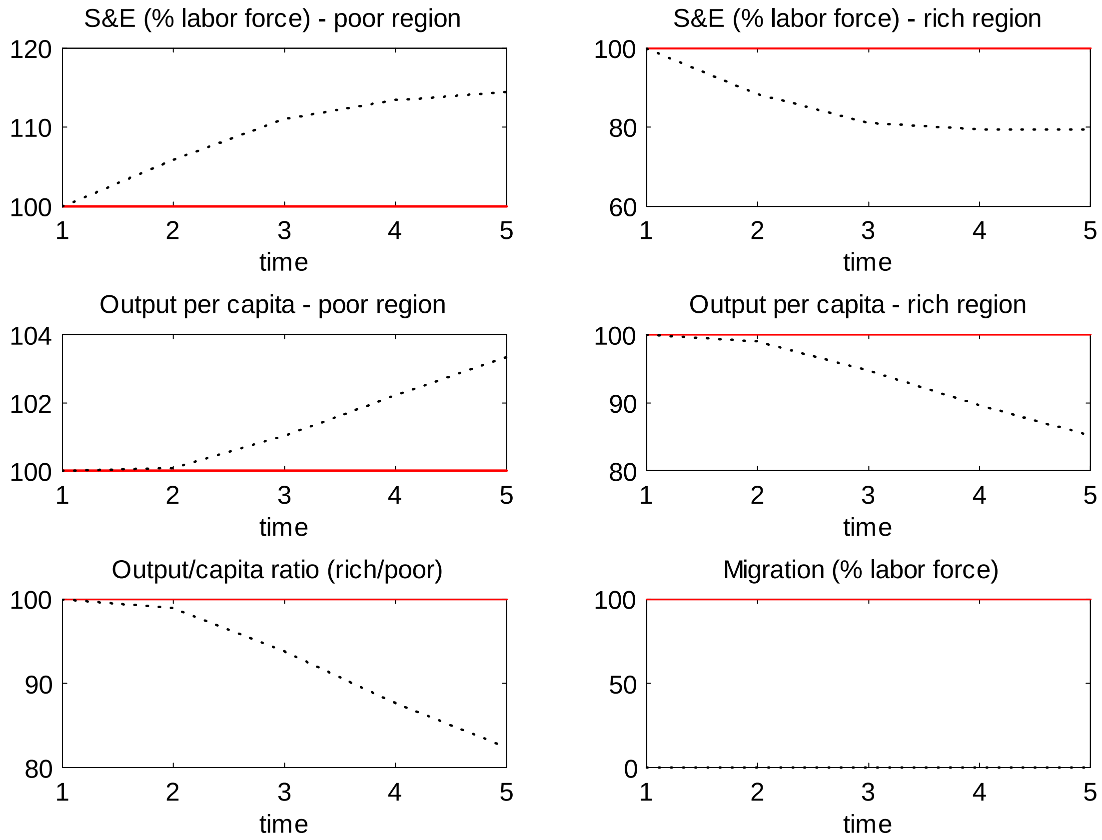

Figure 6: The role of migration. The benchmark (normalized to 100) is the case when both migration (into the rich region) and structural funds are present. The case of zero migration but structural funds is represented by a dotted line.

6 Conclusion

In this paper we have developed a two-region model that allows us to study the short and long run effects of regional redistribution policies such as the European Structural Funds. The model features occupational choice within regions as well as endogenous labor mobility among regions. Economic growth in the model is driven by the endogenous expansion of technologies. There are two outlays of public spending: infrastructure and public education. Supra-national funding of both these outlays is directed to the backward region. The model is calibrated to the Portuguese economy.

The paper characterizes the transitional dynamics of this economy both qualitatively and quantitatively. From a qualitative point of view, we emphasize the link between regional agglomeration and innovation, as an alternative explanation for the overall increase in the share of S&E employment, observed in the developed economies. We then use the model to conduct a series of quantitative exercises.

First, we find that increasing the size of the structural funds allows the poorer regions to catch up faster to the richer regions. This effect is of modest size. Between 1977 and 2001 the income ratio between rich and poor regions increased by around 6% from about 1.55 to about 1.64. While doubling the current structural funds received by Portugal from 4% to 8% of receiving region's GDP keeps the output per capita ratio constant, a threefold increase (to 12% of GDP) would produce convergence - a 9.5% reduction in the 1977 per capita income ratio.

Second, changing the allocation of structural funds between education and infrastructure has sizeable growth effects which vary between the short run and the long run. We also find that the allocation of the structural funds that maximizes output in the poor region (or minimizes divergence between the poor regions) is not optimal for the rich region since it induces sub optimal migration.

Our model relies on a few simplifying assumptions. We assumed that migration is costless. We also assumed that skills of workers are not sector or activity specific and that regions consume a unique, homogenous good. It stands to reason that work in the rich region requires different skills than work in the poor regions. We plan to introduce such features in future work. Our model has pointed to a potentially important political conflict about the allocation of the structural funds between infrastructure and education expenditures. The precise nature, the severity and the implications of this conflict are worthy topics for future investigations.

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7 Appendix

First, given the two public spending outlays are central to our discussion of regional divergence and structural funds, we perform a sensitivity analysis of the model dynamics with respect to changes in public spending elasticities for infrastructure (ε) and education (θ). Second, we investigate the changes due to different assumptions about the depreciation rate for technologies (δ). The first five rows in the table summarize the benchmark values for the rich and poor regions in the first two periods.

Decreasing the output elasticities with respect to public education expenditures θ and infrastructure investment ε decreases the effects on both output and migration. Increasing the depreciation rate of technologies has large positive effects on migration rates.

	Rich t	Rich $t+1$	Poor t	Poor $t+1$
$\varepsilon = \theta = 0.1;\ \delta = 0$				
S&E (% labor force)	1.423	1.842	0.226	0.360
Output growth rate (% annual)	1.950	1.518	1.655	0.689
Output/capita ratio (rich/poor)	1.550	1.636		
Migration (% lab for)	1.810	1.457		
$\varepsilon = \theta = 0.05;\ \delta = 0$				
S&E (% labor force)	1.058	1.215	0.122	0.172
Output growth rate (% annual)	1.156	0.949	0.981	0.516
Output/capita ratio (rich/poor)	1.338	1.445		
Migration (% lab for)	0.860	1.154		
$\varepsilon = 0.05; \theta = 0.1;\ \delta = 0$				
S&E (% labor force)	1.423	1.867	0.226	0.407
Output growth rate (% annual)	1.399	1.215	1.016	0.590
Output/capita ratio (rich/poor)	1.354	1.509		
Migration (% lab for)	1.219	1.318		
$\varepsilon = 0.1; \theta = 0.05;\ \delta = 0$				
S&E (% labor force)	1.058	1.242	0.122	0.157
Output growth rate (% annual)	1.712	1.231	1.622	0.621
Output/capita ratio (rich/poor)	1.532	1.566		
Migration (% lab for)	1.466	1.268		
$\varepsilon = \theta = 0.1;\ \ \delta = 0.05$				
S&E (% labor force)	1.625	2.299	0.264	0.470
Output growth rate (% annual)	1.690	1.335	1.239	0.290
Output/capita ratio (rich/poor)	1.562	1.690		
Migration (% lab for)	2.064	1.657		
$\varepsilon = \theta = 0.1;\ \ \delta = 0.1$				
S&E (% labor force)	1.862	2.862	0.310	0.617
Output growth rate (% annual)	1.445	1.192	0.807	-0.111
Output/capita ratio (rich/poor)	1.575	1.758		
Migration (% labor force)	2.366	1.887		

Table 5: Sensitivity analysis