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Knowledge Spillovers in Neoclassical Growth Model: an extension with Public Sector

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Abstract

We propose a framework to analyze convergence between regions, incorporating the public sector and technological knowledge spillovers in the context of a Neoclassical Growth Model. Secondly, we apply novel estimation methods pertaining to the spatial econometrics literature introducing a spatial autoregressive panel data model based on instrumental variables estimation. Additionally, we introduce marginal effects associated with changing explanatory variables. Our model makes it possible to analyze, in terms of convergence, the results obtained in Spanish regions with the policies implemented during the period 1980–2007. The results support the idea that investments in physical, private and public capital, as well as in education have a positive effect on regional development and cohesion. Therefore, we can conclude that it is possible to obtain better results for regional convergence with higher rates of public investment. We also obtain interesting results that confirm the existence of spillover effects in economic growth and public policies, identifying their magnitude and significance.

Key words: speed of convergence; growth models; public policies.
JEL Codes: E13; O41; H54

1 Introduction

The main goal of this paper is the analysis of the impact of the public sector in economic growth and cohesion. With this aim in mind, we evaluate the effect of public policies on cohesion based on a generalized version of the Neoclassical Growth Model proposed by Mankiw et al. (1992) and, following Ertur and Koch (2007) and Fischer (2011), include spatial interactions. The literature on economic growth has

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devoted considerable effort to the analysis of the determinants of economic growth and the speed of convergence. An extensive and influential number of research papers demonstrate the existence of conditional convergence; that is, the tendency of the most backward economies to systematically grow at a faster rate than more developed economies, once the conditioning factors of this process are controlled for (Mankiw et al., 1992; Barro and Sala-i Martin, 2004).

In the context of European Union, and specifically for the case of Spanish regions, development and cohesion policies have received a great attention due to the fact that, according to European Commission, they have positively contributed to regional growth and convergence.[1] However, public investment policies oriented to intensify infrastructure equipment and education have often been questioned arguing that they mainly serve distributional purposes, but have little effect on fostering economic growth and convergence.[2] Numerous papers in this literature show that the speed of convergence varies across studies, depending on the specification and controlling for investment rates in physical and human capital.[3] Some other studies have tried to consider this issue but using different alternative measures. This is the case of Dowrick et al. (2003), Becker et al. (2005), Philipson and Soares (2001), among others. Dowrick et al. (2003) proposed their own index based on consumption and life expectancy, Becker et al. (2005) analyzed welfare inequality, while Philipson and Soares (2001) examined the properties associated to income.

Most recently, Pastor and Serrano (2012) focused on the inequality in permanent income in the context of European integration, using an approach complementary to Serrano (2006) and Pastor and Serrano (2008). At the same time, and following the convergence studies based on current per capita income, several authors enriched this approach with a methodology that also includes spatial interactions in an extended neoclassical model as determinant of convergence (Ertur and Koch, 2007; Fischer, 2011).[4] Although the standard model used in the literature does not take into account the public sector and fiscal policies as determinants of economic growth and regional cohesion.

This paper seeks to make a contribution to this debate offering a useful proposal to value how the convergence process might have resulted under alternative public policies which differ in the rate of public investment. Particularly, in this study we pay attention to the effect on the speed of convergence of an increase in the rate of investment in public and in human capital endowments, since development and cohesion policies incorporate spatial interactions through knowledge spillovers in the production process.

Furthermore, it is worth noting that in this study we introduce this contribution in three distinctive ways. In the first place, we incorporate public sector and fiscal policies in the Mankiw et al. (1992) extended neoclassical growth model with human capital, along with knowledge spillover, in line with the recent literature that introduces spatial interactions to analyze the determinants of convergence. Secondly,

[1]See the different Cohesion Reports of the European Commission (1997, 2001, 2004, 2007). For a good survey of the models used to evaluate the macroeconomic impact of EU cohesion policies, see Ederveen et al. (2003).

[2]For a criticism on structural policies in Europe see, for example, Boldrin and Canova (2001).

[3]See De la Fuente (2002) for an extended revision of the literature.

[4]LeGallo et al. (2003) and LeGallo and Dall'erba (2008) introduce spatial interactions in convergence between European regions performing empirical contrasts based on spatial econometric techniques.

following Álvarez et al. (2013) we implement programming routines in MATLAB[5] that allow us to apply novel estimations methods pertaining to the spatial econometrics literature (Kelejian and Prucha, 1998, 2010; Baltagi and Liu, 2011).[6] Thirdly, using a novel dataset, an empirical contrast is performed with Spanish regions during 1980-2007, a critical period in Spanish economic growth after joining the EU in 1986. Particularly, the weight matrix reflects proximity between NUTS-3 provinces based on contiguity.

Building on the proposed framework, the estimated convergence equation is based on spatial econometric techniques developing a proposal in which estimations are repeated with different public policies. Two types of scenarios are derived: the first scenario makes it possible to estimate the marginal contributions to income per worker growth resulting from increases in the rate of investment in each regressor; and a second scenario where we estimate the speed of convergence in Spanish regions resulting from increases in each one by dividing the sample by income per worker levels. These analyses allow us to provide some public policies recommendations in order to improve economic convergence and regional cohesion.

This paper is organized as follows. Section 2 outlines the derivation of the growth model employed. Section 3 presents the data and results. The last section draws the main conclusions.

2 The Model

2.1 The production function with knowledge spillovers

Each economy is characterized by a Cobb-Douglas production function for n regions along T periods with constant returns to scale:

$$Y_{it} = A_{it} K_{it}^{\alpha_K} P_{it}^{\alpha_P} H_{it}^{\alpha_H} L_{it}^{1-\alpha_K-\alpha_P-\alpha_H} \tag{1}$$

where Y_{it} is the production of the i-th region in period t, K_{it} and P_{it} are the physical private and public capital, respectively, H_{it} represents human capital, and L_{it} is the employment level. The parameter A_{it} captures the level of technological knowledge. The production function is well-behaved satisfying the desirable neoclassical properties or regularity conditions: i) the marginal productivities are positive and decreasing; ii) it satisfies the Inada's conditions; and iii) it shows decreasing scale performance in the cumulative factors. We assume α_K, α_P and $\alpha_H > 0$, allowing us to analyze the behavior of this economy in the steady state, as well as to empirically solve the corresponding convergence equation.

Equation (1) can be rewritten in per worker terms by dividing both sides by the employment L_{it}:

$$y_{it} = A_{it} k_{it}^{\alpha_K} p_{it}^{\alpha_P} h_{it}^{\alpha_H} \tag{2}$$

where y_{it}, k_{it}, p_{it} and h_{it} are production, physical private and public capital, and human capital per worker respectively.

[5] These routines are available on `http://www.paneldatatoolbox.com`.

[6] Arbia et al. (2008) analyze the convergence in European regions on the basis of the neoclassical Solow model. These authors consider variations on the basic specification of the convergence equation ranging from standard panel data models to Bayesian models. The results obtained from different estimation strategies conclude that the evidence on regional convergence depends to a larger extent on the econometric techniques.

We define the technological knowledge as:

$$A_{it} = \Omega_t k_{it}^{\theta} p_{it}^{\phi} h_{it}^{\gamma} \prod_{j=1}^{n} k_{jt}^{\theta\rho w_{ij}} p_{jt}^{\phi\rho w_{ij}} h_{jt}^{\gamma\rho w_{ij}} \tag{3}$$

It is worth noting several aspects of modeling the aggregate level of technology proposed as in (3), in accordance with the specification introduced by Fischer (2011). Technology is expressed as a function of a term Ω_t, reflecting the exogenous common knowledge, physical and human capital of the own region, but depends on the technological progress of other regions. The technological parameters, $0 < \theta, \phi, \gamma < 1$ reflect the size of the home externalities, and the last term in (3) allows us to formalize the connectivity between regions by mean of spatial weight terms, w_{ij}. As for these spatial parameters of the model, we assume that these terms are positive, the spatial-weight matrix is row-normalized $\sum_{j=1}^{n} w_{ij} = 1 \quad \forall i = 1, \ldots, n$, and $w_{ij} = 0$ if $i = j$. The parameter ρ represents the regional technological interdependence, with $0 < \rho < 1$.

The technological knowledge depends on the level of private, public and human capital of the own region as well as its neighbor regions.

Inserting (3) into the production function per worker (2), we have:

$$y_{it} = \Omega_t k_{it}^{\alpha_K+\theta} p_{it}^{\alpha_P+\phi} h_{it}^{\alpha_H+\gamma} \sum_{j=1}^{n} k_{jt}^{\theta\rho w_{ij}} p_{jt}^{\phi\rho w_{it}} h_{jt}^{\gamma\rho w_{it}} \tag{4}$$

Equation (4) represents the output per worker incorporating the knowledge spillovers and allowing us to relate the per worker output in region i to the capital investment in the same region and its neighbors.[7] With respect to this specification it is worth highlight that changes in output can be due to variations in the own capital stocks and in the stocks from the rest of the regions.

2.2 Dynamical transitions and steady state in Neoclassical Growth Model

The Neoclassical Growth Model assumes that labor in economy i grows at rate n_i. On the other hand, it is assumed that constant shares of income, s_i^K, s_i^P and s_i^H are invested in private, public and human capital and those rates of investment are given exogenously, while these stocks depreciate at the same rate δ.[8]

We introduce the capital accumulation equations following Mankiw et al. (1992), in the case of human capital, and Barro (1990) and Bajo-Rubio (2000) for disaggregating physical capital into private and public. This induces the following dynamic equations for k_{it}, p_{it} and h_{it}.

$$\dot{k}_{it} = s_i^K (1-\tau) y_{it} - (n_i + \delta) k_{it} \tag{5}$$

$$\dot{p}_{it} = s_i^P \tau y_{it} - (n_i + \delta) p_{it} \tag{6}$$

$$\dot{h}_{it} = s_i^H \tau y_{it} - (n_i + \delta) h_{it} \tag{7}$$

[7] If we set $\theta = \phi = \gamma = 0$ there would be no spillover effects and the per worker production function would be characterized by $y_{it} = \Omega k_{it}^{\alpha_K} p_{it}^{\alpha_P} h_{it}^{\alpha_H}$, which represents a world with closed economies.

[8] The Solow model assumes exogenous savings, contrary to what happens in the expansion performed in the Ramsey-Cass-Koopmans model. This limitation does not prevent us from obtaining the steady state solution and deriving the convergence equation allowed by their determinants.

where τ is the size of the public sector, s_i^K , s_i^P and s_i^H are the fractions of income invested in private, public and human capital, respectively.[9] The dots above the capital variables denote derivatives with respect to time.

In the steady state, private, public and human capital grow at a constant rate g:

$$\frac{\dot{k}_{it}}{k_{it}} = g \qquad \frac{\dot{p}_{it}}{p_{it}} = g \qquad \frac{\dot{h}_{it}}{h_{it}} = g \tag{8}$$

Substituting the dynamic equations (5)–(7) into (8) and solving, we get the capital-output ratios:

$$\frac{k_{it}^\star}{y_{it}^\star} = \frac{s_i^K(1-\tau)}{n_i+g+\delta} \tag{9}$$

$$\frac{p_{it}^\star}{y_{it}^\star} = \frac{s_i^P\tau}{n_i+g+\delta} \tag{10}$$

$$\frac{h_{it}^\star}{y_{it}^\star} = \frac{s_i^H\tau}{n_i+g+\delta} \tag{11}$$

with the star representing the steady state levels.

Inserting these expressions back into the production function per worker with the technological knowledge (4) and solving for the output:

$$\begin{aligned} y_i^\star =&\Omega^{\frac{1}{1-\eta}} \left(\frac{s_i^K(1-\tau)}{n_i+g+\delta}\right)^{\frac{\alpha_K+\theta}{1-\eta}} \left(\frac{s_i^P\tau}{n_i+g+\delta}\right)^{\frac{\alpha_P+\phi}{1-\eta}} \left(\frac{s_i^H\tau}{n_i+g+\delta}\right)^{\frac{\alpha_H+\gamma}{1-\eta}} \\ &\prod_{j=1}^{n} \left(\frac{s_j^K(1-\tau)}{n_j+g+\delta}y_j^\star\right)^{\frac{\theta\rho w_{ij}}{1-\eta}} \left(\frac{s_j^P\tau}{n_j+g+\delta}y_j^\star\right)^{\frac{\phi\rho w_{ij}}{1-\eta}} \left(\frac{s_j^H\tau}{n_j+g+\delta}y_j^\star\right)^{\frac{\gamma\rho w_{ij}}{1-\eta}} \end{aligned} \tag{12}$$

with $\eta = \alpha_K+\alpha_P+\alpha_H+\theta+\phi+\gamma$.

We can group exponentials and get the following expression for output per worker in the steady state:

$$\begin{aligned} y_i^\star =&\Omega^{\frac{1}{1-\eta}} \left(\frac{(s_i^K)^{\alpha_K+\theta}(1-\tau)^{\alpha_k+\theta}(s_i^P)^{\alpha_p+\phi}(s_i^H)^{\alpha_H+\gamma}(\tau)^{\alpha_p+\alpha_H+\phi+\gamma}}{(n_i+g+\delta)^\eta}\right)^{\frac{1}{1-\eta}} \\ &\prod_{j=1}^{n} \left(\frac{(s_j^K)^{\theta}(1-\tau)^{\theta}(s_j^P)^{\phi}(s_j^H)^{\gamma}(\tau)^{\phi+\gamma}}{(n_j+g+\delta)^{\theta+\phi+\gamma}}(y_j^\star)^{\theta+\phi+\gamma}\right)^{\frac{\rho w_{ij}}{1-\eta}} \end{aligned} \tag{13}$$

[9]The budget constrain of the public sector is given by $\tau y_{it} = c_i^P\tau y_{it} + s_i^P\tau y_{it} + s_i^H\tau y_{it}$, where c_i^P is the share of public consumption, and $c_i^P + s_i^P + s_i^H = 1$.

Taking logarithms we obtain the following expression:

$$
\begin{aligned}
\ln y_i^{\star} =& \frac{1}{1-\eta}\ln\Omega + \frac{\alpha_K+\theta}{1-\eta}\ln s_i^K + \frac{\alpha_P+\phi}{1-\eta}\ln s_i^P + \frac{\alpha_H+\gamma}{1-\eta}\ln s_i^H \\
&+\frac{\alpha_K+\theta}{1-\eta}\ln(1-\tau) + \frac{\alpha_P+\alpha_H+\phi+\gamma}{1-\eta}\ln\tau - \frac{\eta}{1-\eta}\ln(n_i+g+\delta) \\
&+\frac{\theta}{1-\eta}\rho\sum_{j=1}^{n} w_{ij}\ln s_j^K + \frac{\phi}{1-\eta}\rho\sum_{j=1}^{n} w_{ij}\ln s_j^P + \frac{\gamma}{1-\eta}\rho\sum_{j=1}^{n} w_{ij}\ln s_j^H \\
&+\frac{\theta}{1-\eta}\rho\sum_{j=1}^{n}\ln(1-\tau) + \frac{\phi+\gamma}{1-\eta}\rho\sum_{j=1}^{n}\ln\tau \\
&-\frac{\theta+\phi+\gamma}{1-\eta}\rho\sum_{j=1}^{n} w_{ij}\ln(n_j+g+\delta) \\
&+\frac{\theta+\phi+\gamma}{1-\eta}\rho\sum_{j=1}^{n} w_{ij}\ln y_j^{\star}
\end{aligned} \tag{14}
$$

2.3 Conditional convergence

Our model predicts that income per worker converges to its steady state. To obtain the convergence equation, we take differences in the logarithmic transformation of production function per worker:

$$
\begin{aligned}
\frac{d\ln y_{it}}{dt} =& (\alpha_K+\theta)\frac{d\ln k_{it}}{dt} + (\alpha_P+\phi)\frac{d\ln p_{it}}{dt} + (\alpha_H+\gamma)\frac{d\ln h_{it}}{dt} \\
&+\theta\rho\sum_{j=1}^{n} w_{ij}\frac{d\ln k_{jt}}{dt} + \phi\rho\sum_{j=1}^{n}\frac{d\ln p_{jt}}{dt} + \gamma\rho\sum_{j=1}^{n} w_{ij}\frac{d\ln h_{jt}}{dt}
\end{aligned} \tag{15}
$$

where $\frac{d\ln k_{it}}{dt}$, $\frac{d\ln p_{it}}{dt}$, $\frac{d\ln h_{it}}{dt}$, $\frac{d\ln k_{jt}}{dt}$, $\frac{d\ln p_{jt}}{dt}$, and $\frac{d\ln h_{jt}}{dt}$ are the differences in the logarithmic transformations of capital per worker.

Inserting (4) into the dynamic equations in (5)–(7) and dividing by the corresponding capital, we obtain:

$$\frac{\dot{k}_{it}}{k_{it}} = s_i^K(1-\tau)\Omega_t k_{it}^{-(1-\alpha_K-\theta)} p_{it}^{\alpha_P+\phi} h_{it}^{\alpha_H+\gamma}\sum_{j=1}^{n} k_{jt}^{\theta\rho w_{ij}} p_{jt}^{\phi\rho w_{it}} h_{jt}^{\gamma\rho w_{it}} - (n_i+\delta) \tag{16}$$

$$\frac{\dot{p}_{it}}{p_{it}} = s_i^P\tau\Omega_t k_{it}^{\alpha_K+\theta} p_{it}^{-(1-\alpha_P-\phi)} h_{it}^{\alpha_H+\gamma}\sum_{j=1}^{n} k_{jt}^{\theta\rho w_{ij}} p_{jt}^{\phi\rho w_{it}} h_{jt}^{\gamma\rho w_{it}} - (n_i+\delta) \tag{17}$$

$$\frac{\dot{h}_{it}}{h_{it}} = s_i^H\tau\Omega_t k_{it}^{\alpha_K+\theta} p_{it}^{\alpha_P+\phi} h_{it}^{-(1-\alpha_H-\gamma)}\sum_{j=1}^{n} k_{jt}^{\theta\rho w_{ij}} p_{jt}^{\phi\rho w_{it}} h_{jt}^{\gamma\rho w_{it}} - (n_i+\delta) \tag{18}$$

The main result in our model is the existence of diminishing returns to the reproducible capital: $\partial(\dot{k}_{it}/k_{it})/\partial k_{it} < 0$, $\partial(\dot{p}_{it}/p_{it})/\partial p_{it} < 0$ and $\partial(\dot{h}_{it}/h_{it})/\partial h_{it} < 0$. When an economy increases its capital per worker, the rate of growth decreases and converges to its own steady state. However, an increase in capital per worker in a neighboring economy j increases the production in economy i if $\partial(\dot{k}_{it}/k_{it})/\partial k_{jt} > 0$

, $\partial(\dot{p}_{it}/p_{it})/\partial p_{jt} > 0$ and $\partial(\dot{h}_{it}/h_{it})/\partial h_{jt} > 0$, and positive technological interdependence is observed. Therefore, the convergence result is still valid under the hypothesis

$$(\alpha_K + \alpha_P + \alpha_H) + \frac{\theta + \phi + \gamma}{1 - (\theta\rho + \phi\rho + \gamma\rho)} < 1,$$

in contrast with endogenous growth models, where the marginal productivity in capital is constant.

As in the literature, the transitional dynamics can be quantified by using a log linearization of equations (5)–(7) around the steady state (Appendix A):

$$\frac{d\ln k_{it}}{dt} = g - (1 - \alpha_K - \theta)(n_i + g + \delta)\left[\ln k_{it} - \ln k_i^\star\right] \tag{19}$$

$$\frac{d\ln p_{it}}{dt} = g - (1 - \alpha_P - \phi)(n_i + g + \delta)\left[\ln p_{it} - \ln p_i^\star\right] \tag{20}$$

$$\frac{d\ln h_{it}}{dt} = g - (1 - \alpha_H - \gamma)(n_i + g + \delta)\left[\ln h_{it} - \ln h_i^\star\right] \tag{21}$$

Introducing (19)–(21) into equation (15), for $i = 1, \ldots, n$,and the corresponding to j, for $i \neq j$, we obtain:

$$\begin{aligned}
\frac{d\ln y_{it}}{dt} =& (\alpha_k + \theta)\left[g - (1 - \alpha_K - \theta)(n_i + g + \delta)\left[\ln k_{it} - \ln k_i^\star\right]\right] \\
&+ (\alpha_P + \phi)\left[g - (1 - \alpha_P - \phi)(n_i + g + \delta)\left[\ln p_{it} - \ln p_i^\star\right]\right] \\
&+ (\alpha_H + \gamma)\left[g - (1 - \alpha_H - \gamma)(n_i + g + \delta)\left[\ln h_{it} - \ln h_i^\star\right]\right] \\
&+ \theta\rho\sum_{j=1}^{n} w_{ij}\left[g - (1 - \alpha_K - \theta)(n_j + g + \delta)\left[\ln k_{jt} - \ln k_j^\star\right]\right] \\
&+ \phi\rho\sum_{j=1}^{n} w_{ij}\left[g - (1 - \alpha_P - \phi)(n_j + g + \delta)\left[\ln p_{jt} - \ln p_j^\star\right]\right] \\
&+ \gamma\rho\sum_{j=1}^{n} w_{ij}\left[g - (1 - \alpha_H - \gamma)(n_j + g + \delta)\left[\ln h_{jt} - \ln h_j^\star\right]\right]
\end{aligned} \tag{22}$$

We consider the following relations between the gaps of economies with respect to their own steady states, in order to reduce the difficulty of solving the convergence equation in (22):

$$\ln k_{it} - \ln k_i^\star = \Theta_j\left[\ln k_{jt} - \ln k_j^\star\right] \tag{23}$$

$$\ln p_{it} - \ln p_i^\star = \Phi_j\left[\ln p_{jt} - \ln p_j^\star\right] \tag{24}$$

$$\ln h_{it} - \ln h_i^\star = \Gamma_j\left[\ln h_{jt} - \ln h_j^\star\right] \tag{25}$$

$$\ln y_{it} - \ln y_i^\star = \Psi_j\left[\ln y_{jt} - \ln y_j^\star\right] \tag{26}$$

These assumptions allow us to simplify the convergence equation in (22)

$$\frac{d\ln y_{it}}{dt} = -\lambda_{it}\left[\ln y_{it} - \ln y_i^\star\right], \tag{27}$$

where λ represents the speed of convergence.[10] Solving the first order differential equation in (27) and subtracting the income per worker at some initial date $\ln y_{it-T}$:

$$\frac{\ln y_{it} - \ln y_{it-T}}{T} = -\frac{1-e^{-\lambda_{it}}}{T}\ln y_{it-T} + \frac{1-e^{-\lambda_{it}}}{T}\ln y_i^\star \tag{28}$$

This model predicts convergence, due to the fact that growth of real income per worker is a negative function of income at initial date. Therefore, poor economies grow faster than rich ones, indicating convergence in economic growth, after controlling for the determinants of the steady state. For this reason, we obtain the expression that allows us to contrast the existence of conditioned convergence, or convergence of economies to its own steady states.

Finally, substituting the income per worker in the steady state we can rewrite this equation for economy i:

$$\begin{aligned}
\frac{\ln y_{it} - \ln y_{it-T}}{T} &= -\frac{\left(1-e^{-\lambda_{it}}\right)}{T}\ln y_{it-T} + \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{1}{1-\eta}\ln\Omega \\
&+ \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{\alpha_K+\theta}{1-\eta}\ln s_i^K + \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{\alpha_P+\phi}{1-\eta}\ln s_i^P + \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{\alpha_H+\gamma}{1-\eta}\ln s_i^H \\
&+ \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{\alpha_K+\theta}{1-\eta}\ln(1-\tau) + \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{\alpha_P+\alpha_H+\phi+\gamma}{1-\eta}\ln\tau \\
&- \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{\eta}{1-\eta}\ln(n_i+g+\delta) + \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{\theta}{1-\eta}\rho\sum_{j=1}^{n} w_{ij}\ln s_j^K \\
&+ \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{\phi}{1-\eta}\rho\sum_{j=1}^{n} w_{ij}\ln s_j^P + \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{\gamma}{1-\eta}\rho\sum_{j=1}^{n} w_{ij}\ln s_j^H \\
&+ \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{\theta}{1-\eta}\rho\sum_{j=1}^{n}\ln(1-\tau) + \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{\phi+\gamma}{1-\eta}\rho\sum_{j=1}^{n}\ln\tau \\
&- \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{\theta+\phi+\gamma}{1-\eta}\rho\sum_{j=1}^{n} w_{ij}\ln(n_j+g+\delta) \\
&+ \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{\theta+\phi+\gamma}{1-\eta}\rho\sum_{j=1}^{n} w_{ij}\ln y_j^\star \\
&+ \frac{\left(1-e^{-\lambda_{it}}\right)}{T}\frac{\theta+\phi+\gamma}{1-\eta}\rho\sum_{j=1}^{n}\frac{1}{(1-e^{-\lambda_{it}})}w_{ij}\left[\ln y_{jt} - \ln y_{jt-T}\right]
\end{aligned} \tag{29}$$

The convergence equation in expression (29) allows contrasting conditioned convergence on income and its determinants. Here, the growth of income per worker is a negative function of the initial level

[10] See Appendix 2 for further details.

of income per worker, after controlling for the determinants of the steady state. More specifically, the growth rate of income per worker depends positively on physical investment, private and public, and human capital, and negatively on its own labor growth. Also, the growth on income per worker is a function of the same variables in neighboring economies because of technological interdependence. We can observe that the income growth is higher in economies with less initial income, indicating the existence of convergence, although the growth rate is higher, the larger is the initial income in neighboring economies. Finally, this is qualified by the last term in (29) indicating that income growth in an economy also depends on its neighbor's income growths. In what follows we contrast empirically the effectiveness of this spatial augmented neoclassical model with public sector in Spanish regions. Then, we will show how the technological interdependence as well as public and human capital can influence convergence in economic growth. Additionally, since we have introduced fiscal policy, we can analyze the tax income effect and the existence of fiscal spillovers in Spanish regions.

3 Econometric specification, data and results

3.1 Econometric specification and methods

The empirical contrast of the convergence equation in (29) is performed on the basis of the following Spatial Autoregressive Regression (SAR) model:

$$\begin{aligned}\ln y_{it} - \ln y_{it-1} =& \beta_0 - \beta_1 \ln y_{it-1} + \beta_2 \ln s_{it}^K + \beta_3 \ln s_{it}^P + \beta_4 \ln s_{it}^H + \beta_5 \ln \tau_{it} \\ & - \beta_6 \ln(n_i + g + \delta) + \rho_1 W \ln y_{it-1} + \rho_2 W \ln s_{it}^K + \rho_3 W \ln s_{it}^P \\ & + \rho_4 W \ln s_{it}^H + \rho_5 W \ln \tau_{it} - \rho_6 W \ln(n_{it} + g + \delta) \\ & + \rho_7 W [\ln y_{it} - \ln y_{it-1}] + u_{it} \\ u_{it} =& \mu_i + v_{it},\end{aligned} \tag{30}$$

where $\frac{(1-e^{-\lambda_{it}})}{T}\frac{1}{1-\eta}\ln\Omega = \beta_0$, and β_k and ρ_k are the $(kx1)$ vectors of parameters to be estimated. The two components error term u_{it} includes a vector of province effects μ_i and a vector of identically and independently distributed disturbance terms v_{it}. It is assumed that μ_i and v_{it} are independent of each other, and the regressors matrix. The $nTxnT$ spatial weight matrix W defines dependence across n provinces along the T periods. In our study the spatial interdependence is based on the consideration of a physical contiguity matrix, in which its elements would be 1, for two bordering provinces and 0 for all others. Since contiguity does not change, the spatial weight matrix W_n for one period is the same for all time periods, and the big $W_{nT} = W$ matrix for all observations, $N = nT$, is computed as $W = W_n \otimes I_T$. The row-normalization of W implies that $\sum_j^N w_{ij} = 1$. These matrices specify physical proximity as the main driver for the presence of spillovers.

The Spatial Autoregressive model in (30) can be expressed as:

$$(I_N - \rho W)Y_{it} = \beta_0 + \beta_k \ln X_{kit} + \rho_k W \ln X_{kit} + \mu_i + v_{it}, \tag{31}$$

where ρ represents the autoregressive coefficient associated to income per worker growth, Y_{it} is the independent variable, and X_{kit} denotes the explanatory variables. From this expression, we can observe that changes of each explanatory variable will have direct and indirect effects, since income per worker growth in a province can be affected by variations in the explicative variable in this province and its neighbors. We follow LeSage and Pace (2009) to estimate the direct and indirect effects of the regressors included in the convergence equation (30). Thereby, the own- and cross-partial derivatives on average for the T periods correspond to the following expression:

$$\frac{\partial \ln Y_{it}}{\partial \ln X_{kit}} = (I_N - \hat{\rho}W)^{-1}(I_N\hat{\beta}_k + W\hat{\rho}_k), \tag{32}$$

which provides an NxN matrix for each regressor. The total effect is estimated from these matrices as the average of the rows sum (or columns). The direct effect is computed as the average of the diagonal elements, whereas the difference between the total and direct effects reflects the indirect effects, which can also be computed as the row sum of the off-diagonal elements. The derivative (32) can be further decomposed into the internal effect: $(I_N - \hat{\rho}W)^{-1}(I_N\hat{\beta}_k)$, and the spillover effect: $(I_N - \hat{\rho}W)^{-1}(W\hat{\rho}_k)$. Additionally, we obtain equivalent results if we consider internal values of the explanatory variables evaluated in each province, and values in the neighboring provinces or spillover effects separately.

In the estimation of equation (30) we consider spatial panel econometric techniques that allow us to introduce specific heterogeneities (Baltagi, 2008). We base our estimation on the spatial error component model, with random effects, which is the most general and appropriate specification to make unconditional inferences on the population based on a sample (Beenstock and Felsenstein, 2007). We focus on the spatial error component best two stage least squares estimator (SEC-B2SLS), provided by Baltagi and Liu (2011). These authors extend Baltagi (1981) error component two-stage least square estimator, following the method introduced by Kelejian and Prucha (1998) and using Lee (2003) optimal instruments for this spatial autoregressive panel model. Additionally, we check robustness comparing the obtained results with other different standard methods in the literature of spatial models: Kelejian and Prucha (1998) 2SLS, and the most extended estimator in spatial panel models, the fixed effects spatial panel FE-S2SLS.

3.2 Data

The proposed convergence equation is estimated using individual information on the Spanish provinces from 1980 to 2007. Data came from two main statistical sources: Gross Domestic Product (GDP) and private labour (number of employees) from the *Spanish National Statistics Institute* (Instituto Nacional de Estadística, INE). The series of productive (i.e., non-residential) private capital (K), public capital (P) and human capital (H) are taken from the database compiled by Mas et al. (2011) at the *Instituto Valenciano de Investigaciones Economicas* (IVIE) constructed using a perpetual inventory method. The tax income is included in the database on the public sector ("*Las diferencias regionales del sector publico español*") elaborated also by the *Instituto Valenciano de Investigaciones Economicas* (IVIE). All variables are expressed in 2000 constant values.

Income is expressed in per capita terms, while the capital investment represents the share of income invested in private, public and human capital; the last corresponds to public expenditure on education. Furthermore, the size of the public sector is introduced in terms of the fiscal policy, which is analyzed through tax revenues. Finally, the labor growth rate includes technological growth and depreciation rates .[11] Table 1 shows the descriptive statistics corresponding to variables used in the analysis.

Table 1: Descriptive statistics

Variables	Mean	Standard deviation	Minimum	Maximum
Income per worker: y	30,113.149	5,020.943	12,435.481	41,420.183
Private Capital: s^K	0.145	0.046	0.039	0.533
Public Capital: s^P	0.040	0.017	0.007	0.127
Human Capital: s^H	0.004	0.002	$<$0.001	0.025
Tax Income: τ	0.130	0.067	0.040	0.491
Labor Growth: $n+g+\delta$	0.067	0.036	$<$0.001	0.418

3.3 Results

We analyze the contribution of public policies on convergence introducing spatial interactions. The period of time used is of special interest given that it coincides with an increase in the decentralization of public functions as Spain joined the European Community. Both events gave rise to substantial growth in public investment intended to improve public infrastructure, while the whole tax and revenue system was perfected so as to match European guidelines. Results following spatial panel data analysis techniques are shown in Table 2. Wald statistics of joint significance show that all the equations estimated are significant.

Looking at the results reported in Table 2 we can see how the popular fixed effects spatial panel two stage least squares estimator (FE-S2SLS) and the error component best two stage least squares estimator (SEC-B2SLS) by Baltagi and Liu (2011) yield similar results. These results show robustness, in comparison with those obtained in some other papers, in which the authors estimate convergence equations following spatial econometric techniques. For instance, Arbia et al. (2008) analyze $\beta-$convergence linked to the Neoclassical Growth Model in a set of NUTS 2 EU regions, concluding that the model implied by the cross-sectional approach differs from panel data models. In our case, the estimation obtained from spatial panel techniques, FE-S2SL and SEC-B2SLS estimators, are similar than the cross-sectional estimation by 2SLS estimator.

Focusing on the SEC-B2SLS estimator, we observe convergence in income per worker with an implied speed of convergence of 4%. Although the spillover effects on income level and growth are positive. Therefore, the income level and the economic growth of neighboring provinces affect positively the economic growth, with values of 0.033 and 0.731 respectively, indicating that the income per worker growth

[11] As is standard in the growth literature, we take $g+\delta$ to be equal to 0.05 for all provinces and years (Mankiw et al., 1992).

Table 2: Spatial estimation results

$\ln y_{it} - \ln y_{it-1}$	$2SLS$	$FE-2SLS$	$SEC-B2SLS$
$Constant(c)$	$-0.297(-0.51)$	$-0.437(-0.60)$	$0.359(0.91)$
$\ln y_{it-1}$	$-0.042(-5.15)***$	$-0.069(-4.56)***$	$-0.043(-6.67)***$
$\ln s^K_{it}$	$0.014(335)***$	$0.010(1.93)*$	$0.013(3.85)***$
$\ln s^P_{it}$	$-0.005(-1.71)*$	$-0.0005(-0.11)$	$-0.004(-1.74)*$
$\ln s^H_{it}$	$0.0002(0.11)$	$0.0005(0.16)$	$-0.0005(-0.26)$
$\ln \tau_{it}$	$0.005(1.53)$	$-0.013(-1.21)$	$0.006(2.23)**$
$\ln(n_i+g+\delta)$	$-0.031(-17.29)***$	$-0.032(-15.53)***$	$-0.030(-21.95)***$
$W\ln y_{it-1}$	$0.053(2.58)***$	$0.087(2.59)***$	$0.033(2.27)**$
$W\ln s^K_{it}$	$-0.015(-2.63)***$	$-0.011(-1.40)$	$-0.015(-3.33)***$
$W\ln s^P_{it}$	$0.004(0.88)$	$-0.002(-024)$	$0.006(1.71)*$
$W\ln s^H_{it}$	$0.002(-0.39)$	$-0.0001(-0.02)$	$-0.001(-0.32)$
$W\ln \tau_{it}$	$-0.006(-0.95)$	$0.015(1.03)$	$-0.002(-0.33)$
$W\ln(n_i+g+\delta)$	$0.034(3.68)***$	$0.035(3.55)***$	$0.024(3.72)***$
$W[\ln y_{it} - \ln y_{it-1}]$	$1.202(2.95)***$	$1.254(2.93)***$	$0.731(2.63)***$
Associated λ	0.04	0.07	0.04
Wald test	607.78	461.2	989.44

Notes: *t*-statistic in parenthesis. * Parameter significant at 90%. ** Parameter significant at 95%. ** Parameter significant at 99%. Observations = 1269. 2SLS =Two Stage Least Squares Estimator, Kelejian and Prucha (1998). FE-2SLS= Fixed Effects Spatial Two Stage Least Squares Estimator. SEC-B2SLS = Spatial Error Component Best Two Stage Least Squares Estimator, Baltagi and Liu (2011).

in other provinces is more intense than the income per worker level, in accordance with other studies using Spanish provincial data (Baños et al., 2012). This can be explained by the fact that having richer provinces as neighbors benefit economic activity since this contributes to intensify economic interactions with those provinces.

In the case of private capital, there is a direct positive effect on growth, but the spillover effect is negative and slightly higher, by 1.15 percent, because of competition between provinces to attract private investment. Furthermore, the positive contribution of public capital also exhibits spillovers effects with a value of 0.006. Again, these results are in line with those obtained in the literature for Spanish regions (see Mas et al. (1995, 1998), among others). Particularly, Mas et al. (1995) estimate convergence equations for the 17 Spanish regions for the 1955–1991 period, concluding that public capital had a significant role in the convergence process, with a coefficient of 0.005. Furthermore, Mas et al. (1998) discuss the existence of convergence among Spanish regions during 1964 – 1993 and the importance of of public capital endowments in explaining Total Factor Productivity (TFP), with an elasticity of 0.1107. So, in general, public capital has a positive effect on income growth due to this indirect effect, reflecting that economic activity is benefited from the public investment localized in the nearest provinces. Finally, regarding tax income, we can observe a direct positive effect, indicating that the higher the financial support for public activities results in internal benefits.

Table 3: Summary estimates of direct and indirect effects

	Internal Effect	Spillover Effect	Total Effect
Income per worker: $\ln y_{it-1}$			
Direct	-0.05208	0.009777	-0.04231
Indirect	-0.10694	0.112625	0.005688
Total Effects	-0.15902	0.122402	-0.03662
Private Capital: $\ln s_{it}^{K}$			
Direct	0.015292	-0.00454	0.010756
Indirect	0.031397	-0.05224	-0.02085
Total Effects	0.046688	-0.05678	-0.01009
Public Capital: $\ln s_{it}^{P}$			
Direct	-0.00458	0.001795	-0.00279
Indirect	-0.00941	0.020674	0.011265
Total Effects	-0.01399	0.022469	0.008477
Human Capital: $\ln s_{it}^{K}$			
Direct	-0.00056	-0.00029	-0.00085
Indirect	-0.00114	-0.00337	-0.00451
Total Effects	-0.0017	-0.00366	-0.00536
Tax Income: $\ln \tau_{it}$			
Direct	0.006789	-0.00046	0.006332
Indirect	0.013939	-0.00526	0.008676
Total Effects	0.020728	-0.00572	0.015008
Labor Growth: $\ln(n_{it}+g+\delta)$			
Direct	-0.03641	0.007040	-0.02937
Indirect	-0.07476	0.081098	0.006335
Total Effects	-0.11118	0.088138	-0.02304

Table 3 shows the disaggregation between direct and indirect effects, according to the different terms in (32). The results corresponding to the total effects, including their direct and the indirect terms, can be compared to the coefficients' estimates in Table 2. We observe that both sets of results are rather similar. Regarding the initial level of income per worker, the direct effect is negative, while the indirect effect is positive and lower, indicating that income in the nearest provinces affects positively, although the direct effect predominates. For this reason, the total effect is negative, allowing us to corroborate the existence of convergence at a 4% rate.

With regards to the private capital, its direct effect is positive and lower than the indirect effect, which is negative. As a result the net total effect is negative with a value of -0.01. In contrast, public capital affects positively economic growth, with an elasticity of 0.008, because it presents a positive indirect effect that is four times larger than the negatively valued direct effect. As previously commented, this elasticity is similar to the one obtained in Mas et al. (1995), in which the authors obtained a positive effect of public capital on convergence with a coefficient of 0.005. Furthermore, tax income affects positively, with a value of 0.015, which is the sum of direct, 0.006, and indirect effects, 0.009. In addition, the human capital is not relevant for the convergence process, according to the coefficients significance in Table 2. If we look at Table 3, we can see that the total effect of education investment is negative, with both negative direct and indirect effects. Some authors argue that the human capital, as educational attainment, contributes to divergence due to the unequal distribution and educational policies in Spanish provinces (Serrano, 1998).[12] Finally, it is worth noting that the total effect corresponding to labor growth is negative, with the direct effect predominating over the indirect positive effect. This would be an indirect corroboration of the existence of agglomeration economies drawing production factors to locations with larger economic activity and whose growth is reinforced; which contributes to intensify divergence and constitutes the main proposition of theories explaining core-periphery patterns (Barbero and Zofío, 2012).Additionally, this methodology allows us to predict growth income per worker. In Figure 1 we can observe the forecasting power of the model.

Figures 2 and 3 present these analyses, focusing on the marginal contribution to income per worker growth, and the sensitivity of the speed of convergence with respect to changes in the explanatory variables. Figure 2 differentiates between internal and spillover effect. In this case, we can observe a positive response in public investment and tax income. However, the marginal effects on income decrease when public policies intensify both public investment and the financial support received by public administrations, due to the trends observed in spillovers and internal effects, respectively. So, as we increase public investment and tax revenues, economic growth decreases because of reductions in the spillover effects in public investment and the internal effect on fiscal policies. Furthermore, private, human capital and labor growth produce negative effects on economic growth. Nevertheless, it is worth noting that while these negative effects show an increasing rate in the case of private capital due to spillover effect, the growth of labor increases its influence on income in response to an increasing internal effect.

Analyzing the marginal effects on income growth of both the internal and spillover effects of the explanatory variables, we conclude that, firstly, public capital has a positive impact on economic growth through spillover effects, although these effects are decreasing while the internal effect increases. Secondly, the other interesting result is that tax revenues generate a positive and decreasing effect on income growth due to internal effect, improving the spillover effect.

Figure 3 shows the contribution on the speed of convergence of the explanatory variables. We divide the sample according to the provincial income level, in order to explore the effect of the different policy instruments on cohesion. The private capital investment contributes to improving the speed of

[12] Castello and Domenech (2002) obtain similar results introducing the Gini distribution of education in a convergence equation for 108 countries over five-years intervals from 1960 to 2000.

convergence below 50 per cent increments in low income economies, and large increases in high income economies. When we consider the public capital the situation is substantially different. In this case, we can observe that there is a level of percentage increase for which improvements in investment in low income economies contribute to increase the speed of convergence. Moreover, labor growth shows similar results. Furthermore, investment in education contributes to accelerate convergence in both low and high income economies, while tax revenues affects positively to cohesion in low income economies but for high income ones they intensify disparities.

4 Conclusions

In this article we analyze the convergence in Spanish regions during the period 1980–2007, extending the neoclassical growth model with public sector and fiscal policies, and incorporating knowledge spillovers in the production process by taking into account spatial interactions. With this aim in mind, we perform empirical contrasts on the basis of novel spatial econometric techniques recently proposed in the literature, and that introduce these spatial spillovers as determinants of convergence. We make use of new programming routines that allow the implementation of these approaches in MATLAB.

Results show strong evidence of convergence in economic growth and, therefore, a reduction in economic disparities. Moreover, the spillover effects on the regions' income levels and growth are positive. Consequently, we confirm that the level of economic activity of neighboring provinces affect positively the development of a given geographical area. This can be explained by the fact that having richer neighbor provinces can benefit a region's economic activity since this contributes to intensify the commercial relations with those provinces. In the case of private capital, we identified a direct positive effect on growth, but characterized by negative spillover effects, because of competition between provinces to attract private investment. Furthermore, the positive contribution of public capital is provided by spillover effects. So, in general, the public capital has a positive effect on income growth through this indirect channel, reflecting that economic activity is also benefited from the public investment localized in the nearest provinces. Finally, regarding tax income, we can observe a direct positive effect, indicating that public financial support results in internal benefits.

Additionally, this methodology allows us to evaluate the marginal effects of regressors on income growth and the speed of convergence. Analyzing the marginal effects on income growth of both the internal and spillover effects associated to the explicative variables, it is worth noting that: Firstly, public capital has a positive impact on economic growth through spillover effects, although these effects are decreasing in magnitude, while the internal effect increases. The human capital affects negatively, but with increasing impact trends on economic growth. Furthermore, the other interesting result is that tax revenues bring a positive but decreasing effect on income growth due to internal effect, and also improve the spillover effect. Therefore, we can conclude that public policies oriented to reinforce the economic growth and regional cohesion should pay attention to public investment and expenditure in education taking into account the increasing importance of the internal effect, particularly with respect to public capital. Moreover, the spillover effects of tax revenues from neighbor provinces is increasing with respect to internal benefits, reflecting some competition between provinces to obtain resources provided by public administration.

Regarding convergence, it can be fostered by promoting investment on education given its accelerating effect on the speed of the catching-up process. Moreover, considering public policies oriented to increase public investment it is worth highlight that there is a growth rate from which improvements in investment in low income economies contribute to enhance the speed of convergence. Given this result, the better option is orienting public investment efforts on rich economies. Also, tax revenues affect cohesion positively in low income economies; on the contrary they intensify disparities in high income economies. As a result, from these analyses we conclude that fiscal policies do affect economic growth and regional cohesion in different and even opposing ways, sometimes contributing to it in a direct and indirect way, and sometimes being detrimental.

These findings have important implications for policy makers that can be qualified for low and high income regions. In fact, our results also show that it is necessary to take into account the departing income levels when determining the positive effects of public investment on economic growth and regional cohesion. While investing in human capital has positive effects across all regions, this is not the case of investment in public capital and tax revenues, where high income economies tend to benefit most from the former, and low income countries from the latter. Finally, the spatial nature of the effects should not be overlooked; for instance, the fiscal policy proxied by tax revenues, contributes to economic growth through spillover effects, which intensify competition between regions for public resources, and would allow reducing disparities reallocating the financial support from public administration to the poorest economies.

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A Taylor approximation of transitional dynamics

The log linearization of equations (5)–(7) is obtained by differentiation w.r.t each capital:

$$\frac{\partial \dot{k}_{it}}{\partial k_{it}} = s_i^K(1-\tau)\frac{\partial y_{it}}{\partial k_{it}} - (n_i+\delta)$$
$$\frac{\partial \dot{p}_{it}}{\partial p_{it}} = s_i^P\tau\frac{\partial y_{it}}{\partial p_{it}} - (n_i+\delta)$$
$$\frac{\partial \dot{h}_{it}}{\partial h_{it}} = s_i^H\tau\frac{\partial y_{it}}{\partial h_{it}} - (n_i+\delta)$$

Multiplying and dividing by the income yields:

$$\frac{\partial \dot{k}_{it}}{\partial k_{it}} = \frac{s_i^K(1-\tau)\frac{\partial y_{it}}{\partial k_{it}}y_{it}}{y_{it}} - (n_i+\delta)$$
$$\frac{\partial \dot{p}_{it}}{\partial p_{it}} = \frac{s_i^P\tau\frac{\partial y_{it}}{\partial p_{it}}y_{it}}{y_{it}} - (n_i+\delta)$$
$$\frac{\partial \dot{h}_{it}}{\partial h_{it}} = \frac{s_i^H\tau\frac{\partial y_{it}}{\partial h_{it}}y_{it}}{y_{it}} - (n_i+\delta)$$

Since in the steady state $s_i^K(1-\tau)y_{it}$, $s_i^P\tau y_{it}$, and $s_i^H\tau y_{it}$ are equal to $(n_i+g+\delta)k_{it}$, $(n_i+g+\delta)p_{it}$, and $(n_i+g+\delta)h_{it}$ respectively:

$$\frac{\partial \dot{k}_{it}}{\partial k_{it}} = \frac{(n_i+g+\delta)k_{it}\frac{\partial y_{it}}{\partial k_{it}}y_{it}}{y_{it}} - (n_i+\delta)$$
$$\frac{\partial \dot{p}_{it}}{\partial p_{it}} = \frac{(n_i+g+\delta)p_{it}\frac{\partial y_{it}}{\partial p_{it}}y_{it}}{y_{it}} - (n_i+\delta)$$
$$\frac{\partial \dot{h}_{it}}{\partial h_{it}} = \frac{(n_i+g+\delta)h_{it}\frac{\partial y_{it}}{\partial h_{it}}y_{it}}{y_{it}} - (n_i+\delta)$$

Now, taking into account that $(k_{it}\frac{\partial y_{it}}{\partial k_{it}})/y_{it} = \alpha_K+\theta$, $(p_{it}\frac{\partial y_{it}}{\partial p_{it}})/y_{it} = \alpha_P+\phi$, and $(h_{it}\frac{\partial y_{it}}{\partial h_{it}})/y_{it} = \alpha_H+\gamma$, one gets:

$$\frac{\partial \dot{k}_{it}}{\partial k_{it}} = (n_i+g+\delta)(\alpha_K+\theta) - (n_i+\delta)$$
$$\frac{\partial \dot{p}_{it}}{\partial p_{it}} = (n_i+g+\delta)(\alpha_P+\phi) - (n_i+\delta)$$
$$\frac{\partial \dot{h}_{it}}{\partial h_{it}} = (n_i+g+\delta)(\alpha_H+\gamma) - (n_i+\delta)$$

Rearranging, the following expressions are obtained:

$$\frac{\partial \dot{k}_{it}}{\partial k_{it}} = g-(1-\alpha_K-\theta)(n_i+g+\delta)$$
$$\frac{\partial \dot{p}_{it}}{\partial p_{it}} = g-(1-\alpha_P-\phi)(n_i+g+\delta)$$
$$\frac{\partial \dot{h}_{it}}{\partial h_{it}} = g-(1-\alpha_H-\gamma)(n_i+g+\delta)$$

The Taylor approximation around the steady state is obtained following these expressions:

$$f(\ln k_{it}) = f(\ln k_i^\star) + f'(\ln k_i^\star)\,[\ln k_{it} - \ln k_i^\star]$$
$$f(\ln p_{it}) = f(\ln p_i^\star) + f'(\ln p_i^\star)\,[\ln p_{it} - \ln p_i^\star]$$
$$f(\ln h_{it}) = f(\ln h_i^\star) + f'(\ln h_i^\star)\,[\ln h_{it} - \ln h_i^\star]$$

Finally, since $f(\ln k_i^\star) = f(\ln p_i^\star) = f(\ln h_i^\star) = 0$, and inserting the former expressions into the latter for the derivatives we get equations (19)–(21).

$$\frac{d\ln k_{it}}{dt} = g-(1-\alpha_K-\theta)(n_i+g+\delta)\,[\ln k_{it} - \ln k_i^\star]$$
$$\frac{d\ln p_{it}}{dt} = g-(1-\alpha_P-\phi)(n_i+g+\delta)\,[\ln p_{it} - \ln p_i^\star]$$
$$\frac{d\ln h_{it}}{dt} = g-(1-\alpha_H-\gamma)(n_i+g+\delta)\,[\ln h_{it} - \ln h_i^\star]$$

B Convergence speed

Introducing equation (27) into the production function for $i = 1, \ldots, n$ and rewriting the convergence equation (22):

$$
\begin{aligned}
\frac{d\ln y_{it}}{dt} =& (\alpha_k + \theta)\left[g - (1-\alpha_K-\theta)(n_i+g+\delta)([\ln y_{it} - \ln y_i^\star] - [\ln k_{it} - \ln k_i^\star])\right] \\
&+(\alpha_P + \phi)\left[g - (1-\alpha_P-\phi)(n_i+g+\delta)([\ln y_{it} - \ln y_i^\star] - [\ln p_{it} - \ln p_i^\star])\right] \\
&+(\alpha_H + \gamma)\left[g - (1-\alpha_H-\gamma)(n_i+g+\delta)([\ln y_{it} - \ln y_i^\star] - [\ln h_{it} - \ln h_i^\star])\right] \\
&+\theta\rho\sum_{j=1}^{n} w_{ij}\left[g - (1-\alpha_K-\theta)(n_j+g+\delta)([\ln y_{it} - \ln y_i^\star] - \left[\ln k_{jt} - \ln k_j^\star\right])\right] \\
&+\phi\rho\sum_{j=1}^{n} w_{ij}\left[g - (1-\alpha_P-\phi)(n_j+g+\delta)([\ln y_{it} - \ln y_i^\star] - \left[\ln p_{jt} - \ln p_j^\star\right])\right] \\
&+\gamma\rho\sum_{j=1}^{n} w_{ij}\left[g - (1-\alpha_H-\gamma)(n_j+g+\delta)([\ln y_{it} - \ln y_i^\star] - \left[\ln h_{jt} - \ln h_j^\star\right])\right]
\end{aligned}
$$

Following hypothesis (23)–(25) we obtain the relation:

$$
\left\{
\begin{aligned}
&\theta\rho\sum_{j=1}^{n} w_{ij}\left[g - (1-\alpha_K-\theta)(n_j+g+\delta)\left[\ln k_{jt} - \ln k_j^\star\right]\right] \\
&+\phi\rho\sum_{j=1}^{n} w_{ij}\left[g - (1-\alpha_P-\phi)(n_j+g+\delta)\left[\ln p_{jt} - \ln p_j^\star\right]\right] \\
&+\gamma\rho\sum_{j=1}^{n} w_{ij}\left[g - (1-\alpha_H-\gamma)(n_j+g+\delta)\left[\ln h_{jt} - \ln h_j^\star\right]\right]
\end{aligned}
\right\} =
$$

$$
= \lambda_{it}\left\{
\begin{aligned}
&(\alpha_k + \theta)\left[g - (1-\alpha_K-\theta)(n_i+g+\delta)[\ln k_{it} - \ln k_i^\star]\right] \\
&+(\alpha_P + \phi)\left[g - (1-\alpha_P-\phi)(n_i+g+\delta)[\ln p_{it} - \ln p_i^\star]\right] \\
&+(\alpha_H + \gamma)\left[g - (1-\alpha_H-\gamma)(n_i+g+\delta)[\ln h_{it} - \ln h_i^\star]\right] \\
&+\theta\rho\sum_{j=1}^{n} w_{ij}\left[g - (1-\alpha_K-\theta)(n_j+g+\delta)\left[\ln k_{jt} - \ln k_j^\star\right]\right] \\
&+\phi\rho\sum_{j=1}^{n} w_{ij}\left[g - (1-\alpha_P-\phi)(n_j+g+\delta)\left[\ln p_{jt} - \ln p_j^\star\right]\right] \\
&+\gamma\rho\sum_{j=1}^{n} w_{ij}\left[g - (1-\alpha_H-\gamma)(n_j+g+\delta)\left[\ln h_{jt} - \ln h_j^\star\right]\right]
\end{aligned}
\right\}
$$

with

$$
\Lambda_{it} = \frac{\left(\theta\rho\sum_{j=1}^{n} w_{ij}\frac{1}{\Theta} + \phi\rho\sum_{j=1}^{n} w_{ij}\frac{1}{\Phi} + \gamma\rho\sum_{j=1}^{n} w_{ij}\frac{1}{\Gamma}\right)(n_j+g+\delta)}{\left(\theta\rho\sum_{j=1}^{n} w_{ij}\frac{1}{\Theta} + \phi\rho\sum_{j=1}^{n} w_{ij}\frac{1}{\Phi} + \gamma\rho\sum_{j=1}^{n} w_{ij}\frac{1}{\Gamma}\right)}
$$

Taking this relationship and with hypothesis (26) we can simplify the convergence equation:

$$\begin{aligned}\frac{d\ln y_{it}}{dt} =& \theta\rho\sum_{j=1}^{n} w_{ij}(n_j+g+\delta)[\ln y_{jt}-\ln y_j^{\star}]+\phi\rho\sum_{j=1}^{n} w_{ij}(n_j+g+\delta)[\ln y_{jt}-\ln y_j^{\star}]+\\ &\gamma\rho\sum_{j=1}^{n} w_{ij}(n_j+g+\delta)[\ln y_{jt}-\ln y_j^{\star}]-\Lambda_{it}[\ln y_{it}-\ln y_i^{\star}]=-\lambda_{it}[\ln y_{it}-\ln y_i^{\star}]\end{aligned}$$

And then, we obtain finally the speed of convergence as:

$$\begin{aligned}\lambda_{it} =& \frac{\left(\theta\rho\sum_{j=1}^{n} w_{ij}\frac{1}{\Theta}+\phi\rho\sum_{j=1}^{n} w_{ij}\frac{1}{\Phi}+\gamma\rho\sum_{j=1}^{n} w_{ij}\frac{1}{\Gamma}\right)(n_j+g+\delta)}{\left(\theta\rho\sum_{j=1}^{n} w_{ij}\frac{1}{\Theta}+\phi\rho\sum_{j=1}^{n} w_{ij}\frac{1}{\Phi}+\gamma\rho\sum_{j=1}^{n} w_{ij}\frac{1}{\Gamma}\right)}\\ &-(\theta+\phi+\gamma)\rho\sum_{j=1}^{n} w_{ij}\frac{1}{\Psi}(n_j+g+\delta)\end{aligned}$$

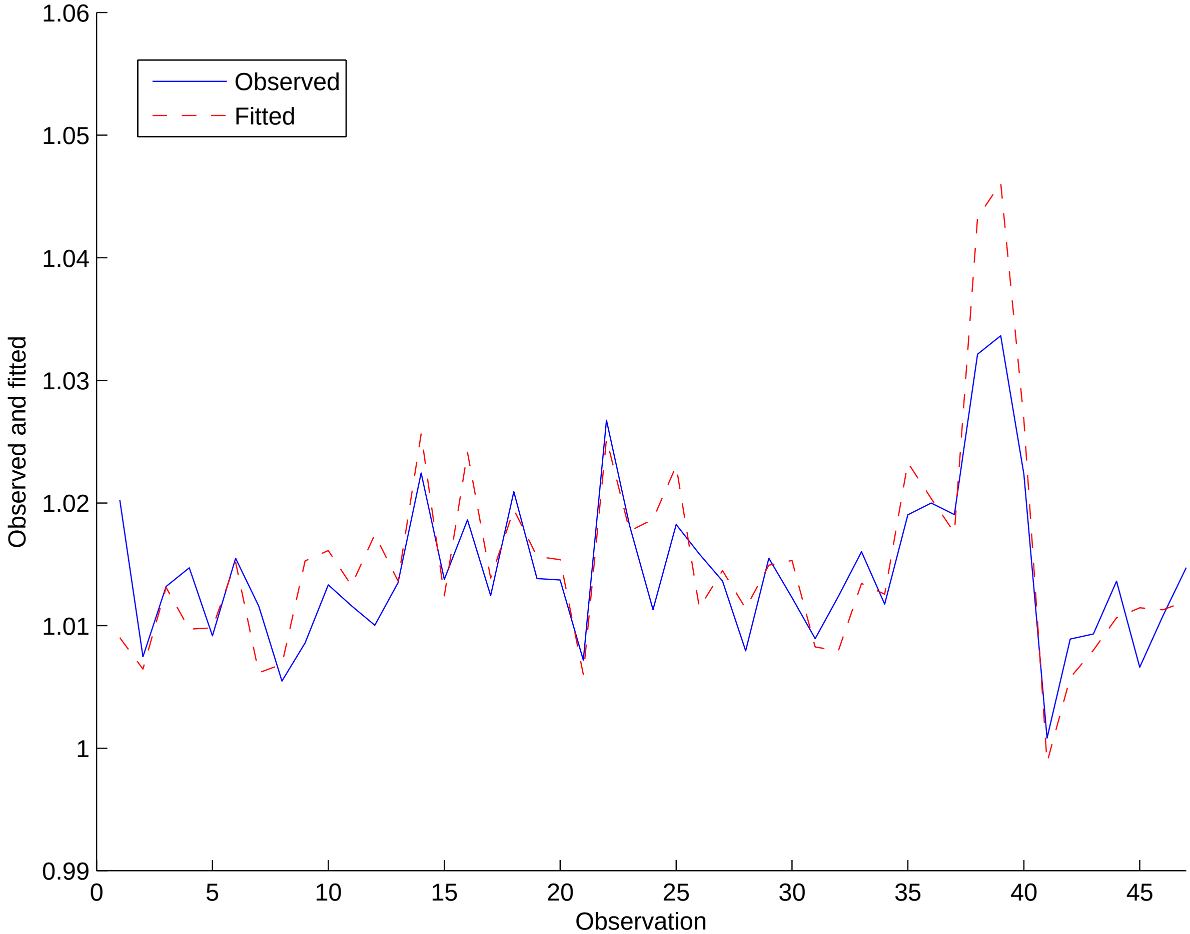
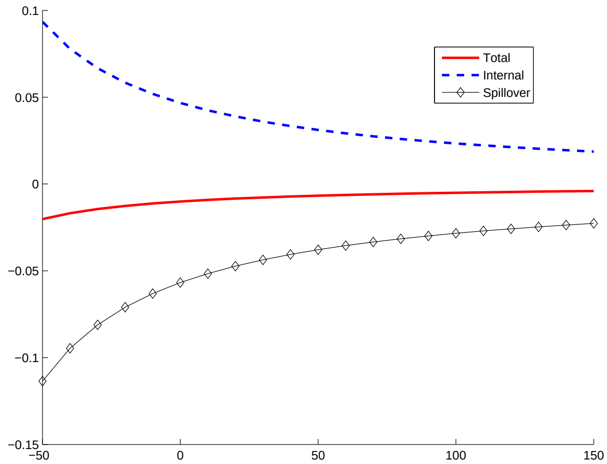
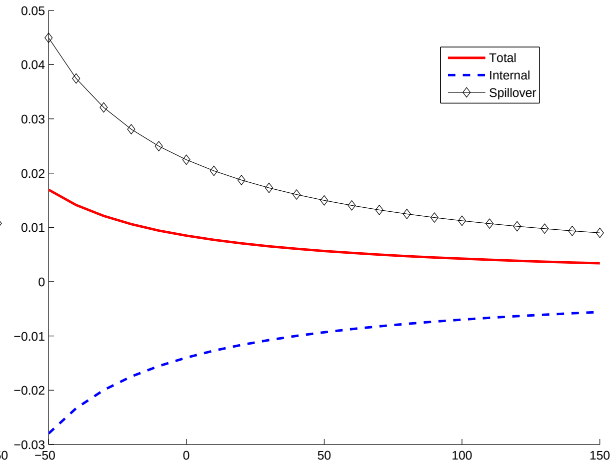


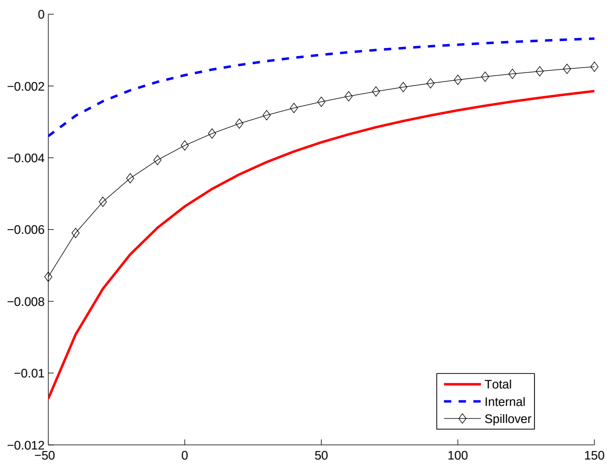
Figure 1: Observed and Fitted values



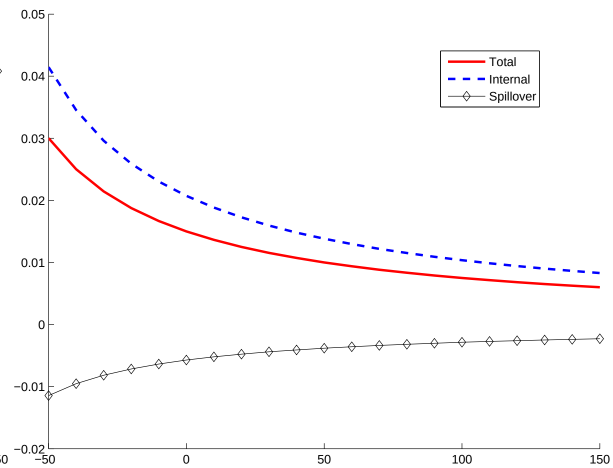
(a) Private capital



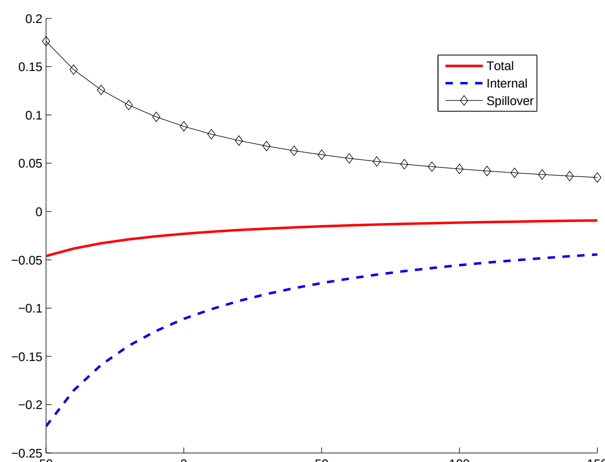
(b) Public capital



(c) Human capital

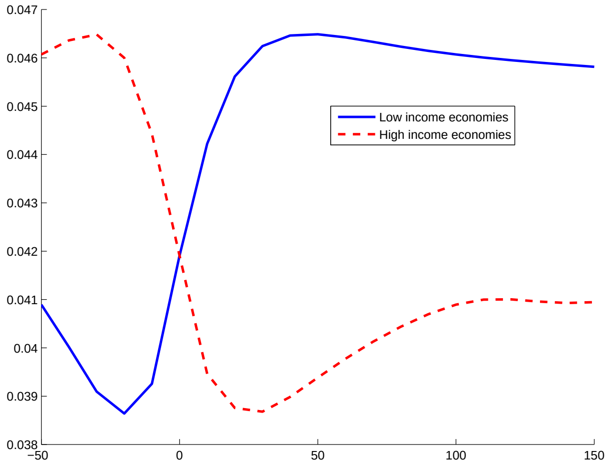


(d) Tax income

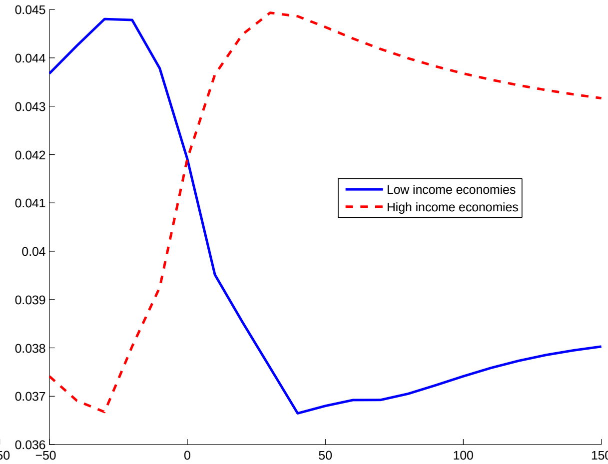


(e) Labor Growth

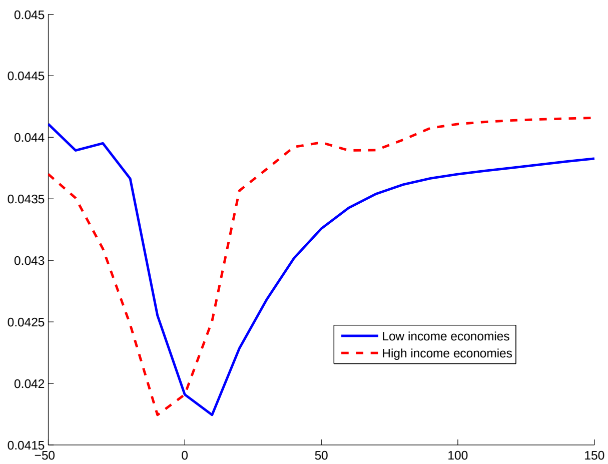
Figure 2: Marginal contribution to income per capita growth



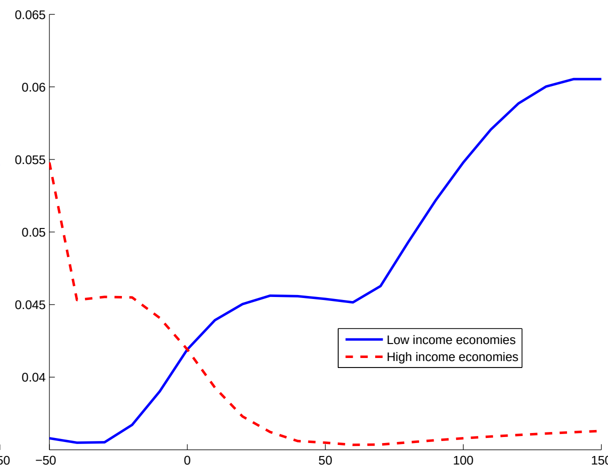
(a) Private capital



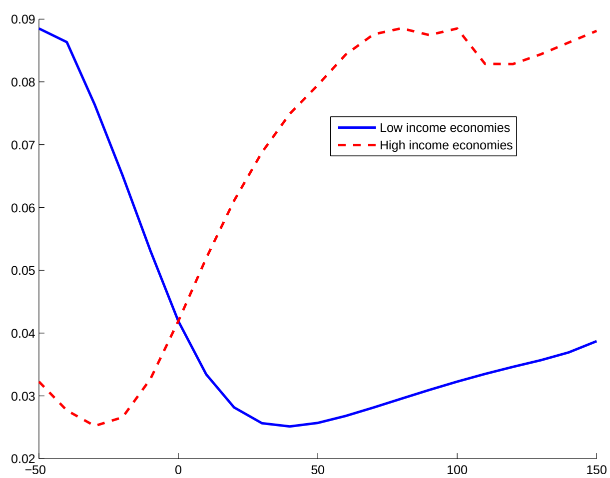
(b) Public capital



(c) Human capital



(d) Tax income



(e) Labor Growth

Figure 3: Contribution to speed of convergence