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# Grow, neighbour grow, grow... Neighbour be good!

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**38<sup>th</sup> Congress of the European Regional Science Association  
28 August-1 September 1998**

**Grow, neighbour, grow, grow...Neighbour be good!**

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**ABSTRACT:**

This paper considers the effects of externalities across neighbouring regions on economic growth. From a simple growth model that includes such externalities, we derive that they may cause endogenous growth even in the presence of decreasing returns within the regional economy. Investment rates of a region will be lower than the optimal, causing growth in the market solution to be lower than in the supra-regional solution. We have also tested for the presence of such spillovers in the Spanish regions applying spatial econometrics techniques. Furthermore, the empirical specification allows to disentangle internal from external within the region externalities using aggregate regional data.

**Keywords:** growth, externalities, technological interdependence, spatial econometrics, regions

“...technology...will be used to refer to something common to all countries, something *pure* or *disembodied*, something whose determinants are outside the bound of our current inquiry.” Lucas (1988)

## 1. INTRODUCTION

Recent theoretical models have emphasized the role of external effects in the accumulation of factors of production in explaining economic growth (Romer 1986 and 1990; Lucas 1988). The increase in the stock of (broadly speaking) capital causes an improvement in the technology level that cannot be fully appropriated by the agent that makes the investment. As a result, the aggregate (social) return of the investment is larger than the return obtained by the individual agent (private return). The assumption is that knowledge spills over across the entire economy, therefore affecting each firm’s technology level.

This paper shares the idea about the relevance of these external effects. However, we consider that these externalities cross the barriers of regional economies belonging to the same economic area. This is in line with the idea of interactions across economies in Lucas (1993): when there are cross-economy spillovers in accumulating human capital, all economies will converge to the same steady state whatever their initial conditions. However, this prediction seems to be at odds with empirical evidence. Then, we will assume that externalities do not spread out in the space without bounds. On the contrary, diffusion of innovations will be easier within groups (clubs) of closed economies. That is, we agree with the point in Durlauf and Quah (1998): *“It is easy to see that if we allowed natural groupings of economies to form, so that economies within a group interact more with each other than with those outside, then the “average” H (in their case human capital) that they converge to will, in general, vary across groups.”*

The literature has recently stated the relationship between growth and trade, where trade would be the main channel for diffusion of technology (Grossman and Helpman 1991; Coe and Helpman 1995). Keller (1997) has empirically cast doubt on this point

for the case of national economies, that is, there could exist some other channels by which innovations *travel* from one economy to the others.

In the case of regional economies within an integrated area, we may think of the role of trade and the other channels as being more intense. Forward and backward linkages across regional economies seem to be more important than those across countries. The case for common markets of inputs and output is more likely in the cross-regional than in the cross-national case as well. As far as these factors may contribute to the diffusion of knowledge (technological and pecuniary externalities), spillovers could be stronger across regions than across countries.<sup>i</sup>

It is not necessary to carry out a deep economic analysis to realize that economic activity and welfare are not equally or randomly distributed in the geographical space. The observation of a map of the world displaying the levels of product per capita in each country clearly shows clusters of countries in specific areas characterized by high or low levels. We can also observe this picture for the case of regions within a specific economy; for instance the NUTS regions in the European Union or the states in the USA. Actually, this fact can also be observed in the case of more reduced national economies (as for instance the case of the North-South duality in Italy or Spain).

This evidence can be explained by spatial correlation in the investment rates but also by spatial correlation in the average level of technology of each economy. In the first case similarities in saving rates and other preference parameters may mostly explain the correlation. In the case of technology, the higher intensity in knowledge diffusion across neighbouring economies will be the main assumption of this paper.

Some of the questions that we would like to answer at the end of the paper are:

- \* Is it worth considering externalities across regional economies?
- \* What is the role of these externalities in explaining growth and convergence?
- \* May across-regions externalities help explaining features such as persistence in the inequality of the levels of economic development among regions located in different territories or *poverty traps* linked to geographical location?

To achieve this objective, the paper is organised as follows. In section 2 an assessment of the importance of aggregate regional spillovers is carried out. The empirical evidence shows how they are at least as important as cross-industry externalities and how links among (neighbouring) regional economies may explain an important amount of inequality in the regional income per capita distribution. Section 3 presents a simple growth model in which diffusion of knowledge, as a result of investment in capital, is not confined to the limits of the economy in which the innovation is generated but spills over into the neighbouring economies. As a result, the rate of growth of an economy will be a function of the investment, and therefore of the level of technology, of its neighbours. The mechanism could be strong enough to generate endogenous growth and shows the relevance of having what we could qualify as *good neighbours*.

In section 4, an empirical model that allows to measure and test the significance of regional spillovers is formulated. Besides, it permits the identification of the private return and the externalities in the accumulation of factors (physical and human capital) within an economy from regional aggregated data. Section 5 describes the proposal of applying spatial econometric techniques to consider empirically regional externalities, while the following shows the empirical evidence for the Spanish regions in the period 1964-1991. Finally, section 7 concludes.

## 2. REGIONAL EXTERNALITIES: ARE THEY IMPORTANT?

Marshall (1920) formulated the distinction between internal and external returns. The story is one of increasing returns that are external to the firm but internal to the industry as a whole. The inclusion of aggregate knowledge as an input to production may provoke non-convexity, leading to long-run growth and lack of tendency towards convergence in factors intensity and income levels across economies (Romer 1986 and 1990; Lucas 1988; Grossman and Helpman 1991; Jones 1995). The assumption of incomplete appropriation of ideas or innovations is the foundation for the consideration of aggregate knowledge in firm's technology. New bits of knowledge spill over into other firms in the economy, increasing their own technology level. Azariadis and Drazen (1990) have emphasized the role of the interaction between

private or individual knowledge and aggregate knowledge; returns of additional bits of private knowledge would be higher for a large enough level of aggregate knowledge.

Besides knowledge spillovers, marshallian externalities could arise due to other reasons. This would be linked to the existence of both a specialised market for labour and output, and of forward and backward linkages. These have been considered as pecuniary externalities (as opposed to technological externalities) by Scitovsky (1954) and incorporated in the new theories of industrial location and trade as engines for agglomeration (Krugman 1991; Krugman and Venables 1995; Puga and Venables 1996; Venables, 1996).

An interesting question is what the geographical boundaries for these externalities are. Henderson (1992) and Glaeser *et al* (1992) outline the importance of proximity for sharing innovations. De Lucio (1997) argues that generation of new ideas and diffusion of technology is more likely in urban agglomerations. He also shows the significance of the degree of urbanization in explaining growth of product per capita for a wide sample of countries.

However, despite agreeing with urban agglomerations as being *fountains* for new ideas and innovations, it is sensible thinking of external effects crossing from one city to the others of, at least, an integrated economy. The role of distance could be more important for pecuniary externalities than for technological diffusion, because neighbours may take advantage of contiguity to a *saturated* economy. That is, it could be profitable for some of the suppliers to be located in a neighbouring region with a lower degree of agglomeration, and still take advantage of proximity (Puga and Venables, 1996). Contiguous regions may also share the labour market and the market for final goods.

Coe and Helpman (1995) showed the relevance of international spillovers in R+D investments to growth. Knowledge from R+D investments is embodied in traded goods. Thus trade partners of a country take profit of innovations in this country.<sup>ii</sup> Helpman (1997) summarizes the channels through which the technology levels of different economies are interrelated: “*The theory thus suggests two broad ways in*

*which trade and (foreign direct) investment contribute to total factor productivity: by making available products and services that embody foreign knowledge, and by providing foreign technologies and other types of knowledge that would otherwise be unavailable or very costly to acquire” (pg 5).*

In the case of regional economies, externalities linked to the diffusion of knowledge may be even more important than in the case of countries. This would be true for the trade-channel as well as for other possible channels. As an example, in a national economy, a small number of regions may concentrate most of the laboratories and centres of R+D, although the result of the research can be applied by different firms located in some other regions. Furthermore, in the case of public R+D centres the administration will be interested in spreading out the results to the entire territory and not to be confined to the firms located in that particular region.

Technology diffusion, further, is likely to be higher across close regions. Relative amounts of traded goods could be higher in this case than among regions very far away from each other. Furthermore, *local social conditions* play an important role in the way in which each economy incorporates and adapts ongoing innovations (Rodríguez-Pose, 1998). When contiguous or close economies share similar *local conditions*, transfers of technology among neighbouring regions could be more intense.

Several works, starting from the seminal one by Caballero and Lyons (1990), have tried to test empirically the existence and size of technological spillovers across industries within an economy. One of the practical implications of this kind of works is that, not properly specified, external economies may bias the estimated internal returns to scale. Nevertheless, most of the empirical models on growth that have used data for national or regional economies have given no space to spillovers across those economies.<sup>iii</sup> This could be justified if there existed externalities across industries within an economy but not across economies. Costello (1993) showed how total factors productivity growth is more correlated across industries within one country than across countries within one industry. However, Kollmann (1995) observed that productivity growth is more strongly correlated across the regions of the USA than

across the G7 countries. Moreover, correlations across industries within a region are weaker than across regions within an industry.

Tables 1 and 2 summarize correlations across regions and across industries for the Spanish regions and manufactures. The upper triangle of each table shows the results for the growth of Solow residuals, while those for the growth of gross value added are in the lower triangle. From these results, across-regional correlations seem to be as strong as across-industry correlations. In the case of total factor productivity this result supports the relevance of transfers of technology across regions. The larger integration of the regions, in this case of Spain, would explain why technological innovations spread more intensely than across heterogeneous countries.

More evidence on the relevance of regional spillovers is given in Quah (1996) and in López-Bazo et al (1998). Quah shows how, once conditioned to the levels in the neighbouring regions, the distribution of the product per capita in the regions of the EU would be more strongly concentrated than the real distribution. In the second work, the authors obtain strong spatial correlation among contiguous regions in the EU, detecting significant spatial clusters of regions showing values above and behind the average.

Summing up, theoretically as well as empirically, it seems to exist evidence on the relevance of external economies that cross the weak and sometimes artificial regional boundaries.

### 3. A SIMPLE GROWTH MODEL WITH REGIONAL EXTERNALITIES

In this section we describe a simple model of growth in which externalities arising from the increase in the level of technology in the neighbouring regions are considered. The model shows that the stock of accumulative factors in the neighbours may affect both the steady-state and the growth rate of an economy. It also may explain non decreasing returns and therefore endogenous growth depending on the strength of regional spillovers.



The model is based on two key assumptions: 1) there are externalities due to the accumulation of capital within a regional economy, and 2) there are also externalities due to the aggregate level of technology of the neighbours (that are linked to their capital stock as well).

We consider a simple economy in which the (average) labour productivity in region  $i$  in period  $t$ ,  $y_{it}$ , is a function of a vector of accumulative factors per worker which will be synthesized in  $k_{it}$  (for instance physical or human capital), and the state of the technology,  $A_{it}$ :

$$y_{it} = A_{it} k_{it}^{\alpha} \quad (1)$$

with decreasing returns in factors accumulation ( $\alpha < 1$ ).

Following the reasoning in Romer (1986) and Lucas (1988), the aggregate level of technology is a function of the aggregate level of  $k^{iv}$ . Moreover, we introduce the assumption that innovations/ideas (linked to investments in  $k$ ) can *flow* between economies, that is, there exists technological interdependence between regional economies. Therefore:

$$A_{it} = \Delta_t k_{it}^{\delta} k_{pit}^{\gamma} \quad (2)$$

where  $\Delta_t$  is a component of the technology that grows exogenously at a rate  $g^v$ ,  $\delta$  is the measure of the degree of external returns to  $k$  within the region and  $k_{pit}$  is the amount of capital per worker in the neighbours to region  $i$ .  $\gamma$  is the measure of the regional spillover effect that is supposed to be positive: when  $k_{pit}$  increases by 1% (causing an increase in the technology of those regions), technology in region  $i$  will increase by  $\gamma\%$ .

Obviously, when  $\delta = \gamma = 0$  and  $\alpha < 1$  we are facing the traditional Solow-Swan production specification, whereas the Romer-Lucas specification with (general) external effects will be represented by  $\delta > 0$  and  $\gamma = 0$ .

Substituting (2) on (1):

$$y_{it} = \Delta_t k_{it}^{\tau} k_{pit}^{\gamma} \quad (3)$$

where  $\tau=\alpha+\delta$ . When a regional economy increases its factors intensity it gets a return of  $\tau$ . If its neighbours increase simultaneously their intensity as well, there will be a spillover effect that will go up to  $\tau+\gamma$  returns in region  $i$ . Productivity in region  $i$  will also increase with  $k_{pi}$  even in the case of no further investments in  $k_i$ . This is because of the technology diffusion from the neighbours which makes the stock of capital in region  $i$  more productive.

The growth rate of  $k_i$  will be:

$$\frac{\dot{k}_i}{k_i} = \Delta k_i^{\tau-1} k_{pi}^{\gamma} - \frac{c_i}{k_i} - (d+n) \quad (4)$$

where  $c_i$  is consumption per capita in region  $i$  and  $d+n$  the effective rate of depreciation (temporal subindexes are omitted for simplicity in the notation). The rate of investment in  $k_i$  is a decreasing function of its stock in the case of decreasing returns within the region ( $\tau < 1$ ), while it is an increasing function of the stock in the neighbours. This means that investments in productive factors will be larger in those regions placed in areas with high stocks of these factors, because externalities across those regions will increase the returns of these investments. On the contrary, incentives to invest will be lower in a region *surrounded* by others with low capital intensity.

Considering this technology we can solve the representative agent's optimization problem to obtain the optimal growth path for the regional economy:

$$\begin{aligned} \max U &= \int_0^{\infty} e^{-(\varphi-n)t} \left( \frac{c_i^{1-\sigma} - 1}{1-\sigma} \right) dt \\ \text{subject to } \dot{k}_i &= \Delta k_i^{\tau} k_{pi}^{\gamma} - c_i - (d+n)k_i \end{aligned} \quad (5)$$

where  $\varphi > 0$  is the time preference parameter,  $n$  the growth rate of population ( $\varphi > n$ ) and  $\sigma > 0$  the risk aversion.

The Hamiltonian in this case is:

$$H = e^{-(\varphi-n)t} \left( \frac{c_i^{1-\sigma} - 1}{1-\sigma} \right) + v(\Delta k_{pi}^\tau k_{pi}^\gamma - c_i - (d+n)k_i) \quad (6)$$

and the first order conditions for solving this problem are:

$$\begin{aligned} \frac{dH}{dc_i} = 0 &\rightarrow v = e^{-(\varphi-n)t} c_i^{-\sigma} \\ \dot{v} = -\frac{dH}{dk_i} &\rightarrow \dot{v} = -v(\tau\Delta k_i^{\tau-1} k_{pi}^\gamma - (d+n)) \\ \lim_{t \rightarrow \infty} v_t k_{it} &= 0 \quad (\text{transversality condition}) \end{aligned} \quad (7)$$

The solution of this system gives the optimal growth rate of per capita consumption:

$$g_c = \frac{\dot{c}_i}{c_i} = 1/\sigma (\tau\Delta k_i^{\tau-1} k_{pi}^\gamma - \varphi - d) \quad (8)$$

As a general result in the case of this family of models:  $g_c = g_k = g_y$ , so that, as shown previously in (4), the growth rate of region  $i$  is a function of the stock of productive factors in its neighbours. In equilibrium we can assume capital intensity to be equal in all regional economies,  $k_i = k \forall i$ :

$$g_c = \frac{\dot{c}}{c} = 1/\sigma (\tau\Delta k^{(\tau+\gamma)-1} - \varphi - d) \quad (9)$$

When  $\tau+\gamma < 1$ , that is, when there are global decreasing returns to capital accumulation,  $g_c = g_y = 0$  at the steady-state. Hence, from (9) we obtain the steady-state capital intensity:

$$k^* = \left( \frac{\tau\Delta}{\varphi + d} \right)^{1/(1-(\tau+\gamma))} \quad (10)$$

It depends on the usual technological and preference parameters and on the strength of regional externalities. The stronger the regional interdependence, the higher the stock of capital per worker. In this case, all regions share a common steady state because returns to investment in a group of neighbours is globally a decreasing function of the average intensity in this group. Therefore, per capita product will equalize within groups and across groups in the equilibrium.

In the case of total constant returns,  $\tau+\gamma=1$ , we face the constant growth rate of the AK models:

$$\frac{\dot{c}}{c} = 1/\sigma (\tau\Delta - \varphi - d) \quad (11)$$

In this case externalities across regions increase investment returns within a region towards the threshold of endogenous growth, despite decreasing returns of the accumulated factors at the regional level. Regional economies grow at a constant rate in the steady-state, so that the gap in product per capita will remain constant as well. When regional externalities are strong enough to cause  $\tau+\gamma>1$ , growth rates are increasing in  $k$  and the gap will diverge without bound.

### *Supra-regional solution*

We have described above some characteristics of this simple growth model with regional externalities. It is well known that externalities cause a non-optimal solution due to the fact that agents are not able to fully appropriate the returns of the investment. This is the situation in the Romer-Lucas kinds of models. In our case, a *supra-regional* agent would consider that an increase in  $k$  in region  $i$  will increase technology both in region  $i$  and in its neighbours. Therefore this agent will face the following optimization problem:

$$\begin{aligned} \max U &= \int_0^{\infty} e^{-(\varphi-n)t} \left( \frac{c^{1-\sigma} - 1}{1-\sigma} \right) dt \\ \text{subject to } \dot{k} &= \Delta k^{\tau+\gamma} - c - (d+n)k \end{aligned} \quad (12)$$

That is, she will consider the average  $k$  instead of just the one in a single region. The Hamiltonian in this case is:

$$H = e^{-(\varphi-n)t} \left( \frac{c^{1-\sigma} - 1}{1-\sigma} \right) + v(\Delta k^{\tau+\gamma} - c - (d+n)k) \quad (13)$$

The solution of the system from the first order conditions gives the optimal *supra-regional* growth rate of per capita consumption:

$$g_c(sr) = \frac{\dot{c}}{c} = 1/\sigma((\tau+\gamma)\Delta k^{(\tau+\gamma)-1} - \varphi - d) \quad (14)$$

Given that  $\gamma>0$ , comparing (14) with (9),  $g_c < g_c(sr)$ , that is, the *market solution* will be sub-optimal. Therefore, we can say that a region invests at a lower rate than the optimal for the set of the regional economies, given that it is just considering the return within the region. On the other hand, a *supra-regional* agent will select a higher investment rate because it will consider that an additional unit of investment increases the aggregate level of technology, increasing thus the one in its neighbours. Here we

can, for instance, think of the role of investments in human capital, R+D or public infrastructures. This result would justify the existence of supra-agencies for spurring regional investment.

### *Regional Poverty Traps*

Murphy et al (1989) and Azariadis and Drazen (1990) showed that the return of an investment made by an agent may be highly affected by the aggregate stock in the economy. In the case of industrialization, “...*coordinated investment across sectors leads to the expansion of markets for all industrial goods and can thus be self-sustaining even when no firm can break even investing alone*” (Murphy et al, 1989, pg 1005). In the case of, let’s say, investment in human capital by an agent, additional amounts will be more productive when the aggregate level in the economy is high, whereas they may cause no effect for very low levels.<sup>vi</sup>

In a similar way, we think that across regional externalities may help explaining spatial clusters of regions sharing high or low levels of development. That is, in the latter case, the existence of a *poverty trap* due to geographical location.

Let’s assume two groups of regional economies: regions in group A characterized by low levels of  $k$ , and regions in group B with high levels of  $k$ . Regions within each group share a common geographical space. From (8),  $g_c^A = g_k^A = g_y^A < g_c^B = g_k^B = g_y^B$ , that is, regions surrounded by other regions with high capital intensity and high product per capita will have higher steady-state values (in the case of decreasing returns within the region) or higher growth rates (in the case of non decreasing returns within the region).

Figure 1 describes the rates of growth for regions in each group when  $\tau=1$ . In this case economies grow at a constant rate in the steady state given the values for  $\Delta$  and  $k_{p,i}$ . Given the same  $\Delta$  for all the economies,  $1/\sigma(\Delta k_{p,i}^\gamma)$  will be higher in B, thus  $g_k^A < g_k^B$ . Regions in group B will grow faster than regions in A just because they are close to regions with high  $k$ . In this case, continuous polarisation in two groups will emerge, with constant inequality within each group.

When there are decreasing returns to capital factors within the region,  $\tau < 1$ , the story is described by Figure 2.<sup>vii</sup> In the proximities of  $k_A^*$ , decreasing returns operate. However, from  $x$  the externality due to capital in the neighbours more than compensates decreasing returns to the own stock, forcing an upward sloping curve. In any case, the steady state is given by  $k_A^*$  for such levels of  $k$ . Once the threshold level  $k_m$  is reached, the economy converges to an upper steady state, characterized by  $k_B^*$ . For the group of regions with high level of  $k$ , the regional spillover ( $\gamma$ ) may or may not compensate the mechanism for internal decreasing returns for values of  $k$  beyond  $z$ . In the former case (dashed line), constant growth would characterize regions in B, while in the latter the steady state will be determined by  $k_B^*$ . Figure 3 summarizes the evolution of product per capita for each one of the cases.<sup>viii</sup>

Therefore, as a consequence of the interdependence between neighbouring regions, a situation with two (or more) separate spatial clusters may emerge. A group of regional economies characterized by low endowment of factors that are not able to leave each one alone the gravity attraction of the group and another group with high endowments that can even show long run per capita growth.

The fundamental question at this point will be how can a regional economy get out of this poverty trap?. It is obvious that the effort needed to escape will be lower when their neighbours are simultaneously investing. If they are not, the individual effort could be useless.

An important point in this analysis is the one of the break point in the space. That is, why does not technological diffusion span to all regions or what is the origin of nonconvexities that generate multiple steady states associated to different spatial locations?. Following the idea of threshold externalities in Azariadis and Drazen (1990), the spillover measure,  $\gamma$ , may be different across the two groups in our previous example, tending to zero in the case of regions in one group with regions in the other. Another possibility will be in line with the idea in Leung and Quah (1996) and Quah (1997). Natural grouping of economies emerges when economies within a

group interact more with each other than with others in other groups. The result is convergence toward a similar steady state of the members of each group although the steady state varies across groups.

Rodríguez-Pose (1998) discusses the receptivity or aversity to incorporate and to adapt innovations from other economies. Even in a world with no barriers or frictions to the diffusion of technology, economies will diverge in their ability to appropriate these innovations. If we just think that neighbouring regions share similar social, cultural and economic characteristics, diffusion and appropriation of innovations will be more intense among them than in the case of regions in different *spaces*.

#### 4. EMPIRICAL MODEL

The empirical model that will be estimated in this paper is based on equations (1) and (2). Specifically, and following Barro and Sala-i-Martin (1991) and Mankiw, Romer and Weil (1992), we include in the production function both physical and human capital:

$$y_{it} = A_{it} k_{it}^{\theta_k} h_{it}^{\theta_h} \quad (15)$$

being  $k_{it}$  and  $h_{it}$  physical and human capital per worker respectively, and  $\theta_i$  ( $i=k,h$ ) the measure of internal returns at the firm level. As exposed above,  $A_{it}$  is partially endogenous in this model, reflecting both an externality within the region  $i$  of accumulation in  $k$  and  $h$ , and the technological interdependence across neighbouring regional economies. Then:

$$A_{it} = \Delta_t k_{it}^{\delta_k} h_{it}^{\delta_h} A_{pit}^\gamma \quad (16)$$

where  $\Delta_t$  collects the state of technology generated exogenously and  $\delta_i$  ( $i=k,h$ ) are the measure of external returns within the region to physical and human capital (caused by the effects of the accumulation of these factors in each region).  $A_{pit}$  is total factors productivity of the neighbours to region  $i$ , collecting the process of diffusion of ideas and innovations across close regions, being  $\gamma$  the intensity of these interdependences.

From (15) we can rewrite  $A_{pit}$  as:

$$A_{pit} = \frac{y_{pit}}{k_{pit}^{\theta_k} h_{pit}^{\theta_h}} \quad (17)$$

Then, substituting (16) and (17) into (15), the final expression for the production function is, after log-linearization:<sup>ix</sup>

$$\ln y_{it} = \ln \Delta_t + (\theta_k + \delta_k) \ln k_{it} + (\theta_h + \delta_h) \ln h_{it} + \gamma (\ln y_{pit} - \theta_k \ln k_{pit} - \theta_h \ln h_{pit}) \quad (18)$$

As we can see from (18),  $(\theta_k + \delta_k)$  and  $(\theta_h + \delta_h)$  capture the strength of total (internal plus external within the region) returns to physical and human capital associated with the stock of domestic factors. But we can actually get an estimation of the internal returns  $(\theta_i)$  from the parameters associated to factors in the neighbours. In this way we will be able to get an estimation of internal returns to physical and human capital, *social* returns within the region (or externalities within the regional economy),  $\delta_i$ , and the spillover or across-regions externalities parameter  $(\gamma)$ . As has been noted by Ciccone (1997), all of these can be obtained by using aggregated regional or national data.

Moreover, it is noteworthy that, in order to simplify the final specification, the same value for the internal and external returns is assumed for all regions, as well as the same intensity for the across-regions spillover. In this sense, it is sensible thinking that, depending on the characteristics of each region, the effect of factors accumulation in the neighbouring regions could be different. For example, Coe and Helpman (1995) show that the effects of foreign R+D on domestic productivity are stronger the more open the economy is to foreign trade. So, in small economies the elasticity is larger with respect to the foreign R+D capital stock (the reverse applies in large economies). In the same way, Kubo (1995) theoretically specifies different parameters for internal returns and for regional externalities for two different regions, studying the consequences on regional development depending on which parameter is higher in each region.

Finally, it is necessary to point out two questions regarding expression (18). Firstly, we will relax the assumption of a common  $\Delta_t$  for all the economies in the sample. As pointed out by Islam (1995), even assuming equal growth in technology, its initial level may differ across economies if it reflects not just technology but resource endowments, climate, institutions etc. Secondly, we assume that innovations instantaneously spill over across economies, that is, the specification does not include



a dynamical process of technological diffusion. This would be a restrictive assumption when innovations spread quickly within the territory of the economy where the innovation has been generated, but only a fraction in each time period spills over into other economies or there is a lag in this process.

## 5. SPATIAL ECONOMETRICS: A PROPOSAL FOR CONSIDERING REGIONAL EXTERNALITIES

From expression (18) two relevant points must be noted. First, we are considering the same production function for all regions. However, it may exist differences across them, specially in the exogenous technological parameter. Considering this fact, rewrite  $\ln \Delta_t$  as follows:

$$\ln \Delta_t = \ln(\Delta_{0i} e^{g(t)}) = \ln \Delta_{0i} + g(t) \quad (19)$$

In this way,  $\ln \Delta_{0i}$  is allowed to be different for each region, while  $g(t)$  summarizes the exogenous rate of technological change. As stated above, and following Mankiw et al (1992) and Islam (1995),  $\Delta_{0i}$  would be reflecting initial differences not only in technology but also in resource endowments, climate and institutional conditions. Given that in our empirical exercise we deal with a pool of data, we will implement a panel data approach to consider these differences in the form of unobservable individual effects. So, as Islam (1995) notes, the omitted variable bias, due to the likely correlation among  $\ln \Delta_{0i}$  and the included explanatory variables, could be avoided. Regarding the  $g(t)$  component, we can either include a trend as a regressor or time dummies. In the latter case, a common cyclical behaviour for the regions will be, in some sense, considered.<sup>x</sup>

The second point that is noteworthy from expression (18) is its similarities with the habitual specifications used in Spatial Econometrics.<sup>xi</sup> It allows us to use the concept of spatial dependence (or spatial autocorrelation)<sup>xii</sup> in order to test for the presence of regional externalities in the production function. Specifically, equation (18) could be rewritten as (including an error term):

$$\ln y = \ln A + (\theta_k + \delta_k) \ln k + (\theta_h + \delta_h) \ln h + \gamma(W \ln y - \theta_k W \ln k - \theta_h W \ln h) + u \quad (18')$$

where a bold character represents a vector  $(N \times T) \times 1$  with the information for each region ( $n=1, \dots, N$ ) and time period ( $t=1, \dots, T$ ).  $\mathbf{Wlny}$ ,  $\mathbf{Wlnk}$  and  $\mathbf{Wlnh}$  are respectively the spatial lags for labor productivity and physical and human capital per worker. In our specific case,  $\mathbf{W}$  is a  $(N \times T) \times (N \times T)$  block diagonal matrix:

$$\mathbf{W} = \begin{pmatrix} \mathbf{C}_1 & \mathbf{0} & \mathbf{0} & \cdot & \mathbf{0} \\ \mathbf{0} & \mathbf{C}_2 & \mathbf{0} & \cdot & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{C}_3 & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \cdot & \mathbf{C}_T \end{pmatrix} \quad (20)$$

being  $\mathbf{O}$  a  $(N \times N)$  matrix of zeros and  $\mathbf{C}_t$  ( $t=1, 2, \dots, T$ ) a  $(N \times N)$  matrix of weights, where each element  $c_{ij,t}$  is defined as:

$$c_{ij,t} = \frac{P_{jt} S_{ij}}{\sum_{j=1}^N P_{jt} S_{ij}} \quad (21)$$

$P_{jt}$  is the employed population in region  $j$  in period  $t$  and  $S_{ij}$  a contiguity factor that equals 1 when  $i$  and  $j$  are neighbours and 0 otherwise. Expression (20) implies that only contemporaneous spatial dependence is considered, that is, spatial dependence between different periods is supposed to be zero. In this way, interdependencies across regions are considered by including a weighted average of the value of labor productivity and physical and human capital in the neighbouring regions. In addition, it is interesting to note that the omission of a significative spatial lag of any variable would lead to the presence of spatially correlated residuals (substantive spatial dependence).

Moreover, it could be possible that the spatial autocorrelation was just present in the error term as a consequence of the existence of spatial dependence among some variables included on it or a poor matching between natural and administrative boundaries of the analysed spatial units (spatial dependence as a nuisance). In this second case, the correct specification for the production function would be:

$$\ln \mathbf{y} = \ln \mathbf{A} + (\theta_k + \delta_k) \ln \mathbf{k} + (\theta_h + \delta_h) \ln \mathbf{h} + \mathbf{u} \quad (22)$$

$$\mathbf{u} = \lambda \mathbf{W}\mathbf{u} + \mathbf{e} \quad \mathbf{e} \sim N(0, \sigma^2 \mathbf{I})$$

that includes a spatial autoregressive structure in the error term, being  $\lambda$  the spatial autoregressive parameter. It measures the intensity of interdependencies across the residuals. In this sense, it is necessary to point out that the omission of a significant scheme of residual spatial autocorrelation has important consequences to the least squares estimation: inefficient estimators, biased estimation of the residual variance, inflated values for the  $R^2$  and the invalidation of the habitual inference procedures.

Taking into account these ideas and in order to check if regional externalities are empirically significant in the production function, we adopt the strategy proposed for this case in Vayá et al (1998):<sup>xiii</sup>

- Firstly, start estimating the habitual production function, without lags of the endogenous and exogenous variables, by the appropriate panel estimation technique (pool, fixed or random regional and/or time effects). A Hausman test and the significance of the effects will be the criteria for the choice.
- Secondly, we compute for the appropriate model before, a) the LM-err (Burrige, 1980) and the LM-EL (Bera and Yoon, 1992) statistics, and b) the LM-lag (Anselin, 1988b) and LM-LE (Bera and Yoon, 1992), in order to test for the null hypothesis of respectively no residual and no substantive spatial autocorrelation.<sup>xiv</sup>

Then,

- if both groups of tests lead to the non rejection of the null hypothesis, we will assume the non existence of regional externalities in the production function;
- if just the tests of substantive spatial autocorrelation were significant or if both groups were significant but the probability value for the former group was higher, it would be necessary to introduce a spatial lag of the labor productivity ( $\mathbf{W} \mathbf{lny}$ ), using the spatial maximum likelihood estimator (ML) instead of the

LS estimator.<sup>xv</sup> Next, a spatial lag for physical and human capital per worker could be included, checking their significance by means of the LR-test. Finally, in the case that these lags were jointly significant and there were no evidence of residual spatial autocorrelation in the last model, (18') would be the correct production function, confirming the relevance of the technological interdependence among neighbouring regions;

-if only the residual autocorrelation tests were significant or, in the case that both groups were significant but the probability of the tests in the former group was higher,<sup>xvi</sup> we would estimate (22) by ML.<sup>xvii</sup> At this point, if there is no evidence of substantive spatial dependence, we must conclude on the absence of any external effect in the variables included in the production function, although the spatial correlation in the residuals advises on the existence of other sources of spatial dependence.

## 6. EMPIRICAL EVIDENCE

### *Data*

We have estimated a production function considering the likely existence of regional spillovers using data for the Spanish regions (NUTII classification) for the period 1964-1991. Data have been obtained from three sources. First, gross value added in constant pesetas and the number of employed population from the periodical publication *Renta Nacional de España y su distribución provincial*, published by Banco Bilbao-Vizcaya. The net stock of privately held physical capital comes from Fundación BBV (1996). It is measured in constant pesetas. Finally, human capital is approached by the fraction of the employed population which has at least started secondary schooling. They include, thus, workers that have started higher studies. This information is from Mas et al (1995).

Given that the first source publishes the data every two years (excluding 1964 and 1967), we have information for 14 periods. Then, we deal with a panel of 17 regions and 14 time periods. This will allow us to consider unobservable regional and time effects. The variables for the neighbours of each region has been computed by

multiplying a  $(17 \times 14) \times (17 \times 14)$  weighted contact matrix  $W$  to the variables in the model, as described above.

### *Results*

The results for our empirical exercise are summarized in table 3. We have followed the strategy described in the previous section, considering the empirical model with across-regions externalities as well.

Results for the production function without regional spillovers are in columns 1 to 3 whereas those including externalities are in columns 4 and 5. In column 1 we have the estimation of equation (15) using the OLS estimator for the pooled data. Results of the estimation considering fixed regional effects and fixed regional and time effects are in columns 2 and 3 respectively. We also considered the estimation including a time trend instead of the time effects but this was not significant. A Hausman test for choosing between the random and the fixed effect specification clearly discriminates in favour of the latter. Furthermore, both the F and the likelihood-ratio tests strongly reject the null hypothesis of non significance of both the regional and time effects.

Then, we take column 3 as the proper estimation. It does not allow to separate internal from external within the region returns to physical and human capital. In the case of physical capital, we obtain  $\theta_k + \delta_k = 0.47$ , being highly significant. The return for human capital is 0.19 (highly significant as well). These results are similar to those estimated in previous studies for the Spanish case (Mas et al, 1994; De La Fuente, 1996a and 1996b).

In order to check for the presence of (substantive and nuisance) spatial autocorrelation in the residuals of the estimated function, we compute the Lagrange Multipliers tests commented in the previous section. In the specification without time effects (column 2), all of these tests reject the null of no spatial autocorrelation. However, when time effects are included (column 3) results are not so conclusive. So, although the LM-err and specially LM-lag test evidence a strong misspecification of the estimated function due to the omission of a spatial dependence scheme, the robust tests (LM-EL and LM-LE) are not significant, dramatically in the case of nuisance autocorrelation. In this

case, the asymptotic properties and the dependence of these kinds of tests on residuals normality could explain these results.

In any case and given the mixed evidence, we incorporate a spatial lag of the endogenous variable ( $Wlny$ ) with the aim of removing the probable spatial autocorrelation in the residuals of the production function. Once the strong significance of this variable was observed,<sup>xviii</sup> we also included a spatial lag of physical and human capital. This is consistent with the strategy exposed previously and also with the specification of technological interdependence in our empirical model.

Results for the non linear least squares estimation of the equation (18') with regional dummies appear in column 4. Unlike previous results, this will allow us to disentangle internal from external within the region returns to physical and human capital. In addition, we obtain an estimation for  $\gamma$ , that is, the intensity of regional externalities. Its estimated value in this specification is quite large (0.79) and the hypothesis of absence of across regions spillovers is strongly rejected. This means that a 10 percent increase in the level of total factor productivity of the neighbours rises the level of technology in one region by almost 8 percent. This result supports the idea of very strong technological spillovers or interdependencies across neighbouring regions. The estimated value is slightly higher than the one estimated by Ciccone (1997) for a wide sample of countries.<sup>xix</sup>

Moreover,  $\theta_k + \delta_k = 0.46$  and  $\theta_k = 0.47$ , being  $\delta_k$  negative although not statistically different from zero. In the case of human capital,  $\theta_h + \delta_h = 0.19$  while  $\theta_h$  is 0.14. As a result, estimated external returns within the regions associated to the accumulation of human capital,  $\delta_h$ , reach 5%, opposite to what happened in the case of physical capital. So, the larger the aggregate stock of human capital in an economy, the higher the total effect of new investments in this factor. The latter result is in line with the idea in, for instance, Lucas (1988), although for a sample of countries Ciccone (1997) obtained no external effect from human capital accumulation. Among the possible explanations, we could mention the smaller territory in the case of regional economies, that could exacerbate externalities from human capital, and the evolution of this factor in the

Spanish economy in the last decades. It is worth noting that the Spanish regions all went from less than 10% in the percentage of employed population with medium-high schooling to more than 50% in the period considered in this study (see Mas et al, 1995).

Non linear least square estimation with fixed time effects was also computed. However, the hypothesis of no significance of these effects was not rejected. This is against the result obtained with the estimation without externalities (column 3). This could mean that the spatial lag of the variables are picking up most of the behaviour considered by the time dummies. That is, it could be incorporating a cyclical component common across neighbouring regions. So that, the estimation for the spillover parameter could be collecting both a technological and a demand-driven externality (in the sense of Bartelsman et al, 1994).

Finally, as a consequence of the inconsistency of the least square estimation when a spatially lagged endogenous variable is included, we estimate equation (18') by ML. Column 5 displays the results for this case. The estimation for  $\theta_k + \delta_k$  and for  $\theta_h + \delta_h$  are similar to those obtained in column 4. However, the value for the regional externality is just 0.47 in this case, although it continues to be significantly different from zero. External returns within the regions to physical capital take a value similar to that in the previous estimation (not different from zero), but the ones to human capital dramatically increase. Therefore, in this estimation less than the 25% of the total effect of the human capital accumulation is due to internal returns, whereas the rest would be due to the externality within the region. It has to be said that once the externality has been included the spatial autocorrelation in the residuals totally disappears, as evidenced by the non significance of the LR-err test.

To sum up, two facts could be derived from column 4 and 5: first, the existence of external returns within the regions to, specifically, human capital, that could be even more important than internal returns; and, second, the relevance of technological interdependences across neighbouring Spanish regions.

## 7. CONCLUSIONS

This paper has considered the effects of externalities across regional economies. Two main objectives were established at the beginning of the paper: to analyse the theoretical role of regional externalities in growth and convergence and to check the empirical relevance of these effects.

A simple model of growth has been exposed, in which the level of technology of a region depends on the one of its neighbours. It considers that technology is a function of capital stock and the flow of innovations and ideas across neighbouring regions. From this simple model, three main conclusions have been derived. Firstly, the growth rates of a region are a function of the stock of capital in its neighbours. Then, the presence of regional externalities may cause endogenous growth, even in the presence of decreasing returns within the region. Secondly, as a consequence of the externality, the market solution is not Pareto-optimal: a region decides to invest at a rate lower than the optimal considering the benefits that this action causes to its neighbours. This result could justify the existence of supra-regional agencies for promoting regional investment, due that they could take into account this kind of externality. Thirdly, we have shown how across-regional externalities may explain the presence of clusters of regions, spatially concentrated, with low levels of development, that is, the existence of poverty traps due to geographical location.

Regarding the empirical evidence, using data for the Spanish regions during the period 1964-1991, some results could be pointed out. First, we have detected the existence of high (from 0.47 to 0.78, depending on the estimation) and significant technological spillovers across regions in the production function. It would support the idea that spatial autocorrelation in product per capita across regions would be due not just to autocorrelation in investment rates but also to interdependence in technological levels. Second, the empirical specification has allowed us to estimate internal and external within the region returns to physical and human capital from aggregate regional data in a straight forward way. There seems to be no evidence for an externality in physical capital accumulation. The opposite happens in the case of human capital, where the external within region returns to this factor has a value that ranges from 5% to 16%, depending on the estimation.



This paper has also shown a natural framework for considering empirically regional externalities. We have proposed the use of spatial econometrics techniques for this purpose.

Finally, some questions derived from the paper are in our future research agenda. A deeper analysis on the channels for the diffusion of technology must be done. In this sense, the paper has considered physical contiguity for defining *neighbourhood*. Nevertheless, it seems sensible considering some others mechanisms as trade or network communications that could strongly connect two or more regions, whatever the physical distance among them. Furthermore, the same production function has been specified for all regions, while it could be the case of, for instance, different intensity in the diffusion of technology across different types of economies. Finally, and in line with Vayá et al (1998), it would be worthy to analyze theoretically and empirically the consequences of the presence of regional externalities for the rate of convergence of regional economies.

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<sup>i</sup> In the rest of the paper we will refer to regional externalities and regional spillovers as across-regions externalities.

<sup>ii</sup> Nevertheless, Keller (1997) casts some doubts on trade as the unique channel for diffusion of technology. Foreign R+D investments keep their significance in a growth equation when they are randomly weighted, instead of using the volume of imports in the trade partners as weights. The conclusion is that other channels must exist for knowledge diffusion besides trade in goods.

<sup>iii</sup> Barro and Sala-i-Martin (1995, ch.12), Ades and Chua (1997), Ciccone (1997) and Vaya et al (1998) are exceptions to this sentence.

<sup>iv</sup> It is noteworthy that we consider the aggregate level of technology as a function of capital intensity instead of as a function of the stock. In this way we avoid the problem of a scale effect.

<sup>v</sup> We consider this component common to each economy although in the empirical model we will allow for differences across economies.

<sup>vi</sup> Just imagine the *solitude* of a genetic engineer in the pre-historic era.

<sup>vii</sup> This figure has been frequently used to illustrate the mechanism of *poverty traps*. See for instance Barro and Sala-i-Martin (1995 pg 50).

<sup>viii</sup> We have taken the idea of these graphs from Durlauf and Quah (1998).

<sup>ix</sup> This specification has much in common with the one in Ciccone (1997). The main difference would be that in here we have an autoregressive spatial representation instead of the moving average in the Ciccone's paper. The estimation of all the effects from (18) is straight forward.

<sup>x</sup> Despite in this kind of analysis both fixed and random effects models could be estimated, the first one is habitually preferred given that it is likely that the unobservable regional effects were correlated with regressors in the equation, causing the inconsistency of the random effects model. In any case, a Hausman test will be computed in order to choose the appropriate specification.

<sup>xi</sup> See Anselin (1988a) and Anselin and Florax (1995) for a detailed survey of Spatial Econometrics.

<sup>xii</sup> Spatial dependence appears when one thing happening in one region affects to another region and the reverse, that is, when there are interdependencies among different spatial units.

<sup>xiii</sup> We adapt the strategy of Spatial Variable Expansion 2 (SAVE) proposed by Florax and Folmer (1992) to the case of regional spillovers in the production function.

<sup>xiv</sup> A brief description of these tests is given in the appendix.

<sup>xv</sup> The presence of a spatially lagged endogenous variable causes the LS estimator to be biased and inconsistent (see Anselin 1988a).

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<sup>xvi</sup> See Bera and Yoon (1992) and Anselin *et al* (1996) for the advantages of computing the robust tests of LM-EL and LM-LE and their utility in the process of choosing between the residual or the substantive spatial autocorrelation model.

<sup>xvii</sup> Once (22) has been estimated by ML it is necessary to compute the common factor test (COMFAC test) in order to check the consistence of this model. The model with spatially correlated errors would not be appropriate when the value for the COMFAC test were highly significant.

<sup>xviii</sup> Result not supplied but provided by the authors upon request.

<sup>xix</sup> He gets a value of 0.58 for international technology spillovers using the sample of 98 countries in Mankiw et al (1992).

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## Appendix 1. Spatial dependence tests

a) The expression of the LM-err test is (Burrige, 1980):

$$\text{LM-err} = \frac{\left( e'Ce / \hat{\sigma}^2 \right)^2}{P} \sim \chi_1^2$$

where  $C$  is a  $(N \times N)$  matrix of weights,  $\hat{\sigma}^2$  is the standard deviation of the OLS residuals (the product of the vector of OLS estimated residuals ( $e$ ) divided by the number of observations  $-N-$ ), and  $P = \text{trace}(C'C + C^2)$ . Under the null hypothesis of no spatial residual correlation in the residuals, the test is distributed as a  $\chi_1^2$ .

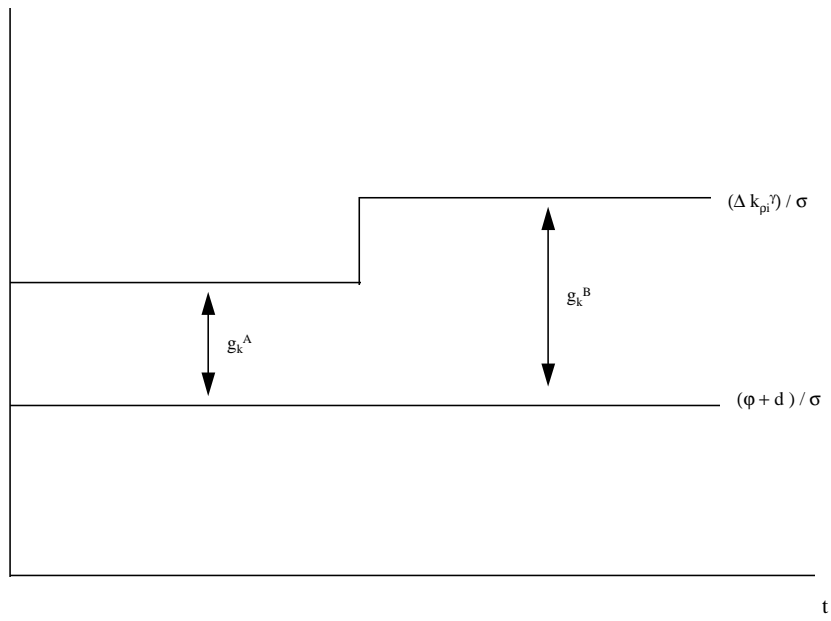
b) The expression of the LM-lag test is (Anselin, 1988b):

$$\text{LM-lag} = \frac{\left( e'Cy / \hat{\sigma}^2 \right)^2}{RJ} \sim \chi_1^2$$

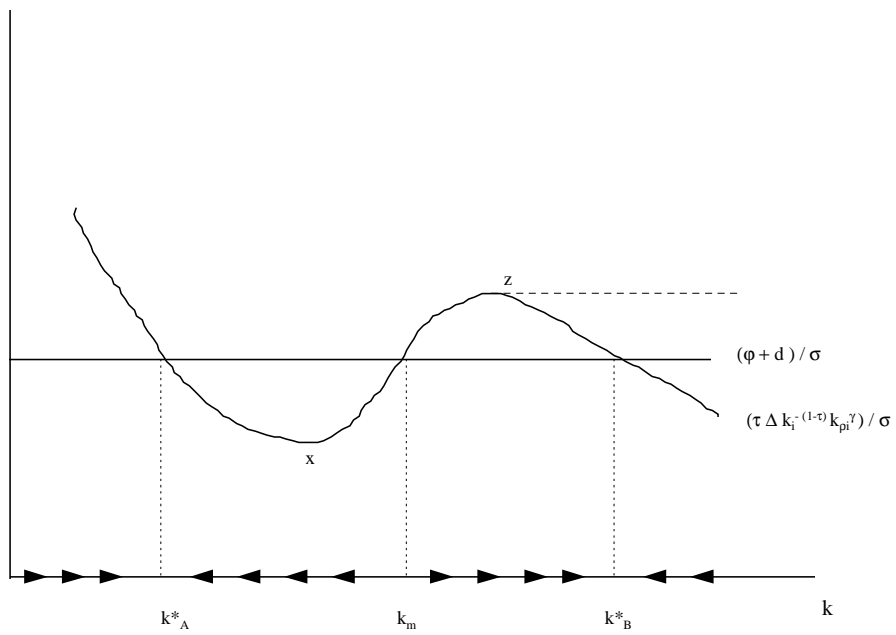
where  $y$  is the endogenous variable,  $RJ = P + (CX\beta)'M(CX\beta) / \hat{\sigma}^2$ ,  $CX\beta$  is the spatial lag of the predicted values from the OLS estimation,  $M = I - X(X'X)^{-1}X'$  is the projection matrix,  $P$  and  $C$  are defined as above. Under the null hypothesis of no significant spatial lag of the endogenous variable, the test is distributed as a  $\chi_1^2$ .

Despite these statistics were specified for a cross-section sample, it is possible to use them for a pooled data. In our case, we have replaced the  $(N \times N)$  matrix of weights  $C$  by a matrix  $W$ ,  $(N \times T) \times (N \times T)$  as defined in (20).

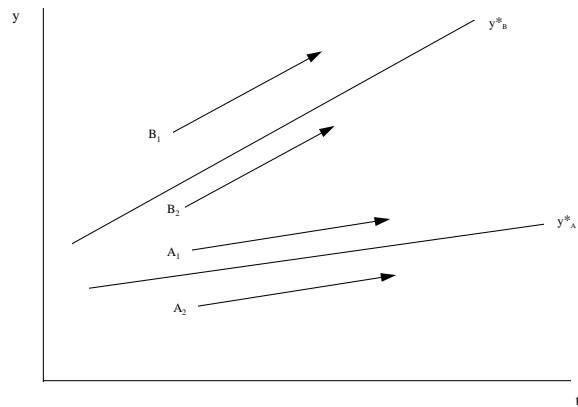
**Figure 1.** Growth in two groups of regions with different  $k$ , when  $\tau=1$



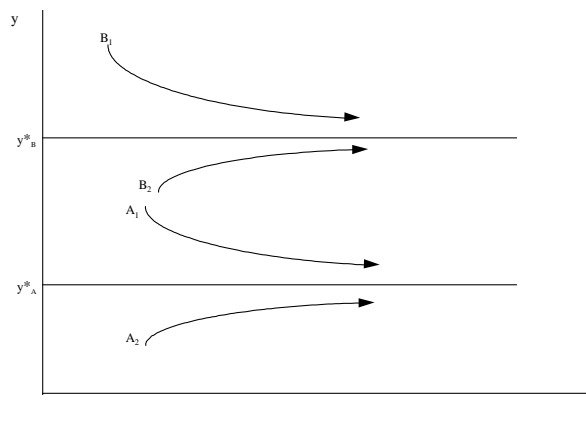
**Figure 2.** Growth in two groups of regions with different  $k$ , when  $\tau < 1$



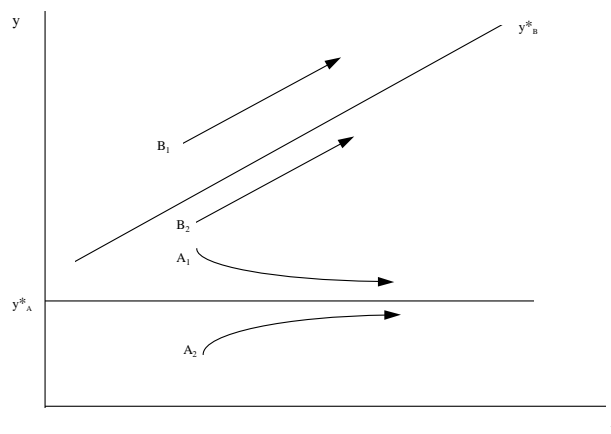
**Figure 3a.** Evolution of  $y$  in two groups of regions with different  $k$  when  $\tau=1$



**Figure 3b.** Evolution of  $y$  in two groups of regions with different  $k$  when  $\tau=1$



**Figure 3c.** Evolution of  $y$  in two groups of regions with different  $k$  when  $\tau < 1$  but  $\tau + \gamma = 1$  in group B.







**Table 1.** Aggregate cross-industry correlations, Solow's residual growth (upper) and GVA growth (lower)

|     | s1          | s2          | s3          | s4          | s5          | s6          | s7          | s8          | s9          | s10         | s11         | s12         |
|-----|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| s1  |             | 0.47        | 0.24        | -0.24       | -0.12       | <b>0.77</b> | 0.41        | -0.37       | 0.45        | 0.07        | 0.31        | 0.16        |
| s2  | 0.45        |             | 0.15        | -0.12       | -0.32       | <b>0.65</b> | 0.17        | -0.09       | 0.17        | 0.21        | 0.41        | <b>0.56</b> |
| s3  | 0.25        | 0.31        |             | 0.13        | 0.17        | 0.22        | 0.45        | 0.25        | 0.42        | <b>0.94</b> | 0.22        | -0.07       |
| s4  | 0.33        | <b>0.70</b> | 0.32        |             | 0.26        | -0.20       | <b>0.54</b> | -0.05       | 0.16        | 0.16        | 0.41        | -0.23       |
| s5  | 0.22        | 0.45        | <b>0.55</b> | 0.51        |             | -0.06       | -0.09       | <b>0.54</b> | 0.41        | 0.08        | 0.00        | -0.38       |
| s6  | <b>0.76</b> | <b>0.76</b> | 0.43        | <b>0.60</b> | <b>0.54</b> |             | 0.20        | -0.01       | <b>0.59</b> | 0.08        | 0.14        | 0.20        |
| s7  | 0.39        | 0.21        | 0.33        | <b>0.62</b> | 0.24        | 0.47        |             | -0.20       | 0.34        | 0.43        | <b>0.68</b> | -0.28       |
| s8  | 0.02        | 0.50        | <b>0.71</b> | 0.40        | <b>0.68</b> | 0.51        | 0.20        |             | 0.46        | 0.36        | -0.00       | -0.09       |
| s9  | <b>0.52</b> | <b>0.61</b> | <b>0.64</b> | <b>0.74</b> | <b>0.69</b> | <b>0.80</b> | <b>0.60</b> | <b>0.60</b> |             | 0.34        | 0.33        | -0.07       |
| s10 | <b>0.55</b> | <b>0.58</b> | <b>0.83</b> | <b>0.65</b> | <b>0.63</b> | <b>0.74</b> | <b>0.65</b> | <b>0.69</b> | <b>0.87</b> |             | 0.39        | 0.02        |
| s11 | 0.49        | <b>0.69</b> | 0.42        | <b>0.78</b> | <b>0.55</b> | <b>0.77</b> | <b>0.71</b> | <b>0.63</b> | <b>0.81</b> | <b>0.83</b> |             | -0.07       |
| s12 | 0.46        | <b>0.92</b> | 0.37        | <b>0.75</b> | 0.45        | <b>0.79</b> | 0.20        | <b>0.59</b> | <b>0.69</b> | <b>0.62</b> | <b>0.71</b> |             |

Average correlation Solow residual = 0.28, GVA = 0.56

**Table 2.** Aggregate cross-region correlations, Solow's residual growth (upper) and GVA growth (lower)

|     | AND         | ARG         | AST         | CNT          | CL          | CM          | CAT          | VAL          | EXT   | GAL         | MAD         | MUR         | NAV         | PV          | RIO          |
|-----|-------------|-------------|-------------|--------------|-------------|-------------|--------------|--------------|-------|-------------|-------------|-------------|-------------|-------------|--------------|
| AND |             | 0.47        | 0.28        | 0.19         | -0.00       | 0.34        | <b>0.61</b>  | 0.23         | 0.13  | <b>0.77</b> | <b>0.57</b> | 0.37        | 0.35        | 0.42        | -0.44        |
| ARG | 0.51        |             | -0.21       | 0.23         | -0.08       | 0.38        | -0.05        | 0.15         | -0.15 | <b>0.69</b> | <b>0.70</b> | <b>0.74</b> | 0.43        | 0.23        | -0.20        |
| AST | 0.45        | 0.36        |             | 0.05         | <b>0.57</b> | -0.18       | 0.38         | 0.13         | 0.09  | -0.02       | -0.21       | -0.02       | 0.23        | <b>0.68</b> | -0.03        |
| CNT | 0.06        | 0.38        | <b>0.60</b> |              | 0.28        | 0.43        | 0.36         | <b>-0.57</b> | 0.47  | 0.42        | 0.06        | 0.21        | 0.27        | 0.06        | -0.39        |
| CL  | 0.17        | 0.10        | <b>0.75</b> | 0.39         |             | -0.13       | 0.41         | -0.26        | 0.00  | -0.15       | 0.10        | -0.02       | 0.46        | 0.38        | -0.24        |
| CM  | <b>0.59</b> | 0.51        | -0.37       | <b>0.53</b>  | 0.11        |             | 0.45         | 0.33         | 0.27  | 0.31        | <b>0.55</b> | 0.29        | 0.00        | 0.31        | -0.24        |
| CAT | <b>0.84</b> | <b>0.67</b> | 0.48        | 0.35         | 0.33        | <b>0.67</b> |              | 0.18         | 0.19  | 0.37        | 0.39        | -0.08       | 0.38        | 0.51        | <b>-0.60</b> |
| VAL | 0.35        | <b>0.68</b> | 0.46        | <b>-0.53</b> | 0.18        | <b>0.62</b> | <b>0.64</b>  |              | -0.45 | -0.00       | 0.41        | 0.12        | 0.01        | <b>0.52</b> | -0.06        |
| EXT | 0.41        | 0.09        | 0.23        | <b>0.54</b>  | 0.00        | <b>0.58</b> | 0.32         | 0.08         |       | 0.16        | -0.27       | 0.04        | -0.45       | -0.24       | 0.40         |
| GAL | <b>0.52</b> | <b>0.60</b> | -0.33       | 0.39         | 0.17        | 0.23        | <b>0.67</b>  | <b>0.55</b>  | 0.14  |             | 0.46        | 0.49        | 0.36        | 0.23        | -0.39        |
| MAD | <b>0.72</b> | <b>0.83</b> | -0.40       | 0.20         | 0.32        | <b>0.63</b> | <b>0.85</b>  | <b>0.70</b>  | 0.11  | <b>0.54</b> |             | <b>0.61</b> | 0.37        | 0.24        | <b>-0.53</b> |
| MUR | 0.50        | <b>0.85</b> | -0.26       | 0.44         | 0.07        | <b>0.57</b> | <b>-0.72</b> | <b>0.54</b>  | 0.33  | 0.44        | <b>0.74</b> |             | -0.03       | -0.00       | -0.18        |
| NAV | 0.34        | 0.41        | 0.49        | 0.21         | <b>0.63</b> | 0.21        | <b>0.55</b>  | 0.51         | -0.34 | <b>0.62</b> | <b>0.59</b> | 0.15        |             | <b>0.60</b> | <b>-0.57</b> |
| PV  | 0.40        | 0.46        | <b>0.92</b> | 0.51         | <b>0.59</b> | 0.37        | 0.41         | 0.51         | 0.03  | 0.32        | 0.39        | 0.22        | <b>0.54</b> |             | -0.26        |
| RIO | -0.31       | -0.14       | -0.03       | -0.40        | -0.12       | -0.12       | -0.33        | 0.03         | 0.51  | -0.01       | -0.33       | -0.12       | -0.48       | -0.12       |              |

Average correlation Solow residual = 0.30, GVA = 0.41

**Notes:** Significant coefficients at 10% in bold. Data from the Industrial Survey of Spain supplied by the Instituto Nacional de Estadística for the period 1980 to 1991. Grow in the Solow residuals has been obtained as the residual in a Cobb-Douglas production function using labour and private capital as inputs.

**Table 3.** Results for the empirical model

|                                    | (1)           | (2)               | (3)              | (4)           | (5)              |
|------------------------------------|---------------|-------------------|------------------|---------------|------------------|
| $\theta_k + \delta_k$              | 0.244 (0.038) | 0.442 (0.033)     | 0.471 (0.042)    | 0.457 (0.040) | 0.4502(0.0378)   |
| $\theta_h + \delta_h$              | 0.498 (0.024) | 0.346 (0.021)     | 0.195 (0.046)    | 0.187 (0.037) | 0.205 (0.036)    |
| $\gamma$                           |               |                   |                  | 0.787 (0.104) | 0.478 (0.062)    |
| $\theta_k$                         |               |                   |                  | 0.474 (0.058) | 0.476            |
| $\theta_h$                         |               |                   |                  | 0.138 (0.051) | 0.042            |
| regional dummies                   | NO            | YES               | YES              | YES           | YES              |
| time dummies                       | NO            | NO                | YES              | NO            | NO               |
| Ln L                               | 234.252       | 371.302           | 404.946          | 411.548       | 397.594          |
| Hausman-test <sup>1</sup>          |               |                   | 28.160 (p:0.000) |               |                  |
| Likelihood-Ratio test <sup>2</sup> |               | 274.1(p:0.000)    | 67.28 (p:0.000)  |               |                  |
| LM-err                             |               | 31.938 (p:0.0000) | 5.079 (p:0.024)  |               |                  |
| LM-EL                              |               | 10.652 (p:0.001)  | 0.059 (p:0.806)  |               |                  |
| LM-lag                             |               | 30.939 (p:0.000)  | 6.820 (p:0.009)  |               |                  |
| LM-LE                              |               | 9.653 (p:0.001)   | 1.801 (p:0.179)  |               |                  |
| LM-LAG                             |               |                   |                  |               | 40.490 (p:0.000) |
| LR-ERR                             |               |                   |                  |               | 0.524 (p:0.469)  |

- Notes:** 1) Hausman test for selecting between a fixed effects and a random effects models.  
2) Likelihood ratio test for significance of regional fixed effects in column 2 and for time fixed effects in column 3.  
3) For the estimated parameters in the model, the standard deviation is supplied in brackets.  
The probability value in (p:) is supplied for the values of the tests.