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GROWTH AND EXTERNALITIES ACROSS ECONOMIES. AN EMPIRICAL ANALYSIS USING SPATIAL ECONOMETRICS

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Abstract: Recent theoretical models of economic growth have emphasised the role of external effects on the accumulation of factors of production. Although most of the literature has considered the externalities across firms within a region, in this paper we go a step further and consider the possibility that these externalities cross the barriers of regional economies. We assess the role of these external effects in explaining growth and economic convergence. We present a simple growth model, which includes externalities across economies, developing a methodology for testing their existence and estimating their strength. In our view, spatial econometrics is naturally suited to an empirical consideration of these externalities. We obtain evidence on the presence of significant externalities both across Spanish and European regions.

Resumen: Diversos modelos han destacado recientemente el papel de los efectos externos en la acumulación de los factores productivos a la hora de explicar el crecimiento económico. Sin embargo, la mayor parte de la literatura se ha centrado en el estudio de *spillovers* entre los agentes productivos de una misma economía. Por el contrario, en este trabajo se considera la posibilidad de que dichas externalidades traspasen las fronteras de las economías, analizando sus consecuencias sobre los procesos de crecimiento y convergencia, especialmente en el caso regional. Para ello, se presenta un sencillo modelo de crecimiento que incorpora el supuesto de externalidades entre regiones, desarrollando posteriormente una metodología que permite contrastar la existencia de estas últimas y estimar su intensidad. En este sentido, la econometría espacial se revela como la vía natural para la consideración empírica de dichas externalidades. En el trabajo se ha obtenido evidencia a favor de la presencia de externalidades significativas entre las regiones españolas y europeas.

Keywords: growth, convergence, across-economy spillovers, spatial econometrics
JEL classification: O4, R11

1. Introduction

Recent theoretical models of economic growth have emphasised the importance of external effects on the accumulation of factors of production (Romer 1986, 1990; Lucas 1988). An increase in the stock of reproducible factors leads to an improvement in the level of technology which cannot be fully appropriated by the agent making the investment. As a result, the aggregate return (social return) on the investment is larger than that obtained by the individual agent (private return). The assumption is that knowledge spreads over the entire economy, thereby affecting the level of technology of each individual firm.

This paper shares the belief that these external effects are indeed relevant. However, we also believe that these externalities spill over the barriers of economies, in line with the idea of across-economy interactions outlined in Lucas (1993): when there are across-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 the empirical evidence. Therefore, we will assume that externalities do not spread spatially without any limits, and that the diffusion of innovations will always be easier within groups (clubs) of closely related economies. We thus agree with the point raised in Durlauf and Quah (1999): "*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*."

In the case of regions integrated in a particular area, the economies can be thought of as interacting strongly with each other. As long as these relationships influence growth, the models built to explain such growth must explicitly include some measure of the linkages across economies.

This paper therefore discusses the importance of across-region relationships in growth and the dynamics towards the steady state. Specifically, in the first stage, we present a simple growth model in which diffusion of knowledge as a result of investments in capital is not confined to the limits of the economy in which the innovation is generated, but rather this spills over into the neighbouring economies. In the second stage, the growth equation is derived from that simple model.

Further, we propose the use of spatial econometrics techniques to test and estimate the existence of these externalities, due to the similarities between the final models and the specifications used in the presence of spatial dependence in econometric models.

The rest of the paper is organised as follows. Section 2 presents theoretical and empirical justification for regional spillovers in growth. Section 3 presents a simple growth model including across-region externalities, from which a growth equation is derived; section 4 describes the empirical models that permit the existence of these spillovers to be tested and their magnitude to be estimated. In section 5 various issues concerning spatial econometrics techniques are discussed with the aim of optimising testing for the existence of externalities across economies and estimating their strength. Section 6 presents evidence for the case of the Spanish and the European regions. Finally, section 7 concludes.

2. Do externalities across regions matter for growth?

Theoretical issues regarding externalities across regions

Recent studies have stated that linkages across economies may be important in explaining growth. A well-known source of such linkages comes from foreign R&D investments, basically among trade partners (Coe and Helpman, 1995; Park, 1995; Helpman, 1997). Most analyses consider R&D investments in foreign countries embodied in traded goods as the main channel for technological diffusion. However, this cannot be the sole channel. Keller (1998) advocates multiple channels for technological diffusion. He shows that import-weighted R&D investments in foreign countries are no more significant than other random combinations.

Technological diffusion has been shown to be considerable between national economies, and it is thought to be even stronger between regions of the same economy. In the case of regional economies, externalities linked to the diffusion of knowledge may be even more significant than in the case of countries. This may be true for the trade channel as well as for other possible channels. As an example, in a national economy, most laboratories and R+D centres might be concentrated in only a few regions, though firms located in other regions are able to apply the results of the research; in the case of public R+D centres, governments will be concerned to ensure that the results spread throughout the entire territory and are not confined to firms located in one particular region (López-Bazo *et al*, 1998).

The diffusion of technology, moreover, is likely to be higher between regions that are geographically close to each other. In such cases, relative amounts of traded goods are likely to be higher than between regions that are more distant.[1] Furthermore, *local social conditions* play an important role in the way each economy incorporates and adapts ongoing innovations (Rodríguez-Pose, 1999). When neighbouring economies share similar *local conditions*, transfers of technology between these regions are likely to be more intense.

Moreover, as proposed in Vayá *et al* (1998), in the case of regional economies constituting an integrated area further direct channels for the diffusion of technology, as well as for other types of externalities can be identified, including, for instance, common markets for skilled labour and final goods, access to similar types of capital throughout the entire area, and managerial talent. Pecuniary externalities (Glaeser *et al*, 1992; Venables, 1996) may lead to the concentration of firms in macro-areas spanning several regions, thereby translating externalities at the firm level to the aggregate regional level. Once the centrifugal forces (costs of production in a specific location relative to those of other locations) have surpassed the effects of the agglomeration economies in a region, a plausible hypothesis is that firms will look for locations in contiguous regions where production costs are lower, while at the same time taking advantage of some degree of external economies, given the short

[1] When analysing the role of distance in spatial diffusion of technology, the idea of contagious or

distances involved. This hypothesis is in line with the process of progressive industrialization in the periphery proposed in Puga and Venables (1996), when the distance between economies was a factor in selecting a location. In this case, agglomeration economies would operate at a supra-regional level, giving rise to an external regional effect.

Kubo (1995) presented a theoretical consideration of the role of the inputs of production of a region in the output of another region. This model shows how the likelihood of even or uneven development depends on the magnitude of the internal returns to scale of both regions, as well as on the value of the externality.

Empirical evidence

Despite the apparent significance of regional spillovers, most of the literature has focused on externalities to firms and industries (Caballero and Lyons, 1990; Raut, 1995; Burnside, 1996; Ravallion and Jalan, 1996). In this connection, Costello (1993) shows how total factor productivity growth is more strongly correlated across industries within one country than across countries within one industry. However, Kollmann (1995) observes that correlations across industries within a region are weaker than across regions within an industry. Moreover, he reports that productivity growth is more strongly correlated across the regions of the USA than across the G7 countries. More evidence on the relevance of regional spillovers is given in Quah (1996). This author shows how, once conditioned to the levels in the neighbouring regions, the distribution of the product per capita in the regions of the European Union (EU) appears to be more strongly concentrated than the real distribution. Other authors (Vayá, 1998, López-Bazo et al., 1999, and Rey and Montouri, 1999) have detected strong spatial dependence in the distribution of product per capita or productivity for different geographical areas. In all the cases, the spatial distribution of such variables seems to be far from random or equal. This situation could be

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hierarchical spread is of interest (see Cliff and Ord, 1981, and Morril et al., 1988 for a discussion).

caused by spatial autocorrelation in investment rates and also by spatial autocorrelation in the average level of technology of each economy. In the first case, similarities in saving rates and other preference parameters may largely explain the autocorrelation. In the case of technology, the greater intensity of knowledge diffusion across neighbouring economies and the presence of agglomeration economies that surpass regional barriers are the main assumptions made by this paper.

Theoretically as well as empirically, the above argument underlines the importance of external economies that cross the weak and sometimes artificial regional boundaries. However, to our knowledge, only a few papers have considered the performance of other economies in explaining growth. Barro and Sala-i-Martin (1995), following the proposal in Chua (1993), include as a regressor in the growth equation the weighted average of the income per capita for a country’s immediate geographical neighbours. Their findings provide support for an external effect, though small, across countries. Ciccone (1996) observes how a large fraction of growth in total factor productivity spreads out to the neighbours for a large sample of 98 countries. Moreno and Trehan (1997), using distance and other measures of proximity, also show how neighbours’ growth may affect a country’s growth, while Ades and Chua (1997), considering political instability in nearby countries rather than their growth, observe a significant effect. Meanwhile, evidence for the regional case has been provided by Finglenton and McCombie (1998). They find a significant externality effect in labour productivity for a sample of EU regions. Studies of this kind are few in number, and those that exist have applied a rather *ad hoc* approach to the modelling and empirical study of spillovers across economies. The following sections address the theoretical modelling of these effects and the question of how they might be considered empirically.

3. A simple model of growth with spillovers across regions

In this section, we first describe a simple model of growth initially proposed in López-Bazo *et al.* (1998), in which externalities arising from an increase in the level of technology in neighbouring regions are considered.[2] We then follow Vayá *et al* (1998) in deriving a growth equation in the presence of these externalities.

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

$$y_{it} = A_{it} k_{it}^{\alpha} \tag{1}$$

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

From expression (1), we introduce two key assumptions. First, we assume that there are externalities due to the accumulation of capital within a regional economy. Thus, following the reasoning in Romer (1986) and Lucas (1988), the aggregate level of technology is a function of the aggregate level of k.[3] Second, there are also externalities due to the aggregate level of technology of the neighbours (which are linked to their capital stock as well). This means that innovations/ideas (linked to investments in k) can *flow* across economies. Therefore:

$$A_{it} = \Delta \; k_{it}^{\delta} k_{\rho it}^{\gamma} \tag{2}$$

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[2] We use the concept of neighbourhood in a broad sense, not strictly confined to physical contiguity.
[3] 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.

where Δ is an exogenous component which, for the sake of simplicity, we assume to be constant,[4] δ is the measure of the degree of external returns within the region, and subscript ρi denotes the set of regions neighbouring region i. Therefore, $k_{\rho i}$ is the amount of capital per worker in the regions neighbouring region i. γ is the measure of the regional spillover effect, which is assumed to be positive: when $k_{\rho it}$ increases by 1% (causing an increase in the technology of those regions), technology in region i will increase by γ%.

Clearly, when $\delta=\gamma=0$ and $\alpha<1$ we are dealing with 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):

$$y_{it} = \Delta k_{it}^{\tau} k_{\rho it}^{\gamma} \tag{3}$$

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

The growth rate of k_i will be:

$$\frac{\dot{k}_i}{k_i} = s\Delta k_i^{-(1-\tau)} k_{\rho i}^{\gamma} - (d+n) \tag{4}$$

[4] We consider this component as being common to each economy although in the empirical model we will allow for differences across groups of economies.

where s is the saving rate (which for the sake of simplicity we consider here as exogenous) and (d+n) the effective rate of depreciation (the temporal subscript is omitted to simplify notation). The rate of investment in k_i is a decreasing function of its stock in the case of decreasing returns within the region (τ<1), while it is an increasing function of the stock in the neighbours. This means that investments in reproducible factors will be greater in those regions located in areas with high stocks of these factors, because externalities across regions within the area will increase the returns on these investments. In contrast, incentives to invest will be lower in a region *surrounded* by others with low capital intensity.

Moreover, under the assumption of similar capital intensity in the steady state in all regional economies, $k_i^* = k_{\rho i}^* = k^*$, the growth of the economy in the equilibrium is[5]

$$g_k = \frac{\dot{k}}{k} = s\Delta k^{-(1-(\tau+\gamma))} - (d+n) \tag{5}$$

In the long-run g_k is defined as zero, so when $\tau+\gamma<1$ the economy will converge to the following steady state capital intensity:

$$k^* = \left(\frac{s\Delta}{n+d}\right)^{\frac{1}{1-(\tau+\gamma)}} \tag{6}$$

or, in terms of productivity,

$$y^* = \Delta^{\frac{1}{1-(\tau+\gamma)}}\left(\frac{s}{n+d}\right)^{\frac{\tau+\gamma}{1-(\tau+\gamma)}} \tag{7}$$

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[5] This will be the case when there are no boundaries to externalities across economies. When technological diffusion and/or agglomeration economies are limited within a certain distance, the following will be true only for the economies within each *geographical club*.

The steady state 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 are globally a decreasing function of the average intensity in this group. Therefore, productivity will equalize within groups and across groups in the equilibrium. However, when for any group of regions externalities are strong enough to cause $\tau+\gamma\geq 1$, we face endogenous growth for that group despite decreasing returns to reproducible factors at regional level. In this case, the initial gap across regions will still exist, or even increase, in the long run, preventing convergence to steady state levels.

A growth equation in presence of regional spillovers

Under the assumption of decreasing returns to scale, it is possible to derive the dynamic path to the equilibrium associated with the growth model above. After log-linearization, using a first order Taylor expansion of (4) around the steady state, we obtain:

$$\left(\ln k_{it} - \ln k_{i0}\right) = \left(1 - e^{-\beta t}\right)\left(\ln k^{*} - \ln k_{i0}\right) \tag{8}$$

where β=(1-τ)(n+d) is the usual speed of convergence. In addition, taking into account that

$$\ln k_{it} = \frac{\ln y_{it} - \ln\Delta - \gamma \ln k_{\rho it}}{\tau}$$
$$\ln k^{*} = \frac{\ln y^{*} - \ln\Delta}{\tau+\gamma} \tag{9}$$

we can obtain this expression in terms of labour productivity,

$$\left(\ln y_{it} - \ln y_{i0}\right) = \xi - \left(1 - e^{-\beta t}\right)\ln y_{i0} + \gamma\left(\ln k_{\rho it} - \ln k_{\rho i0}\right) + \gamma\left(1 - e^{-\beta t}\right)\ln k_{\rho io} \tag{10}$$

ξ being a constant measuring the level of y in the long run equilibrium,

$$\xi = (1-e^{-\beta t})\left[\frac{1-\gamma}{1-(\tau+\gamma)}\ln\Delta + \frac{\tau}{1-(\tau+\gamma)}\ln s - \frac{\tau}{1-(\tau+\gamma)}\ln(n+d)\right] \quad (11)$$

From the above expressions three conclusions can be drawn. First, the consideration of regional externalities does not affect the speed of convergence, as β is a function of the usual parameters τ, n and d. Second, two new elements appear in the growth equation: the growth rate of capital per worker in the neighbours, and their initial levels. In this context, in the presence of positive interregional spillovers (γ>0), both variables increase the growth of productivity in region i. Finally, the assumption of growth diffusion across regions has a positive effect on the steady state of both capital intensity and labour productivity.

4. Empirical specifications

In the previous section we described the main characteristics of a growth model that includes the effects of economic activity in nearby regions. Although different expressions have been derived for the steady state levels and the growth rates, empirical counterparts for these expressions become necessary. With this aim, we now develop empirical specifications for the production function and the growth equation that include regional spillovers. It should be stressed that in this way the variables measuring the spillover effect find their place in the specifications as a result of the hypothesis under which the model is built, not as a result of *a posterior* inclusion.

An empirical production function with regional spillovers

The following specification for the production function allows us to estimate the strength of regional spillovers as well as to distinguish between internal and external returns within the region. Following Mankiw, Romer and Weil (1992), we include both physical and human capital in the production function:

$$y_{it} = A_{it} k_{it}^{\theta_k} h_{it}^{\theta_h} \tag{12}$$

y_{it} being the average level of output per worker in region i in period t, and k_{it} and h_{it} the average levels of physical and human capital per worker respectively. θ_l (l=k,h) measures the average internal returns at the firm level.[6] As stated above, A_{it} is partially endogenous in this model, reflecting both an externality within the region i to investments in k and h, and the technological interdependence across neighbouring regional economies. Then:

$$A_{it} = \Delta k_{it}^{\delta_k} h_{it}^{\delta_h} A_{\rho it}^{\gamma} \tag{13}$$

where Δ represents the exogenous level of technology and δ_l (l=k,h) is 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). $A_{\rho it}$ is total factor productivity of the neighbours to region i, collecting the process of diffusion of ideas and innovations across close regions, γ being the intensity of these interdependencies. From (12) we can rewrite $A_{\rho it}$ as:

$$A_{\rho it} = \frac{y_{\rho it}}{k_{\rho it}^{\theta_k} h_{\rho it}^{\theta_h}} \tag{14}$$

As usual, in order to simplify the final specification, in this expression the same value for the internal and external returns is assumed for all regions, as well as the same

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[6] If $y_{ji} = A_{ji} k_{ji}^{\theta_k} h_{ji}^{\theta_h}$ is the production technology for firm j in region i in any period of time, equation (12) can be obtained in the usual manner by averaging across firms in region i, under the (maybe strong) assumption of homogeneity.

intensity for the across-regions spillovers, γ.[7] Then, substituting (13) and (14) in (12), the final expression for the production function is, after log-linearization:[8]

$$\ln y_{it} = \ln\Delta + (\theta_k + \delta_k)\ln k_{it} + (\theta_h + \delta_h)\ln h_{it} + \gamma(\ln y_{\rho it} - \theta_k \ln k_{\rho it} - \theta_h \ln h_{\rho it}) \quad (15)$$

As we can see from (15), $(\theta_k+\delta_k)$ and $(\theta_h+\delta_h)$ reflect 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 obtain an estimate of the internal returns (θ_l) from the parameters associated to factors in the neighbours. In this way, we will be able to obtain an estimate of internal returns to physical and human capital, *social* returns within the region (or externalities within the regional economy), δ_l, and the parameter measuring the externalities across regions (γ). As has been noted by Ciccone (1996), all of these can be obtained by using aggregated regional or national data.

An empirical specification for the growth equation with regional spillovers

When homogeneous data for the stock of capital of a sample of economies is available, estimation of the parameters in (10) is straightforward. However, it is commonly the case that the only data available are figures for output per inhabitant or per worker (examples are the US states, the regions in Europe or large samples of countries). As a result, equation (10) cannot be estimated in these cases. Nevertheless, based on the assumption that any one region alone is large enough to exert a significant effect on productivity in the group of neighbouring regions as a

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[7] Some authors have advised on the possibility of differences in the strength of the externalities depending on the characteristics of each region (Coe and Helpman, 1995; Kubo, 1995).

[8] This specification has much in common with that in Ciccone (1996). However, one difference is that here we use an autoregressive spatial representation rather than the moving average in Ciccone's paper.

whole, and that all regions share the same within the region return parameters (α and δ),

$$\ln k_{\rho it} = \frac{\ln y_{\rho it} - \ln\Delta}{\tau} \tag{16}$$

Substituting (16) into (10), we obtain the expression for the growth equation in terms of the initial productivity and its growth in the neighbours

$$\left(\ln y_{it} - \ln y_{i0}\right) = \xi' - \left(1 - e^{-\beta t}\right)\ln y_{i0} + \frac{\gamma}{\tau}\left(\ln y_{\rho it} - \ln y_{\rho i0}\right) + \frac{\gamma}{\tau}\left(1 - e^{-\beta t}\right)\ln y_{\rho io} \tag{17}$$

where

$$\xi' = (1 - e^{-\beta t})\left[\frac{\tau^2 - \gamma^2 + \gamma^2(\tau+\gamma)}{\tau(\tau+\gamma)[1-(\tau+\gamma)]}\ln\Delta + \frac{\tau}{1-(\tau+\gamma)}\ln s - \frac{\tau}{1-(\tau+\gamma)}\ln(n+d)\right] \tag{18}$$

Note that the coefficients affecting growth and initial levels in the neighbours now depend on the ratio between the external effect and the returns within the region ($\varphi=\gamma/\tau$). Therefore, from the above model it is not possible to estimate the externality parameter, only its importance when compared with the returns within the region to reproducible factors.

5. Spatial econometrics: a proposal for considering externalities across economies

The expressions for the production function (15) and for the growth equation (17) with externalities have much in common with the specifications defined in spatial econometrics. In fact, empirically, externalities across economies translate into dependence across the units of analysis.

In the case of the production function and under the assumption that there is information for a pool with N regions and T time periods, equation (15) could be rewritten as (including a well behaved error term):

$$\mathbf{lny} = \mathbf{ln\Delta} + (\theta_k + \delta_k)\mathbf{lnk} + (\theta_h + \delta_h)\mathbf{lnh} + \gamma\left(W_1\mathbf{lny} - \theta_k W_1\mathbf{lnk} - \theta_h W_1\mathbf{lnh}\right) + \mathbf{v}, \quad \mathbf{v} \sim N(0, \sigma^2 I) \qquad (19)$$

where a bold character represents a vector (N*T)x1 with the information for each region (i=1,...,N) and time period (t=1,...,T). **LnΔ** potentially collects any difference in the exogenous level of technology across regional economies and over time.[9] W_1**lny,** W_1**lnk** and W_1**lnh** are, respectively, the spatial lags for labour productivity and physical and human capital per worker, that is, a weighted average of the values of **lny, lnk** and **lnh** in the regions neighbouring region i, while I is the (N*T)x(N*T) identity matrix. Finally, W_1 is a (N*T)x(N*T) matrix with the following general expression:

$$W_1 = \begin{pmatrix} C^{11} & 0 & 0 & . & 0 \\ 0 & C^{22} & 0 & . & 0 \\ 0 & 0 & C^{33} & . & 0 \\ . & . & . & . & . \\ 0 & 0 & 0 & . & C^{TT} \end{pmatrix} \qquad (20)$$

0 being a (NxN) matrix of zeros and C^{tt} a (NxN) spatial matrix of weights, where each of its elements**,** c_{ij}^{tt}**,** reflects the interaction between region i and region j in period t.

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[9] Following Mankiw, Romer and Weil (1992) and Islam (1995), **lnΔ** can differ for each region since it may reflect initial differences not only in technology but also in resource endowments, climate, and institutional conditions.

In a similar way, the growth equation in (17) could be rewritten as:

$$\mathbf{g}_{\mathrm{y}} = \mathbf{a} - (1 - e^{-\beta})\mathbf{lny} + \varphi W_1 \mathbf{g}_{\mathrm{y}} + \varphi(1 - e^{-\beta}) W_1 \mathbf{lny} + \mathbf{v}, \qquad \mathbf{v} \sim N(0, \sigma^2 I) \quad (21)$$

where, for yearly data, $\mathbf{g}_{\mathrm{y}}$ denotes annual growth rates, a bold character represents a vector [N*(T-1)]x1 with the information for each region and time period (t=2,...,T for $\mathbf{g}_{\mathrm{y}}$ and t=1,...,T-1 for **lny**) and I is the [N*(T-1)]x[N*(T-1)] identity matrix. Again, $W_1\mathbf{g}_{\mathrm{y}}$ and W_1**lny** are the spatial lags for the growth rates and the initial level of income respectively. Finally, **a** collects any difference in the steady state across economies. It might be composed by variables approaching the factors including ξ' in (18).

It is important to note that both empirical specifications differ from the spatial AR error model. In the case of the growth equation, this model will be expressed as:

$$\begin{aligned} &\mathbf{g}_{\mathrm{y}} = \mathbf{a} - (1 - e^{-\beta})\mathbf{lny} + u \\ &\mathbf{u} = \lambda W_1 \mathbf{u} + \mathbf{v}, \quad v \sim \mathbf{N}(\mathbf{0}, \sigma^2 I) \end{aligned} \quad (22)$$

that in the COMFAC form:

$$\mathbf{g}_{\mathrm{y}} = (I - \lambda W_1)\mathbf{a} - (1 - e^{-\beta})\mathbf{lny} + \lambda W_1 \mathbf{g}_{\mathrm{y}} + \lambda(1 - e^{-\beta}) W_1 \mathbf{lny} + \mathbf{v}, \quad \mathbf{v} \sim N(0, \sigma^2 I) \quad (23)$$

The restrictions in the parameters involving growth rates and the initial conditions match those in our specifications, but in the COMFAC representation the spatial lag of the variables affecting the steady state (summarised by **a** in the empirical specification) influences growth rates. If the COMFAC model were to be correct, transitional dynamics for an economy would not only depend on the distance to its own steady-state but also on the distance of the neighbours to their steady state. In contrast, in our model, the latter distance does not exert any direct influence.

The same reasoning can be applied to the production function. In this case, our assumptions state that the exogenous level of technology (**lnΔ**) in the neighbours does not directly influence labour productivity in the economy. It should, however, be noticed that the exogenous level of technology in the whole system affects labour productivity in a given economy throughout the effect of the lag of the endogenous variable. The same can be applied to the steady state level in the growth equation. The COMFAC specification would violate such an assumption. Conversely, equations (19) and (21) may be considered as the mixed regressive-spatial regressive model in the terminology of Anselin (1988) and Florax and Folmer (1992) (where only the spatial lag of **lnk** and **lnh** for the production function, and the spatial lag of the initial income for the growth equation are included as regressors), but including the theoretical restrictions on the parameters.

Rewriting the two empirical models in terms of the specifications used in spatial econometrics presents three major advantages: 1) as stated above, different hypotheses as to the sources of the externalities can be defined by means of the specification of the weight matrix; 2) the significance of regional externalities can be checked; and 3) the intensity of the across-region externalities can be quantified consistently.

Definition of W

The assumption of technological dependence across neighbouring regions has led to the appearance of spatial lags in both the production function and the growth equation. However, by defining the concept of *neighbourhood* precisely, several hypotheses about the process of technology diffusion can be considered. First, we can identify two possibilities, depending on the timing of the absorption of the external effects: the externality is generated in one economy and incorporated by the others within one period of time, or over several periods. In the former case, considering contemporaneous spatial dependence will suffice to account for external effects. This is the assumption in the empirical exercises in which we deal with long-run relationships. In this case, the matrix of weights will be defined as W_1 in (20), and the empirical specifications will be given by (19) and (21).

The other possibility will require the inclusion of further lag terms in equations (19) and (21), as a result of the effect on the current productivity or growth rates of the spatial interactions in previous periods. For instance, for a first order autoregressive process characterising the spatial dependence across economies, we may write the growth equation as

$$\mathbf{g}_y = a - (1-e^{-\beta})\mathbf{lny} + \varphi_1 W_1 \mathbf{g}_y + \varphi_2 W_2 \mathbf{g}_y + \varphi_1 (1-e^{-\beta}) W_1 \mathbf{lny} + \varphi_2 (1-e^{-\beta}) W_2 \mathbf{lny} + \mathbf{v}, \qquad \mathbf{v} \sim N(0, \sigma^2 I) \tag{24}$$

where W_1 is defined as in (20) and

$$W_2 = \begin{pmatrix} 0 & 0 & 0 & . & 0 \\ C^{21} & 0 & 0 & . & 0 \\ 0 & C^{32} & 0 & . & 0 \\ . & . & . & . & . \\ 0 & 0 & . & C^{T(T-1)} & 0 \end{pmatrix} \tag{25}$$

with $C^{t(t-1)}$ a matrix of weights whose elements $c_{ij}^{t(t-1)}$ reflect the interaction between region i in period t and region j in period t-1. It should be remembered that for the parameters of the model being identified, the error term should not show an AR spatial process unless the weight matrices for the lag dependence and the error dependence are different (Anselin, 1988; Anselin and Florax, 1995). In the case of expression (24) this should be the case for contemporaneous spatial dependence as well as for spatial dependence with one period lag. Then, the assumption of non-contemporaneous spatial dependence requires stronger independence assumptions on the error term in order that the model can be identified.

Focussing on the case of contemporaneous dependence, the next step is to define the matrices C^{tt} in the diagonal of W_1. There are at least three possibilities:

(i) physically adjacent regions take direct advantage of the diffusion of technology. In this case,

$$W_1 = I_T \otimes C \qquad (26)$$

with I_T being a (TxT) identity matrix, and each element of C,

$$c_{ij} = \frac{S_{ij}}{\sum_{j=1}^{N} S_{ij}} \qquad (27)$$

S_{ij} being a contiguity factor that equals 1 when i and j are neighbours and 0 otherwise. In this case, the matrix C does not change over time. However, if we weighted the influence of each of the contiguous regions by, for instance, their population or production, the matrices in the diagonal of W_1 would change for the different periods in the analysis.[10]

(ii) Following the concept of spatial diffusion, it is logical to think that technology spreads throughout the space, with the influence of one region on another declining as the distance between them increases. In this second case,

[10] As noted by the editors, there would be no reason to assume that the spatial parameters were equal over time on a priori grounds, especially when W is allowed to change.

this hypothesis can be directly addressed by defining matrix C in (26) as the square inverse distance between the centres of each region.

(iii) Finally, in line with arguments in the literature on technological diffusion among trade partners, we can think of economies exchanging intermediate goods (embodying innovations) as taking more advantage of technological improvements and pecuniary externalities in other economies. In this case, a possible definition for the weights of C^{tt} in (20) could be the percentage of goods that region i buys from region j as a share of the total volume of goods imported by the former in each period. This is in line with some recent studies on applied spatial econometrics that define weight matrices based on different economic priors (see for instance Case et al, 1993, Molho, 1995, and Aten, 1997).

In our empirical models, regardless of the definition of C, it is assumed that potentially exist a spatial spread of the effects of changes in the exogenous variables given the presence of the spatial lag of the endogenous variable as a regressor.

In all three cases, in our empirical exercises the matrices are such that they satisfy the necessary regularity conditions required to guarantee the properties of estimators and tests. Specifically, the weights are nonnegative and remain finite (for further details see Anselin, 1988). Further, row-standardised matrices are used. For the matrix based on distance, this makes the metrics for measurement of distance negligible.

Testing for the existence of externalities across economies

Empirical studies aiming at estimating returns to scale and the rate of convergence have dealt with expressions such as (19) and (21) excluding the spatial lags. However, the omission of such lags when significant will cause problems of spatial dependence. This, in turn, will give rise to misleading inferences in the traditional specifications. Testing for spatial dependence in models of this kind is therefore advisable.

In our cases, the hypothesis of the existence of spillovers across economies leads to the empirical models already defined. If both fit the data properly, we can expect the Lagrange multiplier (LM) tests for spatial dependence (Anselin and Florax, 1995) to reject their null hypotheses of non-spatial dependence. It should be noted that the nonlinearity in the parameters of the models does not affect the well-known expressions of the tests. This is because under the null hypotheses of the spatial dependence tests the model is linear. Although we advocate the use of the above mentioned tests to detect misspecifications arising from spatial dependence in the estimation of the production function and the growth equation using cross-sections of data, the adequacy of our empirical models can be tested straightforward. In the case of the growth equation, the absence of spillovers means φ=0 in (21). The model under the null is the traditional growth equation:

$$\mathbf{g}_y = \mathbf{a} - (1 - e^{-\beta})\mathbf{lny} + \mathbf{v} = X\theta + \mathbf{v}, \qquad \mathbf{v} \sim N(0, \sigma^2 I) \tag{28}$$

The LM test for the null of φ=0 is given by:

$$LM - EXT = \left(\frac{\hat{\mathbf{v}}' W_1 \left[\mathbf{g}_y + \left(1 - e^{-\beta}\right) \mathbf{lny} \right]}{\hat{\sigma}^2} \right)^2 \left[T_1 + G \right]^{-1} \tag{29}$$

where $\hat{\mathbf{v}}$ are the residuals in (28), $T = tr(W_1 ' W_1 + W_1^2)$, and

$$G = \frac{1}{\hat{\sigma}^2} \left[\left\{ W_1 \left[X\hat{\theta} + \left(1 - e^{-\beta}\right) \mathbf{lny} \right] \right\}' M \left\{ W_1 \left[X\hat{\theta} + \left(1 - e^{-\beta}\right) \mathbf{lny} \right] \right\} \right]$$

with $M=I-X(X'X)^{-1}X'$. The expression for the test follows immediately noting that $\frac{\partial[\mathbf{g}_y - h(\cdot)]}{\partial\varphi} = -W_1\left[\mathbf{g}_y + \left(1-e^{-\beta}\right)\mathbf{lny}\right]$, where $\mathbf{h}(\cdot)$ is the nonlinear function of the parameters in the RHS of the empirical model.[11] Under the null of no externalities across economies, the LM-EXT is distributed as χ^2 with one degree of freedom.[12]

When it comes to the production function in (19), the LM-EXT can also be applied to test for the existence of externalities. Nevertheless, in this case we should note that in order for the statistic to be "identified", the external within the economy effects, δ_l (l=k,h), needs to be zero. This is a consequence of the fact that only under the alternative of the existence of externalities across economies can the externalities within the economy be identified. Otherwise, we cannot distinguish internal (θ_l) from external within the region (δ_l) returns.

Estimating the magnitude of the externalities across economies

The inclusion of the spatial lag of the endogenous variable requires estimation methods that guarantee consistency. Additionally, the empirical models in the previous sections share certain particularities that call for some discussion. Specifically, there are some nonlinear restrictions in the parameters of the models. From (19) it is clear how the internal to the firm returns (θ_l) affect the stock both in region i and in its neighbours. Besides, the parameter measuring the strength of the externalities affects the level of technology in the neighbours, thus interacting with the θ_l parameters. A similar situation is observed in (21), where the parameter reflecting the strength of the externality interacts with the term that involves the rate of convergence when measuring the role of the initial level of income in the neighbours. Still, in both cases the parameter affecting the spatial lag of the

[11] The full derivation is available from the authors upon request.

[12] As in the LM-ERR and LM-LAG tests, the degrees of freedom for the test should be T instead of 1 if we allowed the spatial parameter to change in each time period. This will be especially

endogenous variable is involved in the restrictions. As a consequence, the process of estimation will have to account for this fact.

A consistent estimation in the presence of a lag of the endogenous variable is provided by the maximum likelihood (ML) estimator. In our cases, the likelihood function to be maximised needs to include the restrictions in the parameters to fit the empirical specification. For example, in the case of the growth equation,

$$
\begin{aligned}
L(\beta,\varphi,\sigma^2) = {} & \sum_i \ln(1-\varphi\upsilon_i) - \frac{N*(T-1)}{2}\ln(2\pi) - \frac{N*(T-1)}{2}\ln(\sigma^2) - \\
& \frac{1}{2\sigma^2}[\mathbf{g}_y - \varphi W_1\mathbf{g}_y - a + (1-e^{-\beta})\mathbf{lny} - \varphi(1-e^{-\beta})W_1\mathbf{lny}]' \\
& [\mathbf{g}_y - \varphi W_1\mathbf{g}_y - a + (1-e^{-\beta})\mathbf{lny} - \varphi(1-e^{-\beta})W_1\mathbf{lny}]
\end{aligned}
\tag{30}
$$

with υ_i (i=1,…,N*(T-1)) as the eigenvalues of the weight matrix W_1.

The maximisation of (30) provides the ML estimation of the parameters when the usual conditions are satisfied. However, it is important to note that in this context we cannot allow for unobservable fixed regional effects (a different steady-state for each single economy) in the estimation of the relevant parameters of the model, given that this will create an incidental parameter problem.[13] This will not be the case when the random effect model is assumed. However, we have not considered such a specification given that, as well established in the literature, both in the case of the production function and in the growth equation, the unobservable effects are correlated with the regressors in the model (causing inconsistency in the estimation of the parameters). Undoubtedly, the best thing to do is to include variables approaching differences across economies in the exogenous level of technology and the steady-state. Unfortunately, lack of data usually prevents such a solution. Therefore, we have

reasonable when the weight matrix is allowed to change over time.

[13] We are indebted to the editors for pointing out this problem.

adopted an intermediate solution: differences in these magnitudes have been accounted for by means of a dummy for different types of regions.

It needs to be noted that our empirical models meet the identification condition, which allows estimates of the parameters to be obtained from the information in the data for the variables, as well as the constraints implied by the functional forms. This is possible because the columns of the matrix of the pseudo-regressors are linearly independent both in the case of the growth equation and the production function. Again, the only problem arises in the production function for the value of $\gamma=0$. As discussed above, in this case the identification of internal and external within the economy returns cannot be achieved.

With this in mind, the maximisation of (30) can be achieved by a standard optimisation routine. Nonetheless, the process can be simplified slightly by adapting the procedure suggested in Anselin (1988) for the model including a spatial lag of the dependent variable. Given that the spatial parameter, φ in (21), is involved in the restriction, the estimation process can proceed following these steps:

1. For values of $0\leq\varphi\leq1$[14], compute the matrix of pseudo-regressors to be used in step 2 for the nonlinear specification:

$$X_0 = \frac{\partial f(\cdot)}{\partial \theta'} \tag{31}$$

where $f(\cdot) = a - (1-e^{-\beta})\mathbf{lny} + \varphi(1-e^{-\beta})W_1\mathbf{lny}$ and θ is the vector of parameters. This is because we can write the terms in brackets in (30) as $A\mathbf{g_y} - \mathbf{f(\cdot)}$ where $A=I-\varphi W_1$.

2. For each value of φ carry out ordinary least square (OLS) of X_0 on $\mathbf{g_y}$ and OLS of X_0 on $W\mathbf{g_y}$. This yields $\hat{\theta}_0$ and $\hat{\theta}_L$.

[14] We constrain φ to this range given that we are excluding the possibility of negative spillovers and returns to external effects higher than within the economy returns. In any case, negative values for φ considerably reduced the likelihood in all cases.

3. Compute residuals $\hat{\mathbf{v}}_{\mathbf{0}}$ and $\hat{\mathbf{v}}_{\mathbf{L}}$ and evaluate the concentrated likelihood for each value of φ:

$$L_C = \sum_i \ln(1-\varphi\upsilon_i) - \frac{N*(T-1)}{2}\ln(2\pi) - \frac{N*(T-1)}{2}\ln\left[\frac{1}{N*(T-1)}(\hat{v}_0 - \varphi\hat{v}_L)'(\hat{v}_0 - \varphi\hat{v}_L)\right] - \frac{N*(T-1)}{2} \quad (32)$$

4. Select the value of φ that maximises L_C and compute the associated estimation of θ.

Again, the same discussion and procedure can be applied to the production function expanded with external effects.

6. Empirical evidence

This section estimates the role of regional spillovers in the production function and in the growth equation for two different samples of regional economies. In the case of the production function, we present the results for the Spanish regions, while we comment on those for the European regions in order to illustrate the analysis of the growth equation. The unavailability of homogeneous data for physical and human capital in the latter case meant that we were unable to estimate the production function for all the European regions as a set. Results in this section were obtained using codes in Gauss v.3.2.8 (available from the authors upon request).

6.1. Externalities across economies in the production function: the Spanish regional case

Data

We estimated the production function using data for the Spanish regions (NUTSII EUROSTAT classification) for the period 1964-1993. Data were obtained from three sources. First, gross value added at constant 1990 prices and the number of population in employment are taken 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 prices. Finally, human capital is the fraction of the population in employment that has at least started secondary schooling. This information is taken from Pérez and Serrano (1998). Given that the first source publishes the data every two years (except for 1964 and 1967), we have information for 15 periods. We are therefore working with a panel set of 17 regions and 15 time periods.

In order to obtain the spatial lags of the endogenous and exogenous variables in our model, we have defined two different weight matrices: one based on physical contiguity and another on trade flows between regions.[15] In the latter matrix the factor S_{ij} in (27) is the total volume of transported goods by road and train with origin in region j and destination in region i. These data are available from the EUROSTAT REGIO database.[16]

Results

Although our empirical model incorporates regional externalities based on theoretical grounds, following the reasoning in section 5 we first estimate the production function without any kinds of spillover, in order to determine whether their omission leads to spatial dependence. As previously mentioned, we introduce a regional dummy in order to capture the heterogeneity in the exogenous level of technology. It takes the values of ones for regions with higher productivity than the average over the period. Besides, a time trend is included to pick up exogenous technical progress. Both are significant in all the estimates, with the regional dummy indicating a higher level of exogenous technology in the more productive regions. Results for the OLS estimation are summarised in Table 1. As already mentioned, it does not allow the separation of internal and external within the region returns to physical and human

[15] The heterogeneous size of the Spanish regions and their small number prevents the square inverse matrix from picking up the real proximity across regions in this case.

[16] We used the average volume from 1988 to 1992 as homogeneous trade, since data before 1988

capital. In the case of physical capital, we obtain $\theta_k+\delta_k = 0.31$, that is approximately the share of physical capital in national income in developed economies, while human capital returns within the region are equal to 0.48 (both results being highly significant). As for the spatial autocorrelation statistics, both traditional LM tests rejects the null hypothesis of non spatial autocorrelation at the standard significance levels, using both the first order contiguity matrix and the trade flows matrix. The LM-EXT defined in (29) allows the existence of externalities advocated in our model to be tested specifically. The results clearly support our hypothesis for the Spanish regions when diffusion of technology is supposed to exist across contiguous regions as well as between trade partners.

The ML estimation of equation (19) is summarised in Table 2. The likelihood ratio (LR) test for the joint significance of the spatial lags, computed using the two spatial matrices, confirms the appropriateness of the empirical model. As for the results of the estimation using the contiguity matrix, we obtain that $\theta_k+\delta_k$=0.28 and θ_k=0.22, indicating the existence of a positive within the region externality to physical capital, δ_k. In the case of human capital, $\theta_h+\delta_h$=0.49 while θ_h=0.46. Therefore, in this estimation more than 20% of the returns to the accumulation in physical capital is due to externalities to such factor within the economy. So, the larger the aggregate stock of physical capital in an economy is, the higher the total effect of new individual investments in this factor. This agrees with the results obtained by Ciccone (1996) for a wide sample of countries. Conversely, our estimates assign a much lower effect to externalities within the economy to human capital investments (about 6%). Although lower in magnitude, this effect provides support to the story in Lucas (1988).

The estimate for γ indicates an appreciable value (0.27) for the intensity of regional externalities, and a value that is significantly different from zero. This confirms that the hypothesis of the absence of across-region spillovers is strongly rejected. This

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was unavailable. Then matrices in the diagonal of W_1 are the same for each year.

means that a 10 percent increase in the level of total factor productivity of the neighbours raises the level of technology in one region by almost 3 percent. This result supports the idea of strong technological spillovers or interdependencies across neighbouring regions. The estimated value is lower than that obtained by Ciccone (1996) for a wide sample of countries,[17] though in line with that obtained by Fingleton and McCombie (1998) for the European regions.

We also estimate the production function with externalities for the matrix of trade flows. The estimates are similar to those for the contiguity case. This might be because, as shown by empirical evidence, trade is mainly between contiguous economies. What, however, is surprising in this case are the high values for the externalities within the region, mainly in the case of physical capital. However, we should interpret these estimates carefully given the large standard errors for θ_k and θ_h.

In both cases we also estimated the model without imposing restrictions on the parameters and tested their reliance. They were strongly supported by the data. Therefore, the results for the Spanish regions seem to support our hypothesis regarding the relevance of externalities across regional economies in the production process.

6.2. Externalities across economies in the growth equation: the European regional case

Data

In order to test for the presence of across-region spillovers in the growth equation, we have examined data from 108 regions in the EU spanning the period 1975-1992. The main source is the EUROSTAT REGIO database, complemented with other sources at the national level. The variable of interest is labour productivity. This magnitude in each region has been divided by the average value for the EU. Lack of homogeneous data for capital stocks prevents the estimation of (10), so we estimate (17) instead.

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[17] He obtains a value of 0.58 for international technology spillovers using the sample of 98

Results

Table 3 summarises the results for the growth equation before including externalities. The estimation is carried out both for a cross-section dataset (where the endogenous variable is labour productivity growth rate for the period 1975-1992 and the initial income level is measured in 1975) and for the yearly pooled data. In order to reflect differences in the steady state of groups of European regions, in both estimations we include dummies for three categories of regions: less than 80% of the average labour productivity in the EU, between 80 and 110%, and more than 110%. In all cases such dummies are significant, with the signs and values reflecting the expected differences in the steady states. In the cross-section, significant, though slow, convergence within each group is observed. The rate of convergence is slightly higher than the usual 2% per year (2.3%), increasing up to 3.3% when estimating for the pooled data.

In this case, we carry out the spatial analysis defining two matrices of weights: the physical contiguity matrix and the square inverse distance matrix (both row-standardised). Unfortunately, data for flows of trade between EU regions are not available. However, if trade flows decreased with distance we could think of the results for the second matrix as partly proxying for external effects through traded goods. In this case as well, the significance of the LM-ERR and the LM-LAG statistics shows how the omission of the across-region externalities leads to spatial dependence in the estimation of the traditional growth equation. In addition, the LM-EXT statistic, which tests the significance of the externality with the empirical proposed model as the alternative hypothesis, clearly rejects the null of non-existence of externalities across economies. This is the case both for the cross-section as well as for the pooled sample. Thus, following the same reasoning as in the previous exercise, the model in (21) is estimated. Results for the ML estimation are summarised in Table 4.

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countries in Mankiw, Romer and Weil (1992).

For the cross-section and the first order contiguity matrix, the estimate of φ indicates that the effects of the spillovers across regions represent approximately two thirds of the returns within the region. This means that under the assumption that the share of physical capital in total income is about 0.3, the externalities across economies to capital accumulation will be around 0.2 (quite similar to the value observed in the previous exercise for the Spanish regions). The estimation also reveals that a 1 point increase in (logs) labour productivity in the neighbouring regions causes an increase of 0.011 in the rate of growth of a region. Meanwhile, the effect of the acceleration in growth rates in the neighbours is highly important (a 1 point increase in the weighted growth rate of the neighbouring regions is associated with an increase of 0.63 in the growth rate of a region). As proposed in section 2, it might be thought that the income level of the neighbours affects the growth of a region as a result of technological or pecuniary spillovers. This effect might be considered as supply-side externalities. Besides, the high value for the implied parameter affecting $W_1\mathbf{g}_y$ would show how a large proportion of the growth experienced by any regional economy is due to a "contagious effect", where rates of growth are larger when neighbours are also growing at high rates and smaller when neighbours are stagnating or growing slowly. This effect might be considered to be related to a demand-side externality, as a consequence, for instance, of demand from neighbours for final goods or inputs produced in a region. This kind of externality has been frequently considered for the case of industries since Caballero and Lyons's (1990) seminal paper. Furthermore, the rate of convergence seems not to be affected by the omission of the across-region externalities. Finally, the consideration of the square inverse distance matrix gives rise to an increase in the estimated supply and demand-side externalities.

Results for the pool are qualitatively similar. For the first order contiguity matrix, once again, the supply and demand-side externalities are highly significant. In this estimation, a 1 point increase in the growth rate in the neighbours leads to an increase of approximately 0.7 points in the growth rate of a region, a higher value than that in the case of the cross-section. The difference may be accounted for by the fact that this demand-side externality also captures a pro-cyclical relationship in growth between neighbouring economies, since we are considering annual growth rates. On the other hand, a 1 point increase in (logs) labour productivity in the neighbours implies a 0.02 points increase in the growth rate of the region. As for the rate of convergence, there are only minor changes when compared to the estimation without externalities. These conclusions are very similar to those obtained with a square inverse distance matrix, with slight increases for all the parameters in the model.

7. Summary and conclusions

This paper has considered the role of externalities across regional economies in growth. A simple model of growth has been presented, in which the level of technology of a region depends on the level of technology 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, it has been deduced that the growth rates of a region are a (positive) function of the stock of capital in its neighbours. This may counteract the neoclassical tendency of decreasing returns to capital in one region. Then, a growth equation approaching the transitional dynamics to the steady state has been derived from this model. It shows how, besides the fact that across-region externalities help to raise the steady state level, growth rates are positively affected by both investments and the existing stock in the neighbouring economies. It is notable that the parameter measuring the speed of convergence is not affected by the spillover effect.

Spatial econometrics techniques have provided us with the *natural* framework for testing the presence of across-region externalities and estimating their relevance. We have suggested how the validity of the empirical model presented for the consideration of across-region externalities can be checked, both for the production function and the growth equation. The particularities of these empirical models have called for some adaptations in the spatial statistics and the estimation techniques. In addition, thanks to the utilisation of the weight matrix, we were able to define different hypotheses regarding the channels of the externalities. Finally, we have provided evidence of the relevance of these externalities for the case of the regions of Spain and Europe.

The results in this paper have several implications for regional policy. First, actions aimed at spurring regional growth in less developed regions should bear in mind that some of the effects may spill over across the neighbouring regions. Our results confirm that a region surrounded by prosperous economies can achieve higher growth rates (the reverse also being true). Similarly, co-ordinated investments in such regions may be more successful than isolated actions. This finding supports the creation of supra-regional agencies to promote regional investment, as they are better able to take this kind of externality into account. Second, the existence of externalities across regions could lead to the existence of a *poverty trap* due to geographical location. The fundamental question at this point is how a regional economy can escape from this poverty trap. Clearly, the effort required will not be as great when neighbours are simultaneously investing. If, however they are not, individual efforts may be to no avail.

Obviously, the many questions arising from this paper are in our future research agenda. A more exhaustive analysis of the channels by which externalities spread is needed. Furthermore, we have assumed stability in the parameters of the models, particularly in those measuring spatial dependence. Violation of this assumption would cast doubt on our results, as would the existence of a dynamic process in the diffusion of externalities. Further efforts in the development and adaptation of spatial econometrics tools for panel data sets might shed more light on the applied issues addressed in this paper. Finally, the dynamics of the growth equation indicates that analyses with other panel data estimation techniques would be valuable.

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Table 1. Results for the production function without externalities across economies for the Spanish regions

	OLS
Within the region returns to physical capital ($\theta_k + \delta_k$)	0.309 (0.029)
Within the region returns to human capital ($\theta_h + \delta_h$)	0.486 (0.024)
Ln L	316.265

Spatial Statistics	first order contiguity	trade flows
LM-ERR	11.473 p:0.001	3.568 p:0.059
LM-LAG	7.564 p:0.006	5.353 p: 0.021
LM-EXT (H_0: γ=0)	11.393 p:0.001	4.158 p:0.041

Note: Robust standard errors in brackets. p: probability value. A time trend and the regional dummy described in the text are included in the estimation. N=17 ; T=15

Table 2. Results for the production function with externalities across economies for the Spanish regions

	ML	
	first order contiguity	**trade flows**
Within the region returns to physical capital ($\theta_k + \delta_k$)	0.284 (0.034)	0.283 (0.032)
Within the region returns to human capital ($\theta_h + \delta_h$)	0.489 (0.025)	0.498 (0.025)
Externality across-regions γ	0.276 (0.077)	0.223 (0.096)
Internal returns to physical capital (θ_k)	0.216 (0.202)	0.096 (0.281)
Internal returns to human capital (θ_h)	0.456 (0.176)	0.374 (0.321)
Ln L	322.863	319.619
LR test[(1)]	13.195 p:0.004	6.708 p:0.082

Note: Robust standard errors in brackets. p: probability value. A time trend and the regional dummy described in the text are included in the estimation. N=17; T=15

[(1)] Likelihood Ratio Test for the global significance of the spatial regressors.

Table 3. Results for the growth equation without externalities across economies for the European regions

	OLS			
	Cross-section		Pool	
Rate of convergence (β)	0.023 (0.005)		0.033 (0.005)	
Ln L	67.608		2756.178	
Spatial Statistics	**first order contiguity**	**square inverse distance**	**first order contiguity**	**square inverse distance**
LM-ERR	38.727 p:0.000	58.470 p:0.000	1170.772 p:0.000	1872.528 p:0.000
LM-LAG	34.493 p:0.000	43.874 p:0.000	1162.923 p:0.000	1838.166 p:0.000
LM-EXT (H_0: φ=0)	22.520 p:0.000	22.336 p:0.000	1125.199 p:0.000	1714.875 p:0.000

Note: Robust standard errors in brackets. p: probability value. Dummies for three categories of regions as described in the text are included in the estimation. N=108; T=17

Table 4. Results for the growth equation with externalities across economies for the European regions

	ML			
	Cross-section		**Pool**	
	first order contiguity	**square inverse distance**	**first order contiguity**	**square inverse distance**
Rate of convergence β	0.022 (0.005)	0.024 (0.005)	0.032 (0.006)	0.035 (0.006)
***Relative* externality φ**	0.630 (0.063)	0.840 (0.069)	0.686 (0.016)	0.919 (0.011)
***Implied* φ $(1-e^{-\beta})$[(1)]**	0.011 (0.003)	0.016 (0.004)	0.021 (0.004)	0.031 (0.005)
Ln L	88.912	89.020	3297.762	3309.17
LR test[(2)]	42.608 p:0.000	42.824 p:0.000	1083.168 p:0.000	1111.984 p:0.000

Note: Robust standard errors in brackets. p: probability value. Dummies for three categories of regions as described in the text are included in the estimation. N=108; T=17

(1) In the cross-section, the implied parameter is given by $\varphi(1-e^{-\beta T})/T$

(2) Likelihood Ratio Test for the global significance of the spatial regressors.