Empirical Growth Models with Spatial Effects

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Abstract: Recent contributions to the regional science literature have considered spatial effects in empirical growth specifications. In the case of spatial dependence, following theoretical arguments from the new economic geography and the endogenous growth models, this phenomenon has been associated to the existence of externalities that cross regional borders. However, despite the general consensus that interactions or externalities are likely to be the major source of spatial dependence, they have been modelled in a rather *ad hoc* manner in most of existing empirical studies. More surprisingly, the empirical evidence on the preferred spatial specification is mixed and seems to depend on the set of regions, time period and specification. The assumption in this paper is that externalities across regions in long-run growth is mostly a substantive phenomenon caused by technological diffusion and pecuniary externalities, while regional transmission of random shocks should only play a minor role in the process of growth in the long-run. Accordingly, spatial dependence in empirical growth models should be of the substantive type (spatial lag and/or spatial cross-regressive) rather than nuisance error dependence (the so-called spatial error specification). However in a large number of studies, the standard spatial econometrics tools fail to detect the true externality mechanisms, especially when the growth model is underspecified. In contrast to the *ad hoc* method applied in most of the literature so far, we propose to base the analysis on structural growth models including externalities across economies and to apply the appropriate spatial econometrics tools to test for their presence and to estimate their magnitude in the real world.

1. Introduction

Economic growth is a topic that has for a long time attracted the attention of economists, more so in recent decades. Theoretical contributions have emphasised the role of different factors in determining the steady state level of income per capita and in promoting growth, added to which there is an enormous amount of empirical evidence relating to the assumptions and predictions from theoretical models, with a large number of empirical contributions focussing on regional economic growth (Neven and Gouyette, 1995; Sala-i-Martin, 1996; Carlino and Mills, 1993, 1996; Bernat and Jones, 1996; Chatterji and Dewhurst, 1996; Armstrong, 1995). One interesting characteristic of these analyses is that, as in the case of heterogeneous countries, regions have been considered as isolated economies, in other words, empirical specifications almost invariably exclude interactions across regions. However, theoretical and empirical arguments suggest that regions, as well as not being homogeneous, are also not independent. For instance, Rey and Montouri (1999, page 144) indicate that "*Despite the fact that theoretical mechanisms of technology diffusion, factor mobility and transfer payments that are argued to drive the regional convergence phenomenon have explicit geographical components, the role of spatial effects in regional studies has been virtually ignored*".

The problem with aspatial empirical analyses that have ignored the influence of spatial location on the process of growth is that they may have produced biased results and hence misleading conclusions. To address this problem, some regional economists and economic geographers suggest accommodating spatial heterogeneity and dependence in regional growth specifications (Amstrong, 1995; Rey and Montouri, 1999; López-Bazo et al, 1999). Their suggestions are broadly consistent with assumptions and predictions made from endogeneous growth theory and new economic geography models, which stress the role of interactions across agents that, for instance, cause economic activity to agglomerate in some areas and not in others (see for instance Fujita et al, 1999). External effects are supposed to be linked to the size of the market, to the access to specialised services, to forward and backward linkages, to knowledge diffusion, and to similar norms, institutions and policies across different regions. Put very simply, if we assume that firms are heterogeneous and always interacting with each other, then the fact that they are often located in different regions will also cause regions to be heterogeneous and interdependent.

Bernat (1996) and Rey and Montouri (1999) were among the first to specifically include spatial effects in empirical growth exercises (see also Fingleton and McCombie, 1998, Fingleton 1999, López-Bazo et al, 1999). Bernat (1996), for example, tested the simplest version of the so-called Kaldor's Laws in the set of US States, controlling for spatial dependence. Likewise Rey and Montouri (1999), coming from a neoclassical rather than heterodox perspective, checked for absolute β-convergence under spatial heterogeneity and spatial dependence. These early analyses precipitated a series of studies explicitly including spatial effects in growth specifications, mainly in the form of the spatial error model and the spatial lag model, although there has also been some estimation of the spatial cross-regressive model (see Anselin, 1988 for a description). The selection of one of these models is almost invariably based on a statistical criterion, basically the one proposed in Anselin and Rey (1991) and in Florax and Folmer (1992). Hence, despite the broad agreement that interactions or externalities across regions are likely to be the major source of spatial dependence, they have been modelled in a rather *ad hoc* manner in most of the existing empirical studies. And what it is more surprising, the empirical evidence on the preferred spatial specification is mixed and seems to depend on the set of regions, time period, specification, etc (Armstrong, 1995; Bernat, 1996; Rey and Montouri, 1999; Pons-Novell and Viladecans, 1999; Vayá y Moreno, 2002; Niebuhr, 2001; Kosfeld et al, 2002; Baumont et al, 2003; Arbia et al, 2003; Ying, 2003; Fingleton, 2001, 2004).

The question of the correct specification is a very important one, since it turns out that each spatial specification (substantive or nuisance) produces rather different interpretations and policy implications for the process of economic growth. Using the words by Bernat (1996, page 466) in the case of the spatial error model "*a region's growth is affected by growth in neighbouring regions only to the extent that neighbouring regions have above or below normal growth*", while for the spatial lag model "*a region's growth is directly affected by growth in neighbouring regions, and this effect is independent of the effect of the exogenous variables*". In the words of Rey and Montouri (1999, page 150 and 153), the reasoning for the spatial error model has to do with the fact that "*movements away from some steady state equilibrium may not be a function of region-specific shocks alone, but instead (…) of a* *complex set of shock spillovers*", whereas in the spatial lag specification the "*growth rate in a region may relate to those in its surrounding regions after conditioning on the starting year levels of income*".

The assumption in this paper is that externalities across regions in long-run growth is mostly a substantive phenomenon caused by technological diffusion and pecuniary externalities, while the regional transmission of random shocks only plays a minor role in the process of growth in the long-run. Accordingly, spatial dependence in empirical growth models should be of the substantive type (spatial lag and/or spatial cross-regressive), the preference for the nuisance case (spatial error) in a large number of studies being the result of the failure of the standard spatial econometrics tools to detect the true externality mechanisms, especially when the growth model is underspecified. In contrast with the *ad hoc* method applied in most of the literature so far, we propose to base the analysis on a structural growth model including externalities across economies and to apply the appropriate spatial econometrics tools to test for their presence and to estimate their magnitude in the real world. This is basically the approach used in recent contributions by Fingleton (2001 and 2004) and López-Bazo et al (2004). The rest of the paper tries to illustrate these points for the case of the Baumol/Barro/Mankiw et al equation and for the so-called Verdoorn's Law equation (second Kaldor's Law).

The structure of the paper is as follows. The next section briefly describes empirical growth specifications with substantive and with nuisance spatial dependence. It also discusses the type of externalities related to the resulting specifications. Section 3 presents the major characteristics of two growth models that include externalities across regions caused by technological diffusion. It is shown the similarity between their empirical specifications and the Durbin representation of the spatial error model when no control variables are included in the regression. The empirical evidence that illustrates that the *ad hoc* application of the spatial econometrics selection method procedures can provoke misleading conclusions on the type of spatial externalities is presented in section 4. Finally, section 5 concludes.

2. Empirical Growth Models and Spatial Dependence

There are two traditional specifications that have been extensively used in the literature to analyse regional growth. The first one is the renowned convergence equation that, with some minor variations, was derived and applied in the seminal papers of Baumol (1986), Barro and Sala-i-Martin (1992) and Mankiw et al (1992). The second is the specification linked to the Verdoorn's Law, that relates growth in labour productivity with growth in production (for evidence using samples of regions see Harris and Lau, 1998; Fingleton and McCombie, 1998; León-Ledesma, 2000). As mentioned above, a growing number of contributions have accounted for spatial dependence in both specifications.

Spatial dependence in the convergence equation

In the case of the convergence equation, growth in a region over a given period (g_y) is inversely related to its initial income per capita (y_0) as a result of the mechanism of convergence towards its steady state caused by decreasing returns to capital accumulation. Additional variables in the specification (X) control for factors determining differences in the steady states across regions. The resulting specification is of the following form:

$$g_y = \text{constant} - (1 - e^{-\beta T})\ln y_0 + X\delta + \varepsilon \qquad (1)$$

where ε denotes a well-behaved error term and the scalar β is the measure of the speed of convergence. When $\beta > 0$ and δ is a vector whose elements are non-significant we conclude in favour of absolute β-convergence, while in the case of $\beta > 0$ and with δ a significant vector of coefficients, the outcome is conditional β-convergence.

Spatial versions of the convergence equation include the spatial lag of growth rates (spatial lag model), a spatial structure in the perturbance (spatial error model) or the spatial lag of the initial income per capita (spatial cross-regressive model). In brief, the expression for the spatial lag convergence equation is:

$$g_y = \text{constant} - (1 - e^{-\beta T})\ln y_0 + X\delta + \rho W g_y + \varepsilon \qquad (2)$$

where Wg_y, the spatial lag of growth rates, is obtained by premultiplying the vector of regional growth rates by the so-called spatial weights matrix, W. This matrix quantifies the interactions across regions.

The spatial lag specification in (2) includes the fact that growth in each region is potentially affected by growth in its neighbours. In addition, we can rewrite (2) as:

$$g_y = \left(I - \rho W\right)^{-1} \left(\text{constant} - (1 - e^{-\beta T})\ln y_0 + X\delta + \varepsilon\right) \qquad (3)$$
$$g_y = \left(I - \rho W\right)^{-1} (Zb + \varepsilon) = \left(I - \rho W\right)^{-1} Zb + \left(I - \rho W\right)^{-1} \varepsilon$$

Which we have also given in generic form, with *Z* equal to the matrix of variables with columns equal to the constant, ln y_0 and the set of conditioning variables *X*. Following the typology of spatial externalities introduced by Anselin (2003), we can associate the structure in (3) with the presence of global externalities in the process of growth. On the one hand, growth in each region is affected by its initial per capita income and its conditioning variables, and by these magnitudes in the whole system of regions, although, depending on the structure of the W matrix, usually with strength that decreases with distance. This is represented by the product of *Z* and the inverse spatial transformation $(I - \rho W)^{-1}$ in (3). Additionally, growth in each region is influenced by random shocks within the region and by shocks coming from all the other regions ($(I - \rho W)^{-1}\varepsilon$), but once again with an effect that usually decays with distance. Finally, it should be notice that (3), i.e. the spatial lag model, imposes an important constraint in the structure of spatial externalities, the fact that the spatial transformation and thus the mechanism of spatial diffusion is exactly the same in both *Z* and *ε*.

The typical expression for the spatial error convergence equation can be written as:

$$g_y = \text{constant} - (1 - e^{-\beta T})\ln y_0 + X\delta + \varepsilon, \quad \varepsilon = \lambda W \varepsilon + \nu$$
$$g_y = \text{cons tan t} - (1 - e^{-\beta T})\ln y_0 + X\delta + (I - \lambda W)^{-1}\nu \qquad (4)$$

In this case, it is observed how a random shock in a region affects growth rates in that region and additionally impacts all the other regions through the spatial transformation. As a result, (4) recognises the presence of global externalities associated solely with random shocks.

The spatial error model in (4) can be expressed in the form of the spatial Durbin representation:

$$g_y = (I - \lambda W)\text{constant} - (1 - e^{-\beta T})\ln y_0 + \lambda W g_y + \lambda(1 - e^{-\beta T})W \ln y_0 + X\delta - \lambda WX\delta + \nu \quad (5)$$

The spatial Durbin makes explicit the large number of parametric constraints that are involved in the spatial error model when conditioning variables are included in the growth equation.

Finally, the spatial cross-regressive model includes the spatial lag of initial income per capita as a right-hand-side variable:

$$g_y = \text{constant} - (1 - e^{-\beta T})\ln y_0 + X\delta + \tau W \ln y_0 + \varepsilon \quad (6)$$

As the effect of the spatial lag of income per capita is restricted to the first order neighbours, externalities are in this case local.

It should be emphasised that most of the contributions have focused their attention on the spatial lag and the spatial error models, neglecting the spatial cross-regressive specification. This might be due to the non-significance of the coefficient for the spatial lag of initial income in some influential studies (see Fingleton, 2003). Table 1 summarises the major characteristics and the preferred specification for studies that have included spatial dependence in the convergence equation. Results from most of the studies favour the spatial error model against the spatial lag specification, that is they support nuisance spatial dependence in the convergence equation. However, the presence of residual spatial dependence, and its modelling as a spatial error model, may reflect a more insidious cause, that it is a manifestation of the omission of one or more spatially autocorrelated variable from matrix X in equation (1). After all, it is unlikely that such a simple model is likely to capture all of the actual causes of variation in productivity growth. Only two of the studies select the spatial lag model and then conclude in favour of substantive spatial dependence. Interestingly, the first group of studies does not include conditioning variables in the growth equation, while the two selecting the spatial lag model do.

Spatial dependence in the Verdoorn's Law

In its simplest form, the empirical specification for the Verdoorn's Law can be written as:

$$p = \text{cons}\tan t + \frac{\gamma - 1}{\gamma} q + \varepsilon \tag{7}$$

where p and q are growth in labour productivity and in output of the manufacturing sector respectively, and ε is a well-behaved error term. When $\gamma > 1$ the technology of production in manufactures is characterised by increasing returns to scale, and thus output grows more than proportionally with employment.

The spatial counterparts of (7) mimic those previously given for the convergence equation. Specifically, the spatial lag model is:

$$\begin{aligned} p &= \text{cons}\tan t + \frac{\gamma - 1}{\gamma} q + \rho W p + \varepsilon \\ p &= (I - \rho W)^{-1} \left(\text{cons}\tan t + \frac{\gamma - 1}{\gamma} q + \varepsilon \right) \end{aligned} \tag{8}$$

The spatial error model is:

$$\begin{aligned} p &= \text{cons}\tan t + \frac{\gamma - 1}{\gamma} q + \varepsilon, \quad \varepsilon = \lambda W \varepsilon + \nu \\ p &= \text{cons}\tan t + \frac{\gamma - 1}{\gamma} q + (I - \lambda W)^{-1} \nu \end{aligned} \tag{9}$$

The spatial Durbin representation becomes:

$$p = \text{cons}\tan t + \frac{\gamma - 1}{\gamma} q - \lambda \frac{\gamma - 1}{\gamma} W q + \lambda W p + \nu \tag{10}$$

Finally, the cross-regressive model is:

$$p = \text{cons}\tan t + \frac{\gamma - 1}{\gamma} q + \tau W q + \varepsilon \tag{11}$$

As for the empirical evidence, Table 2 summarises the contributions that have introduced spatial dependence as an additional element of Verdoorn's Law. Bernat (1996), for the US States, prefers the spatial error model given the absence of spatial regimes, although when they are included the preferred model has the spatial lag of labour productivity. Pons-Novell and Viladecans (1999) replicating the same analysis for the NUTS I EU regions, and Fingleton (2001, 2004) also opts for the spatial lag model using data for the NUTS II

EU regions. In the former study no additional RHS variable variables are included, while in the later they are.

Summing up, the empirical evidence on growth models with spatial dependence suggests that, especially when no additional variables are included in the list of regressors, the spatial error model is the chosen specification. In fact the spatial error specification may be a catch-all for omitted spatially autocorrelated regressors. Nevertheless the implication of the spatial error specification for the transmission of externalities is that they are essentially transmitted as random shocks. This is contrary to our idea that spatial externalities such as described above are essentially a substantive phenomenon, in other words we prefer to treat them as effects with explicit and defined causes that can be modelled, we believe they have little to do with random shocks diffusing through space.

3. Externalities in Growth and Substantive Spatial Dependence

In this section, we will show how two growth models with externalities across regions due to knowledge diffusion can help us to understand why straightforward application of spatial econometrics tools are likely to fail to select the appropriate spatial dependence structure for empirical growth specifications. The models have been recently proposed in the literature by Fingleton (2001 and 2004) in the tradition of the Verdoorn's Law but with foundations from the New Economic Geography, and by López-Bazo et al (2004) within the framework of the economic growth models.

Substantive spatial externalities in the convergence equation

López-Bazo et al (2004) start from a simple economy in which average labour productivity in region i in period t, y_{it}, is a function of the average level of physical and human capital per unit of labour (k_{it} and h_{it}) and the state of technology, A_{it}:

$$y_{it} = A_{it} k_{it}^{\tau_k} h_{it}^{\tau_h} \tag{11}$$

where τ_k and τ_h are internal returns to physical and human capital respectively. Technology in a region, A_{it}, is assumed to depend on the technological level of the neighbours, which in turn is related to their stock of both types of capital:

$$A_{it} = \Delta_t (k_{\rho it}^{\tau_k} h_{\rho it}^{\tau_h})^{\gamma} \qquad (12)$$

where $k_{\rho it}$ and $h_{\rho it}$ denote the physical and human capital-labour ratios in the neighbouring economies, and γ measures the externality across economies that is assumed to be positive: when $k_{\rho it}$ ($h_{\rho it}$) increases by 1% —causing an increase in the technology of those regions, technology in region i goes up by $\gamma\tau_k$ % ($\gamma\tau_h$ %).

Under such technology of production, the steady state level of labour per capita in any given region will positively depend on the stock of physical and human capital in its neighbouring regions in the case of positive spatial externalities ($\gamma > 0$):

$$y^* = \left(\frac{s_k^{\tau_k} s_h^{\tau_h} k_\rho^{\gamma\tau_k} h_\rho^{\gamma\tau_h}}{(n+g+d)^{\tau_k+\tau_h}} \right)^{\frac{1}{1-\tau_k-\tau_h}} \qquad (13)$$

while the dynamics in the proximity of the steady state is characterised by the following growth equation:

$$\begin{aligned} g_y = \xi - (1-e^{-\beta T})\ln y_0 + \frac{(1-e^{-\beta T})\gamma}{1-(\tau_k+\tau_h)} \ln y_{0\rho} + \gamma g_{y_\rho} + \\ \frac{(1-e^{-\beta T})}{1-(\tau_k+\tau_h)} \left[\tau_k (\ln s_k - \ln(n+g+d)) + \tau_h (\ln s_h - \ln(n+g+d)) \right] \end{aligned} \qquad (14)$$

where β=(1-τ_k-τ_h)(n+g+d) is the rate of convergence and

$$\xi = (1+\gamma)g - (1-e^{-\beta T})\left(1 - \frac{\gamma}{1-(\tau_k+\tau_h)}\right)(\ln\Delta_0 + gT)$$

The empirical counterpart of (14) can be expressed as:

$$g_y = \text{constant} - (1-e^{-\beta T})\ln y_0 + X\delta + \phi_{Wy}\ln Wy_0 + \gamma W g_y + \varepsilon \qquad (15)$$

This expression clearly indicates that both growth and initial income in the neighbours matter for regional growth, and those externalities across economies originated by knowledge diffusion induce substantive spatial dependence in the convergence equation. It can also explain why the empirical evidence based on the traditional spatial model selection procedure has shown preference for the spatial error specification. In brief, it is because the similarity between the expression in (15) and the Durbin representation of the spatial error model when no conditioning —X— variables are included:

Spatial Durbin representation

$$g_y = (I - \lambda W)\text{constant} - (1 - e^{-\beta T})\ln y_0 + \lambda W g_y + \lambda(1 - e^{-\beta T}) W \ln y_0 + u$$

Our model (16)

$$g_y = \text{constant} \qquad - (1 - e^{-\beta T})\ln y_0 + \gamma W g_y + \gamma(1 - e^{-\beta T})\ln W y_0 + u$$

However, when control variables are included, both expressions clearly differ (the more the higher the number of conditioning variables):

Spatial Durbin representation

$$g_y = (I - \lambda W)\text{constant} - (1 - e^{-\beta T})\ln y_0 + \lambda W g_y + \lambda(1 - e^{-\beta T}) W \ln y_0 + X\delta - \lambda W X \delta + u \qquad (17)$$

Our model

$$g_y = \text{constant} \qquad - (1 - e^{-\beta T})\ln y_0 + \gamma W g_y + \gamma(1 - e^{-\beta T})\ln W y_0 + X\delta + u$$

Substantive spatial externalities in the Verdoorn's Law

Building on a new economic geography model, Fingleton (2001 and 2004) derives an expression equivalent to the Verdoorn Law. Concretely, in his model output per worker in the manufacturing sector (Q/E) is related to output and to the rate of technical progress (η):

$$\ln(Q/E)_t = \frac{\ln(\phi)}{\gamma} + \left[\frac{\gamma - 1}{\gamma}\right]\ln(Q)_t - \ln(\beta) + \ln(A_0) + \eta t \qquad (18)$$

where γ is the measure of the returns to scale in the manufacturing sector, A_0 the initial level of technology, t is time, and ϕ and β parameters that characterise the technology of production of manufactures. The rate of technical progress is assumed to depend on three groups of variables: human capital (H), the initial level of technology (G) and the spillover of knowledge across regional boundaries ($W\eta$):

$$\eta = \nu H + \pi G + \rho W \eta + \xi$$

$$\eta = (I - \rho W)^{-1}(\pi G + \upsilon H + \xi) \tag{19}$$

where an autonomous rate, ξ, is added since it is assumed that technical progress will occur as a result of learning by doing irrespective of the other factors.

Inserting (19) into (18) and differentiating with respect to time and inserting a well-behaved perturbance, ε, results in:

$$\begin{aligned} p &= \frac{\gamma - 1}{\gamma} q + (I - \rho W)^{-1}(\pi G + \upsilon H + \xi) + \varepsilon \\ p &= \frac{\gamma - 1}{\gamma} q - \rho \frac{\gamma - 1}{\gamma} Wq + \rho Wp + \pi G + \upsilon H + \xi + (I - \rho W)\varepsilon \end{aligned} \tag{20}$$

where p and q are growth in labour productivity and in output respectively.

As in the case of the convergence equation in (15) derived from a growth model with externalities across regions, the expression in (20) includes the spatial lag of growth of labour productivity and of growth of output. Thus, once again knowledge diffusion across regional boundaries provokes substantive spatial dependence in a Verdoorn-like growth specification. The equivalence of the Durbin representation of the spatial error model and the specification in (20) when human capital and the technology gap are omitted is again obvious in this case, suggesting that choosing the spatial error model in preference to substantive spatial dependence in the Verdoorn specification might be erroneous and mostly caused by misspecification due to the omission of factors determining the rate of technical progress.

4. Empirical Evidence

The aim of this section is twofold. Firstly, we illustrate for the case of the EU regions how the traditional spatial model selection procedure might not provide robust evidence on the preferred type of spatial dependence, and thus might lead to erroneous conclusions on the kind of external effects across regions. Secondly, we show estimates of the growth specifications discussed in the previous section. Strong conclusions can be drawn on the existence and the strength of spatial externalities as in this case specifications are built on a structural model of growth with knowledge diffusion across regions. We present the empirical evidence for both the convergence equation and Verdoorn's Law.

Convergence equation

Here we summarised some of the results obtained in López-Bazo et al (2004) to show that the spatial error model is preferred over the spatial lag specification only when the analysis is based on the absolute β-convergence equation, that is when no conditioning variables are included in the regression. In contrast, when we test for conditional β-convergence the evidence supports substantive spatial dependence. The sample and the variables used in the analysis are described in detail in the above-mentioned reference. It is a sample of 108 EU regions for the 12 first-entry countries. The variable under analysis is labour productivity in the period 1980-1996.

Table 3 shows the results for the spatial dependence tests (see for instance Anselin et al, 1996) and the COMFAC test. As stated above, they have been used to select the preferred specification for spatial dependence. Results were obtained for a weight matrix based on the inverse of the square distance, although they are robust to some other definitions of the W matrix. In the case of the absolute convergence specification (first column of Table 3), results for the spatial dependence test suggest strong spatial dependence, and clearly point to the spatial error model as the favourite specification (the robust version of the Lagrange Multiplier error test rejects its null hypothesis of no spatial dependence, while the test for the spatial lag does not). In addition, the COMFAC test does not reject the null hypothesis, that is to say the parametric constraints in the spatial Durbin representation in (16) are not rejected in the sample of EU regions.

The conclusion completely changes when conditioning variables are included in the convergence equation. In this case, results for the spatial autocorrelation tests in column 2 of Table 3 clearly indicate that there is substantive spatial dependence (the robust spatial lag test rejects its null while the robust error test does not). Accordingly, the COMFAC test rejects the parametric constraints in the Durbin representation in (17). As indicated in the previous section, similarity between the empirical specification derived from the theoretical model and the Durbin representation only exist when no control variables that account for differences in the steady-states are considered in the analysis. When they are both models are not longer observationally equivalent.

Following our proposal, we base our conclusions about the existence and strength of spatial externalities on estimates from our structural growth model in (15). Table 4 summarises these results in the case of not including conditioning variables (first column) and when they are included (second column). The coefficient associated with knowledge diffusion across regions is statistically significant, positive and very large in magnitude. Thus, results for the sample of EU regions support our assumption on the importance of externalities in the production process that cross regional boundaries. It should be notice that this result is robust to the inclusion of conditioning variables in the estimated model. Additionally, there is no evidence of remaining spatial dependence or heterogeneity in the growth equation once we include externalities across regions.

The Verdoorn Law specification

The evidence that is used to illustrate the issue of spatial effects under the Verdoorn law specification is taken from Fingleton (2004) and from our own calculations. In this case the data are for 178 EU regions over the period 1975-1995, and focus on productivity in the manufacturing sector. The weight matrix takes into account the size of each regional economy, measured by its output, and the square of the distance between each pair of regions ($Q_j d_{ij}^{-2}$). Table 5 reproduces the results of the spatial dependence tests for the case of the expanded Verdoorn's specification in Fingleton (2004). There is strong evidence of spatial autocorrelation in the non-spatial Verdoorn equation. As in the case of the conditional convergence equation, the preferred specification with additional regressors is the spatial lag (only the robust LM-LAG rejects the null hypothesis, and constraints on the parameters of the Durbin representation are rejected at the 5% level, as indicated by the COMFAC test).

Estimation of the coefficients of the structural model (Table 6) confirms the existence of a high rate of technological diffusion across regions: more than 50% of technical progress generated in a representative EU region diffuses to its 'neighbours'. And the inclusion of technological diffusion in the growth equation completely accounts for spatial dependence in the manufacturing productivity growth rates.

5. Conclusions

There has been a remarkable surge of interest in 'geographical economics' or 'the new economic geography', prompted by the publication of the book by Fujita, Venables and Krugman(1999). This new wave of theory put economic geography centre stage within mainstream economics, since it established the notion that increasing returns could coexist within a theoretical framework with explicit microeconomic foundations. Regional science and regional economics, which had tended to be somewhat marginalized, has now become a focus of attention. However the development of formal models has been at a cost, for although the idea of externalities is central to the new economic geography theory, and in related urban economic theory (Abdel Rahman and Fujita, 1990, Rivera Batiz 1988), in the purest form of these models the only externalities present are pecuniary externalities, representing market interdependence. The idea that technological externalities are also relevant is somehow squeezed out, being too difficult to accommodate within formal models. Nonetheless, many geographical economists have attempted to capture both pecuniary and technological external economies in their empirical models, reflecting their broader emphasis both on theoretical consistency and on empirical veracity. This is particularly the case when regional economists have applied spatial econometric models, fitting these models to real data. Without controlling also for externalities, in the form of spillovers between regions, the models are invariably poorly specified and fail the diagnostic tests that are the accepted professional standards of the spatial econometrics community. Various approaches have been adopted in attempting to introduce externalities into spatial econometric models, with two main strands appearing in the literature. One treats the externalities in a somewhat ad hoc manner as random shocks, which impact within a specific region and simultaneously spill over into other, frequently neighbouring, regions. In these models there is no attempt to explicitly model the sources of these external effects. The second strand attempts to model the causes of the externalities. This paper argues that there is good reason to favour this second approach, although it may be more demanding in terms of data. Looking at some of the literature, we find that usually it is the spatial error model that is preferred on the basis of simple specifications that are devoid of conditioning variables. The external effects are simply treated as nuisance variables. On the other hand, in the presence of conditioning variables, such as in neoclassically-oriented conditional convergence models of economic growth or in enhanced Verdoorn-like models with a basis in the new economic geography and urban economics, it is frequently models with an explicit representation of the spillover process that are chosen. Often these models have exogenous spatial lags or perhaps an endogenous spatial lag, or both, thus representing spillovers as substantive rather than nuisance effects. Our preference is for this type of explicit externality modelling, since it is our understanding that often the selection of the spatial error model on the basis of diagnostic indicators reflects the existence of omitted effects that should, if possible, be included as important and explicit variables in our modelling.

References

Abdel-Rahman H Fujita M (1990) Product variety, Marshallian externalities and city size, *Journal of Regional Science* 30: 165-183.

Anselin L (1988) *Spatial econometrics: methods and models*. Dordrecht: Kluwer Academic Publishers.

Anselin L, Bera AK, Florax R and Yoon MJ (1996) Simple diagnostic tests for spatial dependence, *Regional Science and Urban Economics* 26: 77-104.

Anselin L (2003) Spatial externalities, spatial multipliers and spatial econometrics, *International Regional Science Review* 26, 153-166.

Arbia G, Basile R and Salvatore M (2003) Measuring spatial effects in parametric and nonparametric modelling of regional growth and convergence, mimeo, Univeristy G. D'Annunzio, Pescara, Italy.

Anselin L and Rey SJ (1991) Properties of tests for spatial dependence in linear regression models, *Geographical Analysis* 23: 112-131.

Armstrong H (1995) Convergence among regions of the European Union, 1950-1990, *Papers in Regional Science*, 74, 143-152.

Barro R and Sala-i-Martin X (1992) Convergence, *Journal of Political Economy* 100: 223-251.

Baumol WJ (1986) Productivity Growth, convergence, and welfare: what the long-run data show, *American Economic Review* 76: 1072-1085.

Baumont C, Ertur C and Le Gallo J (2001) A spatial econometric analysis of geographic spillovers and growth for European Regions, 1980-1995, *LATEC - Document de travail - Economie* # 2001-04

Bernat A (1996) Does manufacturing matter? A spatial econometric view of Kaldor's laws, *Journal of Regional Science* 36: 463-477.

Bernard A and Jones C (1996) Productivity and convergence across U.S. States and industries, *Empirical Economics* 21: 113-135.

Carlino G and Mills L (1993) Are U.S. regional incomes converging?: A time series analysis, *Journal of Monetary Economics* 32: 335-346.

Carlino G and Mills L (1996) Convergence and the US States: a time series analysis, *Journal of Regional Science* 36: 597-616.

Chatterji M and Dewhurst J (1996) Convergence clubs and relative economic performance in Great Britain: 1977-1991, *Regional Studies* 30: 31-40.

Fingleton B (1999) Estimates of time to economic convergence : an analysis of regions of the European Union *International Regional Science Review* 22: 5-35.

Fingleton B (2003) Externalities, economic geography, and spatial econometrics: conceptual and modeling developments, *International Regional Science Review* 26: 197-207.

Fingleton B (2004) Regional economic growth and convergence: insights from a spatial econometric perspective, in Anselin L, Florax R and Rey S (Eds) *Advances in Spatial Econometrics*, Springer-Verlag, Berlin.

Fingleton B (2001) Equilibrium and economic growth: spatial econometric models and simulations, *Journal of Regional Science* 41: 117-147.

Fingleton B and McCombie JSL (1998) Increasing returns and economic growth: Some evidence for manufacturing from the European Union regions, *Oxford Economic Papers* 50: 89-105.

Florax R and Folmer H (1992) Specification and estimation of spatial linear regression models: Monte Carlo evaluation of pre-test estimators, *Regional Science and Urban Economics* 22: 404-432.

Fujita M, Krugman P and Venables A (1999) *The spatial economy: cities, regions, and international trade*. MIT Press, Cambridge, MA.

Harris R and Lau E (1998) Verdoorn's law and increasing returns to scale in the UK regions, 1968-91: some new estimates based on the cointegration approach, *Oxford Economic Papers* 50: 201-219

Kosfeld R, Eckey HF and Dreger Ch (2002) Regional convergence in the unified Germany: a spatial econometric perspective, *Economic Discussion Papers* No. 39/02, University of Kassel, Dept. of Economics.

León-Ledesma MA (2000) Economic growth and Verdoorn's law in the Spanish regions, *International Review of Applied Economics* 14: 55-69.

López-Bazo E, Vayá E and Artís M (2004) Regional externalities and growth: evidence from European regions, *Journal of Regional Science* 44: 43-73.

López-Bazo E, Vayá E, Mora AJ and Suriñach J (1999) Regional economic dynamics and convergence in the European Union, *The Annals of Regional Science* 33: 343-370.

Mankiw G, Romer D and Weil D (1992) A contribution to the empirics of economic growth, *Quarterly Journal of Economics* 107: 407-437.

Moreno R and Trehan B (1997) Location and the growth of nations, *Journal of Economic Growth* 2: 399-418.

Neven D and Gouyette C (1995) Regional convergence in the European Community, *Journal of Common Market Studies* 33: 47-65.

Niebuhr A (2001) Convergence and the effects of spatial interaction, *Jahrbuch für Regionalwissenschaft* 21: 113-133.

Pons-Novell J and Viladecans E (1999) Kaldor's laws and spatial dependence: evidence for the European regions, *Regional Studies* 33, 443-451.

Rey S and Montouri B (1999) U.S. regional income convergence: A spatial econometric perspective, *Regional Studies* 33: 143-156.

Rivera-Batiz F (1988) Increasing returns, monopolistic competition, and agglomeration economies in consumption and production , *Regional Science and Urban Economics* 18: 125-53.

Sala-i-Martin X (1996) Regional cohesion: evidence and theories of regional growth and convergence, *European Economic Review* 40: 1325-1352.

Vayá E and Moreno R (2002) Econometría especial: nuevas técnicas para el análisis regional. Una aplicación a las regiones europeas, *Investigaciones Regionales* 1: 83-106.

Ying L (2003) Understanding China's recent growth experience: a spatial econometric perspectiva, *The Annals of Regional Science* 37: 613-628.

Table 1. Studies that have included spatial effects in the convergence equation.

Paper	Regions	Period	Spatial Specification
Armstrong (1995)	EU NUTS I, II	1950-90	Spat Error (no X)
Rey & Montouri (1999)	US States	1929-94	Spat Error (no X)
Vayá & Moreno (2002)	EU NUTS I, II	1975-92	Spat Error (no X)
Baumont et al (2003)	EU NUTS I, II	1980-95	Spat Error (no X)
Niebuhr (2001)	West Germany	1976-96	Spat Lag (with X)
Kosfeld et al (200?)	Germany	1992-2000	Spat Error (no X)
Arbia et al (2003)	Italy	1951-2000	Spat Error (with & without spat regimes)
Ying (2003)	China	1978-1998	Spat Lag (with X)

Table 2. Studies that have included spatial effects in the Verdoorn's model.

Paper	Regions	Period	Spatial Specification
Bernat (1996)	US States	1977-90	Spat Error (no spatial regimes) Spat Lag (with spatial regimes)
Pons-Novell & Viladecans (1999)	EU NUTS I	1984-92	Spat Lag (no X)
Fingleton (2004)	EU NUTS II	1975-95	Spat Lag (with X)

Table 3. Tests for spatial dependence in the convergence equation.

CONTROL VARS	NO	YES
I-Moran	10.896***	8.276***
LM-ERR	93.311***	41.948***
Robust LM-ERR	23.456***	1.007
LM-LAG	69.864***	51.411***
Robust LM-LAG	0.010	10.470***
LR-COMFAC	0.128	17.641**

Notes: Results have been obtained for a distance based weight matrix.

** and *** denote significant at 5% and 1%

Table 4. Estimation of the growth equation with externalities across economies

γ	0.884***	0.893***
β	0.030***	0.024***
ϕ_{Wy}	0.237*	0.281***
CONTROL VAR	YES	NO
LnL	78.48	72.94
AIC	-134.95	-137.87
LR-LAG	46.369***	55.871***
LM-ERR	3.195*	2.63

Notes: Standard errors in brackets.

*, **, ***: means significant at 10%, 5% and 1%.

Table 5. Tests for spatial dependence in the Verdoorn's model

CONTROL VARS	YES
I-Moran	5.891***
LM-ERR	20.092***
Robust LM-ERR	2.460
LM-LAG	35.036***
Robust LM-LAG	17.403***
LR-COMFAC	10.341*

Notes: Standard errors in brackets.

***, **, *: means significant at 1%, 5% and 10%.

From Table 19.2 & Table A4 in Fingleton (2004)

Table 6. Estimation of the Verdoorn's equation with technological diffusion

ρ	0.552***
$(\gamma-1)/\gamma$	0.444***
π	0.041***
ν	0.049**
$\rho(\gamma-1)/\gamma$	-0.245

Notes: Standard errors in brackets.

*, **, ***: means significant at 10%, 5% and 1%.