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Explaining the distribution of manufacturing productivity in the EU regions

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Abstract: Regional inequalities in product per capita and labour productivity in the EU are large and persistent. Building on a model in which aggregate increasing returns is the result of the increase in the number of varieties of composite services, under competitive manufactures, we derive a simple and empirically tractable reduced form linking manufacturing productivity growth to the growth of manufacturing output. This specification is used to simulate the equilibrium distribution of labour productivity in the EU regions, that is compared with "virtual" distributions obtained by equalizing, for instance, the amount of returns to scale and the stock of human capital across regions. This way, the impact of some growth determinants on the whole EU regional equilibrium distribution can be assessed.

Keywords: growth, increasing returns, externalities, distribution dynamics

1 Introduction

In this paper, simulations of manufacturing productivity levels across the EU provide detailed insights regarding possible long-run distributions under various alternative assumptions about the determinants of productivity growth by EU NUTS 2 region. The explanation of manufacturing productivity growth by region is based on an econometric model embodying recent developments in urban economic theory and geographical economics, which includes both internal and external increasing returns and spatial externality (spillover) effects. The model implies market interdependence involving a competitive manufacturing sector and producer services under monopolistic competition. The assumption of technological externalities and the presence of cross-region spillovers in the model lead to a specification that is typical of recent approaches in spatial econometrics, which seeks to avoid bias by a specification involving spatial interdependence. We use recent developments in the analysis of growth empirics, involving the application of the estimated density function and the stochastic kernel, in order to visualize the long-run stochastic distributions under various assumptions. We control for the effects of various ancillary factors assumed to influence the equilibrium distribution so as to isolate the impact of each individual factors of interest. The visualizations enabled by the stochastic kernel clearly identify the effect of the different model variables on the entire regional distribution of manufacturing productivity. We compare and evaluate the different equilibria and discuss implications for the future welfare and development of the regions of the EU.

2 Distribution dynamics of EU regional productivity.

2.1 Density functions and stochastic kernels

Most contributions to the empirical growth literature have estimated growth equations in which growth rates are related to the rate of accumulation of factors of production, variables likely to affect the level of technology, and the initial level of output or income per capita (Barro, 1990; Mankiw et al, 1992; see also the survey of growth regressions in Durlauf and Quah, 1999). From estimates of the sign, magnitude and statistical significance of the coefficients, conclusions have been drawn about the causes of economic growth, and about the dispersion in the levels of development observed across economies. In this regard, attention has been focused in particular on the coefficient attached to the initial income level, which relates to the rate of convergence in a neoclassical growth model (Mankiw et al, 1992; Barro and Sala-i-Martin, 1992).

However, the so-called rate of β-convergence provides minimal information, by itself, about the tendency of the income per capita distribution in a set of economies to become concentrated at a common point or for the mechanisms associated with increased dispersion. It is evident that β-convergence analysis per se tells us little or nothing about other the processes associated with the emergence, stability and persistence of phenomena such as convergence clubs; i.e. the causes and dynamics associated with polarization (two groups) or stratification (more than two groups) in the distribution. These criticisms were originally formulated by Quah in a flurry of papers outlining alternatives to conventional β-convergence analysis(1993, 1996a,b,…). In short, the basic idea behind this critique is that the richness of the distributional changes cannot be captured by single figures such as the first moments. Likewise the analysis of regression coefficients simply gives the change in growth per unit change in the factors determining growth (such as investment in physical and human capital, R&D, fiscal policy, etc), controlling for the other variables, so that the focus is on a single 'typical' region and the impact of say a unit increase say physical capital on a region's growth, rather than providing illumination on the distributional consequences from the perspective of an entire system.

To overcome these shortcomings, when what matters is the relative performance of a set of economies, Quah argues that we should be more concerned with the cross-section distribution dynamics of inter-regional or international income per capita, a form of analysis that had already become well established in the wages and personal income distribution literature, and in studies of firm and industry mobility, etc. This analysis focuses attention on the external shape of the distribution, and on movements within the distribution. With regard to the external shape, one scenario might be that the distribution is undergoing a process of collapsing to a single point, in which case the conclusion would be that the economies are involved in a process of convergence in the sense that the poor ones are approaching the level of the rich regions. Another possibility is that the distribution is characterized by increasing dispersion over time. In both cases, the external distribution shape for different time periods allows us to visualize the ongoing process. Interestingly, the distribution shape also allows visualization of the presence or formation of convergence clubs, that is group of economies (clubs) that show internal convergence to steady states that are specific to each club. It is important to recognize that the external shape can remain unaltered even when there is churning in the distribution. In other words, the shape of the distribution at two points in time might be the same, but the implications differ if poor economies remain poor and rich remain rich compared with the situation in which a significant degree of churning occurs so that those poor at the beginning are now the rich, and vice versa. Thus, the focus on intra-distribution mobility reveals how economies transit from any point in the distribution to any other point at some future time, which at its simplest involves estimating the probability of a poor economy staying poor or becoming rich.

Since Quah's critique, a number of papers have applied methods that focus on mobility and dynamics in income per capita or related measures for systems of regions or sets of national economies (Bianchi, 1997; Fingleton, 1997; Magrini, 1999; López-Bazo et al, 1999; Johnson, 2000; Lamo, 2000). A general conclusion that can be drawn from this diverse set of papers is that the distribution of income per capita is characterized by notable persistence and, if anything, the movements that do occur are because of an ongoing process of polarization in which the poorest economies are being left behind, particularly in the case of a wide sample of countries.

An estimate of the external shape and mobility within the distribution is required to perform the type of analysis described above. This typically involves non-parametric estimation in which there is no a priori structure imposed on the data, on the contrary, non-parametric methods allow the data to speak for themselves. More specifically, the external shape of the distribution of income per capita for a sample of economies is measured by non-parametric estimation of the density function via the kernel method. It is useful to think of this kernel density estimator as a smooth version of a histogram describing the distribution, so that the "bars" in the histogram are replaced by smooth "bumps" (Silverman 1986). Smoothing is accomplished by putting less weight on observations that are further from the point being evaluated. More technically, the kernel density estimate of a series X at a point x is estimated by

$$f(x) = \frac{1}{Nh}\sum_{i=1}^{n} K\left(\frac{x - X_i}{h}\right) \tag{1}$$

where N is the number of observations, h is the bandwidth (or smoothing parameter) and K( ) is a kernel function that integrates to one. The kernel function is a weighting function that determines the shape of the bumps. We have used the Gaussian kernel in our estimates:

$$\frac{1}{\sqrt{2\pi}}\exp\left(-\frac{1}{2}u^2\right) \tag{2}$$

where u is the argument of the kernel function. The bandwidth h controls the smoothness of the density estimate; the larger the bandwidth, the smoother the estimate. Bandwidth selection is of crucial importance in density estimation, and various methods have been suggested in the literature. We have used the data-based automatic bandwidth suggested by Silverman (1986, equation 3.31):

$$h = 0.9N^{-1/5}\min\{s, Q/134\} \tag{3}$$

where s is the standard deviation, and Q is the interquartile range of the series.

Intra-distribution dynamics can be analyzed through the estimation of a stochastic kernel (Stokey and Lucas, 1989) for the distribution of income per capita over the period under analysis. This is merely the counterpart of a first order Markov probability of transitions matrix where the number of states tends to infinity, that is to say, where the length of the range of income defining each state tends to zero. Thus, the stochastic kernel provides the likelihood of transiting from one place in the range of values of income to the others[1].

[1] See Durlauf and Quah (1999) for a formal definition and some properties of stochastic kernels in the study of distribution dynamics.

Following Johnson (2000), let R (the ratio of productivity in each economy to the leading economy) be the variable under analysis, and $f_t(R=x)$ and $f_{t+k}(R=x)$ the probability density of R=x in period t and t+k respectively. Assuming a first-order time-invariant process for the evolution of the distribution of R, and existence of marginal and conditional density functions for the R distribution, the relationship between both distributions can be summarized by:

$$f_{t+k}(R = y) = \int_0^1 g_k(R = y \mid R = x) f_t(R = x) \tag{4}$$

where $g_k(R=y|R=x)$ is the density of R=y in period t+k conditional on R=x, k periods before. Then, $g_k(R=y|R=x)$ summarizes information on movements within the distribution over time. It is computed by first estimating the joint density for the distributions at t and t+k by the kernel method[2] and then dividing it by the marginal density of R at t, obtained by integrating the joint density over R at t+k.

The stochastic kernel, that is the conditional density estimated from the data on R, is depicted in a three-dimensional graph such as the one in Figure 2 below. For each value of R at time t it shows the probability density 5 periods ahead, conditional on the density of that value at t. That is, it provides the probability of an economy starting at any ratio R at t ending up at any of the values after 5 years. The z-axis in the three-dimensional plot measures the conditional density of each pair of points in the x-y space that defines the values of the variable at t and t+5. The lines that run parallel to the t+5 axis measure the probability of transiting from the corresponding point in the t axis to any other point 5 periods ahead. The two-dimensional graph in the top right corner is a contour plot of the three-dimensional plot. Lines in this graph connect points at the same height on the three-dimensional plot, that is, points with the same density.

When the mass of probability is located along the positive diagonal, then this points to low mobility, in other words there is strong persistence. On the other hand, the kernel can shift above/below the diagonal, indicating increases/decreases in values of R at time t+5. It can also twist clockwise or counterclockwise. The former case would indicate convergence in the distribution, with the poor region having a high probability of moving to higher levels while a rich region would tend to move to a level below the starting level. In the limit, when the mass of probability is parallel to the t-axis, all economies end up at similar values in t+5 regardless of their position at time t. Finally, peaks in the kernel appear when there are attractors that encourage the formation of convergence clubs.

The ergodic density of R implied by the dynamics summarized by $g_k(R=y|R=x)$ is an approximation to the long-run shape of the distribution of the productivity ratios. It is the solution to:

$$f_\infty(R = y) = \int_0^1 g_k(R = y \mid R = x) f_\infty(R = x) \tag{5}$$

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[2] A gaussian kernel and bandwidth as described in Silverman (1986, Sect 4.3.2) were applied to estimate the joint densities. The Gauss procedure use to estimate the joint densities is the one created by G. Suettrim.

and can be compared with the actual density to predict what one might expect for the R distribution in the near future (under the assumption that the causes of the dynamics we observed remain stable into the future).

Finally, it is important to point out that the stochastic kernel can also be used to describe movements between two distributions, rather than being restricted to the analysis of the same variable at different points in time (Quah, 1996a). Cross-distribution analysis is carried out in section 5 where we estimate stochastic kernels to analyze movements between actual (unconditional) and simulated (conditional) distributions under different assumptions that are hypothesized to affect future EU regional productivity growth rates. The motivation here is to illustrate how conditioning factors influence the long-run distribution. Following the description given above, the resulting kernel is interpreted as the probability associated with each of the values in the simulated distribution, conditional on any given value in the actual distribution. In this case, when the mass of probability lies along the main diagonal, this indicates that the conditioning factor is not responsible for the variation in the actual distribution. In contrast, when a factor is responsible for most of the dispersion, conditioning out its effect will result in a kernel parallel to the unconditional distribution (so that economies share similar values when the effect of the factor is removed, regardless of their position in the original distribution).

2.2 Actual manufacturing productivity dynamics in the EU regions for the period 1975-1995

In this section we show estimated density functions based on our measure of the level of manufacturing productivity (manufacturing Gross Value Added per worker) for 178 EU regions over the period 1975-95. The analysis is based on the variable $R_{it}=P_{it}/P_t^*$ in which P_{it} refers to the level of labour productivity in region i (i = 1,…,,178) at time t (t = 1975, 1980, 1985, 1990, 1995), and P_t^* refers to the productivity level of the leading region at time t. Hereafter we refer to this variable as the "ratio" at time t. Of course *R'*s upper bound is 1 (the leading region) and its lower bound approaches 0, depending on the productivity level for the least productive region. Hence the densities were estimated by using a truncated Gaussian kernel (see Silverman, 1986).

Figure 1 shows that the distribution in 1975 is centred around a ratio of approximately 0.5, the majority of the distribution being somewhat distant from the leader. The two tails contain an important share of the overall distribution, and there appears to be a cluster of regions characterised by very low productivity (low *R*). Figure 1 also shows the distribution for 1985 and 1995, so we can trace the evolution of the shape of the distribution. It can be seen that there is clear persistence and development of an important "hump" at round about 0.2 and attenuation of the concentration of high productivity regions. We see that by 1985 the distribution has concentrated, although groups of regions with low and high ratios are even more clear in 1985 than in 1975. In the decade that follows, the distribution has become more dispersed. The reasons for this are complex, but seem to relate to the different regional responses to the deepening process of integration, EMU, etc. What is interesting is that the mass of probability at the right of the distribution seems to vanish, indicating that there is no obvious concentration of high productivity regions. In contrast, the cluster of low productivity regions remains a feature throughout the historical series. Generally, the distribution shows signs of polarisation.

The stochastic kernel in Figure 2 confirms what is revealed by visual inspection of densities over time: the distribution at the high and moderate values of R (high and medium productivity levels) is characterised by a comparative degree of fluidity in the "pecking order", while there is relative homogeneity in the very low productivity group, as indicated by the sharp peak on the vertical axis for low R. This suggests that there is minimal "churning" among the "poorer" regions, who are persistently near the bottom of the productivity ladder. However there is some change at the bottom because it is apparent that the very low productivity regions have become more homogenous, as illustrated by the clockwise turn in the kernel. Regions in the range of roughly 0 to 0.4 become more concentrated in the range 0.1 to 0.3.

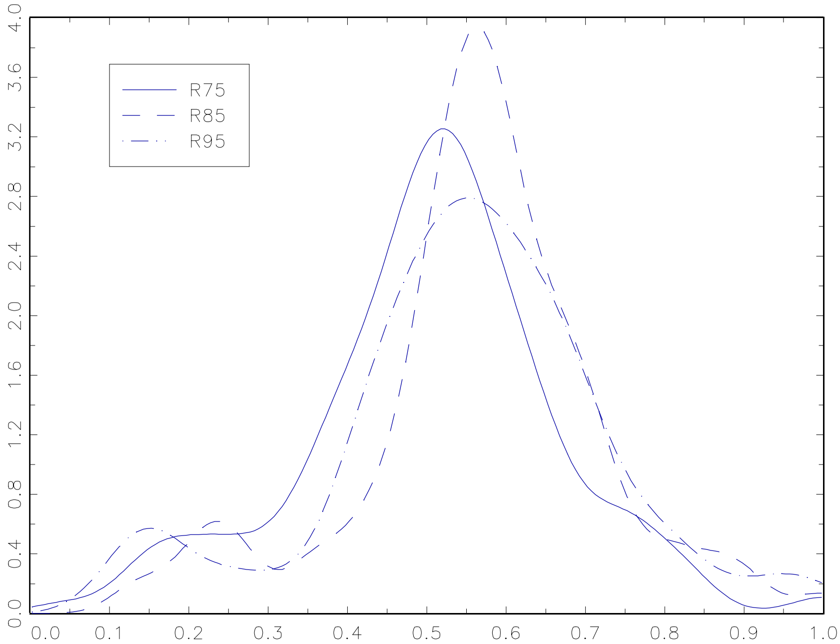

Fig. 1. Estimated density function for the productivity level ratios (R)

The ergodic distribution (Figure 3) is the long run equilibrium derived from the stochastic kernel based on the 5-yearly transitions described above. Some aspects of the historical data (Figures 1) are replicated in the equilibrium, for instance the mode is at roughly the same position, round about 0.4-0.5 . Note that despite the presence of an important right tail, the group of high *R*'s is evidently not a long-run phenomenon. It appears that there is no persistence in the concentration of high productivity regions that was evident in the historical data. On the other hand, the cluster of low productivities (R around 0.2) does appear to be a persistent long-run phenomenon, as indicated by the contrasting shape of the distribution to the left of the mode in Figure 3.

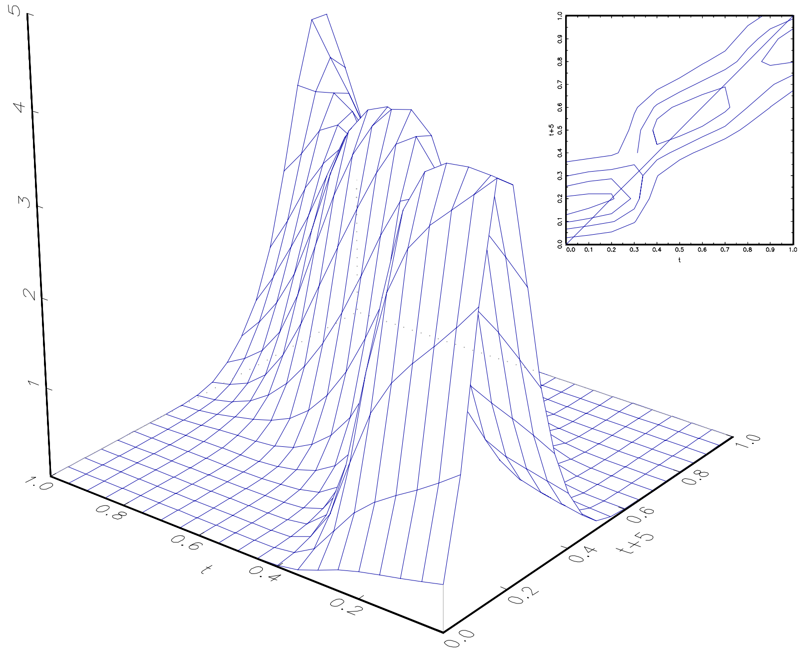

Fig. 2. Stochastic kernel for 5-yearly transitions for the productivity level ratios

3 A productivity growth model – theory

The subsequent empirical analysis of the paper is centred around a model of manufacturing productivity growth for the EU regions. At the core of this model is the concept of increasing returns, which has become popular in recent years within both urban economics (Rivera-Batiz, 1988, Abdel-Rahman and Fujita 1990, Quigley, 1998) and in geographical economics (Fujita, Krugman and Venables, 1999). The main technical innovation in this literature from the point of view of economic theory is that it allows increasing returns in city or region size while at the same time the decision problem for each actor is explicitly stated as one of profit or utility maximization. Increasing diversity or variety in producer inputs with increasing region size can yield external scale economies, even though firms are just breaking even (earning normal profits). So we see increasing returns to the economy as a whole in the context of competitive producers. This genre of model enables a general equilibrium solution by (almost invariably) utilizing the Dixit-Stiglitz theory of monopolistic competition. In the case of geographical economics, at its simplest, the market structure for industry is monopolistic competition while agriculture is competitive. In urban economics it is industry that is competitive, while non-traded producer "services" are treated as operating under monopolistic competition. The model in this paper, following Abdel-Rahman and Fujita (1990), likewise divides the economy into manufacturing and producer services, and follows the line of argument typified by the urban economics approach[3]. This ultimately leads to a simple and empirically tractable reduced form linking manufacturing productivity growth to the growth of manufacturing output, although because of the limitations of the basic theory, the model is extended by the inclusion of additional and necessary factors representing technological externalities (congestion, knowledge spillover) which go un-represented in the basic models outlined above[4].

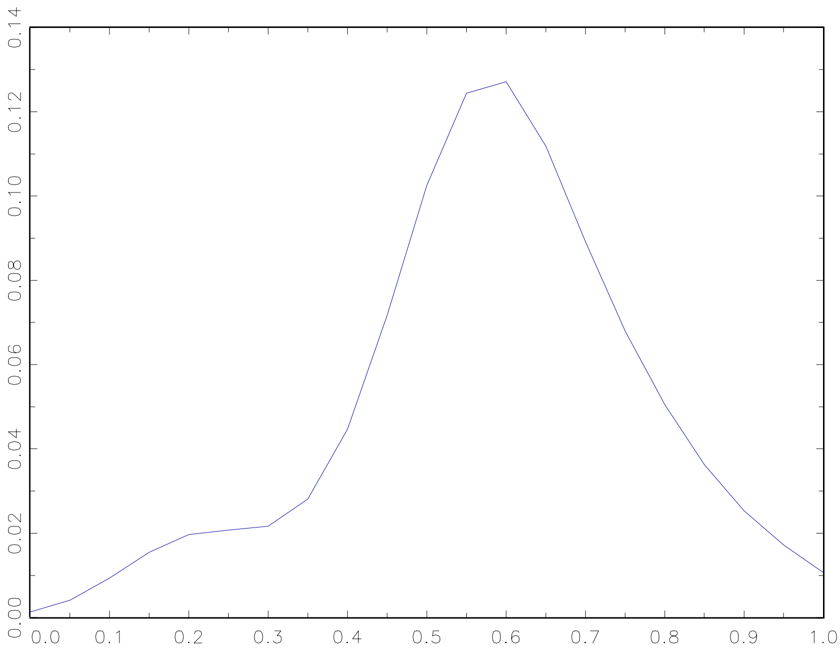

Fig. 3. Ergodic distribution from the stochastic kernel

[3] Fingleton (2001b) shows that the reduced form deriving from the model is identical to Verdoorn's law which is commonly used to represent increasing returns in manufacturing in the post-Keynesian literature.

[4] Krugman(1991) argues that while technological externalities may be relevant, they leave no paper trail and prohibit formal analysis. Pecuniary externalities on the other hand are embodied within the theory.

Figure 4 provides an informal portrayal of the relations involved in the basic Abdel-Rahman and Fujita model. This endeavours to show the impact of an exogenous shock to the labour force (region size) which suddenly becomes larger. This in turn, depending on the allocation of labour between the competitive manufacturing sector and the non-traded service sector, increases the level of composite services by increasing the number of service firms. The increase in manufacturing labour and the increase in the level of composite services increases the level of manufacturing output. The increased number of service firms is entirely equivalent to an increase in the number of varieties of services, and it is assumed that it is the variety of services available that is important to enhancing manufacturing production. A greater variety of intermediate services amounts to a finer division of labour. One has only to think of how much more efficient a manufacturer's production will be employing a range of specialized software writers each skilled in his or her own language (C++, Cobol, Fortran, Open GL etc) rather than a single 'jack of all trades' programmer, who has to get up to speed on each different language as is required. Overall therefore, it is reasonable to assume that manufacturing output in a city or region will be related to the quantities of manufacturing labour, space and to the number of different producer inputs available in that city.

The theory of monopolistic competition provides the reason why an increase in service labour maps to an increase in service variety, rather than more of the same variety. Monopolistic competition envisages a large number of service firms producing differentiated services and firms freely entering the sector until profits go to zero (ie each firm earns normal profits). The existence of fixed costs means that firms prefer to concentrate on a single variety and reap internal economies of scale, there is no point in a variety's production being split. Without fixed costs, average costs do not fall with increasing output, and there are no internal scale economies. Since each firm is the producer of its own differentiated service, the ensuing monopoly power allowing prices to be a mark up on marginal costs. There is an equilibrium level of output and therefore equilibrium labour requirement per service firm which is a constant, these equilibrium values depend on exogenous parameters and are therefore unaffected by an exogeous shock to labour. More service labour with a constant labour requirement per firm equals more firms and hence more varieties. The economics of the service firm are illustrated by the boxes below the dotted line in Figure 4 and the exogenous parameters are indicated by the *s, with the letter c denotes the constant equilibrium level of output and the labour requirement per service firm.

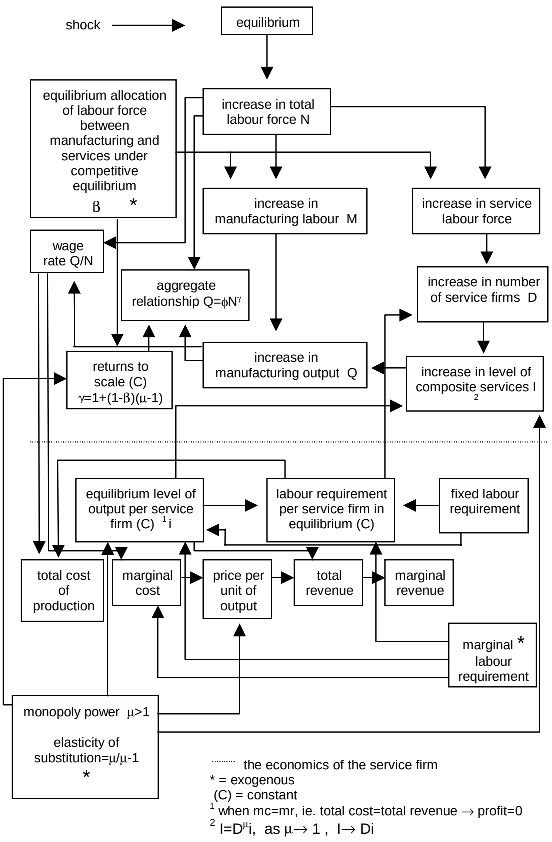

Fig. 4. Relations in the basic Abdel-Rahman and Fujita model

The level of monopoly power in the service sector is given by the exogenous parameter[5] μ. As μ increases, we see rising monopoly power and falling elasticity of substitution. More monopoly power enhances the level of composite services providing an input to manufacturing output. As μ falls back towards 1, the level of composite services approaches the number of firms times the equilibrium level of output per firm. This combines with β, the coefficient of the Cobb-Douglas production function for manufacturing. The set up is such that for $\mu > 1$ and $\beta < 1$, the relationship between the overall level of manufacturing output (*Q*) and the size of the total labour force (*N*) is nonlinear, in other words the initial shock to labour produces a greater than proportionate increase in the level of manufacturing output. The elasticity γ depends on the exogenous parameters and is a measure of returns to manufacturing production with increasing *N*. For increasing returns, services have to be relevant ($\beta < 1$) to manufacturing output and each service firm has to exert a degree of monopoly power under monopolistic competition ($\mu > 1$). Since μ also equals the ratio of average to marginal costs at the equilibrium point for service firms, internal increasing returns in the service sector are translated into external increasing returns for manufacturing.

The equations in the Appendix give the formal model: these lead to the reduced form at the core of the empirical model of the paper linking manufacturing output (*Q*) to the intensity of activity in a unit area given by the total labour force (*N*).

We derive the reduced form by substituting the level of composite services *I* into the Cobb-Douglas production function giving the manufacturing production technology. In this the level of manufacturing output *Q* is a function of the input of manufacturing labour *M* and *I*. Note that manufacturing is competitive, with constant returns.

$$Q = M^{\beta} I^{1-\beta} \tag{6}$$

The level of composite services is determined by the CES production function. This is

$$I = \left[\int_{d=1}^{D} i(d)^{1/\mu} \partial d \right]^{\mu} \tag{7}$$

In which *i(d)* is the "typical" output of a service variety, and there are D varieties. Since we assume a very large number of varieties we approximate the continuous integral by the discrete summation. At equilibrium *i(d)* is a constant across all varieties (see Appendix) and therefore we can reduce the summation to a product as follows

[5] This is the substitution parameter of the CES production function, which determines the elasticity of substitution, the price elasticity of demand and the internal returns to scale given by the average cost to marginal cost ratio for producer services in equilibrium.

$$I = [\sum_{d=1}^{D} i(d)^{1/\mu}]^{\mu} = [Di(d)^{1/\mu}]^{\mu} = D^{\mu} i(d) \quad (8)$$

Given this simplified form, we substitute for *I* and use the equilibrium values for the number of varieties *D* and *M*[6] to obtain the relationship between *Q* and *N,* hence

$$\begin{aligned} &Q = M^{\beta} I^{1-\beta} \quad (9)\\ &I = D^{\mu} i(d)\\ &Q = M^{\beta}(D^{\mu} i(d))^{1-\beta}\\ &Q = M^{\beta} D^{\mu-\mu\beta} i(d)^{1-\beta}\\ &D = \frac{(1-\beta)N}{ai(d)+s}\\ &M = \beta N\\ &Q = N^{\beta+\mu-\mu\beta}\beta^{\beta}(ai(d)+s)^{\mu(\beta-1)} i(d)^{1-\beta}(1-\beta)^{-\mu(\beta-1)}\\ &Q = N^{\beta+\mu-\mu\beta}\phi'\\ &Q = \phi' N^{1+(1-\beta)(\mu-1)} \end{aligned}$$

In which *s* is the fixed labour requirement and *a* is the marginal labour requirement of producer services (see Appendix).

In short,

$$Q = \phi' N^{\gamma'} \quad (10)$$

in which γ is the elasticity with

$$\gamma' = [1 + (1-\beta)(\mu - 1)] \quad (11)$$

The model outlined thus far excludes technological externalities, and yet it is necessary, in the interests of unbiased estimation and realistic simulation, not to exclude significant variables. The "two" externalities we are concerned with are the effects of congestion and the impact of knowledge flows on productivity growth. With regard to congestion, there are of courses many sources, for instance congestion involves interaction between firms, who "get in each others' way" or "step on each other's toes" (Cameron, 1996), and this affects their costs. Congestion arises when firms use common, but unpriced inputs[7] in short supply, such as roadspace or other communications networks or unpolluted air or water.

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[6] This assumes that the economy is at a competitive equilibrium and workers are paid the value of their marginal product.

[7] Since they are unpriced, the market has failed and therefore there is no market; we treat them as technological as opposed to pecuniary externalities. They are concerned with the technical relationship between inputs and outputs, with the structure of the production function rather than with prices in a market. If the congestion effect was due to outputs so

Congestion therefore comes from various sources which make production more costly on a restricted space. Measuring the impact of each is likely to be difficult, and as Gordon and McCann(2000) argue that we can only observe the net realized effects of diverse simultaneous externality mechanisms, rather than individual sources. We are more concerned with the effects of congestion on production rather than its diverse causes, and so simply model its impact in terms of a parameter in the manufacturing production function (see Ciccone and Hall, 1996). In fact it is easy to see the way we model congestion by introducing land (*L*) explicitly, hence

$$Q = \left[M^{\beta} I^{1-\beta}\right]^{\alpha} L^{1-\alpha} \tag{12}$$

In contrast, we have so far assumed L = 1 and worked in terms of output per unit area (since $1^{1-\alpha} = 1$, we could leave *L* out of the production function). However, up to now we have also assumed that $\alpha = 1$, in other words the amount of land (ie *L*=1) makes no difference to the level of production. Hence *Q* per unit of land is not affected by congestion on that unit. By introducing $\alpha < 1$ we acknowledge that congestion is indeed a factor. Hence,

$$\begin{aligned} Q &= (M^{\beta} I^{1-\beta})^{\alpha} = (\phi' N^{\gamma'})^{\alpha} = \phi N^{\gamma} \\ \gamma &= \alpha[1 + (1-\beta)(\mu - 1)] \end{aligned} \tag{13}$$

Compared with what went before, this equation does not automatically imply external increasing returns. In order to move closer to a convenient reduced form, we linearize equation (13) by taking natural logarithms and rearranging to give an expression in terms of the level of manufacturing output per labour unit as a function of the level of manufacturing output, thus

$$\ln(Q/N) = \frac{\ln(\phi)}{\gamma} + \left[\frac{\gamma - 1}{\gamma}\right] \ln(Q) \tag{14}$$

This has the advantage of not requiring knowledge of the service sector per se, whereas information on manufacturing production is more accessible and reliable.

Also, assuming $M/N = \beta$, the preferred expression is in terms of the level of manufacturing output per unit of manufacturing labour, thus

$$\ln(Q/M) = \frac{\ln(\phi)}{\gamma} + \left[\frac{\gamma - 1}{\gamma}\right] \ln(Q) - \ln(\beta) \tag{15}$$

The second type of externality we wish to incorporate is knowledge spillover. This we have said has been largely omitted from formal theory. However technological externalities involving information spillovers within and between regions and cities are increasingly recognized (Fujita and Thisse 1996, Quigley 1998) as

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that the firms costs rise as the output of other firms rises, then we would have a pecuniary externality. However since congestion in a region is caused by the number of firms producing there, an input measure, it is a technological externality.

an important contributor to the spatial concentration of economic activity, reflecting the earlier work of Jacobs (1969) among others[8]. In what follows, attention focuses on the rate of technical progress as a manifestation of technological externalities. We see that technical progress is not confined by what exists within artificial region boundaries but influences and is influenced by technical progress in other regions, so that it varies by region rather than being an un-modeled constant.

In order to model the technical progress rate, consider the labour units to be labour efficiency units, hence

$$M_t = E_t A_t = E_t A_0 e^{\lambda t} \tag{16}$$

where E_t is the level of manufacturing employment and A_t is the efficiency level at time t that is determined by the initial level A_0 and the rate of technical progress λ. It then become possible to re-express the model in terms of the level of manufacturing (raw labour) productivity per unit area by substitution, hence

$$\ln(Q/E)_t = \frac{\ln(\phi)}{\gamma} + \left[\frac{\gamma - 1}{\gamma}\right]\ln(Q)_t - \ln(\beta) + \ln(A_0) + \lambda t \tag{17}$$

The assumption is that the technical progress rate λ depends on three groups of variables, namely human capital (H), the initial level of technology (G) and the spillover of knowledge across regional boundaries (S), plus an autonomous rate (ε) since we assume that technical progress will occur as a result of "learning by doing" irrespective of the other factors. Hence

$$\begin{aligned} &\lambda = \nu H + \pi G + \rho S + \varepsilon \\ &G = 1 - \frac{P}{P^*} = 1 - R \\ &S = Wp \\ &W_{ij}^* = Q_j^{\eta} d_{ij}^{-\delta} \\ &W_{ij} = \frac{W_{ij}^*}{\sum_j W_{ij}^*} \end{aligned} \tag{18}$$

Regions with substantial human capital assets are expected to make faster technical progress ($\nu > 0$) since human capital facilitates research, development and the spillover of knowledge on which technical progress depends. However human

[8] We can distinguish between urbanization externalities or Jacobs externalities (after Jane Jacobs) and localization externalities or Marshall-Arrow-Romer (MAR) externalities. While both involve knowledge spillovers between firms, MAR externalities restrict the spillover to firms in the same industry whereas Jacobs externalities refer to spillovers across different industries.

capital *(H)* itself is probably endogenous[9], being affected by the growth of technology as well as determining it. There is a paucity of accurate pan-European data that we can use as a measure of human capital, but we do have access to data on educational attainment rates by EU region. These data are based on a labour force survey for 1997 and give the share of the population aged 25-59 with higher educational attainment levels. There are undoubted problems of measurement error associated with these data which add to the potential endogeneity. However we are able to nullify these effects in estimation via the use of instrumental variables and two-stage least squares.

The second factor is G which represents the start-of-period level of manufacturing technology gap, or one minus the ratio of the region's manufacturing technology level in 1975 to that of the leading region. The presence of G reflects the ubiquitous public good dimension of knowledge. There is no distance effect involved, reflecting the fact that some components of knowledge are free to diffuse to any region, irrespective of geography. However, the hypothesis is that the impact will be spatially variegated. The reason is differential acceptance of knowledge because of its varying usefulness. Some regions will gain great benefit from the diffusion of knowledge from the technological frontier region, but it seems reasonable to assume that those that are close to the technological frontier will see only minor gains. It is therefore envisaged that there will be a positive relationship ($\pi > 0$) between the technical progress rate and the initial technology gap, although this is a testable hypothesis and not an assumption of the model. A positive relationship indicates catching-up due to the faster growth of the initially lower level technology regions, but a negative relationship implies regional divergence.

Next we turn to spatially impeded information flows. The hypothesis is that regions with fast technical progress occurring in "neighbouring" regions will see faster than otherwise technical progress, and regions with slower technical progress neighbours will see a technical progress slowdown. "Who your neighbours are" matters in this context, because of the impedance to information flow across space. Working with the so-called NUTS 2 regional system of the EU means that we are likely to see flows across region boundaries. This is because this regionalizing does not define quasi-self-contained economic regions[10] but rather regions are largely defined on a formal or administrative basis. In addition, national barri-

[9] For instance it is likely that fast productivity growth have increased schooling and the acquisition of skills, and the data used post-date the period of analysis.

[10] In a series of papers and books (eg Cheshire and Hay, 1989) Paul Cheshire and colleagues argue that functional urban areas (FURs) are more appropriate, but the problem with these is that they are dynamic rather than static entities, so that their definition is not fixed in time. Moreover, their precise definition is likely to be subjective and will not map to accessible data bases like the NUTs 2 system. The more or less self-contained nature of FURs is suggested as an advantage, but we argue that it is preferable to handle spatial interdependence at the modelling level since this gives the data analyst the flexibility to estimate in the context of realised spatial interdependence, rather than accept a definition of spatial independence among FURs that may not be true.

ers have been progressively reduced within the EU with the consequence that there are minimal barriers to remote cross-region spillover.

Two cross-region spill-over mechanisms are envisaged. One is based on the sharing of the same labour pool in a common local labour market area straddling regional boundaries, the thesis being that the rate of productivity growth occurring in one region will be transmitted to other nearby regions as workers embodying knowledge switch jobs within local labour market (i.e. journey to work) areas. It might be argued that this would be entirely a pecuniary externality operating via the labour market[11]. Firms may spend money training labour but not appropriate all the benefits if labour migrates to other firms who gain by not having to pay the full cost of that training. However, some knowledge transfer is not mediated by market transactions. For example some aspects of knowledge will be of a learning-by-doing variety accumulated on the job, and carried to other firms as an incidental attribute (quality) of labour, without price or market, but which nevertheless contributes to technical progress. For example a programmer may incidentally learn how to install and service hardware, and this knowledge may be carried forward and benefit the next firm, even though this knowledge was hidden and played no part in the labour market transaction.

The second mechanism involves demonstration effects[12] of the efficacy of knowledge for productivity. This involves inter-firm interaction across region boundaries. Because of proximity, firms locally and in nearby regions may be competitors for the same local markets (a "creative destruction effect"), or collaborate as part of a localized production chain. In either case, fast technical progress in neighbouring regions will tend to induce technical progress and thus fast productivity growth locally.

The assumptions set out above results in Wp being specified as the weighted average of labour productivity in "surrounding" regions, with surrounding broadly defined so as to acknowledged that even the remotest regions interact and that the EU comprises a more or less integrated economy. Size also is considered relevant, and to a degree offsets remoteness, because of the extensive trade and labour market that a large diverse local economy naturally generates. This is apparent in the definition of the absolute (conditional) level of interaction between regions i and j, namely W^* in which Q_j is the economy size proxy, the 1975 level of output in region j, so that given the size of region i, the interaction with region j is likely to be stronger if region j possesses a larger economy. Proximity is represented by the great circle distance (d_{ij}) between the centres of regions i and j. Given a presumably negative parameter(δ), increasing distance reduces the absolute conditional interaction between i and j. It is assumed that $\delta = 2$ and $\eta = 1$ as a result of trials of different values reported in Fingleton (2001a). The standardized matrix W, so that

[11] This is a version of the "surplus appropriability" problem, where an externality exists which is not a technological externality, due to the innovator not appropriating all the social gains from innovation because of imperfect price discrimination (Cameron, 1996).

[12] Or as Cameron(1996) puts it, a "standing on shoulders effect" due to knowledge leaks, imperfect patenting, in addition to the movement of skilled labour to other firms reducing rivals' costs.

cell entries sum to unity across rows with zeros on the main diagonal, means that the matrix product Wp is a vector of weighted averages.

The outcome of modelling spatial effects using the W matrix is

$$\lambda = \pi G + \upsilon H + \rho Wp + \varepsilon \tag{19}$$

Inserting (?.19) into (?.17), differentiating with respect to time, and inserting a well-behaved perturbance gives

$$p = \varepsilon + \frac{\gamma - 1}{\gamma} q + \pi G + \upsilon H + \rho Wp + \xi \tag{20}$$
$$\xi \sim N(0, \sigma^2 I)$$

where p is the logarithmic growth of manufacturing labour productivity (Q/E) and q is the logarithmic rate of growth of manufacturing output (Q).

The specification in (20) , with the endogenous spatial lag, is a model that is familiar to spatial econometricians. It is interesting to note that it implies labour productivity growth in any region is affected by output growth, the technology gap and the endowment of human capital in all the other regions in the system, though the amount of influence is decreasing in the factors that define the contact matrix, W. The estimation of this model requires two stage least squares to attain consistency.

The results given in Table 1 relate to 2sls estimation using instrumental variables in place of the endogenous regressors. Assuming that the technology gap variable G is exogenous leads to a second instrument, the spatial lag WG. There are two other instruments that we define, q_I and its lag Wq_I . The instrument q_I is defined by the 3 group method (described in Kennedy1992, and Johnston 1984) and takes values 1, 0 or -1 according to whether q is in the top, middle or bottom third of its ranking, which ranged from 1, the region with the slowest manufacturing output growth, up to 178. The assumption is that this mapping eliminates any correlation between q_I and ξ induced by simultaneity. With four instruments, and given three right hand side endogenous variables the necessary order condition for identification is satisfied, hence the equation is identified exactly. There are additional or alternative additional instruments that could be introduced leading to over-identification, and the results of using different instruments or estimation techniques are given in the cited references. Further details of alternative instruments and alternative estimation methods, and diagnostic tests of model assumptions, are given in Fingleton (2000, 2001a, b). Here we simply focus on the parameter estimates and standard errors for the model[13] outlined above as the basis of our simulation exercise. It is sufficient to note that all the variables are highly significant, for instance there is very strong evidence that $\rho > 0$ suggesting that the spillover of knowledge across region boundaries has a significant impact on the

[13] The estimates of Table 1 also include separate estimates of error variance for the two groups (i = 1,2) of regions defined as core (within 500 km of Luxembourg) and peripheral regions, which were shown to be necessary as a result of the diagnostic tests of error heterogeneity previously reported.

growth of manufacturing productivity. This is supplemented by the effect of human capital within each region, which also indicate that technical progress is enhanced by higher levels of human capital. Likewise, the significant link between q and p points to the presence of increasing returns. The estimated value of $\gamma = \alpha[1 + (1 - \beta)(\mu - 1)] \approx 1.5$, so that the effects of congestion (α) have not offset the effects of increasing returns in the service sector ($\mu > 1$) which are evidently relevant as an input to manufacturing production ($\beta < 1$). Finally, there is a strong positive link between productivity growth and the level of technology gap. This has implications for the dynamics associated with this model which are outlined below.

Table 1. Two-stage least squares groupwise heteroscedasticity estimates.

variable	Coefficient estimate	Standard error	t-ratio
constant	-0.0240	0.0084	-2.84
Q	0.3265	0.0820	3.98
G	0.0476	0.0071	6.66
H	0.0716	0.0274	2.61
Wp	0.4327	0.1640	2.64
σ^2 (periphery)	0.00024		
σ^2 (core)	0.00011		

4 Simulation of the long-run distribution of manufacturing productivity in the EU regions.

A pivotal feature of the dynamics is the coefficient on *G,* which determines whether the regions converge to a stable equilibrium or not. Define equilibrium as the state in which the expected rate of productivity growth p is exactly the same across regions. A critical assumption of the dynamics is the relationship between productivity growth p and the level of technology gap $G = 1 - R$, which embodies the level of productivity P which we assume depends on p, in other words,

$$P_{t+1} = P_t \exp(E(p_t)) \tag{21}$$

This indicates that an inexorable rise in productivity levels occurs with positive productivity growth rates. Nonetheless, in equilibrium the ratio of productivity levels $R = P_t/P^*_t$ is non-increasing since both P_t and P^*_t grow at the same rate. This means that the change in R, $R^0 = R_t - R_{t-1} = 0$, hence the proportional rate of growth $R^0/R = 0$.

In equilibrium, all regions grow at the same rate and therefore $E(p - p^*) = 0$, where p^* is the productivity growth rate of the level-of-productivity leader. It is convenient to represent the above model in matrix form, hence

$$p = \rho Wp + Xb + \xi \tag{22}$$

$$\xi \sim N(0, \sigma^2 I)$$

in which X is the n by k matrix of regressors (q,G,H) and b is the k by 1 vector of coefficients. It then is the case that

$$E(p) = (I - \rho W)^{-1} Xb \qquad (23)$$

In order to obtain the equilibrium level of technology ratio $R^e = 1 - G^e$ we use the equivalent expression

$$\begin{aligned} &E(p - p^*) = (I - \rho W)^{-1} Xb - (I - \rho W)^{-1} X^* b = 0 \\ &(I - \rho W)^{-1} X^{\otimes} b^{\otimes} + (I - \rho W)^{-1} X^G b^G - (I - \rho W)^{-1} X^* b = 0 \end{aligned} \qquad (24)$$

in which X^* is a matrix with the same dimensions as X but containing identical rows which are each equal to the productivity leader's row of X. We split matrix X into two matrices, $X^{\otimes}$ which is identical to X apart from the variable G, and X^G which contains the single variable G. We denote the corresponding vectors of coefficients by $b^{\otimes}$ and b^G. From this it follows that

$$R^e = 1 - X^G = 1 - (X^* b - X^{\otimes} b^{\otimes})(b^G)^{-1} \qquad (25)$$

While the above gives the equilibrium vector, it gives no information about the paths to equilibrium. It is worth noting that transitional paths leading to the same steady state are given by iteration. The following equations give one round of iteration; in order to obtain the dynamics, this sequence of calculations is repeated for t =1.....T and we observe how R evolves as t increases. In the dynamics, the vector of productivity growth rates at time t, $E(p_t)$, depends on the matrix X as at time t, but X evolves because one column of the matrix, denoted by $X_{t+1,G}$ contains variable G_{t+1} which depends on the level-of-productivity at time t, P_{t+1}, and the latter is determined by the rate of growth of productivity $E(p_t)$.

$$\begin{aligned} &E(p_t) = (I - \rho W)^{-1} X_t b \\ &P_{t+1} = P_t \exp(E(p_t)) \\ &P^*_{t+1} = P^*_t \exp(E(p^*_t)) \\ &G_{t+1} = 1 - \frac{P_{t+1}}{P^*_{t+1}} \\ &X_{t+1,G} = G_{t+1} \end{aligned} \qquad (26)$$

The results of this section provide the input into our conditioning analysis. That is, using the above expressions we obtain the long-run distribution from the model estimates, and obtain virtual distributions as a result of changing the model coefficient values so as to accommodate assumptions of constant returns to scale and equal endowments of human capital. The same procedure is also used to obtain distributions which allow us to assess sensitivity to the rate of catch-up and different amounts of increasing returns.

5 Effects of increasing returns, human capital and catch-up on the long-run distribution of manufacturing productivity.

In this section we first compare the actual distribution of productivity in the EU regions with long-run distributions derived from the empirical model described in the previous section. In essence, the observed 1995 distribution is compared to the steady-state R^e distribution. It allows us to illustrate the characteristic features of the equilibrium distribution and assess how it differs from the actual distribution. In addition, we compare the R^e distribution, based on an assumption that the actual observed values of factors influencing the equilibrium (i.e. amount of returns to scale, human capital, rate of catch-up) are maintained in the long-run, with simulated distributions based on an assumption that the currently observed differences in factors across the regions are eliminated (we term these conditional equilibrium distributions).

Stochastic kernels are used to summarize the relationship between the actual distribution in 1995 and the distribution for R^e, and the relationship between the unconditional and conditional equilibrium distributions. In the latter case, the stochastic kernel summarizes movements in the equilibrium distribution that are due to the conditioning factor.

5.1 Equilibrium distribution. Full effects model.

Figure 5 shows the stochastic kernel relating the distribution of R in 1995 and that for R^e. It is clear how the kernel twists clockwise for the whole range of R, though the twist is more intense for the medium and high values. For values around and below 0.2, it is evident that there is a high probability that there will be an increased R. Nevertheless, the equilibrium distribution is characterized by considerable dispersion (regions with a productivity level ratio in 1995 of around 0.2 can end up with similar values in the equilibrium distribution or with values around 0.3-0.5). For regions with medium and large R, the distribution is less concentrated and there is a high probability of R^e values similar to those for low R regions. This suggests that convergence at equilibrium is to a level which is only slightly higher on average to that for low R regions, but for the high R regions the dispersion is much greater and there is a much higher probability of attaining a value close to the leading region.

5.2 Conditioning to increasing returns

Increasing returns to scale makes the spatial concentration of manufacturing activities more attractive, which translates into increasing inequality in manufacturing productivity across regions. Therefore, increasing return should be responsible for some of the dispersion in the equilibrium distribution and, is likely to affect (to some extent) the fortunes of the less productive regions. In this spirit, we have simulated the equilibrium R distribution based on the assumption that γ (the coefficient that captures the extent of returns to scale in our model) is equal to one, which in turn means that the coefficient for q in (20) equals zero. This amounts to an assumption that manufacturing output growth rates are equal across regions and therefore do not play a part in determining the rate of growth of manufacturing productivity. The determinants of manufacturing productivity growth under this scenario are therefore human capital, cross-region spillovers and catch-up. In the simulation, the coefficients on these variables are as estimated in the empirical model (see Section 3). The resulting movement between the unconditional and conditional equilibrium distributions is summarized by the stochastic kernel in Figure 6. The kernel shifts above the diagonal, indicating that the conditional distribution shift to the right of the unconditional one. That is, R^e for most of the EU regions would be higher in the case of constant rather than increasing returns. Additionally, we can see that increasing returns contribute to the poor situation of the less advanced regions. The clockwise turn in the kernel for low R^e values indicates clearly that were it not for the existence of increasing returns, the low productivity regions would have a much higher R^e. In contrast, the lack of increasing returns has relatively little impact on high R^e regions' productivity relative to the leading region.

5.3 Conditioning to human capital

As mentioned in Section 3, human capital is an important determinant of technical progress, thus being a key factor for economic development. As such, we anticipate that human capital will also be a factor conditioning the equilibrium regional distribution of manufacturing productivity ratios in the EU. Deficits in human capital in some regions could be condemning them to a low productivity trap. The kernel in Figure 7 adds weight to this hypothesis. The equilibrium distribution, under the assumption of the same levels of human capital across regions, is more concentrated than the distribution assuming human capital differentials by region being maintained at their current levels. It is evident that low human capital is a cause of the low equilibrium level for the lowest technology regions in particular. Once human capital differentials are removed, they show a marked improvement. In contrast, regions with R^e above 0.5 show minimal change.

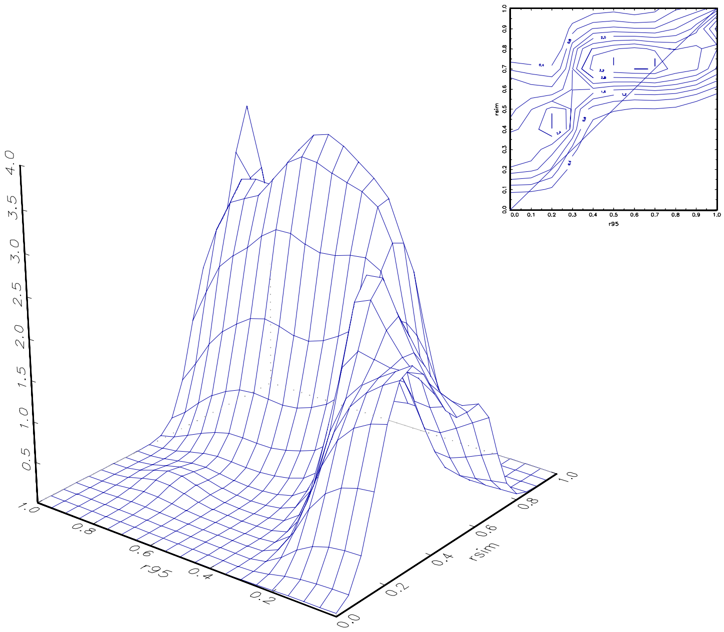

Fig. 5. Stochastic kernel for the distribution in 1995 and the steady-state distribution from model estimates

5.4 Sensitivity to the rate of catch-up

We cannot carry out an equivalent exercise for the catching-up effect because there is no equilibrium solution when catching-up is nullified. Under our model, with no catching-up, regions do not converge to a stable equilibrium. Instead, we explore how the equilibrium to which regions converge differs according to different rates of catch-up. To show this, we assume somewhat arbitrarily two different rates, setting the coefficient for G (the level of technology gap) equal to 80% and to 120% its estimated value. All the other coefficients are set to their estimated values.

The results of assuming faster catching-up are shown by Figure 8. There is a clockwise shift in the kernel, with a slightly less heterogeneous distribution of R^e than would be the case if the assumed parameters were simply the empirical estimates (this effect would be exaggerated if we had chosen 150% rather than 120%). With faster catching up, it is the regions with the lowest long-run level of technology (under the scenario based on the empirical catching-up rate estimates) that benefit most, as one would expect.

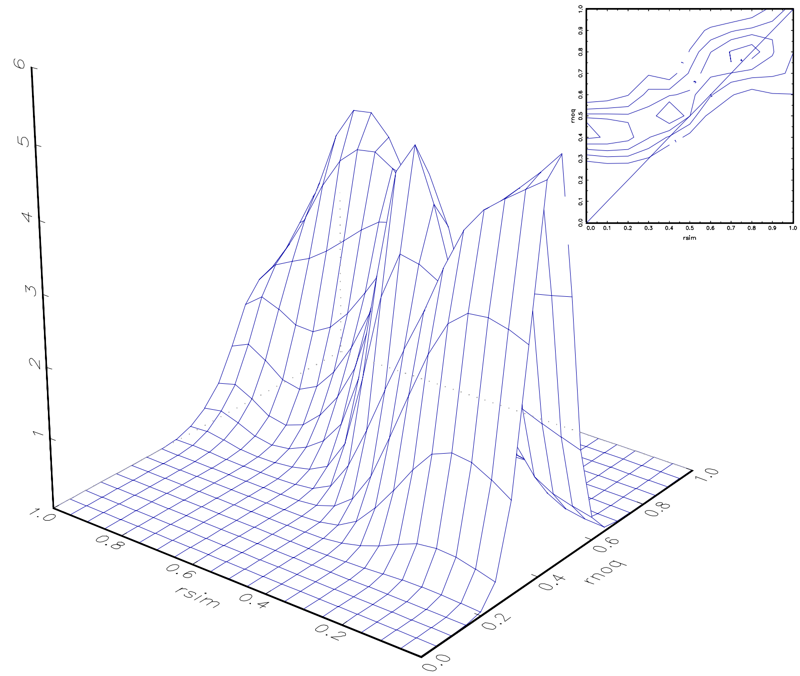

Fig. 6. Stochastic kernel: IRTS conditioning

Figure 9 gives the outcome of the alternative simulation based on slower than estimated catching-up. Here the outcome is not quite the opposite to what we have just seen. Slower catching up means R^e somewhat below what one would anticipate from the empirical estimate and much lower than what one would anticipate from fast catch-up. However the impact of slow catch-up is not confined to the regions with low R^e. The reason is that with slower catch-up, all regions lag behind the leading region which forges ahead and reinforces its leading position.

5.5 Sensitivity to the amount of IRTS

We showed above that if returns to scale were completely eliminated then the lower technology regions would be much closer to the higher technology regions. However, this is not a very realistic scenario, so here we adjust rather than eliminate the returns to scale to gain more insight. Figure 10 illustrates the impact of smaller returns to scale, with the coefficient on q (manufacturing output growth) assumed to equal 75% of the estimated value. Figure 11 shows the result of assuming a coefficient equal to 125% of the estimated value. All other coefficients are set equal to their estimated values.

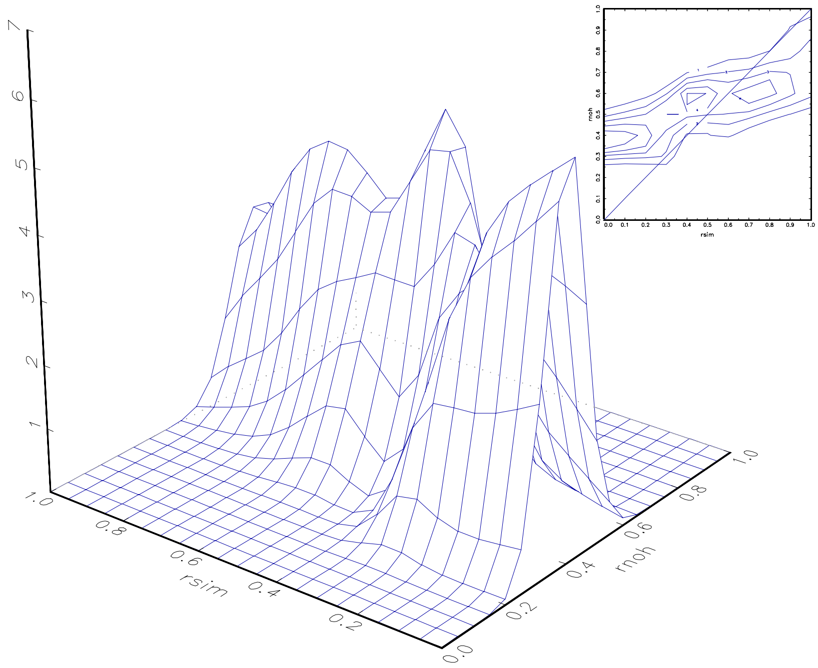

Fig. 7. Stochastic kernel: human capital conditioning

With large returns to scale, regions tend to a lower R^e as the distribution becomes stretched, and one would expect that those with faster manufacturing output growth rates would see the greatest productivity boost and thus the greatest impact in terms of R^e. However, this impact is evidently confined to the very top end of the R^e range; under greater returns to scale the vast majority of regions are seen to be relatively worse off vis-à-vis the technological leadership. In contrast, Figure 10 shows that lower than estimated returns to scale has the effect of pulling the lowest regions upward, with the upward shift the greatest for the very lowest regions. The shift is in the same direction as in Figure 6 but of course less so. We could imagine that returns to scale might fall by to this extent in the real world if congestion worsened significantly, as it is projected to for some regions (eg the South-East of England) unless there is a radical change of policy.

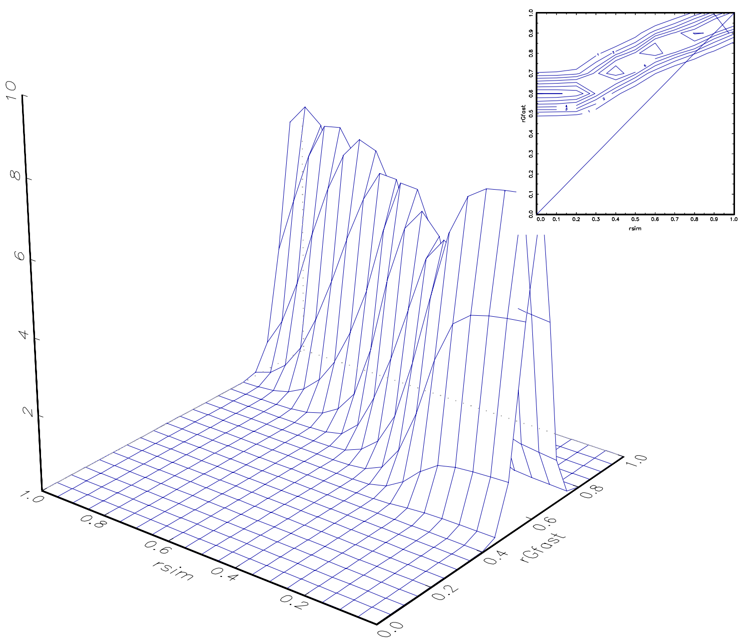

Fig. 8. Stochastic kernel: fast catch-up conditioning

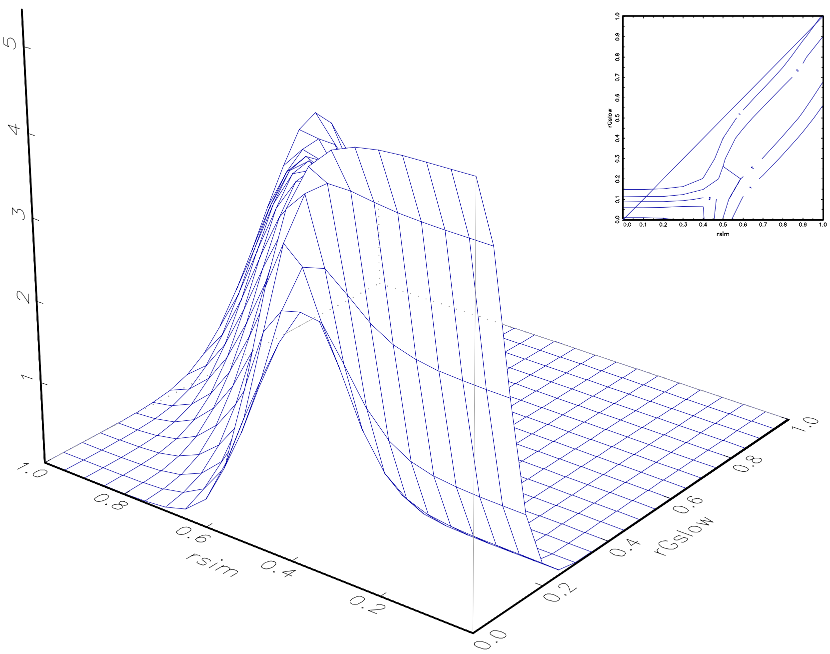

Fig. 9. Stochastic kernel: slow catch-up conditioning

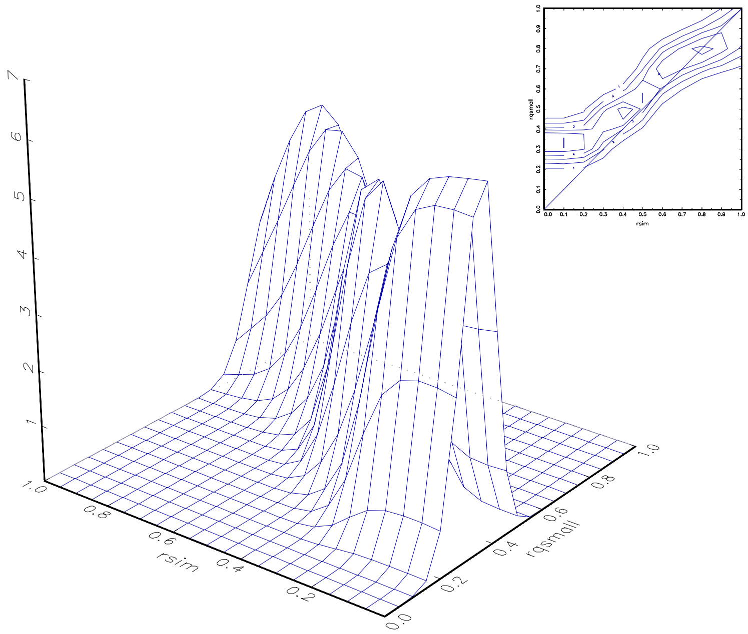

Fig. 10. Stochastic kernel: small RTS conditioning

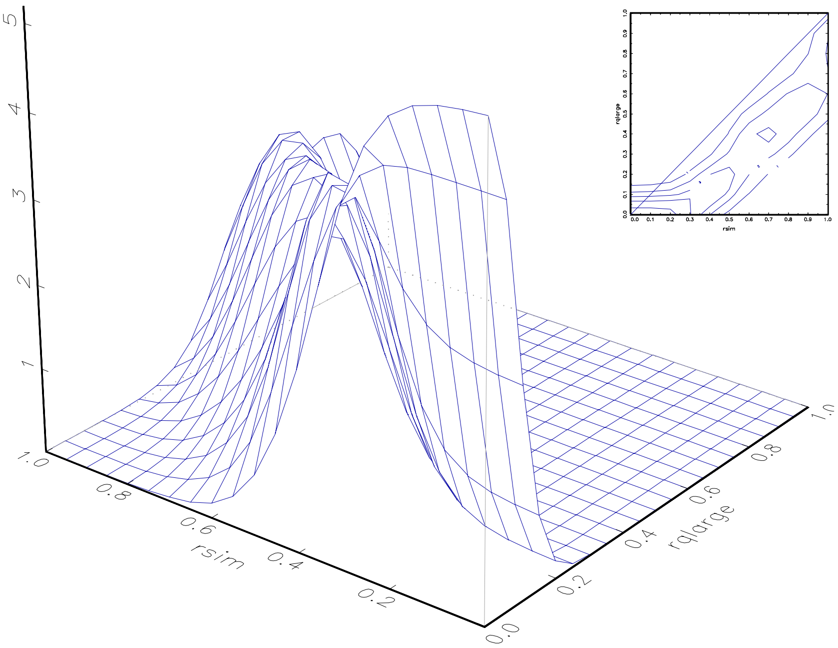

Fig. 11. Stochastic kernel: large RTS conditioning

6 Conclusions

This paper has combined recent developments in urban and geographical economics theory with an empirical spatial econometric model and with the method of stochastic kernels to produce visualizations of different long-run development scenarios under alternative assumptions. We have seen that if the impact and levels of output growth, the technology gap and human capital differences across EU regions remains the same as evident in the recent past, then the long-run distribution is a more concentrated one than "currently" exists (Figure 5), although it remains the case that in the long run equilibrium will be characterized by differences in the level of productivity. There is evidently no absolute converge on the distant horizon. The picture provided by the stochastic kernel approach gives more detail on the various nuances of the difference between the two distributions. We have chosen to simulate the separate impact of our variables by altering the coefficient so that the variable has a different to effect on productivity growth to that of the recent past. By setting the coefficient to zero, as in the case of returns to scale and human capital, we have in effect simulated the outcomes that could occur if by some magic wand (or as a result of enhanced economic integration so that many regions were in fact one) the variable assumes the same values in every region.

The effect of assuming that returns to scale are constant across regions is to enhance the comparative status of the poorer regions, although again the impact is a subtly differentiated one as is apparent from Figure 6. Likewise equalized human capital brings up the lower level regions relative to the higher ones, thus pointing to the importance of this factor for regional development. The estimates given in Table 1 also highlight the significance for growth over the historical period of the initial level of technology, with low technology level regions with a large technology gap growing faster than regions already at a high level, since diffusing innovations in the latter case will have little or no impact for regions already at or near the technology frontier. However, unlike human capital and output growth, technology gap equalization across regions has the effect of destroying the tendency for regions to converge to a steady state. This may be a possibility, but the empirical evidence is to the contrary and so we discount it. As an alternative, we therefore set up scenarios in which different amounts of catching up are envisaged (Figures 8 and 9), and this facilitates illustration via the stochastic kernel approach. Likewise in Figure 10 we do the same for different amounts of increasing returns to scale. This could occur as a result of increased congestion, since as assumed in equation (13) the net effect could be a lowering of the coefficient on returns to scale. One variable which does not enter into our simulations is the impact of spatial external economies as represented by the endogenous lag in our model, which Table 1 shows has been a significant factor affecting productivity growth. Nevertheless, it is apparent from the equilibrium equation derived in section 4 that the steady state, to which regions are tending, is the same regardless of the strength of these spillovers, although the paths leading to steady state do depend on these spatial interactions. There are other simulations that are possible that would be based on altering the assumed levels of the causal would be based on altering the assumed levels of the causal variables in the different regions rather than altering the coefficients. For example, the convergence of the EU regional economies makes it reasonable to envisage a situation in which variance of manufacturing output growth rates across regions is smaller than it has been in the recent past, due to the lowering of barriers to interregional trade and the exposure of industry to similar demand and supply conditions. While this might not produce the exact equality of output growth that we have in effect simulated in this paper, there is scope for looking at different growth assumptions other than exact equality or the assumption that current output growth differences will prevail ad infinitum. Similarly, while ideally equalized educational attainment across regions as we have supposed would be of maximum benefit for regional economic and social cohesion, it is unlikely that this would remain a goal rather than a real outcome. It would however be quite feasible to explore the ramifications of different assumptions about educational attainment disparities across Europe and show the consequences for relative productivity levels.

Appendix: The urban economics model on which the reduced form is based

Endogenous variables

1. Manufacturing labour (workers):

$$M = N\beta \tag{A1}$$

   manufacturing labour (workers) (M) equals total labour (N) times β which is the equilibrium allocation of labour to manufacturing under competitive conditions.

2. Manufacturing output:

$$Q = M^{\beta} I^{1-\beta} \tag{A2}$$

   This is a Cobb-Douglas production function. Output (Q) equals workers (M) raised to the power β, multiplied by the level of composite services (I) to the power (1- β).

3. Composite services:

$$I = \left[\int_{d=1}^{d=D} i(d)^{1/\mu}\, dt \right]^{\mu} \tag{A3}$$

$$I = [Di(d)^{1/\mu}]^{\mu} = D^{\mu} i(d) \quad \text{(A4)}$$

This is the CES (constant elasticity of substitution) (sub) production function for I, which is a function of the output of the typical services firm (i(d)), the number of services firms(D) and the elasticity of substitution, which diminishes with increasing μ. As μ approaches 1, then the services level approaches the number of firms times their output, as $\mu >> 1$ it is more than this due to the effect of the number of varieties (D), so that increasing firms results in a proportionately larger I.

4. Equilibrium output level of typical service firm:

$$i(d) = \frac{s}{a(\mu - 1)} \quad \text{(A5)}$$

When firms are at equilibrium, so that (marginal) costs equal (marginal) revenues and profits are driven to zero, the output per firm can be shown to equal the fixed labour requirement (s) divided by the marginal labour requirement (a) times μ-1.

5. Cost :

$$c = w(ai(d) + s) \quad \text{(A6)}$$

Cost of production equals wage rate (w) times amount of labour (ai(d) + s)
Marginal cost equals wage rate(w) times marginal labour requirement (a):

$$mc = wa \quad \text{(A7)}$$

6. Revenue equals wage rate (w) times marginal labour requirement (a) times markup on costs (μ) [$wa\mu = p$ = price] times equilibrium output (i(d)):

$$r = wa\mu i(d) \quad \text{(A8)}$$

Marginal revenue equals price($p = wa\mu$) times (1-1/E) where E is the constant (subjective) price elasticity of demand [which can be shown to equal 1/(1-1/μ)], thus (1-1/E) = 1/μ.:

$$mr = \frac{wa\mu}{\mu} = wa \quad \text{(A9)}$$

Hence mr = p times 1/μ = p/μ. Note, here we are talking about imperfect competition so that price is unequal to marginal revenue. In fact price (p) = wage rate (w) times marginal labour requirement (a) times markup (μ)

$$p = wa\mu \quad \text{(A10)}$$

.If $\mu = 1$ we have perfect competition so then mr = p

7. The number of service firms (varieties):

$$D = \frac{(1-\beta)N}{ai(d)+s} \qquad (A11)$$

The number of firms (D) equals the total services labour force((1-β)N divided by the labour force per firm (L = ai(d)+s) at equilibrium

8. Labour requirement:

$$L = s + ai(d) \qquad (A12)$$

The labour requirement equal to fixed labour requirement(s) plus marginal labour requirement (a) times firm's output (i(d))

Exogenous variables

1. Marginal labour requirement (a): this is the exogenously determined increase in labour needed by the firm per unit increment of output (note that since output can be measured in any units, this can be left as 1).
2. Fixed labour requirement (s>0): this is the fixed cost in terms of service labour that must be incurred to produce any variety. It implies that increasing returns to scale exist in the service sector.
3. Monopoly power/elasticity of substitution (μ): as μ increases, the elasticity of substitution diminishes, as μ approaches 1, the services approach being perfect substitutes and variety diminishes in importance as a determinant of I.
   Note that the elasticity of substitution is

$$\frac{\mu}{\mu - 1} \qquad (A13)$$

4. Total labour force (N): note how total manufacturing output (Q) is a nonlinear function of N, showing increasing returns with city size. However the latter is not modeled here and we treat N as exogenously determined.
5. The relative importance of workers versus services (β)

Equilibrium

Occurs when the level of output is such that marginal revenue(mr) equals marginal cost (mc), firms have entered shifting the demand curve to the left, driving down profits to zero, at which point entry stops. This is the equilibrium, when total revenue equals total costs and there are zero profits. This determines the equilibrium output level i(d).

Hence, at equilibrium, profits are zero and costs equal revenues,

$$c = w(ai(d) + s) = r = wa\mu i(d) \qquad (A14)$$

Hence,

$$ai(d) + s = a\mu i(d) \tag{A15}$$

$$i(d) = \frac{s}{a(\mu - 1)}$$

We can choose units of output to be anything we want, which means we can choose them so that the marginal labour requirement a = 1. This gives the simplified version

$$i(d) = \frac{s}{\mu - 1} \tag{A16}$$

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