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This paper uses stochastic kernels to analyse the factors driving convergence and divergence processes in the growth dynamics of European urban regions over the period 1978 to 1994. Objections have been raised to the use of a Markov Chain approach (Quah, 1993 and 1996; Magrini, 1999) to simulate alternative distributional outcomes. The approach used in this paper not only achieves the same objective but we compare the results obtained using the two approaches. It is shown that both produce a similar central result. We develop a two-stage procedure. First, we estimate a growth model viewing growth of real GDP per capita as a multivariate process. The distributional dynamics of observed regional incomes exhibit the familiar 'twin peaks' form. Those predicted from the model closely track this pattern. The second stage then uses this approach to evaluate the contribution of individual factors to convergence/divergence dynamics. We use the regression results to simulate alternative end period incomes which, via the estimation of stochastic kernels, enable us to isolate the role of selected variables in shaping the dynamics of the cross-sectional distribution of per capita income. This analysis suggests that the most important factor determining the twin peaks form of FUR growth and convergence dynamics was the differing geographic distribution of human capital and R & D. These results are compared with the Markov Chain approach and it is found both techniques lead to a similar diagnosis.

Key words: growth; distribution dynamics; cities; human capital; convergence;

JEL Codes: H41; H73; O18; R11; R50

1. Introduction[1]

This paper is a further development of work reported in Cheshire and Magrini (2005a and 2005b). In this set of papers, we are trying to do three things. The first is to test the extent to which it is reasonable to assume that there is a unified European urban system within which there is enough factor mobility to generate a spatial equilibrium between cities and regions. Spatial equilibrium is defined in the usual way as a situation in which individuals cannot improve their welfare by moving to another city or region. We reject such a 'compensating differentials' worldview (see Glaeser *et al*., 1995, for an application of this view to the US) as applied to the EU's major city regions because the evidence strongly supports the conclusion that migration flows are not only relatively small but are largely confined within national borders.

The second paper develops and estimates a model of urban growth processes with real GDP per capita as the dependent variable. Again, we find evidence supporting the interpretation that national borders still offer a substantial barrier to spatial adjustment processes. In both this and the paper investigating the applicability of a 'compensating differentials' model in the context of EU spatial adjustment processes, we take particular care to test for and eliminate problems of spatial dependence by including explicit spatial economic adjustment processes.

In all three papers, we use as our units of observation functionally defined urban regions (Functional Urban Regions – FURs). These and the data set we have constructed for them are briefly discussed below in Section 2. This third paper uses an adapted version of one of the growth models estimated in the second paper to investigate the distributional dynamics of FUR incomes both as observed and as predicted on the basis of the estimated parameters of the model. We investigate these dynamics primarily using stochastic kernels but we compare the results with an alternative more traditional method – based on Markov Chains. The results of the two approaches are broadly similar. The purpose of this investigation is first to see whether our growth model is accurately reflecting not just the observed growth performance of the FURs but the distributional dynamics their individual growth rates gave rise to. The second and potentially more interesting aim is to investigate the factors driving the pattern of distributional dynamics we observe. As in Magrini (1999) the basic pattern of growth over the 1979 to 1994 period[2] we can analyse shows a dynamic tendency to generate a 'twin peaks' distribution of regional incomes. A small group of richer regions was tending to form while a large group of poorer FURs' incomes was converging to a lower mean. The predicted values of FUR incomes based on our estimated model show a similar dynamic pattern. We can also simulate alternative end point FUR incomes, however, using the model's estimated parameter values but assuming alternative values of the independent variables. The last part of this paper investigates the dynamic distributional characteristics of these alternative simulations to see what particular variables were driving the twin peaks outcome we observe.

2. The data

All the analysis is performed on a data set built up over a 25 year period relating to Functional Urban Regions (FURs) defined so far as possible according to common criteria across the EU of 12. For a detailed discussion of how the FURs we use were defined see Cheshire and Hay (1989). The basic principle was to identify core cities using the criterion of at least 20 000 jobs.

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[1] The authors have benefited from many discussions with colleagues as this work has developed. The authors retain responsibility for any remaining deficiencies or errors.

[2] Magrini (1999) analysed the dynamics of FUR growth from 1979 to 1990. Since then, we have been able to construct GDP for FURs for 1978 and forward to 1994. We have been unable to reconcile GDP values bridging the definitional changes Eurostat introduced in 1995 – see Section 2 - so our analysis has to end at 1994.

For each of these concentrations of employment, hinterlands were defined from which more commuters flow to the employment core than to any other, subject to a minimum cut off level of commuting. The FURs used here were defined on the basis of data for 1971. They are broadly similar in concept to the (Standard) Metropolitan Statistical Areas used in the US although hinterlands tend to be extensive where there are no competing employment centres (examples are Lisbon or Dublin). The data set only has the full set of variables for the largest FURs – those with a total population of a third of a million or more in 1981 and a core city which exceeded 200 000 at some date since 1951. The unification of Germany means that comparable data for the current FUR of Berlin are only available since 1990. So, Berlin is excluded as are the FURs in the territory of the former GDR. This leaves a total 121 FURs which constitute our observations - so in all statistical estimation N=121.

As has been argued elsewhere (Cheshire and Hay, 1989; Cheshire, 1999) the great variability in the relationship between administrative boundaries and the economic reality of European cities and regions introduces serious error and a strong likelihood of bias into data reported for administratively defined regions and cities. The EU institutions deal in so-called Nomenclature des Unités Territoriales Statistiques (NUTS) regions. This is a nesting set of regions which tries to reconcile different national territorial divisions. The largest are Level 1 regions; the smallest for which a reasonable range of data is available are Level 3. These correspond to Counties in the UK, Départements in France; Provincies in Italy or Kreise in Germany. The size of these NUTS regions – even within the same 'Level' – is highly variable across Europe and even within countries. A further problem is that no 'Level' is actually represented in every country: in many countries they exist only for purposes of reporting data to Eurostat and other EU institutions. Thus, the most widely used regions – the Level 2 – do not exist for German or the UK. Particularly in Germany, this presents serious problems of data availability and comparability because the Level 1 regions correspond to the Länder which not only have considerable independence but also their own statistical services. In addition, Germany has not had a population census since 1987 and uses its own labour market regions to collect most labour market data.

One of the variables most subject to distortion is GDP p.c. because GDP is estimated at workplaces while people are counted where they live. Because people commute to work across administrative boundaries this means GDP p.c. is systematically overestimated in cities which are also NUTS regions where the administrative boundaries exclude significant dormitory areas. In reality this happens for a large number of bigger European cities (Madrid and Paris are two exceptions if the NUTS 1 regions are used) meaning that official figures systematically overstate GDP p.c. for large cities[3]. At last this distortion of GDP p.c. data the present NUTS system generates has been recognised by Eurostat (Eurostat, 2005). Following the 1998 split of Greater London into two official regions[4] – Inner and Outer London – the absurdity of the resulting GDP p.c. measures – with Inner London having a reported per capita GDP 3.15 times the EU mean - became too great to continue to ignore.

> …in some regions the GDP per capita figure can be significantly influenced by commuter flows….[so] that GDP per capita can be overestimated in these regions (e.g.

[3] This potential for distortion is used for political purposes. In 1988 when the criteria for regional assistance were defined and the threshold was set at 75% of the EU mean, the Dutch created a 'poor' region, Flevoland, by combining the suburbs of Amsterdam with the agricultural areas to the north. The British were not dissatisfied with the split of London into two regions in 1998.

[4] The FUR of London used here was nearly 30% larger in population terms than the NUTS Level 1 region of Greater London.

Inner London) and underestimated in the regions where commuters live (e.g. Outer London, Kent and Essex). (Eurostat, 2005)

The FUR and NUTS region of Bremen provide an extreme but not wholly unrepresentative example of how this distorts measured growth rates as well as levels of GDP p.c. as over time people move relative to the location of jobs. Because of strong relative population decentralisation over the relevant period the growth of GDP p.c. is overstated by some 40% for the period of the 1980s if the published Eurostat data for the NUTS Level 1 region identified as Bremen[5] are relied on.

As defined, FURs correspond to the economic spheres of influence of significant employment concentrations and are relatively self-contained in economic terms. The variables used are defined in Appendix Table 1 which also provides a brief description of how they were measured and the sources used. Appendix 2 explores some of the differences between our estimated FUR GDP p.c. and growth and equivalent NUTS 3 data[6]. Two pairs of FURs – Lille and Valenciennes and Portsmouth and Southampton – are entirely contained within two NUTS 3 regions so their GDP p.c. estimates were the same. One other pair of FURs – Sunderland and Newcastle – is mainly within a single NUTS 3 region.

Because of measurement error and short run fluctuations in Eurostat data, we take the start point of the series as the mean for 1978-80 and the end point as the mean for 1992-94. Regional GDP data have been published for most Level 1, 2 and 3 regions since 1978 although for some it is available from 1977. There are however gaps – data for Greek and Portuguese regions, for example, only became available from a later date. In both cases, REGIO data have been supplemented with national data. For some countries, such as Italy, data for earlier years were only published for Level 2 regions. National sources, for example of value added in Italy, have been used to disaggregate from Level 2 to Level 3 values where none are available from Eurostat.

One final point relating to Eurostat regional GDP data is that the basis on which values were estimated was substantially revised in 1995. Eurostat switched from a 1979 base for disaggregating national data (ESA79) to a base-year of 1995 (ESA95). The differences between the two sets of values are remarkable - not even country totals coincide. Although some claim to have successfully bridged this discontinuity in the regional GDP data (particularly affecting Germany) we have not been able to do so to our satisfaction. So our analysis finishes in 1994.

All data are defined to common statistical concepts either weighting data available from the Eurostat REGIO database to estimate values for FURs (as with GDP p.c.) or collected directly from national statistical offices or common data providers and adjusted where necessary to

[5] A curious fact is that Bremen as a Hanseatic League state retained its historic independence so it is a Land – so a NUTS 1 regions. This is despite the fact that its territory is split between two separate enclaves and in 2001 its reported NUTS population was 660 000: while its estimated FUR population was 1 305 000.

[6] To illustrate this process of estimation with the example of Bremen: the population of our FUR was divided between seven NUTS 3 regions for which we had Eurostat GDP p.c. data. In 1991, the proportionate distribution of Bremen's population between these NUTS regions was 0.4345, 0.1508, 0.1128, 0.0942, 0.0767, 0.0713 and 0.0597. These proportions were applied as weights to each of the seven NUTS regions' GDP p.c. to estimate the value of GDP p.c. for the FUR of Bremen. We also have the proportionate distribution of FUR populations between NUTS 3 regions as at 1981. The FUR data for any year were estimated using population weights calculated from national population censuses or registration data closest in time to that for which the Level 3 regions' data (e.g. GDP p.c.) related.

common definitions. There is necessarily some imperfection and imprecision in such data but they have the merit of relating to functionally defined city-regions which are self contained in economic terms. This allows us to estimate our policy capacity variable. They are also substantially more homogenous, all being large metropolitan regions, which is econometrically helpful; and they do not exhaust national territories. This last property allows us to calculate another useful variable – the rate of growth in the area of each country outside its major city-regions.

3. The Growth Model

We do not here elaborate on the fitted growth model which is the subject of Cheshire and Magrini (2005b) except briefly to explain the minor adaptations we have made. It is not a β-convergence model; it does not contain the initial level of FUR GDP p.c. Apart from being logically inconstant with our approach, previous work has shown how unreliable results of such a model are for European FURs (Cheshire and Carbonaro, 1995).

The variables we use here are defined in Appendix Table 1 and the results for the model are set out in Appendix Table 2. The model was subject to a battery of tests and is a development of previous work (see, for example, Cheshire and Magrini 2000). We employ a set of control variables for FUR industrial structure, size and density and a continuous variable measuring growth in each country outside the area of its major FURs (which we see as a better alternative to the more common country dummies[7]). We also include a variable reflecting initial endowments of highly skilled human capital (university students in 1977-78 relative to FUR employment in 1979[8]) and another measuring the concentration of R&D establishments in the FUR. The model also included a measure of the spatial economic gains from European integration and a measure of 'peripherality' (defined as 10 hours or more time-distance from Brussels to avoid subjective judgements). The final variable of interest – in the sense that it is designed to test hypotheses about sources of urban growth – is one designed to reflect the capacity of a FUR to generate effective growth-promoting policies. This was measured simply as the ratio of the estimated FUR population to the population of the largest administrative political unit relating to the area of the FUR which had significant political powers. The theoretical reasoning underlying this variable is the hypothesis that growth promotion in so far as it is successful is the production of a pure local public good so that the normal arguments as to the conditions favouring the emergence of 'clubs' should apply (see Cheshire and Gordon 1996; Olson, 1965 or Oates, 1999). Transactions costs and spillover losses will be minimised if the governmental unit is as large or a little larger than the FUR since the boundaries of FURs are designed to produce economically self-contained city-regions. Their self-containment thus ensures that spillover losses to non-participants in the 'club' promoting growth are minimised and the larger is the size of the leading local government unit the lower the transactions costs are likely to be.

In addition to these more standard variables, we include variables designed to capture mechanisms of spatial adjustment directly. We have found that by doing this, problems of spatial dependence can be eliminated in a way which is theoretically more satisfying than simply employing a technical fix such as including a spatial lag for the dependent variable. If these spatial adjustment mechanisms are excluded from the model specification, there are

[7] We have experimented with these. It is necessary to have country groupings because of single or small numbers of observations in several countries. Models using such dummies give essentially the same results for the interesting variables but perform less well and significant dummies can only be found by manipulating the country groupings.

[8] It is not possible to get total employment for all 121 FURs for 1978; nor university students for 1979.

signs of spatial dependence. Test results for the present model show that there are no indications of spatial dependence even if the spatial adjustment mechanisms are not included so long as the spatial weights matrix does not impose any distance penalty for national borders. If a time distance penalty is added where FURs are separated by a national border, however, problems of spatial dependence appear if the spatial adjustment mechanisms are not included. In the model reported in Appendix Table 2, we observe little change for border penalties of 600 minutes or more and no indications of spatial dependence for any border time distance penalty. We interpret this as re-enforcing the conclusion that urban systems still operate in the EU largely within national borders so that while there may be tendencies for equilibration between FURs within countries (even though any equilibration seems to be sluggish) adjustment is not likely across the urban system of the EU as a whole. These issues are discussed at more length in Cheshire and Magrini 2005b.

For the sake of logical consistency, all our spatial adjustment mechanisms – which measure relative concentrations of university students, R & D establishments and unemployment in each FUR relative to its neighbours up to a distance of 150 minutes (60 minutes for unemployment because of shorter commuting distances for the least skilled) – include the same 600 minute border distance penalty. This in effect means that a FUR's growth rate is not affected by university students, R &D or unemployment concentrations in FURs not within the same country. As well as being logically consistent, this is more effective in eliminating indications of problems of spatial dependence.

4. Application to the Analysis of Convergence

We can identify two broad strands in the huge literature analysing convergence and divergence that has emerged since Barro and Sala-i-Martin (1991). The first, Barro and Sala-i-Martin's regression approach, developed with the explicit intention of testing the convergence predictions of a traditional, long-run neoclassical model of growth. Most of this literature has relied on running a cross-sectional or panel regression of per capita income growth over the initial level of per capita income, conditioned on a set of variables allowing for differences in steady-states and asymmetric shocks (see, to cite but a tiny sample of this huge literature, Barro and Sala-i-Martin 1991, 1992 and 1995, Sala-i-Martin 1996). Convergence is then analysed via the estimated value of the β coefficient on the initial income level. This can be interpreted as representing the speed with which the different economies – regional or national – 'converge' towards their steady states.

Researchers have identified a number of problems with this approach (see, for example, Durlauf and Quah 1999, Temple, 1999 or Magrini 2004 for surveys), ranging from the problem of open-ended alternatives, to the lack of informative content and, finally, to the lack of attention to the role of spatial interaction effects. Dissatisfaction with the regression approach has thus led some researchers to develop alternatives. One is the distribution dynamics approach first suggested by Quah (1993a and b, 1994, 1996a and b, 1997). This approach concentrates directly on cross-sectional distributions of per capita income, using stochastic kernels to describe their evolution. The general features of this approach can be summarised as follows. Let F_t denote the cross-sectional distribution (of FUR GDP p.c. in our case) at time t, and ϕ_t an associated probability measure. The simplest scheme for modelling the dynamics of $\{\phi_t : t \geq 0\}$ is a first order dependence specification:

$$\phi_t = T^*(\phi_{t-1}, u_t) = T^*_{u_t}(\phi_{t-1}) \qquad (1)$$

where u_t is a sequence of disturbances, T^* an operator that maps the Cartesian product of probability measures at time t-1 and disturbances at time t, and $T^*_{u_t}$ absorbs the disturbance into the definition of the operator and encodes information on intra-distribution dynamics.

The most obvious way of making use of using equation (1) to study income divergence or) convergence is to make the income space discrete. The measure ϕ_t can then be represented by probability vectors and $T^*_{u_t}$ simplifies into a transition probability matrix M_t. The rows and columns of this matrix then become indexed by the elements of the discretisation. Each row is then reporting the fraction of economies the starting position of which is that row element and the ending position of which is in the different column elements[9]. If the underlying transition mechanism is time invariant and the following (Markov Property) holds:

$$\Pr\left\{y_i^{t+1} \in c \;\middle|\; y_i^t, y_i^{t-1}, \ldots, y_i^0\right\} = \Pr\left\{y_i^{t+1} \in c \;\middle|\; y_i^t\right\} \qquad (2)$$

the model in equation (1) becomes a time-homogeneous (finite) Markov Chain. Then, iterations of (1) yield a predictor for future cross-sectional distributions

$$\phi_{t+s} = M'^{s}\, \phi_t \qquad (3)$$

since the matrix M'^{s} contains information about the probability of moving between any two income classes in exactly s periods of time. Moreover, taking (3) to the limit as $s \to \infty$, makes it possible to characterise the long-run (or ergodic) cross-sectional distribution of incomes via the ergodic row vector satisfying

$$\phi_\infty = M' \phi_\infty$$

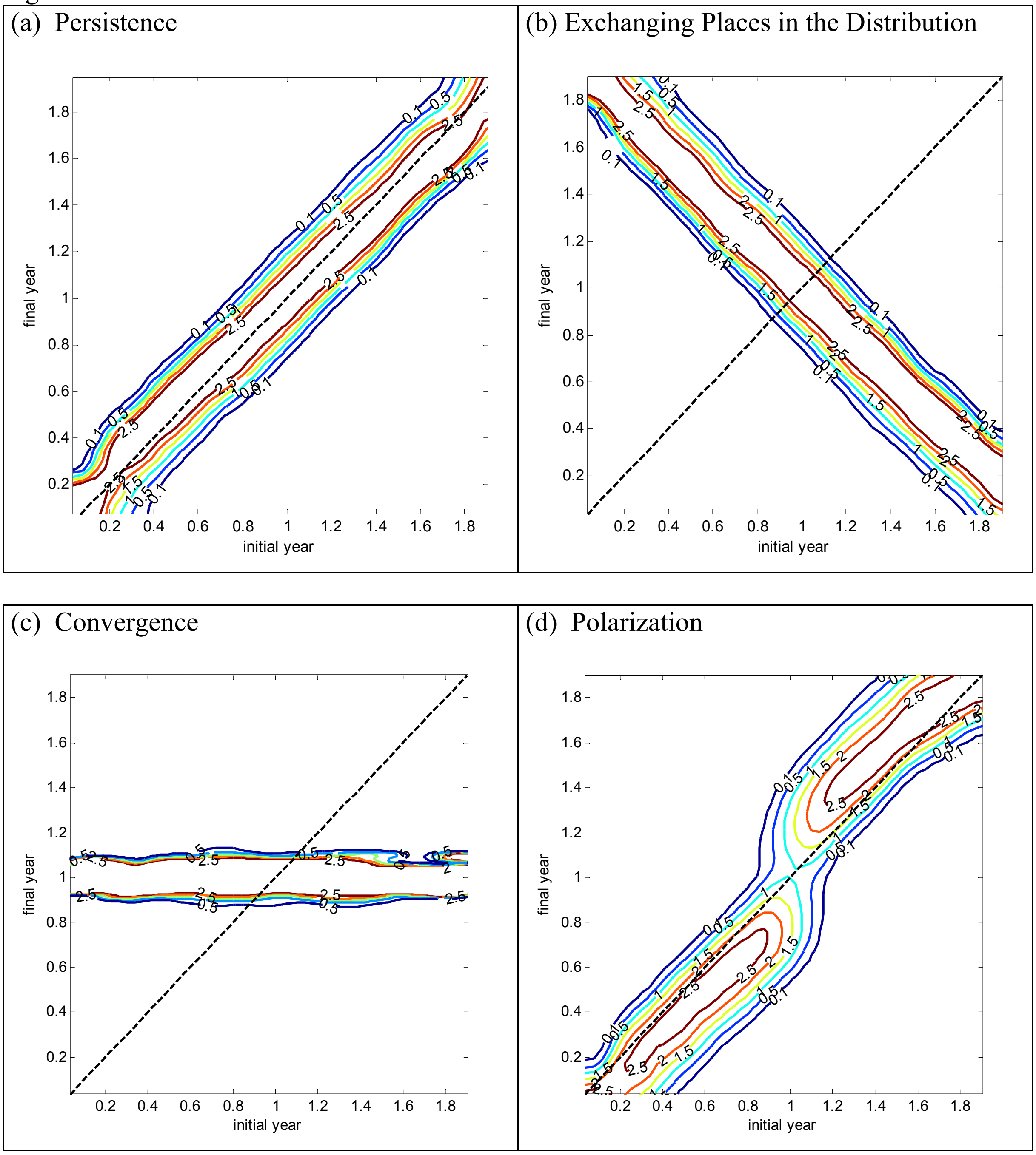
Implications for the convergence debate are then drawn from the study of ϕ_{t+s} or of ϕ_∞. If they display a tendency towards concentrating on a point mass, then we can conclude that there is an underlying tendency in the dynamics of the distribution of incomes which is leading to convergence towards equality. If, on the other hand, ϕ_{t+s} and ϕ_∞ display a tendency towards a two-point mass, one could interpret this as a manifestation of income polarization (Quah's 'twin peaks'). Other more complex outcomes are, of course, possible.

Bickenbach and Bode (2003) point out a general problem with this Markov chain approach, however. This is that it imposes quite restrictive assumptions on the data generating process. Implicitly it assumes that the data generating process is time invariant and satisfies the Markov property. However, as commonly recognised in the literature, discretising a continuous first-order Markov process is likely to remove the Markov property. While Quah (1996b) suggests that any distortion arising from partitioning into five large cells is not likely to conceal the most important features of the process, Magrini (1999) adopts a procedure aimed at reducing the degree of arbitrariness of the discretisation by concentrating on choosing histograms as approximations of the continuous distribution of incomes to minimise the (mean-squared or integrated absolute) error of approximation. Bulli (1999), however, argues that discretisation of a continuous state-space Markov chain concentrating on the distribution of the process at some point in time is misleading, and recommends adopting a regenerative discretisation method originally employed in the Markov Chain Monte Carlo literature.

A radical alternative avoiding all these problems is to get rid of discretisation altogether. In this case, the operator in equation (1) can be interpreted as a stochastic kernel (Quah, 1996a and 1997) and convergence can be studied analysing directly the shape of a three-dimensional plot of the stochastic kernel. This means there is no need to impose restrictive assumptions on the data generating process. Figure 1 illustrates the type of results we might find and how we would interpret them.

[9] Different ways of partitioning the income space are obviously possible but very often subjectively chosen equi-sized cells or cells with variable upper endpoints (so as to get approximately the same number of occurrences in each class) are adopted.

Figure 1

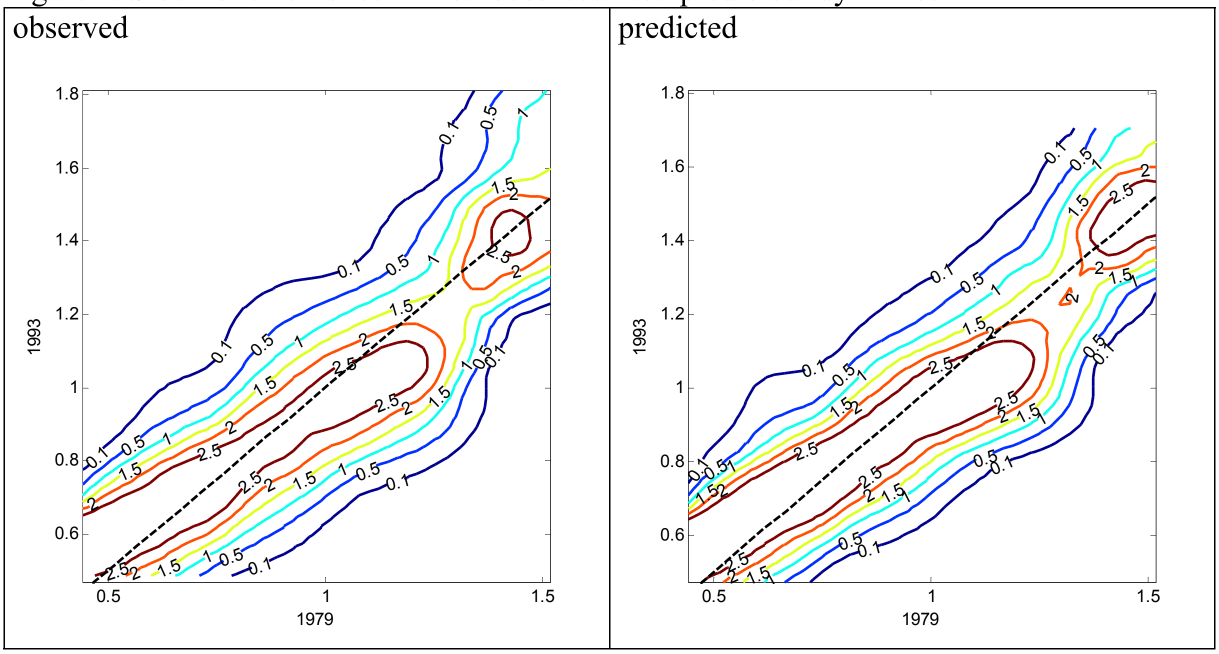


The main diagonal highlights persistence properties. When most of the graph is concentrated along this diagonal, as in Figure 1a, then elements in the cross-sectional distribution remain where they started. In contrast, a 90-degree counter-clockwise rotation from the main diagonal shown in Figure 1b indicates that substantial overtaking occurs. This would mean that poor and rich economies were periodically exchanging their relative positions between the start and end dates of the period under analysis. Figure 1c shows an idealised alternative of pure convergence. The poor FURs are growing faster and the rich more slowly so that at the end of the period all FURs are close to the mean income level. Finally Figure 1d shows an idealised ‘twin peaks’ outcome where growth rates are such that two more or less distinct groups of richer and poorer FURs are tending to emerge with rich FURs converging on a higher mean level of income and poor ones on a lower level.

With these illustrative Figures as a guide we can now turn to Figure 2 which shows the stochastic kernel estimates for the observed FUR growth rates between 1978/80 and 1992/1994 and those predicted on the basis of the growth model set out in Appendix Table 2. The first point to note is that the dynamics appear to reflect a degree of polarisation with 'twin peaks' appearing; a small group of FURs was tending to emerge with GDP p.c. roughly 1.5 times the overall mean and a larger group of poorer FURs – showing some convergence within their group but on a lower modal income. The convergence of this poorer group is shown by the slope of the main mass of FURs which is rather flatter than the 45-degree line. Perhaps comfortingly, this result is entirely consistent with Magrini (1999) which used a discretised Markov Chain approach.

The second point of interest is that the dynamics of the predicted incomes track those of the observed incomes very closely. The same pattern is reproduced providing a different visual test of the performance of the growth model.

Figure 2: Stochastic kernel estimate: 'observed' vs. 'predicted' dynamics

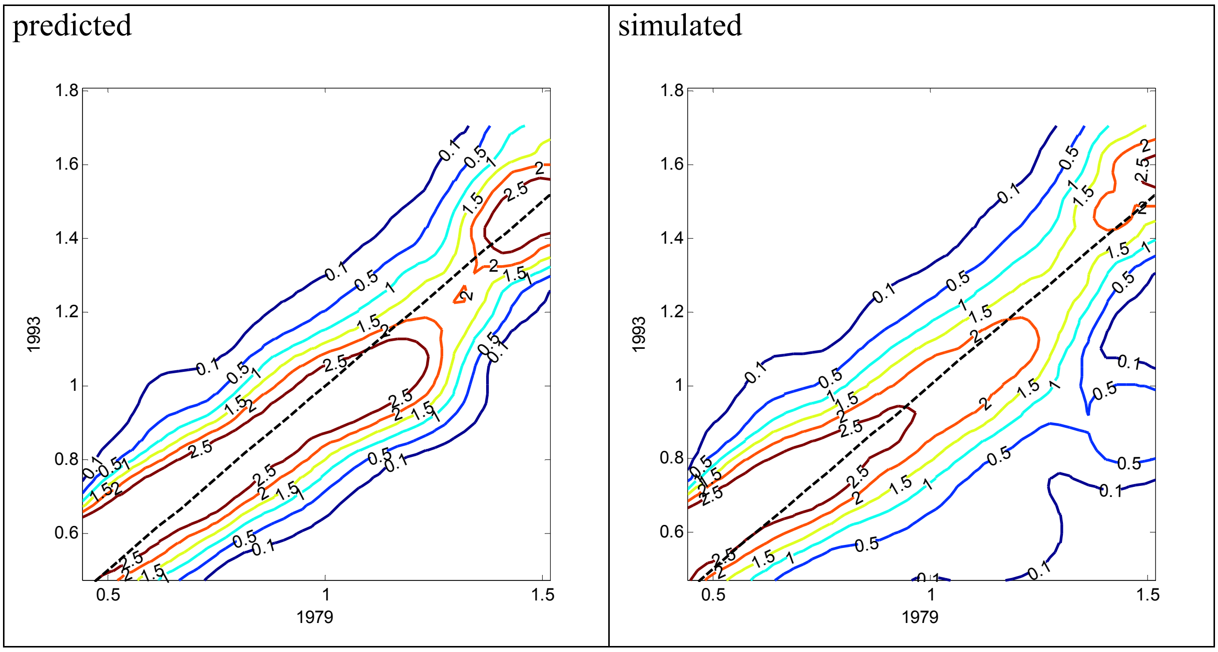


Notes: Estimates use an Epanechnikov kernel with bandwidth chosen optimally (Silverman 1986)

We now turn to the question of whether we can isolate the variable(s) contributing to the emergence of a richer group of FURs with income growing away from the others. We can do this by using the kernel approach to represent the distributional dynamics of FUR incomes over the period comparing the observed start date values with end point values simulated using our model's estimated parameters but imposing alternative values for the independent variables for all FURs. We follow this approach using the parameter values reported in Appendix Table 2. We do this in Figures 3 and 4 in which we plot contour lines of the probability mass for the observed 1978-80 GDP p.c. values compared to those simulated for 1992-94 on the basis of two alternative sets of values for independent variables. We have run many such simulations but show here only those which perturb the dynamics and so seem to give some insight into what specific factors were associated with the emergence of a twin peaked distribution.

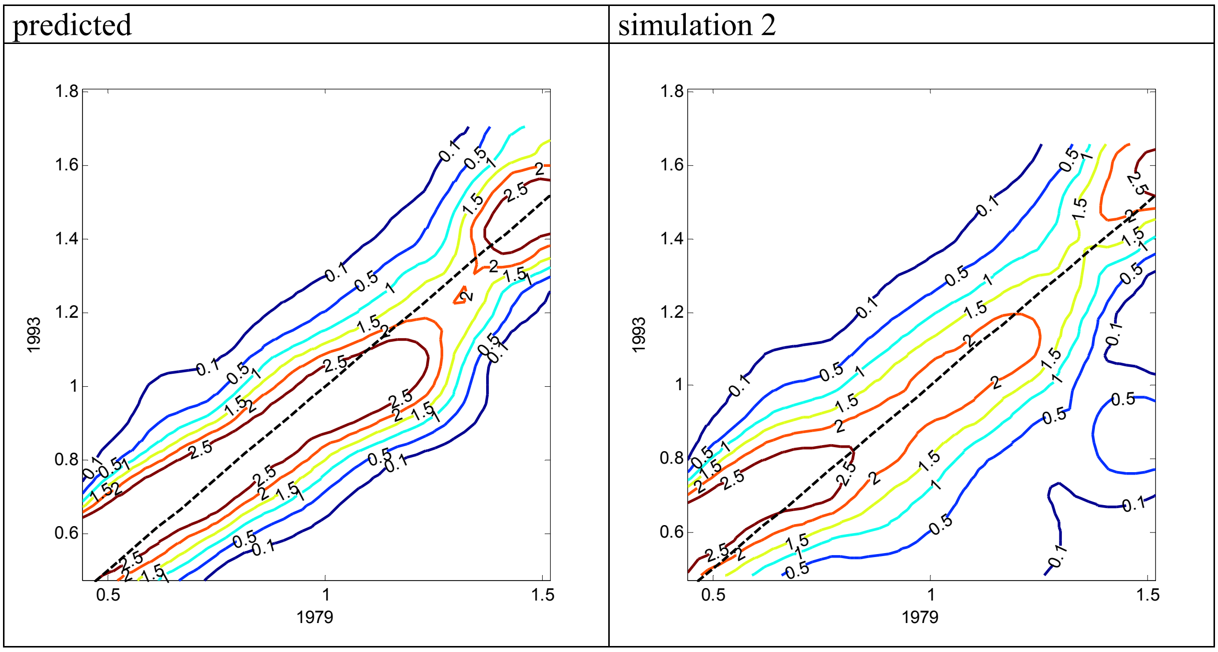
The variables which are active in this way are the number of university students and R & D facilities relative to employment (with the spatialised version of each variable appropriately recalculated). Figure 3 shows a comparison of the distributional dynamics that emerge from end point incomes predicted on the basis of the actual values of all independent variables and those simulated on the basis of the model if all FURs had had the number of university students relative to total employment as observed in the FUR in which that variable had its maximum. The spatialised value of the university students variable in neighbouring FURs is also re-estimated as if all FURs had the maximum value of university students.

Figure 3: Stochastic kernel estimate: ‘predicted’ vs. ‘simulated’ dynamics – University Students



Notes: simulation 1: university students = max (spatial university students recalculated)
Estimates use an Epanechnikov kernel with bandwidth chosen optimally (Silverman 1986)

Figure 4: Stochastic kernel estimate: ‘predicted’ vs. ‘simulated’ dynamics – University Students and R & D values simulated



Notes: simulation 2: university students = max (spatialised university students recalculated); R & D concentration = min (spatialised R & D concentration recalculated)
Estimates use an Epanechnikov kernel with bandwidth chosen optimally (Silverman 1986)

This simulation of end period FUR incomes generates a significantly stronger convergence in the poorer group as well as a reduction in the size of the group. The size of the smaller group of richer FURs growing away from the rest is also reduced. In addition there is a widening of the whole mass - again suggesting more convergence overall.

Figure 4 then shows a more complex set of changes now setting the values of university students for all FURs to the maximum observed but also setting the R & D variable to its minimum observed value (which is zero) for all FURs. Again, the spatialised values of the two variables are recalculated appropriately. This simulation produces an even stronger movement towards convergence with a still smaller mass of poor FURs, a further widening of the probability mass and a further reduction in the size and also – note – the mean income of the richer group of FURs.

We can now compare these results with those that emerge from the more familiar Markov Chain analysis. We do this on the basis of the methodology set out in Magrini 1999 in which we optimise the discretisation of the start and end period distributions. Table 1 shows the goodness of fit tests for this discretisation on the basis of three alternative criteria.

Table 1: Two-sample Kolmogorov-Smirnov goodness-of-fit test

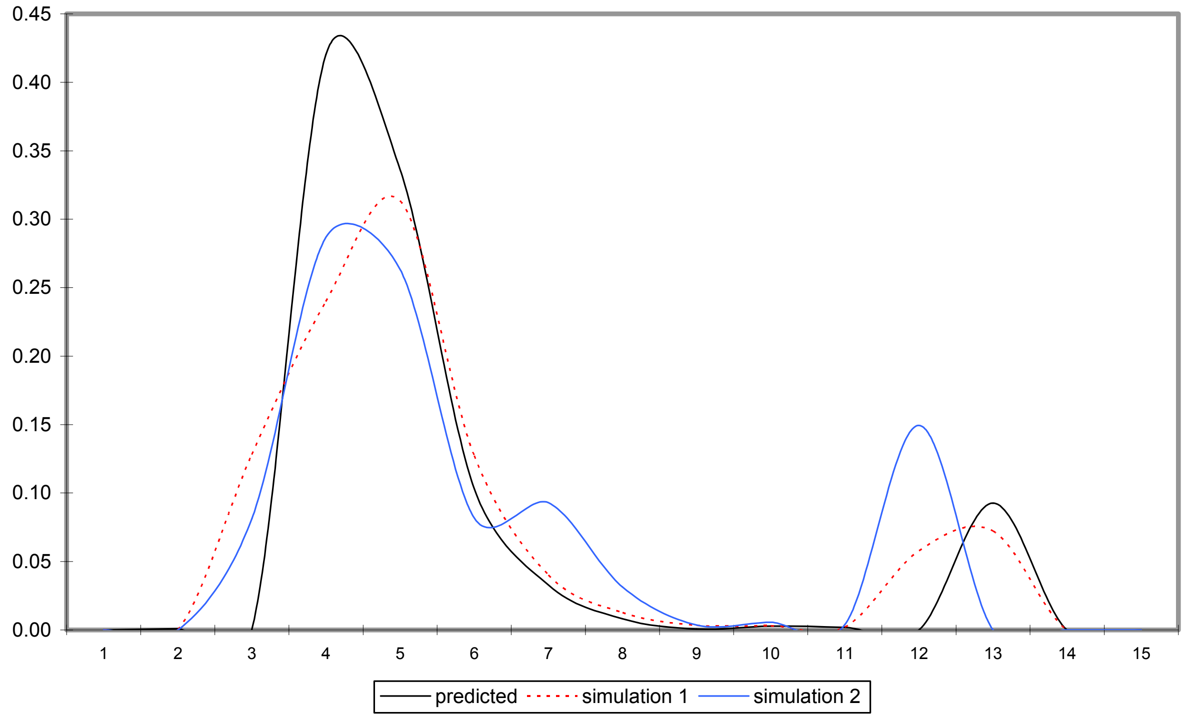
			observed		predicted		simulation 1		simulation 2	
criterion	reference	series	statistic	p-value	statistic	p-value	statistic	p-value	statistic	p-value
SC	1979	1979	0.1736	0.0460	0.1736	0.0460	0.1736	0.0460	0.1736	0.0460
		1993	0.1405	0.1688	0.1818	0.0319	0.1488	0.1252	0.1322	0.2237
	1993	1979	0.1488	**0.1252**	0.1488	**0.1252**	0.1488	**0.1252**	0.1653	**0.0654**
		1993	0.1157	**0.3717**	0.1570	**0.0912**	0.1405	**0.1688**	0.1240	**0.2911**
FD	1979	1979	0.1653	0.0654	0.1653	0.0654	0.1653	0.0654	0.1653	0.0654
		1993	0.1240	0.2911	0.1818	0.0319	0.1322	0.2237	0.1240	0.2911
	1993	1979	0.1653	0.0654	0.1488	0.1252	0.1653	0.0654	0.1653	0.0654
		1993	0.1240	0.2911	0.1570	0.0912	0.1405	0.1688	0.1322	0.2237
DG	1979	1979	0.1653	0.0654	0.1653	0.0654	0.1653	0.0654	0.1653	0.0654
		1993	0.1240	0.2911	0.1818	0.0319	0.1405	0.1688	0.1322	0.2237
	1993	1979	0.1653	0.0654	0.1653	0.0654	0.1653	0.0654	0.1653	0.0654
		1993	0.1322	0.2237	0.1818	0.0319	0.1157	0.3717	0.1240	0.2911

Notes: SC = Scott's (1979) corrected for skewness and kurtosis; FD = Freedman and Diaconis' (1981); DG = Devroye and Gyorfi's (1985)
simulation 1: university students = max (spatial university students recalculated)
simulation 2: university students = max (spatialised university students recalculated); R & D concentration = min (spatialised R & D concentration recalculated))

The best fit criteria we have chosen are highlighted in bold. The resulting transition dynamics are shown in Figure 5 which goes to 20 iterations. It may be noted that there is an underlying very long run tendency for convergence to appear but the ergodic (steady state) distribution using the predicted end point incomes with observed values of independent variables takes some 34886 iterations to emerge[10]. Convergence is reached in successively fewer iterations for the two simulations (which are as before) underlining the greater degree of convergence that is latent in the patterns of FUR growth rates when these are simulated on the basis of alternative values of university students and R & D. Simulation 1 (just assuming university students were everywhere at the maximum observed) takes 12014 iterations to reach its steady state; while simulation 2 (assumed values for both university students and R & D) reaches its steady state – with all FURs in a single group – after 6956 iterations. We may note however that even 6956 iterations 'represent' a period of 97384 years.

[10] Substantively the same as the 36123 iterations taken to reach the ergodic distribution for the observed start and end point incomes.

Figure 5: Transition Dynamics – 20 iterations



What is clear is that the results of these two alternative methods of analysing the distribution dynamics of FUR incomes as they can be observed or simulated on the basis of their behaviour from 1978-80 to 1992-94 produce essentially the same result. The only simulations which perturb the dynamics are those that result from imposing alternative values for the variables measuring highly skilled human capital and the concentration of R & D activities. In both cases, 'endowing' every FUR with the maximum concentration of university students and the minimum concentration of R & D produces a stronger convergence tendency. Simulating R & D at the minimum on its own has only a small effect – it is only when it is interacted with university students that much alteration to the dynamics is observed. Similar results emerge from using stochastic kernels or the more familiar Markov Chain approach.

Thus, the conclusion must be that the most important factor driving the emergence of a rich breakaway club of FURs during the 1980s and early 1990s was differences in the starting levels of students per employee. This interacted with concentration of R & D but the additional effect of R & D was limited.

5. Conclusions

In this paper, we have shown how one can judge a model's performance not only on the basis of its R^2 or other conventional measures of goodness of fit but also on the ability of the model to replicate the dynamic processes it is implicitly estimating. Using an alternative technique we have confirmed the tendency for the distribution of regional incomes to form twin peaks composed of a large group of poorer regions converging on a lower mean level of GDP p.c. and a smaller group of rich regions breaking away; and confirmed that this tendency persisted into the mid-1990s. Furthermore, despite criticisms of the Markov Chain approach we find that the results from a direct application of stochastic kernels are essentially the same as those using the more familiar approach.

The differences between FURs in terms of factors associated with different growth rates which gave rise to this pattern of distributional dynamics seem to have been the distribution of highly skilled human capital and private sector R & D establishments. The only simulations producing stronger underlying convergence were those which endowed each FUR with the maximum number of university students per employee and the minimum (therefore zero) of R & D establishments. We interpret this finding as pointing to the significant role the spatial distribution of the most educated and R & D activity had in driving localised productivity growth.

We doubt that the results identify a policy lever one could pull to change the outcomes observed, however. It does not follow, for example, that if every city had been given the same proportion of university students per employee in 1978 they would all have grown at the same rate as the actually best endowed with universities did. While true that the differences in endowment with universities was one factor in explaining growth differences - and that helps understand what was going on - there is no necessary symmetry about the impact of giving all cities the same sized relative university sectors. It is probable that the unobserved characteristics of the cities with the highest ratios of university students were, and still are, different in important ways from cities with the lowest ratios; and were not independent of the concentration of universities in them. Nor is it possible to think in practical terms of providing all cities with equally high ratios of university students per total employee and maintaining a constant quality of university students (and students who then disproportionately join the local labour force).

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Appendix 1: Variable Definitions and data

Appendix Table 1: The dependent variable was in all cases the annualised rate of FUR growth in estimated GDP p.c. converted at OECD PPS. Growth measured between means of 1978/80 and 1992/94 and estimated from Eurostat NUTS 3 and national data as described in text

	Variable Name	Description
1	Ln Population	Natural log of population in 1979
2	Population density	Density of population in FUR in 1979
3	Coalfield: core	A dummy=1 if the core of the FUR is located within a coalfield
4	Coalfield: hinterland	A dummy=1 if the hinterland of the FUR is located in a coalfield
6	Port size ’69	Volume of port trade in 1969 in tons
7	Agric Emp.’75	Percentage of labour force in agriculture in surrounding Level 2 region in 1975
8	Nat Ex-FUR GDP Grow ’79-‘93	Annualised rate of growth of GDP p.c. in the territory of each country outside major FURs between 1978/80 and 1992/94
9	Policy Capacity	Ratio of FUR population to the that of the largest governmental unit associated with the FUR (1981): see below for details.
10	Integration Gain	Change in economic potential for FUR resulting from movement from individual nation-states to post enlargement EU with reduced transport costs
11	University Students ratio 1977/78/79	Ratio between university and higher education students (1977-1978) and total employment (1979)
12	University Student density in neighbouring FURs within 150 minutes	Sum of university and higher education students per 1000 employees in all FURs within 150 minutes travel time with 600 time penalty added for national borders
13	R&D Facilities per million population	R&D laboratories of Fortune top 300 companies per million employees (1980)
14	R&D Facilities per million in FURs within 150 minutes+600 min border cost	Sum of R&D Facilities per million employees in all FURs within 150 minutes travel time with 600 time penalty for national borders
15	Density of Unemployment in FURs within 60 minutes	Sum of differences between the unemployment rate (average between 1977 and 1981) of a FUR and the rates in neighbouring FURs (60min) weighted by the distance
16	Dummy for peripheral FURs 600 mins or more travel time from Brussels	Dummy variable = 0 if FUR is less than 600 minutes travel time (allowing for sea crossings) from Brussels: =1 for all other FURs

To estimate the **Policy Capacity** variable the rules determining the selection of the largest 'relevant' governmental unit were:

Belgium	The central communes for all except Bruxelles for which the capital region (Arrondissement) was taken;
Denmark	Central Municipality;
Germany	The Kreisfreie Stadte except for Bremen and Hamburg where the NUTS 1 Land region was taken and Frankfurt where the Umlandverband was taken;
France	Since there is a NUTS 1 region, the Ile de France, which has significant powers, was selected for Paris. Elsewhere in France the central Commune was selected except for those FURs for which a Communité Urbaine exists; in those cases the Communité Urbaine was selected
Greece	The central Municipality;
Ireland	The County Borough (of Dublin);
Italy	The central Commune was selected in all cases. Unlike the situation in France (Paris) or Germany (Bremen and Hamburg) there is no NUTS 1 or 2 region corresponding to any city nor is there any city with a city wide tier of government (such as the Communité Urbaine).
The Netherlands	The central Municipality (as Italy);

Portugal	The central Municipality (as Italy);
Spain	Where there was one major FUR in a Communidad Autonoma (a NUTS 2 region), the Communidad Autonoma was selected; where there was more than one major FUR in the Communidad Autonoma but only one in the Provincia (a NUTS 3 region), the Provincia was selected; where there was more than one major FUR within a Provincia then the central Municipio was selected;
United Kingdom	In England, the District was selected except in London where Inner London was used; in Scotland, the regions of Lothian and Strathclyde were taken and for Belfast the NUTS 1 region of Northern Ireland was the government unit identified.

The only case, then, for which no obvious rule was available, was that of London because of the abolition of London-wide government in the middle of the period. In 1985, local government powers were re-assigned down to the 32 boroughs and up to committees of boroughs and to central government. There were further changes to this system in the later part of the period when the Government Office for London was set up. The only stable unit of government relating to London was the City of London or the individual London boroughs but there was a regional authority – Greater London – for some of the period. The selection of Inner London - not really a governmental unit at all - represented no more than the most reasonable compromise. We tested alternatives and as might be expected, substituting the value for the largest borough or the GLC as a whole made no material difference to the results reported here.

Sources for other data

Variable No	
1	National Censuses of population or – where unavailable – national registration data
2	Area from administrative maps
3	*Oxford Regional Economic Atlas*, Oxford: OUP, 1971
4	*Oxford Regional Economic Atlas*, Oxford: OUP, 1971
5	Hanbusch der Europaischen Seehafen Band II, III, IV, V, VI, VII, VIII, IX & X Hamburg: Verlag Weltarchiv, various dates from 1968
6	Eurostat
7	Estimated from Eurostat data
8	See above for details.
9	Estimated from Clark *et al* 1969 and Keeble *et al* 1988
10	University Students taken from *The International Association of Universities*, *International Handbook of Universities*, 1978, (seventh edition), London: The Macmillan Press; *Association of Commonwealth Universities, Commonwealth University Yearbook 1979*, 1978, (fifty-fifth edition) London: The Association of Commonwealth Universities; and *The World of Learning 1978-1979*, 1978, (twenty-ninth edition), London: Europa Publications: total employment estimated from Eurostat data
11	University Student density as per variable11: time distances here and elsewhere from standard road freight software.
12	R&D laboratories of Fortune top 500 companies as reported in *Directory of European Research*, London: Longman, 1982
13	R&D Facilities as per 13: time distances as per 12
14	Unemployment rates estimated for FURs from Eurostat NUT 3 data
15	Time distances from standard road freight software: Microsoft

Appendix Table 2: Dependent Variable Annualised Rate of Growth of GDP p.c. Mean 1978/80 to mean 1992/4:

N=121		Model
Log Lik		513.634
Adj. R^2		0.697
Constant plus:		
Coalfield: core		-0.005895
	t	-4.70
	prob	0.000
Coalfield: hint'land		-0.00381
	t	-2.51
	prob	0.014
Port size '69		-0.001166
	t	-3.12
	prob	0.002
Port size $'69^2$		0.000057
	t	2.40
	prob	0.018
Agric Emp.'75		0.000462
	t	2.85
	prob	0.005
Agric Emp.$'75^2$		-0.000012
	t	-2.79
	prob	0.006
Nat Ex-FUR GDP Grow '79-'93		0.911897
	t	9.18
	prob	0.000
Ln Population 1981		0.001936
	t	3.40
	prob	0.001
Population Density 1981		-0.0000014
	t	-2.22
	prob	0.029
Policy Capacity		0.00755
	t	2.17
	prob	0.033
Policy $Capacity^2$		-0.002119
	t	-1.35
	prob	0.180
University Students ratio 1977/78/79		0.0000272
	t	2.53
	prob	0.013
University Student density in FURs within 150 minutes+600 min border cost		-0.00874
	t	-2.30
	prob	0.024
R&D Facilities per million		0.000423
	t	3.51
	prob	0.001
R&D Facilities per million in FURs within 150 minutes+600 min border cost		0.09897
	t	2.58
	prob	0.011
Integration Gain		0.00566

REGRESSION DIAGNOSTICS

Diagnostics for Error Normality & Heteroskedasticity Test

	DF	Value	Prob.
Jarque-Bara	2	0.4099	0.8147
Breusch-Pagan test	18	19.3602	0.3700

Diagnostics for Spatial Dependence:: weights matrix = inverse of time distance squared + 600 minute border penalty

	DF	Value	Prob.
Lagrange Multiplier error	1	0.7025	0.4019
Lagrange Multiplier lag	1	2.024	0.1520

t	3.96
prob	0.000
Dummy for FURs 600 mins or more travel time from Brussels (Peripheral)	0.004532
t	3.53
prob	0.001
Density of Unemployment in FURs within 60 minutes	-0.007044
t	-2.49
prob	0.014

Appendix 2: FUR and NUTS GDP data

FUR	NUTS Level 3	% Difference FUR:NUTS Growth rate 1978/80 to 1992/94	Mean GDP p.c. 1992-94.
Antwerpen	Antwerpen (Arrondissement)	2.02	-14.26
Bruxelles-Brussel	Reg.Bruxelles-Cap./Brussels Hfdst.Gew.	-4.12	-59.64
Charleroi	Charleroi	-0.17	-8.60
Liege	Liege (Arrondissement)	6.47	-0.43
Aarhus	Aarhus Amt	0.62	0.01
Koebenhavns	Koebenhavns Amt	-2.27	-7.82
Aachen	Aachen, Landkr.	13.39	22.27
Augsburg	Augsburg, Krfr.St.	-4.51	-42.99
Bielefeld	Lippe	0.05	16.26
Bochum	Recklinghausen	8.11	17.50
Bonn	Rhein-Sieg-Kreis	-1.05	21.75
Braunschweig	Braunschweig, Krfr.St.	-3.70	-26.89
Bremen	Bremen, Krfr.St.	0.80	-36.05
Dortmund	Dortmund, Krfr.St.	2.32	-11.76
Duesseldorf	Duesseldorf, Krfr.St.	-0.23	-51.05
Duisburg	Duisburg, Krfr.St.	3.68	-12.00
Essen	Essen, Krfr.St.	-3.76	-13.94
Frankfurt	Frankfurt am Main, Krfr.St.	-0.08	-89.61
Hamburg	Hamburg	0.83	-27.67
Hannover	Hannover, Landkr.	-3.49	38.82
Karlsruhe	Karlsruhe, Landkr.	0.46	21.95
Kassel	Kassel, Landkr.	-12.13	19.47
Koeln	Koeln, Krfr.St.	-0.32	-25.64
Krefeld	Viersen	-16.69	12.38
Manheim	Rhein-Neckar-Kreis	-9.62	30.27
Moenchengladbach	Moenchengladbach, Krfr.St.	-1.12	-13.67
Muenchen	Muenchen, Krfr.St.	0.60	-38.84
Muenster	Steinfurt	2.08	11.20
Nuernberg	Nuernberg, Krfr.St.	-2.73	-47.74
Saarbruecken	Saarbruecken, Stadtverband	3.10	-33.11
Stuttgart	Stuttgart, Stadtkr.	-0.57	-60.71
Wiesbaden	Wiesbaden, Krfr.St.	-22.16	-58.16
Wuppertal	Wuppertal, Krfr.St.	-1.79	-4.24
Athens	Attiki	-0.81	0.07
Saloniki	Thessaloniki	-0.15	-0.04
Alicante	Alicante	0.00	0.00
Barcelona	Barcelona	0.05	0.31
Bilbao	Vizcaya	-0.87	0.19
Cordoba	Cordoba	0.00	0.00
Gijon/Aviles	Asturias	0.00	0.00
Granada	Granada	-0.02	0.34
La Coruna	La Coruna	0.00	0.00
Madrid	Madrid	-0.16	-0.58
Malaga	Malaga	0.02	-0.01
Murcia	Murcia	0.00	0.00
Palma De Mallorca	Baleares	0.00	0.00
Sevilla	Sevilla	-0.43	-0.14
Valencia	Valencia	-0.16	0.19
Valladolid	Valladolid	0.01	-0.01
Vigo	Pontevedra	0.00	0.00
Zaragoza	Zaragoza	-2.31	0.53
Bordeaux	Gironde	0.03	-0.02
Clermont-Ferrand	Puy-de-Dome	0.00	0.00
Dijon	Cote-d'Or	0.00	0.00

Grenoble	Isere	-0.02	-0.01
Le Havre	Seine-Maritime	0.00	0.00
Lille	Nord	0.00	0.00
Lyon	Rhone	-0.45	-5.67
Marseille	Bouches-du-Rhone	0.00	0.00
Montpellier	Herault	0.00	0.00
Mulhouse	Haut-Rhin	0.00	0.00
Nancy	Meurthe-et-Moselle	0.00	0.00
Nantes	Loire-Atlantique	0.81	-6.96
Nice	Alpes-Maritimes	0.00	0.00
Orleans	Loiret	0.37	-0.39
Paris	Paris	-6.12	-78.87
Rennes	Ille-et-Vilaine	0.00	0.00
Rouen	Seine-Maritime	2.19	-6.17
St. Etienne	Loire	3.16	-1.60
Strasbourg	Bas-Rhin	0.00	0.00
Toulon	Var	0.00	0.00
Toulouse	Haute-Garonne	0.00	0.00
Valenciennes	Nord	0.00	0.00
Dublin	East	-7.12	5.94
Bari	Bari	11.43	6.03
Bologna	Bologna	-3.26	-3.72
Brescia	Brescia	4.16	-3.24
Cagliari	Cagliari	5.05	4.21
Catania	Catania	22.76	14.88
Firenze	Firenze(94)	15.27	10.52
Genova	Genova	5.58	6.46
Messina	Messina	12.86	10.51
Milano	Milano(94)	5.03	9.40
Napoli	Napoli	3.90	5.53
Padova	Padova	3.13	-0.34
Palermo	Palermo	12.41	10.30
Roma	Roma	1.36	-0.59
Taranto	Taranto	10.01	7.14
Torino	Torino	-8.16	-2.33
Venezia	Venezia	-3.26	-0.50
Verona	Verona	2.00	0.41
Amsterdam	Groot-Amsterdam	-7.30	-26.55
Rotterdam	Groot-Rijnmond	3.48	-5.48
's-Gravenhage	Agglom.'s-Gravenhage	6.74	-7.40
Utrecht	Utrecht	-0.75	-2.66
Lisboa	Lisboa E Vale Do Tejo	2.88	-5.24
Porto	Norte	9.23	9.78
Belfast	Northern Ireland	0.00	0.00
Birmingham	West Midlands (County)	1.53	-2.93
Brighton	East Sussex	4.68	7.22
Bristol	Avon	-0.99	-2.12
Cardiff	South Glamorgan	-9.49	-20.80
Coventry	West Midlands (County)	5.60	0.61
Derby	Derbyshire	-0.08	-0.18
Edinburgh	Lothian	-0.42	-0.73
Glasgow	Strathclyde	-0.35	-0.04
Hull	Humberside	0.00	0.00
Leeds	West Yorkshire	0.87	0.68
Leicester	Leicestershire	0.00	0.00
Liverpool	Merseyside	0.59	0.58
London	Greater London	1.08	-9.42
Manchester	Greater Manchester	1.42	1.20
Newcastle	Tyne and Wear	-1.83	-6.55
Nottingham	Nottinghamshire	0.05	-0.74
Plymouth	Devon	-2.66	-6.28

Portsmouth	Hampshire	0.00	0.00
Sheffield	South Yorkshire	1.98	0.90
Southampton	Hampshire	0.00	0.00
Stoke	Staffordshire	1.94	3.70
Sunderland	Tyne and Wear	-1.44	-4.95
Teesside	Cleveland	5.59	1.53

The table above shows for each FUR the corresponding NUTS Level 3 region in which the largest proportion of its population resided in 1981. The last two columns show respectively the percentage difference in calculated growth rates for the estimated FUR and corresponding NUTS regions' GDP p.c. between the mean of 1978/1980 and the mean of 1992/1994; and the percentage difference between the two GDP p.c. values for the mean of 1992/94. Other representations are, of course, possible. For example, here we are comparing just FUR and NUTS 3 data. But one could take different NUTS level regions e.g. the most commonly used - NUTS 2 regions – or vary the NUTS Level used according to the size of the city for different FURs and the results would be somewhat different. As can be seen growth rates using the basis of comparison illustrated here vary by up to 23% while estimated GDP per capita varies up to 79%