Towards a Co-Evolutionary Model of Demographics and Infrastructure

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ABSTRACT

National infrastructure systems provide a foundation for economic prosperity and well-being. In addition to factors such as technological change and obsolescence, infrastructure systems need to respond to changing levels of demand, which is strongly driven by population growth. However demographic change is not independent of economic conditions, or the nature and quality of infrastructure. This research is concerned with the interrelationships between demographics, economy and infrastructure.

The paper therefore develops a novel approach to modelling the evolution of a national economy in the context of changing demographics and infrastructure provision. This approach is based in a model with coupled sub-systems which are spatially disaggregate with explicit temporal dynamics. A version of the model is calibrated using a demographic component which incorporates both natural change and migration, and an economic model which recognises both labour and capital as factors of production. Infrastructure is present as an influence on accessibility, geographical attractiveness and economic productivity.

The performance of the model is explored through a variety of scenarios which are offered as an initial proof of concept of the feasibility of implementing a co-evolutionary model of demographic and economic growth over a medium to long time horizon. These scenarios indicate the influence of government policies for international migration and infrastructure investment on regional development and performance.

Keywords: Demographics, Economy, Infrastructure

INTRODUCTION

This paper reports investigations into the feedback and linkages between demographic change and infrastructure provision which are being undertaken by the Infrastructure Transitions Research Consortium (ITRC). National infrastructure systems (NIS) provide a foundation for economic productivity and human wellbeing. They shape many of the interactions between human civilisation and the natural environment[1] . However, the NIS for Great Britain faces considerable challenges in the future to serve a globalised economy and to meet the government's commitment on reduction in greenhouse gas emission[2] . Infrastructure UK (IUK), with support from organisations such as the ITRC, are amongst many groups on the international stage who are tasked with addressing such problems.

1 Hall, J.W., Henriques, J.J., Hickford, A.J. & Nicholls, R.J. (2012, eds). A Fast Track Analysis of strategies for infrastructure provision in Great Britain: Executive Summary. Environmental Change Institute, University of Oxford.

2 Tran, M. et al (2014). National infrastructure assessment: Analysis of options for infrastructure provision in Great Britain, Interim results. Environmental Change Institute, University of Oxford.

The population of the UK is currently growing rapidly under the influence of both international migration and natural change. This growth has been spatially uneven, which has important implications for infrastructure provision. ITRC has therefore laid down a series of spatially explicit demographic scenarios as a driver of future infrastructure requirements[3].

In the ITRC programme to date the reverse coupling of demographics to infrastructure has been articulated less explicitly. Interregional migration flows are typically viewed as business as usual, in common with core national projections. However the dependence of future demographic change on infrastructure is obvious – thus a new high speed link between London and Birmingham would change relative accessibilities, which are the key driver of migration and commuting flows between these regions. Infrastructure can also influence population change indirectly through economic growth – for example, the construction of a new desalination plant in East Anglia (say) would create new jobs, tending to encourage the inflow of migrant workers. In short, “population growth leads to increased demand for infrastructure services, but better infrastructure services also attract population to a region”[4] .

This paper therefore seeks to explore the dynamic co-evolution of demographics, the economy and infrastructure, as series of coupled subsystems. Models of this type have been suggested in the past for abstract multi-agent systems[5] , and co-evolutionary models have been explored to some extent in the context of both ecological systems[6] and economic markets[7] . None of these models includes either infrastructure or a spatially explicit representation of a real demographic system. Of course linkages between population (or at least ‘demand’) and economic sectors, including infrastructure, are a feature of well-established input-output models, but although substantial work has been invested in the regional disaggregation of such models[8] these approaches in turn lack an evolutionary perspective. The approach to be adopted here is therefore unique in exploring the co-dependence of demographics and infrastructure within a spatially explicit modelling framework.

3 Zuo, C., Birkin, M., Malleson, N. (2014) Dynamic Microsimulation Modelling for National Infrastructure Demand in an Uncertain Future, GeoSpatial Information Science, forthcoming.

4 Beaven, R., Birkin, M., Crawford Brown, D., Kelly, S., Thoung, C., Tyler, P., Zuo, C. (2014) Future Demand for Infrastructure Services, in Tran, M. et al (eds) Planning Infrastructure for the 21st Century, Cambridge University Press (forthcoming).

5 Epstein, J., Axtell, R. (1996) Growing Artificial Societies, Brookings Institution.

6 Dove, M. (1993) The coevolution of population and environment: The ecology and ideology of feedback relations in Pakistan, Population and Environment, 15, 89-111.

7 Boucekkine, R., de la Croix, D., Licandro, O. (2002) Vintage Human Capital, Demographic Trends, and Endogenous Growth, Journal of Economic Theory, 104, 340-375.

8 Miller, R., Blair, P. (2009) Input-output analysis: foundations and extensions, Cambridge University Press.

MODELLING FRAMEWORK

The structure of the model in its current form is illustrated in Figure 1. The link from population to the economy is indicated through the flow of labour as a factor of production, while the reverse link is effected through a combination of spatial processes which underpin population movements. The role of infrastructure is articulated as of particular importance in view of the substantive focus of this work.

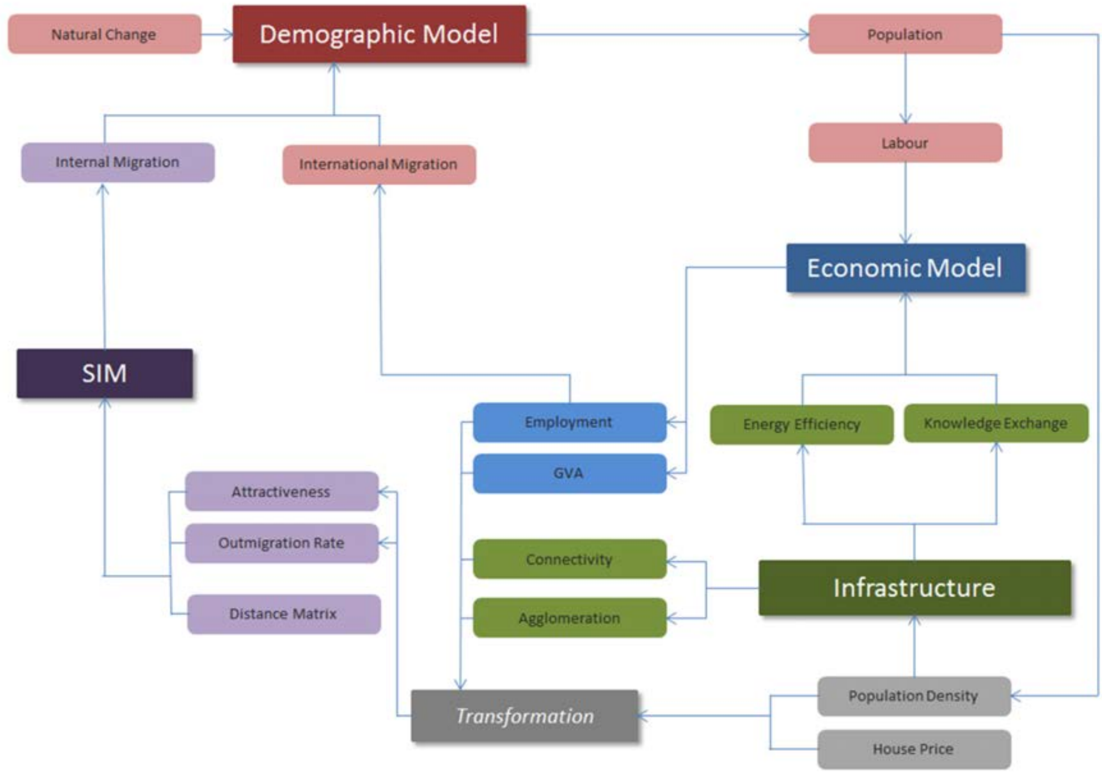

Figure 1 Structure of the modelling framework

The population projection model consists of three standard components which are fertility, mortality and migration:

$$Pop_{LAD}^{Y} = Pop_{LAD}^{Y-1} + NC_{LAD}^{Y} + {}^{O}IM_{LAD}^{Y} + {}^{I}IM_{LAD}^{Y} - {}^{O}OM_{LAD}^{Y} - {}^{I}OM_{LAD}^{Y} \qquad (1)$$

Where: Pop represents the population for a region, i, at year Y. NC represent the natural change which is the difference between the number of live births and the number of deaths. Migration terms are expressed by four variables here which are immigration from overseas (OIM), outmigration to overseas (OOM), immigration from within UK (IIM), and outmigration to somewhere else within UK (IOM).

For a given level of outmigration, a production-constrained spatial interaction model can be introduced to generate inter-regional migration flows:

$$T_{ij} = A_i * OM_i * Att_j * f(d_{ij}), \quad A_i = \frac{1}{\sum_j Att_j * f(d_{ij})} \qquad (2)$$

where T_{ij} represents the migration flow from region (i) to region (j), Att_j is attractiveness of region (j) and d_{ij} is a measure of the distance or trip cost between region pairs. A_i is a balancing factor which ensures that the flows from each region are constrained to the overall level of outmigration.

There are two sets of parameters which need to be calibrated. Typically the distance function is articulated as a negative exponential $f(d_{ij})$ = exp (-€d_{ij}) when €is a parameter related to the efficiency of the transport system; and attractiveness (Att_j) is a synthetic variable which indicates the potential to attract migration into a region (j). These parameters can be calibrated based on historical migration data, which is generated from patient registration data in the National Health Service[9] .

In order to integrate the migration model (SIM) into the demographic model, it is important to understand the variation of attractiveness and out-migration rates, as these two variables are the key inputs of the SIM. Two simple linear models were built to predict these two variables based on a series of socio-economic variables[10] , including Population Density (PD), Total Employment (Emp), Average House Price (HP), Gross Value Added (GVA), Unemployment (Unemp), Average Road Speed (AS) and Total Population (Pop). A stepwise multivariate regression technique was applied to identify the most appropriate predictive variables.

According to the modelling results, the attractiveness of each Local Authority District (LAD) for a given year (Y) can be represented by Population Density, GVA, Average House Price, Total Employment and Average Road Speed of previous year (Y-1), denoted as:

$$Att_{LAD}^{Y} = K_1 PD_{LAD}^{Y-1} + K_2 GVA_{LAD}^{Y-1} + K_3 HP_{LAD}^{Y-1} + K_4 Emp_{LAD}^{Y-1} + K_5 AS_{LAD}^{Y-1} + e_{LAD} \qquad (3)$$

The out-migration rate (OMR) can be written as a function of Average House Price, Population Density, Total Population, Total Employment, and GVA so the model can be written as:

$$OMR_{LAD}^{Y} = M_1 HP_{LAD}^{Y-1} + M_2 PD_{LAD}^{Y-1} + M_3 Pop_{LAD}^{Y-1} + M_4\, Emp_{LAD}^{Y-1} + M_5 GVA_{LAD}^{Y-1} + e'_{LAD} \qquad (4)$$

In equations (3) and (4) $k_1 - k_5$ represent linear weights for the regression model for attractiveness; $m_1 - m_5$ represent equivalent weights for the migration model; $\{e_{LAD}\}$ and $\{e'_{LAD}\}$ are vectors of errors for each Local Authority District. According to these equations, GVA and Employment are needed to estimate the local out migration rate and attractiveness. These two figures can be obtained from the economic model. In this study, Cobb-Douglas production function is chosen as the heart of the economic model. This can be written as:

$$Y = A * L^k * C^{1-k} \qquad (5)$$

where Y is total production (the real value of all goods produced in a year); L is labour input (the total number of person-hours worked in a year); C is capital input (the real value of all machinery, equipment, and buildings), A is total factor productivity (TFP) which accounts for effects in total output caused by many other factors other than labour and capital, including technical innovation, organizational and institutional changes, education level etc.[11]; and k is the output elasticity of labour. The k value is approximately equal to the labour's share (W*L / (W*L+C))[12] , which gives an approximation k = 0.64.

9 Lomax, N., Stillwell, J., Norman, P. and Rees, P. (2014) Internal migration in the United Kingdom: analysis of an estimated inter-district time series, 2001-2011. Applied Spatial Analysis and Policy. Vol.7, pp25-45

10 Rees, P., Fotheringham, S., Champion, T. (2004) Modelling Migration for Policy Analysis, in Stillwell, J., and Clarke, G. (eds.) Applied GIS and Spatial Analysis, Wiley, Chichester

11 Hulten, C., Dean, E., Harper, M. (2001). New Developments in Productivity Analysis, University of Chicago Press. pp. 1–54.

12 Douglas, P.,(1976), The Cobb-Douglas Production Function Once Again: Its History, Its Testing, and Some New Empirical Values, Journal of Political Economy, 84(5), pp.903-916

Assuming the investment on capital and labour are all from the earning (e.g. total production) of the previous year, we have:

$$Y_{Nation}^{year-1} = \sum C_{NUTS2}^{year} + \sum L_{NUTS2}^{year} * W_{NUTS2}^{year} \quad (6)$$

where represents the average annual wage for a labour during a given year in a NUTS2 region. Therefore, when wages and capital are fixed, the optimised employment can be estimated.

Total factor productivity for the whole country, and for individual regions, is calculated based on the GVA, employment and average wage obtained from the ONS official labour market statistics. Table 1 shows the relevant input data and TFP for the first 10 years (2001-2010).

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Wage (£K)	20.3	21.4	21.6	21.9	22.8	24.3	25.5	26.8	28.4	27.4
Employment (million)	27.7	27.9	28.2	28.5	28.8	29.0	29.2	29.4	29.0	29.0
GDP (trillion £)	0.92	0.96	1.02	1.08	1.14	1.20	1.27	1.31	1.28	1.33
Capital (trillion £)	N/A	0.32	0.35	0.40	0.42	0.43	0.45	0.48	0.49	0.48
Labour's Share	N/A	0.65	0.63	0.61	0.61	0.62	0.62	0.62	0.637	0.62
TFP	N/A	1308.	1335.	1339.	1376.	1429.	1481.	1491.	1466.	1524.

Table 1. The economic data and estimated TFPs for the whole country

Then, the projected local TFP for each NUTS2 region is calculated on the basis of a series of assumptions: (1) TFP grows linearly; (2) the relationship between TFP and average wage stays constant; (3) the proportion of investment of each region remains at the 2006 level; (4) the saving rates for each region remains at the 2006 level; and (5) the growth rate of TFP remains as the first 7 years (2001-2007).

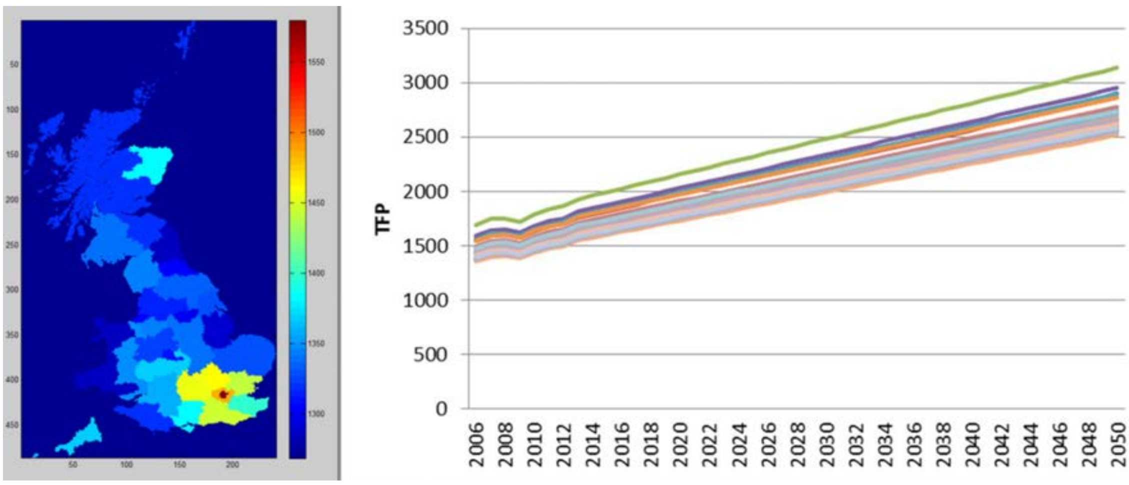

Figure 2 Calibrated TFP by NUTS2 regions (2004) and b) Projected TFP for 2003-2100 by NUTS2 region

The operation of the model can now be summarised as follows. The primary objective is to project changes in population and Gross Value Added for each region under a variety of policy scenarios. Let us suppose for the sake of illustration that laissez faire policies are adopted without restraint on migration, (and furthermore that infrastructure is able to adapt swiftly and smoothly to increased demand. For a given base year, the population, wage rate, TFP and capital employed are all known. Now assuming demographic growth then productivity in the following year will increase with greater availability of labour (from equation (5)). However population growth also affects regional attractiveness and migration rates in (1)-(4), which are also influenced by productivity and employment rates. Hence the dynamics of economic performance and demographic change are interdependent and co-evolutionary.

RESULTS AND DISCUSSION

The relationships between economic growth, demographic change and infrastructure have so far been tested by applying four different policy scenarios. In the first scenario, it is assumed that infrastructure and migration policy can meet the requirements of any growth in population or economy. The second scenario assumes that the investment on infrastructure is just enough to maintain its existing function and standard, but that each region has a ‘carrying capacity’ up to 50% higher than today’s level. In the third scenario the infrastructure can support any population size, but international immigration remains at its existing level. The fourth scenario introduces an explicit link between infrastructure and demographics, as any increase in population gives rise to increased congestion and slower travel speeds on a fixed transport infrastructure. This creates a negative feedback loop because average travel speed correlates to region attractiveness in equation (3).

Indicative results for the four policy scenarios are shown in Figure 3. For convenience, results are presented for three example regions, Inner London, Outer London and West Yorkshire. Growth in both the population and the economy (as measured by GVA) is naturally highest in scenario 1 where labour flows freely as a factor of production. The city of London appears to be the most significant beneficiary of a free flow of (skilled) labour. Scenario 3 indicates that current immigration policies have a significant damping effect on economic growth according to this model. Infrastructure scarcity is a further limiting factor in scenario 2, and this effect is especially pronounced in the London regions as one might expect. Scenario 4 looks rather like scenario 3 in the results presented here, because it rests on the same assumptions about international migration. However in this instance sub-regional variations in the distribution of population are considerable.

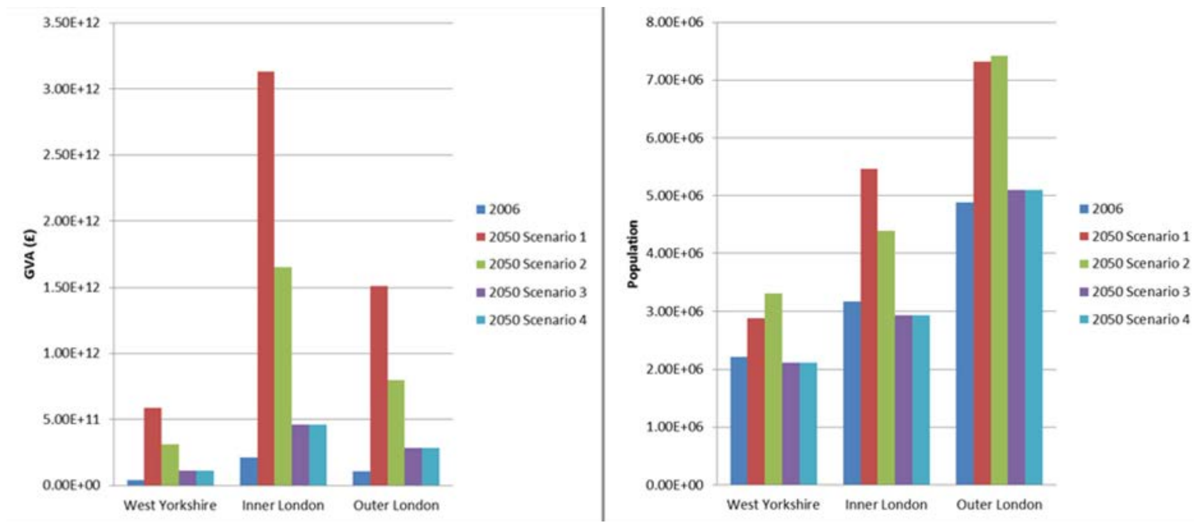

Figure 3 GVA and Population for selected NUTS2 region on 2006 and 2050 under different scenarios

The four scenarios presented here are offered as an initial proof of concept of the feasibility of implementing a co-evolutionary model of demographic and economic growth over a medium to long time horizon. All of the scenarios are based on a rather abstract view of the role of infrastructure. Future work will explore this dimension in greater detail, for example by investigation of the relationship between total factor productivity and agglomeration, energy efficiency and knowledge exchange[13] , as well as connectivity for which scenario 4 constitutes a preliminary test. In this way, a more sophisticated representation of the economy (than equations 5, 6) will be offered, while still recognising the positive relationship between labour, capital and economic performance. Alongside transportation, other key infrastructure sectors such as water, waste, ICT and energy will be represented. This programme promises a distinct and exciting perspective on the dynamic interplay of social and economic policies, regional development, infrastructure provision and prosperity.

13 Carlsson, R., Otto, A., Hall, J. W. (2013). The role of infrastructure in macroeconomic growth theories, Civil Engineering and Environmental Systems, 30th Anniversary Special Issue, 30(3–4).