Modelling the long-term economic and demographic impacts of major infrastructure provision: a simultaneous model approach

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Summary

This paper reports investigations into the feedback and linkages between demographic change and infrastructure provision. In this paper, we seek to explore the coupled dynamic of demographics, the economy and infrastructure simultaneously as a series of subsystems. The modelling results will explore different policy scenarios for regional infrastructure investment to offer an initial proof of concept of the feasibility of implementing a coupled model of demographic and economic growth over a medium to long time horizon, and promises a distinct and exciting perspective on the co-dynamic interplay of social and economic policies, regional development, infrastructure provision and prosperity.

KEYWORDS: infrastructure, demographic change, economic development, scenario modelling, policy analysis.

1. Introduction

This paper reports investigations into the feedback and linkages between demographic change, economic development 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.

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 these regions. Infrastructure can also influence population change indirectly through economic growth – for example, the construction of a new desalination plant in East Anglia 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

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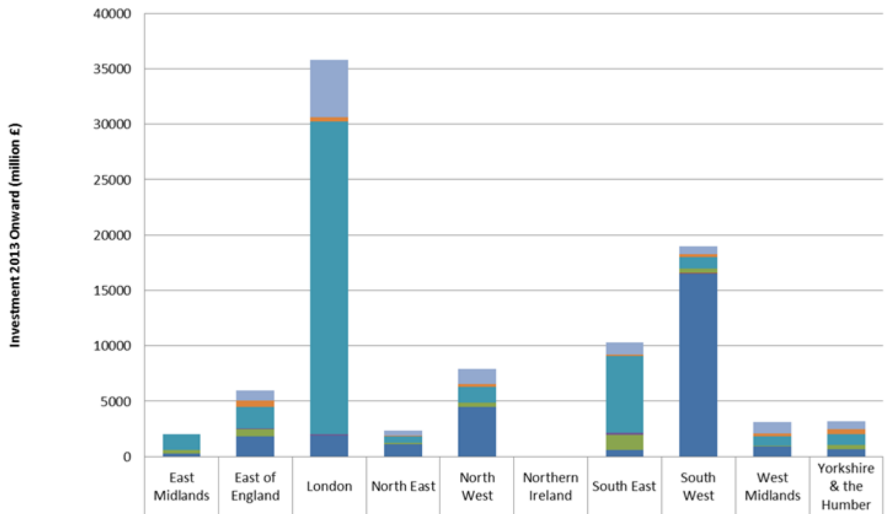
region” (Beaven, et al, 2014).

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 (Zuo et al, 2014).

Since 2010, the UK government starts to publish its National Infrastructure Plan (NIP) in an annually basis in order to setting out *a broad vision of the infrastructure investment required to underpin the UK’s growth*. In the NIP2014, an ambitious infrastructure plan was set out for the till 2020 and beyond by underpinning a pipeline of over £460 billion of planned public and private investment. The diagram below (Figure 1) shows the investment plan specified by the NIP2014. According to the plan, majority of the investment is going to transport and energy sector and mainly located in London and south of England.



	East Midlands	East of England	London	North East	North West	Northern Ireland	South East	South West	West Midlands	Yorkshire & the Humber
Water		872	5206	487	1387		1076	697	1049	720
Waste	0	581	368	45	238		112	275	239	446
Transport	1398	1937	28258	550	1401		6943	1072	878	981
Intellectual capital		46	133				179			
Flood	341	701		148	406		1402	335	20	380
Communication								64		
Energy	257	1803	1868	1123	4493	0	567	16543	937	662

Figure 1. The 2013 onward infrastructure investment

This paper therefore seeks assess the socio-economic impact of these infrastructure developments by deploying a dynamic co-dependence 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, and co-evolutionary models have been explored to some extent in the context of both ecological systems and economic markets. 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 these approaches in turn lack an co-dependence perspective. The approach to be adopted here is therefore unique in exploring the co-dependence of infrastructure economy and demographics within a spatially explicit modelling framework.

2. 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.

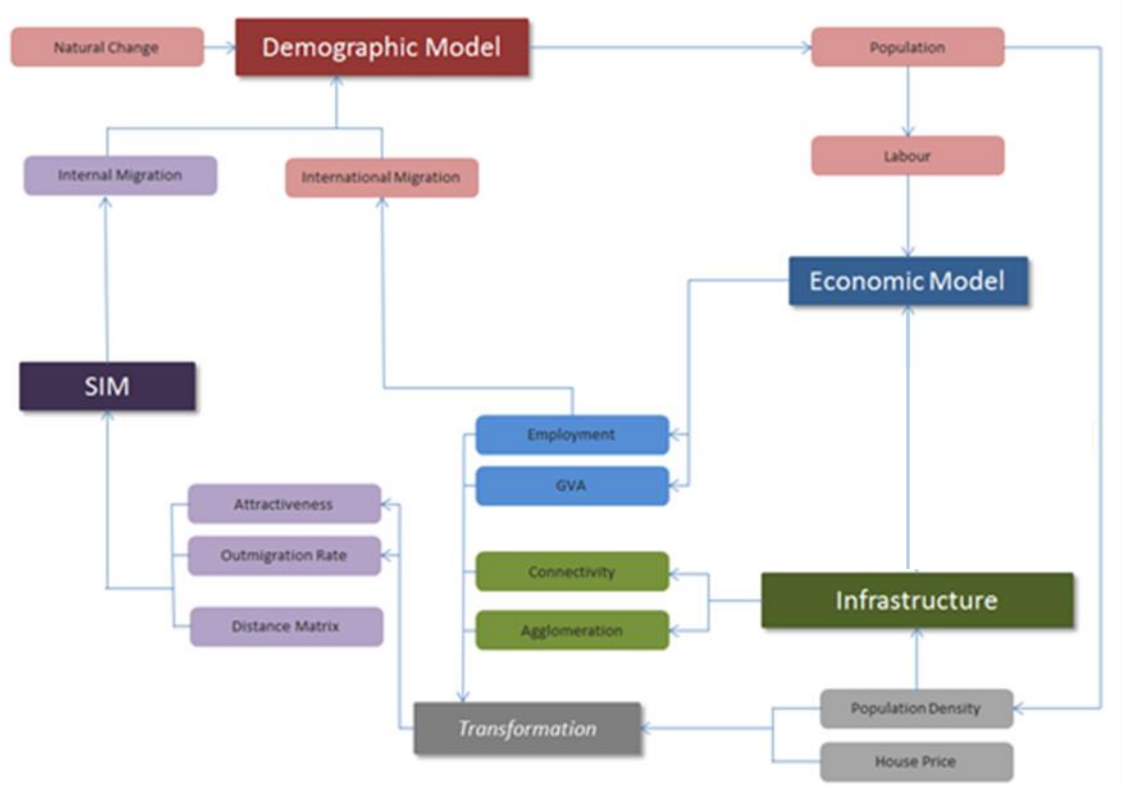


Figure 2 Modelling Framework of Simultaneous model

A standard population projection model consists of three components, which are fertility, mortality and migration, denoted as (1):

$$Pop_Y = Pop_{Y-1} + F_Y - M_Y + NM_Y \quad (1)$$

Where Pop^Y represent the population at year, F and M represent fertility (number of births) and mortality (number of deaths) separately, NM represents net migration which is the difference between immigration and outmigration. In Work Stream 1 (WS1) of the ITRC project, a series of population projection model were established to provide basic population estimations against different scenarios up to 2100. In WS1, a series of linear models were built to represent the net migration of each Local Authority District (LAD). These linear models have two main drawbacks: 1) lack of representing of detailed migration flow pattern; and 2) lack of flexibility in response to any local changes (i.e. infrastructure development in some areas). Therefore, a more sophisticated model is proposed is introduced by express migration in a more detailed way.

$$Pop_Y = Pop_{Y-1} + NC_Y + {}^{O}NM_Y + {}^{I}IM_Y - {}^{I}OM_Y \quad (2)$$

Where: Pop^Y_{LAD} represents the population for a *LAD* at year *Y*. NC represent natural change which the difference in number between ive births and deaths. Migration terms are expressed by four variables here which are net migration from overseas (${}^{O}NM$), immigration from within UK (${}^{I}IM$), and outmigration to somewhere else within UK (^{I}OM).

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

$$T_{ij} = A_i * {}^{I}OM_i * Att_j * d_{ij}^{-\beta}, \qquad A_i = \frac{1}{\sum_j Att_j * f(d_{ij})} \tag{3}$$

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.
$d_{ij}^{-\beta}$ is a distance friction function. So the internal immigration for each area (LAD) in this case can be calculated by sum up the immigration from T_{ij}

$$^{I}IM_j = \sum_i T_{ij} \tag{4}$$

There are two sets of parameters need to be calibrated, where β 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). In practise, a goodness-to-fit statistic (Standardised Root Mean Squared Error - SRMSE) is used to calibrate the SIM and to calculate the attractiveness value of each region based on the historical migration data, which is generated from patient registration data in the National Health Service (Lomax et al, 2014).

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 (Rees et al, 2004), including Population Density (PD), Total Employment (Emp), Average House Price (HP), Gross Value Added (GVA), Unemployment (Unemp), Average Road Speed (AS). A stepwise multivariate regression technique was applied to identify the most appropriate predictive variables. A location specified error e (e' in outmigration model) was introduced. Equations (5) and (6) represent the attractiveness and out migration model respectively.

$$Att_Y = K * PD_{Y-1}^{K1} * GVA_{Y-1}^{K2} * HP_{Y-1}^{K3} * Emp_{Y-1}^{K4} * AS_{Y-1}^{K5} * e \tag{5}$$

$$OMR_Y = M * HP_{Y-1}^{M1} * PD_{Y-1}^{M2} * Emp_{Y-1}^{M3} + GVA_{Y-1}^{M4} * e' \tag{6}$$

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, a modified Cobb-Douglas production function (Canning and Pedroni, 2008) is chosen as the heart of the economic model. This can be written as:

$$Y_{year} = A_{year} * {L_{year}}^{\alpha} * {C_{year}}^{\beta} * {I_{year}}^{\gamma} \tag{7}$$

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), I is infrastructure capital, 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. (Hulten et al, 2001); and α, β and γ are the output elasticity of labour, capital, and infrastructure capital. Assuming the investment on capital and labour are all from the earning (e.g. total production) of the previous year, we have:

$$I_{year} + C_{year} + L_{year} * W_{year} = Y_{year-1} \quad (8)$$

where W represents the average annual wage for a labour during a given year in a region. Therefore, when wages and capital are fixed, the optimised job opportunities can be estimated. Considering the commuting patterns, which is highly depends on transport infrastructure, a SIM based commuting model was built to allocate the residence to the working place, so the real local employment (Emp in Eq. (5) and (6)) can be estimated based on the commuting patterns.

A linear correlation between TFP and average annual wage can be observed from historical data. Assuming this relationship genuinely exists, the local TFP for each region can be estimated based on the regional specified average wage, which can be collected from national labour market statistics. Figure 3 a) shows the disaggregated TFP by NUTS2 region, 2006. Then, the projected local TFP for each NUTS2 region can be estimated based on the trend observed from historical data.

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 (7)). However population growth also affects regional attractiveness and migration rates in (2)-(6), which are also influenced by productivity and employment rates. Hence the dynamics of economic performance and demographic change are interdependent and iteratively.

3. Results and Discussion

In this paper, a High Speed Railway (HS2) scenario was built to test the impact of infrastructure development on demographic and economic growth. HS2 is an ambitious transport infrastructure development project which will connect the biggest cities in England by a Y-shaped high-speed railway network. The project will cost 46 billion pounds and be completed in 2032, according to DfT's plan. Figure 3 shows the evolution of population and GVA by NUTS2 region level during 2006 and 2050 under the baseline model (i.e. without HS2).

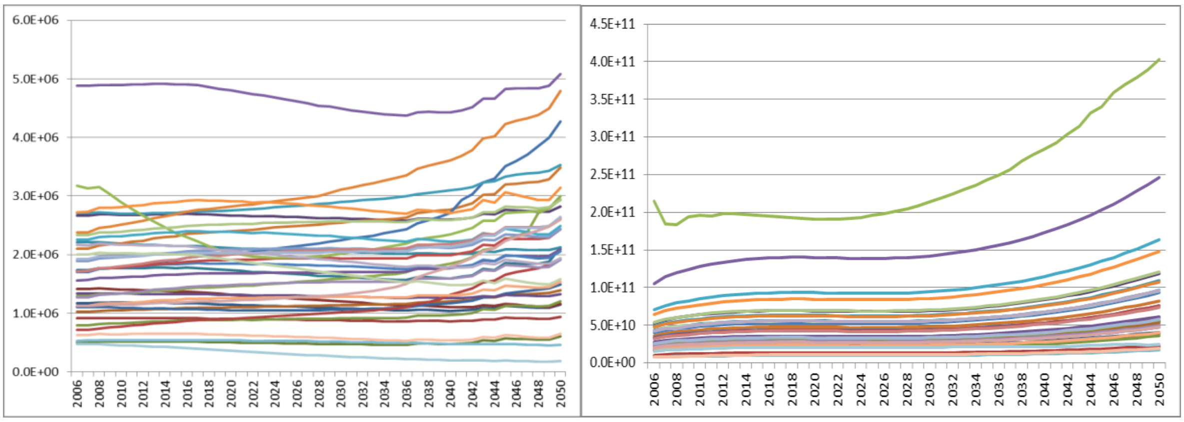


Figure 3 Time series of population and GVA by NUTS2 under baseline Scenario, 2006-2050

Figure 4 illustrates the change of commuting patterns for specific years.

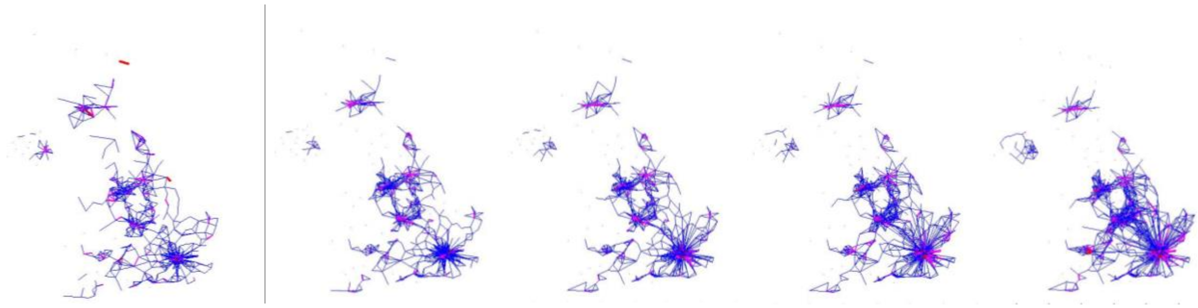


Figure 4 The commuting pattern in 2010, 2020, 2030, 2040 and 2050

The modelling results show there will be a significant increase of commuting flows between London, Birmingham, Manchester and Leeds, which indicates demand for HS2.

Figure 5 shows the impact of HS2 on the distribution of population and GVA in 2050.

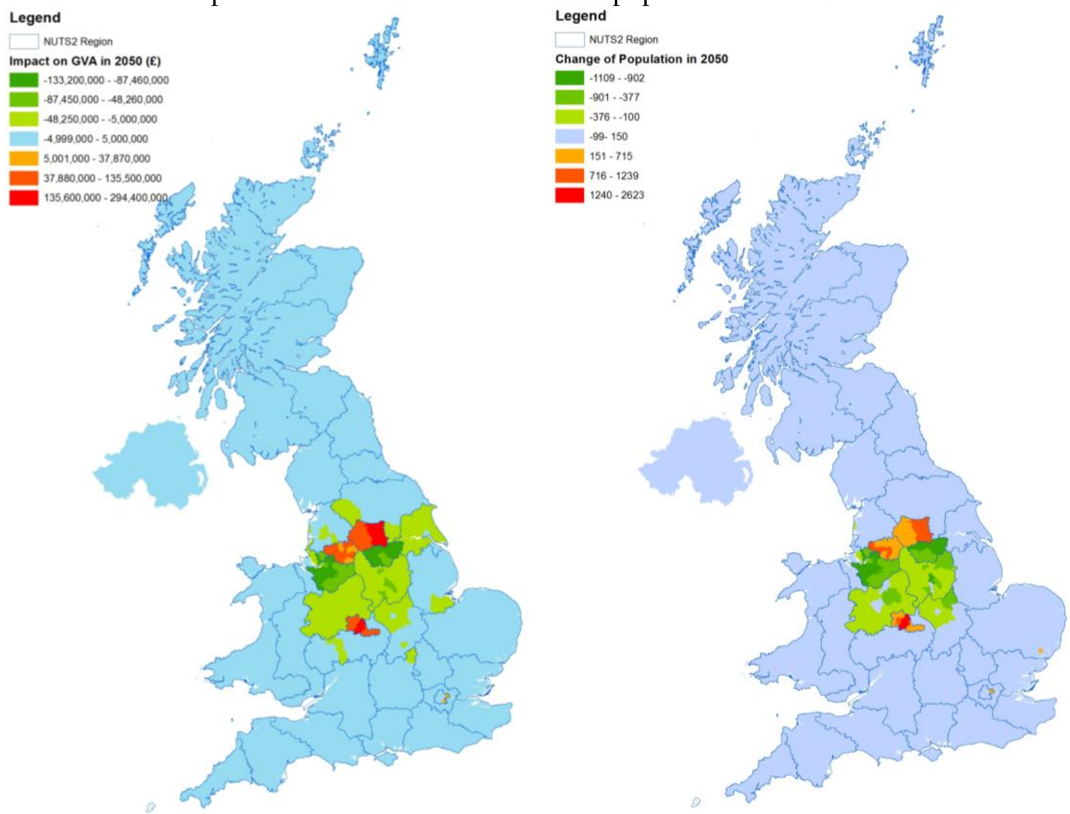


Figure 5 the impact of HS2 on GVA and Population in 2050

The modelling suggests that the HS2 will greatly increase the development of Birmingham, Manchester and West Yorkshire, while having some negative impacts on Cheshire and South Yorkshire. This phenomenon has some similarity to the agglomeration effects leading to accelerated growth of the major urban centres in China when the new High-speed rail network was made operational; (The World Bank, 2014). The reason for the phenomenon may be complicated. In our model, HS2 enables more labour working in the areas with higher economic efficiency, which generate more GVA giving rise to a higher attractiveness for migrants. Here the HS2 scenario shares a common international migration policy with the baseline, which restricts net international migration to today's level. This policy restricts population growth in the UK and also slows down the economy due to the shortage of labour.

4. Conclusion and Discussion

The HS2 scenario presented here is offered as an initial proof of concept of the feasibility of implementing a co-dependency model of demographic and economic growth over a medium to long time horizon. However, the model still lacks an explicit representation of the evolution of infrastructure. The HS2 scenario is 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 (Carlsson et al, 2013), as well as connectivity for which the HS2 scenario constitutes a preliminary test. In this way, a more sophisticated representation of the economy (than equations 7, 8) 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.

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