UK2070 Futures Modelling

Technical Report
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1. Introduction

1.1 Objective of the study

The purpose of the UK2070 Futures Study[1] is to investigate distinct scenarios regarding three basic policy variables of spatial rebalancing and development, which are growth and change in jobs, supply and demand of housing and provision of transport infrastructure and services. The distinct scenarios are designed to explore a wide range of potential economic and demographic development trajectories that are cogent for policy purposes, so as to provide a context in which to examine the effectiveness of existing and potential options for intervention in a long-term policy programme.

The study is intended to fill a persistent gap in the available evidence for making decisions on future developments across the UK. Policy makers, business leaders, community activists and academic researchers all aspire to coordinated interventions on jobs, housing and transport. However, the theories and data regarding the interactions among those sectors are complex, and there are few current studies available examining how these sectors actually connect and interact.

This study builds on world-leading research work from a wide range of institutions and individuals taking part in the UK2070 Commission research, and connects the insights from those distinct disciplines through a theory of spatial equilibrium that articulates the interactions among the sectors of economy and society that are key to spatial development decisions. In particular, a computer simulation model is used to understand and represent the multiple interactions which shape choices on jobs, housing and transport. This computer simulation model[2] is first checked for fidelity in its predictions of business and consumer choices, and then used as a digital laboratory to test a wider range of policy and community interventions than what could be possible through thought experiments or single-sector analyses. The findings from the model are reported for comment by both specialists and non-specialists in an interdisciplinary context.

This report is intended to support the UK2070 Commission in its deliberations on the options of policy interventions and prioritisation against a broad, strategic understanding of the major opportunities and challenges facing the UK.

1.2 Geographical coverage of the study

The geographical reach of the study covers all four countries of the UK, i.e. England, Wales, Scotland and Northern Ireland. Because of the complexities in assembling data for Northern Ireland and in modelling the cross-border travel there, the modelling work takes longer and thus the results below have not yet included the model simulation outputs for Northern Ireland. The model results will be reported for Northern Ireland along with the UK2070 Commission's final report.

The geographic areas (i.e. contiguous land parcels) that the computer simulation model uses to represent the economic, demographic, land use and transport date are defined at the level of local authority districts or equivalent (i.e. English local authority and unitary authority districts, Welsh and Scottish council areas, Northern Ireland district council areas, etc). This is a relatively fine granularity for UK level modelling which will be capable of facilitating the analyses that are planned for the study.

1.3 Contents of this report

Below we outline the methodology for modelling and analyses in Chapter 2, discuss and test alternative scenarios in Chapter 3, consider the findings and insights from this study in Chapter 4 and draw broader conclusions in Chapter 5.

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[1] Referred to below as the "Futures" Study.

[2] Referred to below as the "Futures' Model" or the "model"

2. The UK2070 Futures Model

The UK 2070 Futures Modelling is based on an approach that examines how well demand and supply match in geographic space, between (1) demand from economic activities, jobs and population and (2) supply in housing, transport systems, skills, the provision of goods and services. The modelling is encapsulated in the LUISA model (version 2.03), which is a dynamic spatial equilibrium computer simulation tool that complements macro and regional economic models, land use and housing models and transport planning models. In past studies of a similar type, the LUISA model has also served as a productive interface among the above models in examining the consistency of the assumptions about the future developments and sectoral policy aspirations.

The core methodology of the analytical work in this study is based on a recursive spatial equilibrium theory for modelling the evolution of urban activities at a city region scale, as outlined in the methodological papers e.g. Jin, Echenique and Hargreaves (2013) and Wan and Jin (2017). This builds on a tradition of more than 50 years' research at the Martin Centre of modelling the interactions among land use, built form, business and consumer activities and transport services (Echenique, 1967; 1994; forthcoming; Batty, 2009; UK Research Excellence Framework, 2014).

This model theory incorporates desirable features from
(a) spatial computable general equilibrium modelling which provides a rigorous framework for predicting rents, wages and prices given system constraints, and
(b) dynamic disequilibrium modelling which acknowledges the uncertain timing and indivisibility of many supply-side interventions and the unpredictability of many events in the wider economy.

The resulting recursive spatial equilibrium model is capable of predicting how businesses and individuals trade off a wide variety of choices concerning jobs, housing and travel subject to explicit scenario assumptions.

The new data sources such as observed wages, housing rents/prices and road congestion at a detailed level have greatly extended the capability of this model in representing market equilibria. Census, employment and labour data and business surveys now provide more fine-grained information on population and job locations. This provides opportunities to cross-examine the established time series data from the Census and employment and labour data with trends that are gleaned from up to date business surveys.

The recursive spatial equilibrium theory is encapsulated in a MATLAB based software app that is documented as the LUISA software suite, at the Martin Centre. The specific version of the software app used is LUISA2.03. For further details on the model structure and equations, see Appendix A below. The implementation of the software app for this study is called the UK2070 Futures Model version 1.0D.

The study uses data and insights from the past 50 years (from the mid-1960s) in the UK to calibrate the forecasting model for the coming 50 years (2021-2071). The prediction model mechanisms used are those which have been tried tested in past successful modelling projects (for a retrospective assessment of the performance of past modelling projects, see UK Research Excellence Framework, 2014; Echenique, forthcoming). In particular, the prediction performance of the core models developed for this study has passed our assessment using the more stringent, inter-temporal validation (for validation methodology, see Wan and Jin, 2017).

2.1 Model design - overarching principles

The LUISA model software is designed against the backdrop of severe and worsening regional economic imbalances in the UK, and the policy aspiration to reduce such regional disparities. On the one hand, the model accounts for the agglomerative benefits which drive new and innovative businesses towards growth hot spots. On the other hand, it incorporates the supply constraints for land, housing, business premises, transport infrastructure and services, and the capacity of the natural environment which drive up the rents, prices, financial and social costs which may in turn discourage new investments in existing growth hot spots if the balance is lost between jobs, housing and transport. The specific interactions among the above forces give rise to a wide variety of circumstances, under which individuals, businesses and institutions make their own choices over particular time scales and as far as possible make the best of their current situations and move towards locations that would better suit them.

Examining the regional disparities through this perspective makes it clear that rebalancing economic growth is not necessarily a zero-sum game. For instance, if growth is channelled from the current hot spots to lower growth regions to ease the supply constraints, both types of regions may benefit; if however businesses and institutions are relocated from growth hot spots to lower growth regions with little regard to the logic of how they grow, both types of regions may lose out. One of the objectives of scenario analysis is to investigate the scope and mix of policies that support win-win interventions, as well as inter-regional fiscal transfers. In this way it is possible to enable continued success of high-growth regions whilst the unlocking of the potential of currently low growth regions.
In this context, it is clear that modelling at the national scale has clear added value to local economic analyses and policy making. Regional inequalities cannot all be tackled by local actions alone.

2.2 Modelling approach based on scenario design

In order to provide policy cogent findings in the face of enormous uncertainties regarding economic, social, demographic and technological developments over the long time horizon to 2070, we sketch out the scenarios through

a. clearly separating factors which are subject to great uncertainty or highly political, local decision-making processes, from those factors which are proven to be highly predictable over time using empirically well-validated prediction models. For instance, the sectoral and geographical distribution of jobs over this period will be subject to highly uncertain changes in international trade relations as well as technological shifts; the quantum of housing supply and transport improvements in any geographical area are highly dependent upon local political processes. By contrast, subject to the overall demographic trends and local attitudes towards the natural environment, house building and road construction, the choices people make regarding where house building and transport improvements take place, where they live and work and how they travel have proven to be reasonably predictable by good quality models owing to the fact that (i) demographic, cultural and social trends tend to evolve slowly with reasonably predictable trajectories of change, and (ii) the law of large numbers makes it feasible to estimate good statistical models when dealing with choices across tens of millions of people

b. comprehensively covering all the main planning and development alternatives, drawing upon historical and international experience. At the initial stage, this is done through incorporating scenarios that are considered important to the discussions on the UK2070 Commission's policy initiatives.

The focus of the scenario tests is placed on how balanced it is regarding the distribution of jobs, housing and transport in the UK. The scenario tests aim to quantify the extent of coordination that are likely to be achieved for a given distribution of jobs, housing and transport supply, and the consequences of a significant failure to halt the trends towards growing polarisation in terms where future development takes place. In other words, the model treats developments in jobs, housing and transport as components of one integral system, drawing upon research on from multiple policy areas.

There have been precedents of this type of model-based studies in some city regions. For the historic track record of this type of modelling that has been led by the Cities and Transport Group in Cambridge, see the

2014 UK Research Excellence Framework case study (UK Research Excellence Framework, 2014)[3]. The most recent example is the Cambridgeshire and Peterborough Futures Study that has informed the examination of city region level balances in jobs, housing and transport for the Cambridgeshire and Peterborough Independent Economic Review (CPIER). The model outputs have provided evidence for CPIER's deliberations on policy options and prioritisation against a broad, strategic understanding of the major opportunities and challenges facing the Cambridgeshire and Peterborough Combined Authority area.

The focus of the scenario-based modelling is therefore to introduce fresh thinking into

(a) ensure coherence and consistency of economic policies at the city region scale.
(b) identify the best use of skills and other resources of all city regions.
(c) identify a framework to design national as well as local interventions through informed policy debate.

In order to introduce fresh thinking, the scenario inputs themselves should cover the full range of future possibilities in terms of background trends and policy options. Our past experience shows that novel scenario options often work well in stimulating policy discussions across the stakeholder groups and attract public debate. For this explorative purpose the scenarios are best designed as highly original and contrasting ones, rather minor tweaks of the status quo. It is often preferable not to single out a preferred scenario at the outset of the policy discussions, so that at the consultation stage all stakeholders can be easily invited to comment on all scenarios without the tether of a 'preferred' label.

Scenario inputs should cover all policy levers (e.g. house supply, transport investment options, various aspects of industrial policy) and those economic variables that are highly uncertain (e.g. GDP growth at the national level, GVA and employment growth at the local level).

In summary, it is particularly valuable to include in the scenarios those variables that are may be seen as very unlikely or technically very difficult to predict, as well as those that reflect the main concerns of the UK2070 Commission in its policy deliberations, since the scenarios are not intended to provide predictions but insights into policy choices.

2.3 How are the scenarios assessed?

The assessment is done through pairwise comparison between two scenarios at a time – one of them could be e.g. a baseline or a benchmarking. The model's assessment of a scenario is always based on such comparisons and this implies that the assessment will never indicate that any one scenario is the absolute best or worst. It also implies that it is through judicious design and comparison of human-designed scenarios that one progressively find better and better grouping of policy interventions.

Comparisons using the model outputs and indicators derived from it will provide the basis for a quantified and systematic assessment of key economic, financial, social and environmental impacts.

Furthermore, it is important to highlight the importance of interpreting the model results in the social and political context and provide clear policy-cogent messages and visualisation. In particular the findings from this model should be compared with those from other models, and from business and consumer intelligence to ascertain if the model findings are corroborated where relevant studies exist.

2.4 Definition of base case and alternative scenarios

The first step towards scenario analysis is to establish a draft starting scenario which we call the Base Case. The purpose of this Base is to explore a relatively wide range in the level of uncertain variables in the local development process, particularly in terms of the growth in jobs, and to explore their relationships with other key variables such as housing, business floorspace and transport. This analysis then paves the way towards the design of further alternative scenarios of either un-coordinated or coordinated growth.

[3] https://impact.ref.ac.uk/casestudies/CaseStudy.aspx?Id=23292.

Based on our recent experience in building and running similar models, we divided the scenario design into two broad stages.

At a first stage the work focused on a Base Case, which served as a benchmark for all the other scenarios. Given that the quanta of jobs, housing and transport connections are all highly uncertain this far into the future, this stage also serves as a test bed for examining potentially high regional imbalances, e.g. fast jobs growth vs severe restrictions in housing in high growth areas together with accumulated backlog in transport investment, or slow jobs growth vs a glut of housing and road building, etc.

Once the Base Case quanta was determined through the above, at a second stage, we investigated alternative scenarios that improve the coordination among jobs, housing and transport. We understand that out of many possible scenarios, there is a strong policy interest in the UK2070 Commission to investigate the impacts of tackling the growing spatial inequalities in the UK associated with the increasing concentration of economic activity particularly in London and the wider south east region, and of reversing this trend, under a high economic growth scenario. These are the typical alternative scenarios that we will focus on at this interim stage.

2.5 Time horizons and geographic coverage

The model is run for future time horizons 2031, 2051, 2071 in line with the pattern of existing decennial Census intervals and its expected continuation into the future. The model covers all areas at the local authority district level or equivalent.

2.6 What are the main inputs and outputs of LUISA?

The main inputs of the model are

- Economic projections of GDP growth and jobs at each constituent workplace area represented in the model (i.e. at the local authority district level or equivalent)
- Demographic projections and total population
- Local land use development trajectories, indicating the allocation of land use and the delivery of house building in the past 20 years
- Road, rail and other transport investments and demand management/pricing options

The main outputs from the model are presented in each model zone by decade (2021-2071):

- The number of resident households by ONS social economic classification
- Rents for dwellings and business floorspace
- Costs of living per socio-economic group
- The number of employed residents in each residential zone
- Journey to work matrices
- Business production costs
- Household economic well-being in terms of consumer utility

The model outputs above support a wide range of economic, financial, social and environmental assessments. Follow-up processing of the model outputs may be required in order to follow the UK government's guidelines for each policy assessment indicator used under each of the specialist assessment frameworks. The policy scenarios presented here involve significant demographic, economic, and social changes because of the long time span and unusually radical interventions. For this reason, it is often the case that the conventional assessment frameworks that are designed for incremental and marginal evaluation are not appropriate in portraying the big picture of profound changes. For this reason, in this report we adopt the following broad-brush indicators to highlight the fundamental differences among the scenarios:

- Changes in average dwelling rents relative to expected income growth (as a headline number for housing affordability)

- Changes in average wage costs (as a headline number for labour costs to businesses)
- Changes in the demand for commuting travel crossing boundaries of local authority districts or equivalent (as a proxy to rush hour congestion, the requirements for transport investment to address rush hour traffic bottlenecks, and the scale of impacts on nature conservation around the existing and new traffic bottlenecks)
- Net increase in jobs by multiple deprivation ranking of neighbourhoods (as a headline number for changes in the equality and spread of job opportunities)
- Net land take for house building (including both greenfield and brownfield; as a start point to measure the potential impacts on nature conservation)

Further assessment indicators may be added to this list as the study progresses.

2.7 What the LUISA model does not provide

As discussed above, the focus of the LUISA model is placed on the balance between jobs, housing and transport. This model will be able to test different combinations of balanced or imbalanced scenarios, and provide a wide range of outputs for economic, social and environmental assessment. However, the model will not provide direct answers on how to achieve particular sectoral or geographical distributions – this latter question will require a wide range of policy interventions that would necessitate the modellers to engage closely with policy analysts from all those disciplines. Our experience in previous policy work both in the UK and internationally suggests that a productive partnership among the policy analysts and modellers is achievable for this purpose, but this should be carried out as a separate stream of work running in tandem with the modelling tasks (i.e. both LUISA and other models as discussed below).

2.8 Interfacing with other related analyses and models

QUANT. We have discussed with the QUANT modelling team directed by Professor Michael Batty at the Centre for Advanced Spatial Analysis of University College London. A very productive interface has been established between the two models. The data flows between LUISA and Quant is designed as follows: LUISA produces model results for a given scenario and then pass the local authority district (LAD) level totals (jobs, employed residents, housing and business floorspace stock (exogenous) and the LAD-level origin-destination commuting flows to the Quant model

Quant then distributes the LAD-level totals to MSOAs. The disaggregation generates MSOA-level commuting flows.

This interface has enabled the LUISA model to focus on the UK wide modelling at the LAD level or equivalent, whilst the QUANT model produces a consistent prediction at a fine granularity for policy analysis at a neighbourhood level.

NIESR. We have been discussing with the National Institute of Economic and Social Research (NIESR) for advice and guidance on a range of macro- and regional economic predictions, particularly the more detailed assumptions regarding the growth trends in jobs by industry and location at the LA level, and the trends in education and skill levels over the longer term.

David Simmonds Consultancy (DSC). The DSC have developed a national level land use and transport model using a LUMIT[4] approach as opposed to a full land-use transport interaction (LUTI) approach that is embedded in the LUISA model. We would look to the DSC for advice on the national level land use and transport scenario specifications that have been defined, where such specifications are available for the UK2070 Commission's work. The LUMIT model may also be able to support further analyses on the changes in overall economic productivity and performance through different patterns of distribution in jobs, spatial equity and other opportunities across the population.

Space Syntax (SS). SS have specially adapted a model for the Foresight Future Cities work to identify existing opportunities that cannot be picked up through current statistical methods used to allocate growth and this will complement the modelling carried out above.

[4] LUMIT: land-use modelling influenced by transport. For further information, contact the DSC team at https://www.davidsimmonds.com/.

GreenGauge21. GreenGauge21 have advised us on future rail transport scenarios and it would seem that the transport analyses/modelling work that they have carried out are complementary to the modelling work presented here.

As the modelling work progresses, further connections and interfaces with other models may be developed.

3. Alternative Scenarios

3.1 Overview

The computer modelling has tested three groups of scenarios, using economic growth rate assumptions which are comparable with those of the Office of Budget Responsibility (OBR):

- Scenario Group 1: **Business as Usual**, with continuing trends where jobs are growing and where housing is being built. This was tested for both a low growth and a high growth assumption, and they are named respectively as S1L and S1H.
- Scenario Group 2: **Holding the Line**, with an emphasis on preventing the polarisation in the growth of jobs getting worse. This is tested for a high growth assumption only – although it is possible for this scenario to experience low overall growth (and can be tested by the model), it was considered to be more productive to examine a scenario that engenders high growth. This test is named S2H.
- Scenario Group 3: **Attacking the Problem**, with a focus on more radical reductions in the level of polarisation. Again we focussed on the high growth tests, and this group of tests assumes that over the period 2011-2071, jobs in grow at a much higher rate outside London and the WSE, thus reversing the historic trends of polarisation in job recreation. Three variants have been examined: S3Ha assumes that all UK countries and regions see rates in job creation pick up at a uniform rate; S3Hb assumes the job creation rates rise first in those areas closest to London and WSE and then spread outwards; S3Hc assumes all the core cities outside London and WSE see job creation rates pick up first, as a result of a package of interventions including reducing the door to door travel time between all core cities and London below one hour and 45min, and the growth in jobs spread from those core cities in each of their hinterland.

Figure 1 below summarises the three groups of scenarios that have been tested.

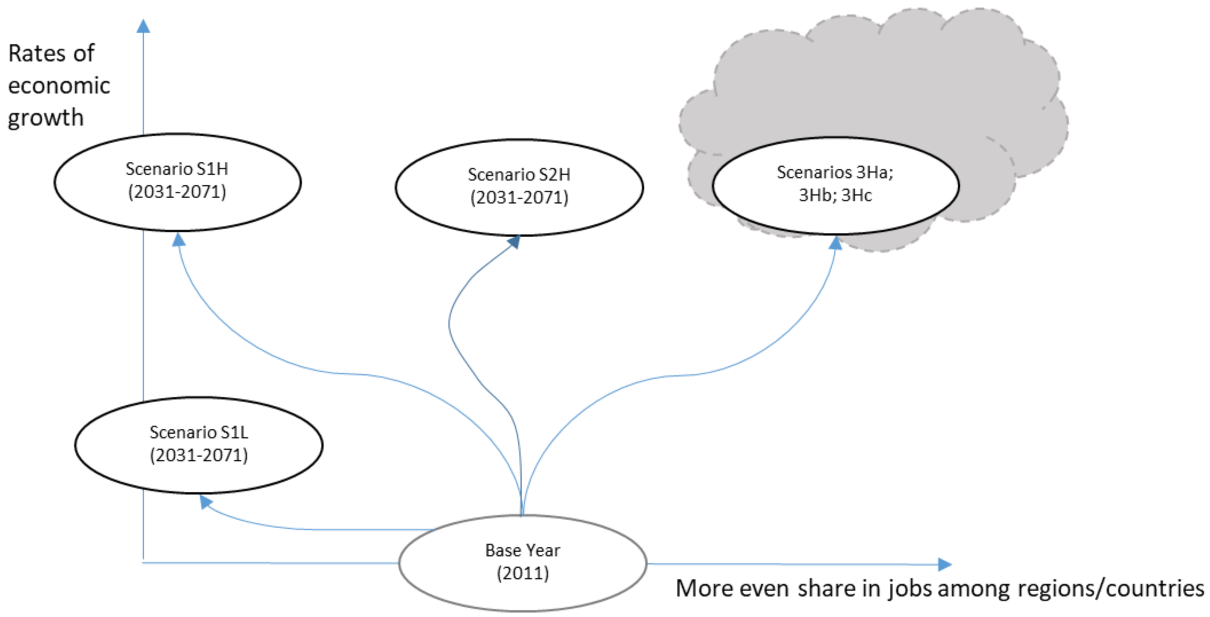

FIGURE 1. SUMMARY OF INITIAL SCENARIOS FOR MODEL TESTING

3.2 Key scenario assumptions

The key assumptions used in testing the scenarios for the next 50 years relate to the following five types of variability. Past modelling shows that once assumptions are made regarding these variables, other types of variables could usually be derived for modelling spatial imbalance.

Overall scale of economic activity in terms of numbers of people, jobs, and total economic output in terms of GVA/GDP. Given all the global political and trade uncertainties, it would be impossible to predict what overall trajectories would be for total GVA/GDP. This would also be true to a large extent for changes in jobs and the flows of international migration. For this reason, we assumed two levels of growth – high and low – with the high scenario having more economic output, productivity, jobs and net in-migration, and the low scenario with the same list of variables but at lower levels of growth. Note that we assumed overall labour participation rate (i.e. employed/total population) to remain constant, which implies that the growth rates for population and workers will be the same from 2019 onwards. For the actual assumptions at the UK level and by broad regions, see Table 1. The assumptions we have made cover a slightly wider range (from 30.7m at the low to 40.2m at the high growth for workplace employed population excluding full time students in 2071) than the OBR projections (which are from 33m at the lowest to 39.4m at the highest for those employed age 16+ in 2068; see Figure 2).

TABLE 1 ASSUMPTIONS REGARDING UK LEVEL ANNUAL GROWTH RATES IN GDP/WORKER, POPULATION, NUMBER OF WORKERS AND OVERALL GDP GROWTH (%)

Annualised growth rates 2019-2071	GDP per worker	Population & workers	Implied overall GDP growth	Growth in earnings per worker
Low Scenario (S1L)	0.5%	0.10%	0.60%	0.25%
High Scenarios (S1H, S2H, S3Ha; S3Hb; S3Hb;)	1.8%	0.55%	2.35%	0.90%

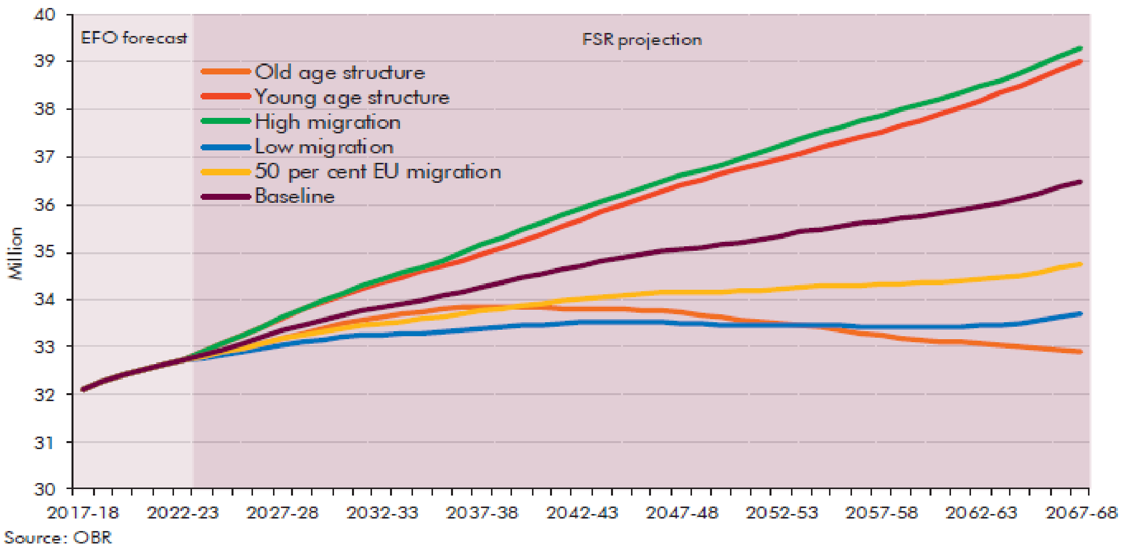

FIGURE 2: EMPLOYMENT PROJECTIONS (EMPLOYED AMONG 16+ POPULATION; SOURCE: OBR, 2018; SEE HTTPS://CDN.OBR.UK/FSR-JULY-2018.PDF).

Planning constraints, especially house building in each local authority or unitary districts (LAUDs) – for simplicity, we assumed that house building rates vary in line with the delivery of housing since 1991 at the LAUD level, subject to the overall assumed levels of growth in housing stock.

Improvements in the levels of education and skills of the residents – this reflects the education, training and immigration policies. Fort the scenario tests here we assumed that there will be an overall level of improvement, although the relative differences among the LAUDs remain.

Investment in transport connectivity – We assumed that transport connectivity within and between all LAUDs remain at the same level as it is today. This assumption is easier to start with, as – at least initially – no transport agencies would be able to provide a proper programme of transport improvements beyond 5-10 years. This assumption enabled the estimation of the broad level of travel demand at today's level of transport connectivity for each location/corridor, which in turn helps define network expansion, upgrading, user charging, deterrence by congestion/facility removal, etc.

In principle all known unknowns (that are hard to predict) are expressed as scenario inputs, so that modelling does not have to prejudge the level of change – the assumptions regarding such changes to be based on reasoned arguments rather than any 'prediction'.

3.3 Scenario Group 1: Business as Usual

In order to illustrate the continuing risks that are faced if the current situation were to continue, Scenario 1 is based on both High and Low growth assumptions. Under both High and Low it is expected there would be increasing spatial imbalance of jobs and people across the UK throughout the period: Over 50% of the job growth would concentrate in the London and Wider South East area, if housing and infrastructure capacities were able to accommodate this growth. The situation under the Low Growth assumptions would be no better: In a period of sustained lower levels of economic growth there may be an overall loss in employment in many places outside the areas that are growing today.

The pattern of economic change would be reflected in diverging patterns of housing cost and levels of commuting. For example, at the higher level of growth, average housing costs in London and the WSE would rise by over 90% (in constant prices), i.e. at a significantly higher rate than other regions, and outstripping expected rise in wage earnings. Even with low economic growth rates, average housing costs in London and WSE would still be expected to rise well above (the lower) average earnings, whilst housing costs in many other regions could fall either in absolute terms or below the expected average earnings. Similar patterns of change would also be reflected in the increasing levels of commuting across local boundaries and in the length of trips.

These impacts are especially important when considered in terms of the analysis by level of deprivation. The situation is quite stark – under low growth, 76% of the net increases in jobs will occur in the least deprived LADs/UAs (i.e. quintile ranking 80-100%). As the trends continue, growth in jobs is expected to focus on the most competitive places within each nation or region. This is shown in Table 2 below for the 2031-2071 period for the low growth assumptions and in Table 7 for the high growth assumptions. This tendency is common to both Low and High growth under Scenario Group 1. This is a particular issue in a scenario of low growth when there is likely to be an adverse economic climate and greater competing local demands generally. This issue is particularly important in considering the policy interventions.

Table 2 **Scenario S1L: Extrapolation of recent trends of regional job distribution, low rates of growth**

Jobs (million)	**1981***	**1991***	**2001**	**2011**	**2031**	**2051**	**2071**
London & WSE	7.6	8.7	9.9	11.2	11.9	12.7	13.5
Midlands	3.4	3.9	4.1	4.6	4.5	4.4	4.4
South West	1.6	2.0	2.3	2.5	2.7	2.8	2.9
N England	5.4	5.7	6.1	6.8	6.6	6.3	6.1
Wales	0.9	1.1	1.2	1.3	1.4	1.4	1.4
Scotland	2.1	2.1	2.3	2.5	2.5	2.5	2.5
All Britain	19.2	23.4	27.3	28.9	29.5	30.1	30.7
% change per year		**1981-91**	**1991-01**	**2001-11**	**2011-31**	**2031-51**	**2051-71**
London & WSE		1.36%	1.31%	1.27%	0.31%	0.31%	0.31%
Midlands		1.26%	0.64%	0.98%	-0.11%	-0.07%	-0.03%
South West		2.45%	1.27%	1.16%	0.25%	0.23%	0.21%
N England		0.52%	0.60%	1.07%	-0.15%	-0.18%	-0.22%
Wales		1.36%	0.76%	1.41%	0.09%	0.05%	0.01%
Scotland		-0.24%	1.04%	0.94%	0.02%	-0.01%	-0.04%
All Britain		2.02%	1.53%	0.59%	0.10%	0.10%	0.10%

Table 3 **Scenario S1L: Extrapolation of recent trends of house-building since 1991**

Dwellings (million)	**2011**	**2031**	**2051**	**2071**
London & WSE	9.6	9.8	10.0	10.2
Midlands	4.3	4.4	4.5	4.6
South West	2.4	2.4	2.5	2.6

N England	6.6	6.8	6.9	7.0
Wales	1.4	1.4	1.4	1.5
Scotland	2.5	2.5	2.6	2.6
All Britain	26.8	27.3	27.9	28.4
% change per year		**2011-31**	**2031-51**	**2051-71**
London & WSE		0.11%	0.11%	0.11%
Midlands		0.10%	0.10%	0.10%
South West		0.12%	0.12%	0.12%
N England		0.08%	0.08%	0.08%
Wales		0.10%	0.10%	0.10%
Scotland		0.09%	0.09%	0.09%
All Britain		0.10%	0.10%	0.10%

Table 4 **Scenario S1L: Model prediction of average dwelling rents 2031-2071**

	Dwelling rents (£(2011) per unit per year				**Change (2011 = 100)**			
	2011	**2031**	**2051**	**2071**	**2011**	**2031**	**2051**	**2071**
London & WSE	11200	12712	13848	15053	100	114	124	134
Midlands	6359	6552	6538	6570	100	103	103	103
South West	7841	8624	9022	9435	100	110	115	120
N England	6201	6334	6200	6017	100	102	100	97
Wales	4839	5132	5256	5339	100	106	109	110
Scotland	5519	5873	5908	5904	100	106	107	107
All Britain	8027	8754	9177	9617	100	109	114	120
% change per year		**2011-31**	**2031-51**	**2051-71**				
London & WSE		0.64%	0.43%	0.42%				
Midlands		0.15%	-0.01%	0.02%				
South West		0.48%	0.23%	0.22%				
N England		0.11%	-0.11%	-0.15%				
Wales		0.29%	0.12%	0.08%				
Scotland		0.31%	0.03%	0.00%				
All Britain		0.43%	0.24%	0.23%				

Table 5 **Scenario S1L: Model prediction of average wage costs 2031-2071**

Changes in wage costs				
2011 = 100	2011	2031	2051	2071
London & WSE	100	108	114	121
Midlands	100	102	103	104
South West	100	106	109	113
N England	100	101	100	99
Wales	100	104	105	107
Scotland	100	104	105	106
All Britain	100	105	109	112

Table 6 **Scenario S1L: Model prediction of the volume of commuting within and between local authority districts (or equivalent) 2031-2071**

	Commuting travel - within LAD/UA only				% change			
	2011	2031	2051	2071	2011-31	2031-51	2051-71	2011-71
London and WSE	4.3	4.7	4.8	5.0	8.0%	3.5%	3.3%	15.5%
Midlands	2.3	2.3	2.3	2.2	0.4%	-2.9%	-2.6%	-5.1%
South West	1.6	1.7	1.8	1.9	9.2%	3.8%	3.8%	17.7%
N England	4.0	4.0	3.8	3.6	-0.3%	-4.0%	-4.8%	-8.9%
Wales	0.8	0.9	0.9	0.9	3.9%	1.2%	0.4%	5.6%
Scotland	1.7	1.8	1.7	1.7	4.5%	-0.7%	-1.3%	2.5%
All Britain	14.8	15.4	15.4	15.3	4.1%	0.0%	-0.2%	3.8%
	Commuters from outside LAD/UA				% change			
	2011	2031	2051	2071	2011-31	2031-51	2051-71	2011-71
London and WSE	6.4	7.3	7.9	8.5	12.7%	8.2%	8.1%	31.9%
Midlands	2.1	2.1	2.1	2.2	3.6%	0.2%	1.6%	5.5%
South West	0.8	0.9	1.0	1.0	9.9%	6.6%	5.4%	23.4%
N England	2.5	2.6	2.5	2.4	4.0%	-3.0%	-3.5%	-2.7%
Wales	0.4	0.5	0.5	0.5	11.2%	0.8%	0.1%	12.2%
Scotland	0.7	0.8	0.8	0.8	7.0%	0.9%	0.5%	8.4%
All Britain	13.0	14.1	14.7	15.4	9.1%	4.2%	4.3%	18.6%

Table 7 **Scenario S1H: Extrapolation of recent trends of regional job distribution, high rates of growth**

Jobs (million)	**1981***	**1991***	**2001**	**2011**	**2031**	**2051**	**2071**
London & WSE	7.6	8.7	9.9	11.2	13.1	15.2	17.7
Midlands	3.4	3.9	4.1	4.6	4.9	5.3	5.7
South West	**1.6**	2.0	2.3	2.5	2.9	3.3	3.8
N England	5.4	5.7	6.1	6.8	7.2	7.6	7.9
Wales	0.9	1.1	1.2	1.3	1.5	1.6	1.8
Scotland	2.1	2.1	2.3	2.5	2.7	3.0	3.3
All Britain	19.2	23.4	27.3	28.9	32.3	36.0	40.2
% change per year		**1981-91**	**1991-01**	**2001-11**	**2011-31**	**2031-51**	**2051-71**
London & WSE		1.36%	1.31%	1.27%	0.76%	0.76%	0.76%
Midlands		1.26%	0.64%	0.98%	0.34%	0.38%	0.42%
South West		2.45%	1.27%	1.16%	0.70%	0.68%	0.67%
N England		0.52%	0.60%	1.07%	0.30%	0.26%	0.23%
Wales		1.36%	0.76%	1.41%	0.54%	0.50%	0.46%
Scotland		-0.24%	1.04%	0.94%	0.47%	0.44%	0.41%
All Britain		2.02%	1.53%	0.59%	0.55%	0.55%	0.55%

Table 8 **Scenario S1H: Extrapolation of recent trends of house-building since 1991**

Dwellings (million)	2011	2031	2051	2071
London & WSE	9.6	10.8	12.1	13.6
Midlands	4.3	4.8	5.4	6.0
South West	2.4	2.7	3.1	3.5
N England	6.6	7.3	8.0	8.8
Wales	1.4	1.5	1.7	1.9
Scotland	2.5	2.7	3.0	3.3
All Britain	26.8	29.9	33.4	37.2
% change per year		**2011-31**	**2031-51**	**2051-71**
London & WSE		0.60%	0.59%	0.59%
Midlands		0.54%	0.54%	0.54%
South West		0.66%	0.65%	0.64%
N England		0.47%	0.47%	0.48%
Wales		0.57%	0.57%	0.56%
Scotland		0.49%	0.50%	0.50%
All Britain		0.55%	0.55%	0.55%

Table 9 **Scenario S1H: Model prediction of average dwelling rents 2031-2071**

	Dwelling rents (£(2011) per unit per year)				**Change (2011 = 100)**			
	2011	**2031**	**2051**	**2071**	**2011**	**2031**	**2051**	**2071**
London & WSE	11200	14349	17665	21723	100	128	158	194
Midlands	6359	7470	8499	9734	100	117	134	153
South West	7841	9610	11326	13314	100	123	144	170
N England	6201	7300	8221	9174	100	118	133	148
Wales	4839	5833	6793	7847	100	121	140	162
Scotland	5519	6751	7798	8939	100	122	141	162
All Britain	8027	9955	11878	14163	100	124	148	176
% change per year		**2011-31**	**2031-51**	**2051-71**				
London & WSE		1.25%	1.05%	1.04%				
Midlands		0.81%	0.65%	0.68%				
South West		1.02%	0.82%	0.81%				
N England		0.82%	0.60%	0.55%				
Wales		0.94%	0.76%	0.72%				
Scotland		1.01%	0.72%	0.68%				
All Britain		1.08%	0.89%	0.88%				

Table 10 **Scenario S1H: Model prediction of average wage costs 2031-2071**

Changes in wage costs 2011 = 100	2011	2031	2051	2071
London & WSE	100	113	142	199
Midlands	100	109	126	158
South West	100	111	134	175
N England	100	109	125	153
Wales	100	110	130	166
Scotland	100	111	133	171
All Britain	100	111	135	180

Table 11 **Scenario S1H: Model prediction of the volume of commuting within and between local authority districts (or equivalent) 2031-2071**

	Commuting travel - within LAD/UA only				% change			
	2011	2031	2051	2071	2011-31	2031-51	2051-71	2011-71
London and WSE	4.3	5.1	5.8	6.6	18.5%	13.6%	13.5%	52.9%
Midlands	2.3	2.6	2.7	2.9	9.9%	6.4%	6.8%	24.9%
South West	1.6	1.9	2.2	2.5	18.9%	14.3%	13.5%	54.2%
N England	4.0	4.4	4.6	4.8	9.1%	5.1%	4.3%	19.6%
Wales	0.8	1.0	1.1	1.2	14.2%	11.2%	10.2%	40.0%
Scotland	1.7	1.9	2.1	2.3	14.3%	8.8%	8.2%	34.5%
All Britain	14.8	16.8	18.5	20.2	13.9%	9.7%	9.4%	36.8%

	Commuters from outside LAD/UA				% change			
	2011	2031	2051	2071	2011-31	2031-51	2051-71	2011-71
London and WSE	6.4	7.9	9.4	11.0	23.1%	18.1%	18.0%	71.5%
Midlands	2.1	2.3	2.6	2.8	13.2%	9.4%	10.8%	37.3%
South West	0.8	1.0	1.2	1.4	21.3%	15.2%	15.4%	61.3%
N England	2.5	2.8	3.0	3.2	13.6%	5.9%	5.3%	26.7%
Wales	0.4	0.5	0.6	0.6	20.7%	9.4%	8.6%	43.3%
Scotland	0.7	0.8	0.9	1.0	16.9%	10.1%	9.6%	41.0%
All Britain	13.0	15.4	17.5	20.0	19.1%	13.7%	13.9%	54.2%

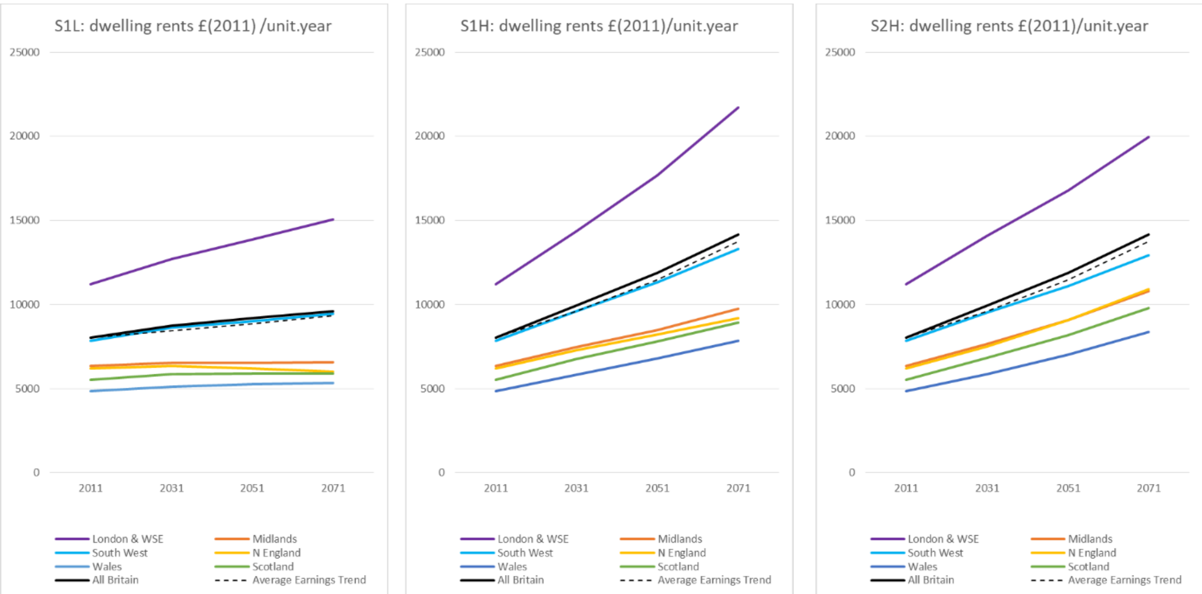

FIGURE 3 COMPARISON OF DWELLING RENTS: SCENARIOS S1L, S1H AND S2H

3.3 Scenario Group 2: 'Holding the Line'

Scenario Group 2 tests the effect of interventions that alter employment growth rates such that all countries and regions grow at the same average rate to 2071. It assumes that the share of total jobs among the UK countries and regions remain constant for the period 2011-2071 – which effectively means that the overall rates of job growth converge to the same national rate among all countries and regions. This would mean reduced rates of polarisation in the first couple of decades, and in the later decades job creation starts to pick up further in favour of historically lower growth areas in terms of jobs.

The overall outcome of such a scenario in conditions of high growth is summarised here. It shows the potential implications of there being comparable job growth in the nations and regions compared with London and its wider region. This more balanced patterns of job growth would reduce the rate of growth of commuting cross local authority boundaries, particularly in those areas that are already suffering from severe traffic bottlenecks and congestion, e.g. in London and WSE. In addition, under this scenario average dwelling rents still rise more than the expected rise in wage earnings in London and WSE.

The impact of growth on more deprived communities would however be marginal because new jobs growth tends to focus on areas that are already doing well. This reinforces the importance of any UK-wide initiative to rebalance the growth overall being complemented by local inclusive policies and strategies.

Table 12 **Scenario S2H: converging rates of regional job distribution, high rates of growth**

Jobs (million)	**1981***	**1991***	**2001**	**2011**	**2031**	**2051**	**2071**
London & WSE	7.6	8.7	9.9	11.2	12.8	14.3	15.9
Midlands	3.4	3.9	4.1	4.6	5.0	5.6	6.2
South West	1.6	2.0	2.3	2.5	2.9	3.2	3.6
N England	5.4	5.7	6.1	6.8	7.4	8.2	9.2
Wales	0.9	1.1	1.2	1.3	1.5	1.7	1.8
Scotland	2.1	2.1	2.3	2.5	2.8	3.1	3.4
All Britain	19.2	23.4	27.3	28.9	32.3	36.0	40.2
% change per year		**1981-91**	**1991-01**	**2001-11**	**2011-31**	**2031-51**	**2051-71**
London & WSE		1.36%	1.31%	1.27%	0.66%	0.55%	0.55%
Midlands		1.26%	0.64%	0.98%	0.45%	0.55%	0.55%
South West		2.45%	1.27%	1.16%	0.63%	0.55%	0.55%
N England		0.52%	0.60%	1.07%	0.43%	0.55%	0.55%
Wales		1.36%	0.76%	1.41%	0.55%	0.55%	0.55%
Scotland		-0.24%	1.04%	0.94%	0.51%	0.55%	0.55%
All Britain		2.02%	1.53%	0.59%	0.55%	0.55%	0.55%

Table 13 **Scenario S2H: Extrapolation of recent trends of house-building since 1991**

Dwellings (million)	**2011**	**2031**	**2051**	**2071**
London & WSE	9.6	10.8	12.1	13.6
Midlands	4.3	4.8	5.4	6.0
South West	2.4	2.7	3.1	3.5
N England	6.6	7.3	8.0	8.8
Wales	1.4	1.5	1.7	1.9
Scotland	2.5	2.7	3.0	3.3
All Britain	26.8	29.9	33.4	37.2
% change per year		**2011-31**	**2031-51**	**2051-71**
London & WSE		0.60%	0.59%	0.59%
Midlands		0.54%	0.54%	0.54%
South West		0.66%	0.65%	0.64%
N England		0.47%	0.47%	0.48%
Wales		0.57%	0.57%	0.56%
Scotland		0.49%	0.50%	0.50%
All Britain		0.55%	0.55%	0.55%

Table 14 **Scenario S2H: Model prediction of average dwelling rents 2031-2071**

	Dwelling rents (£(2011) per unit per year)				**Change (2011 = 100)**			
	2011	**2031**	**2051**	**2071**	**2011**	**2031**	**2051**	**2071**
London & WSE	11200	14101	16775	19963	100	126	150	178
Midlands	6359	7653	9088	10797	100	120	143	170
South West	7841	9531	11088	12926	100	122	141	165
N England	6201	7523	9065	10911	100	121	146	176
Wales	4839	5877	7005	8355	100	121	145	173
Scotland	5519	6849	8192	9786	100	124	148	177
All Britain	8027	9954	11876	14166	100	124	148	176
% change per year		**2011-31**	**2031-51**	**2051-71**				
London & WSE		1.16%	0.87%	0.87%				
Midlands		0.93%	0.86%	0.87%				
South West		0.98%	0.76%	0.77%				
N England		0.97%	0.94%	0.93%				
Wales		0.98%	0.88%	0.88%				
Scotland		1.09%	0.90%	0.89%				
All Britain		1.08%	0.89%	0.89%				

Table 15 **Scenario S2H: Model prediction of average wage costs 2031-2071**

Changes in wage costs				
2011 = 100	2011	2031	2051	2071
London & WSE	100	112	137	184
Midlands	100	110	132	173
South West	100	110	132	170
N England	100	110	133	178
Wales	100	110	133	174
Scotland	100	112	137	184
All Britain	100	111	135	180

Table 16 **Scenario S2H: Model prediction of the volume of commuting within and between local authority districts (or equivalent) 2031-2071**

	Commuting travel - within LAD/UA only				% change			
	2011	2031	2051	2071	2011-31	2031-51	2051-71	2011-71
London and WSE	4.3	5.1	5.6	6.1	16.7%	10.2%	10.3%	41.8%
Midlands	2.3	2.6	2.9	3.2	12.3%	10.2%	9.7%	35.9%
South West	1.6	1.9	2.1	2.3	17.2%	11.3%	11.0%	44.9%
N England	4.0	4.5	5.0	5.5	11.8%	11.0%	11.0%	37.8%
Wales	0.8	1.0	1.1	1.2	14.3%	12.3%	12.2%	44.0%
Scotland	1.7	1.9	2.2	2.4	15.3%	11.2%	11.2%	42.6%
All Britain	14.8	16.9	18.7	20.7	14.5%	10.8%	10.7%	40.3%
	Commuters from outside LAD/UA				% change			
	2011	2031	2051	2071	2011-31	2031-51	2051-71	2011-71
London and WSE	6.4	7.7	8.7	9.8	20.1%	12.5%	12.5%	51.9%
Midlands	2.1	2.4	2.7	3.1	15.5%	13.1%	13.6%	48.4%
South West	0.8	1.0	1.1	1.3	19.4%	12.1%	12.6%	50.7%
N England	2.5	2.9	3.3	3.7	16.6%	12.4%	12.5%	47.6%
Wales	0.4	0.5	0.6	0.6	20.7%	10.3%	10.4%	47.0%
Scotland	0.7	0.8	0.9	1.1	17.9%	12.5%	12.6%	49.3%
All Britain	13.0	15.4	17.3	19.5	18.6%	12.5%	12.6%	50.2%

3.3 Scenario Group 3: 'Attacking the Problem'

Scenario 3 imagines even more radical changes by postulating that the rates of job creation in the currently low growth parts of the UK will pick up sooner and gradually become higher.
This means that over time the distribution in jobs (particularly good quality jobs) would increase outside the areas that are currently experiencing fast growth. This scenario also considers enhanced connectivity between the core cities (with the door to door travel time between all core cities reduced to below one hour and 45 minutes).

This Scenario reflects the aspirations for a UK-wide agenda for

- Improving the quality of life and life-time opportunities for people, in both the fast and slow growing areas
- A rebalanced economy which supports local ambitions
- Maximising impact through joined-up action
- Opening up new markets areas to tip current trends towards better growth
- Supporting places to meet the full needs of their communities

The overall outcome of such a scenario is summarised in the graph. It shows the potential of a change in the balance of development with four million additional jobs in the rest of the UK above the Business as Usual trend scenario whilst there still being a growth of 2.4 m jobs in London and WSE. These serve to illustrate the scale of change that could be involved in terms of job numbers and its consequences in a better-balanced UK. For London and the WSE, this would still imply a significant increase in jobs and business but at the same time a significant reduction in pressures of commuting. Whilst the growth in the number of jobs in London and the WSE would still be at a significant level, the future housing needs in these areas could be met with a housing delivery rate that is no higher than the average in the last two decades.

Table 17 **Scenario S3Ha: higher rates of job growth outside London and WSE, uniform rates**

Jobs (million)	**1981***	**1991***	**2001**	**2011**	**2031**	**2051**	**2071**
London & WSE	7.6	8.7	9.9	11.2	12.0	12.8	13.6
Midlands	3.4	3.9	4.1	4.6	5.2	6.0	6.8
South West	1.6	2.0	2.3	2.5	3.0	3.4	3.9
N England	5.4	5.7	6.1	6.8	7.6	8.8	10.1
Wales	0.9	1.1	1.2	1.3	1.5	1.8	2.0
Scotland	2.1	2.1	2.3	2.5	2.9	3.3	3.8
All Britain	19.2	23.4	27.3	28.9	32.3	36.0	40.2
% change per year		**1981-91**	**1991-01**	**2001-11**	**2011-31**	**2031-51**	**2051-71**
London & WSE		1.36%	1.31%	1.27%	0.36%	0.30%	0.30%
Midlands		1.26%	0.64%	0.98%	0.63%	0.69%	0.68%
South West		2.45%	1.27%	1.16%	0.81%	0.69%	0.68%
N England		0.52%	0.60%	1.07%	0.61%	0.69%	0.68%
Wales		1.36%	0.76%	1.41%	0.74%	0.69%	0.68%
Scotland		-0.24%	1.04%	0.94%	0.70%	0.69%	0.68%
All Britain		2.02%	1.53%	0.59%	0.55%	0.55%	0.55%

Table 18 **Scenario S3Ha: Extrapolation of recent trends of house-building since 1991**

Dwellings (million)	**2011**	**2031**	**2051**	**2071**
London & WSE	9.6	10.8	12.1	13.6
Midlands	4.3	4.8	5.4	6.0
South West	2.4	2.7	3.1	3.5
N England	6.6	7.3	8.0	8.8
Wales	1.4	1.5	1.7	1.9
Scotland	2.5	2.7	3.0	3.3
All Britain	26.8	29.9	33.4	37.2
% change per year		**2011-31**	**2031-51**	**2051-71**
London & WSE		0.60%	0.59%	0.59%
Midlands		0.54%	0.54%	0.54%
South West		0.66%	0.65%	0.64%
N England		0.47%	0.47%	0.48%
Wales		0.57%	0.57%	0.56%
Scotland		0.49%	0.50%	0.50%
All Britain		0.55%	0.55%	0.55%

Table 19 **Scenario S3Ha: Model prediction of average dwelling rents 2031-2071**

	Dwelling rents (£(2011) per unit per year)				**Change (2011 = 100)**			
	2011	**2031**	**2051**	**2071**	**2011**	**2031**	**2051**	**2071**
London & WSE	11200	13461	15411	17654	100	120	138	158
Midlands	6359	7981	9794	12002	100	126	154	189
South West	7841	9932	11938	14355	100	127	152	183
N England	6201	7888	9865	12300	100	127	159	198
Wales	4839	6160	7620	9413	100	127	157	195
Scotland	5519	7184	8921	11043	100	130	162	200
All Britain	8027	9946	11862	14146	100	124	148	176
Average Earnings Trend	8027	9602.1	11486	13741	100	120	143	171
% change per year		**2011-31**	**2031-51**	**2051-71**				
London & WSE		0.92%	0.68%	0.68%				
Midlands		1.14%	1.03%	1.02%				
South West		1.19%	0.92%	0.93%				
N England		1.21%	1.12%	1.11%				
Wales		1.21%	1.07%	1.06%				
Scotland		1.33%	1.09%	1.07%				
All Britain		1.08%	0.88%	0.88%				

Table 20 **Scenario S3Ha: Model prediction of average wage costs 2031-2071**

Change in wage costs 2011 = 100	2011	2031	2051	2071
London & WSE	100	110	129	162
Midlands	100	112	140	193
South West	100	113	139	190
N England	100	113	143	201
Wales	100	113	142	198
Scotland	100	114	146	209
All Britain	100	111	136	182

Table 21 **Scenario S3Ha: Model prediction of the volume of commuting within and between local authority districts (or equivalent) 2031-2071**

	Commuting travel - within LAD/UA only				% change			
	2011	2031	2051	2071	2011-31	2031-51	2051-71	2011-71
London and WSE	4.3	4.8	5.0	5.3	10.2%	5.1%	5.1%	21.6%
Midlands	2.3	2.7	3.1	3.5	16.6%	13.4%	12.6%	48.9%
South West	1.6	1.9	2.2	2.5	21.6%	14.5%	13.9%	58.6%
N England	4.0	4.6	5.3	6.0	16.1%	14.2%	13.9%	51.0%
Wales	0.8	1.0	1.2	1.3	18.7%	15.5%	15.2%	57.9%
Scotland	1.7	2.0	2.3	2.6	19.7%	14.4%	14.1%	56.4%
All Britain	14.8	17.1	19.1	21.3	15.6%	11.7%	11.5%	43.9%
	Commuters from outside LAD/UA				% change			
	2011	2031	2051	2071	2011-31	2031-51	2051-71	2011-71
London and WSE	6.4	7.3	7.8	8.3	13.0%	6.9%	6.9%	29.1%
Midlands	2.1	2.5	2.9	3.4	20.0%	16.4%	16.7%	62.9%
South West	0.8	1.0	1.2	1.4	24.1%	15.4%	15.8%	65.9%
N England	2.5	3.0	3.5	4.0	21.1%	15.7%	15.6%	62.0%
Wales	0.4	0.5	0.6	0.7	25.3%	13.5%	13.4%	61.2%
Scotland	0.7	0.9	1.0	1.2	22.4%	15.8%	15.6%	63.7%
All Britain	13.0	15.2	16.9	18.9	17.3%	11.5%	11.7%	46.1%

Table 22 **Scenario S3Hb: higher rates of job growth outside London and WSE, gradual spread from London and WSE**

Jobs (million)	**1981***	**1991***	**2001**	**2011**	**2031**	**2051**	**2071**
London & WSE	7.6	8.7	9.9	11.2	13.8	13.8	13.6
Midlands	3.4	3.9	4.1	4.6	5.1	5.9	6.8
South West	1.6	2.0	2.3	2.5	2.7	3.2	3.9
N England	5.4	5.7	6.1	6.8	6.8	8.3	10.1
Wales	0.9	1.1	1.2	1.3	1.4	1.6	2.0
Scotland	2.1	2.1	2.3	2.5	2.5	3.1	3.8
All Britain	19.2	23.4	27.3	28.9	32.3	36.0	40.2
% change per year		**1981-91**	**1991-01**	**2001-11**	**2011-31**	**2031-51**	**2051-71**
London & WSE		1.36%	1.31%	1.27%	1.04%	0.00%	-0.08%
Midlands		1.26%	0.64%	0.98%	0.55%	0.73%	0.73%
South West		2.45%	1.27%	1.16%	0.32%	0.93%	0.94%
N England		0.52%	0.60%	1.07%	0.00%	1.03%	0.97%
Wales		1.36%	0.76%	1.41%	0.09%	1.01%	1.02%
Scotland		-0.24%	1.04%	0.94%	0.09%	0.98%	1.00%
All Britain		2.02%	1.53%	0.59%	0.55%	0.55%	0.55%

Table 23 **Scenario S3Hb: Extrapolation of recent trends of house-building since 1991**

Dwellings (million)	**2011**	**2031**	**2051**	**2071**
London & WSE	9.6	10.8	12.1	13.6
Midlands	4.3	4.8	5.4	6.0
South West	2.4	2.7	3.1	3.5
N England	6.6	7.3	8.0	8.8
Wales	1.4	1.5	1.7	1.9
Scotland	2.5	2.7	3.0	3.3
All Britain	26.8	29.9	33.4	37.2
% change per year		**2011-31**	**2031-51**	**2051-71**
London & WSE		0.60%	0.59%	0.59%
Midlands		0.54%	0.54%	0.54%
South West		0.66%	0.65%	0.64%
N England		0.47%	0.47%	0.48%
Wales		0.57%	0.57%	0.56%
Scotland		0.49%	0.50%	0.50%
All Britain		0.55%	0.55%	0.55%

Table 24 **Scenario S3Hb: Model prediction of average dwelling rents 2031-2071**

	Dwelling rents (£(2011) per unit per year)				**Change (2011 = 100)**			
	2011	**2031**	**2051**	**2071**	**2011**	**2031**	**2051**	**2071**
London & WSE	11200	14960	16359	17654	100	134	146	158
Midlands	6359	7689	9593	12002	100	121	151	189
South West	7841	8938	11285	14355	100	114	144	183
N England	6201	6839	9216	12300	100	110	149	198
Wales	4839	5318	7058	9413	100	110	146	195
Scotland	5519	6220	8268	11043	100	113	150	200
All Britain	8027	9963	11870	14146	100	124	148	176
% change per year		**2011-31**	**2031-51**	**2051-71**				
London & WSE		1.46%	0.45%	0.38%				
Midlands		0.95%	1.11%	1.13%				
South West		0.66%	1.17%	1.21%				
N England		0.49%	1.50%	1.45%				
Wales		0.47%	1.43%	1.45%				
Scotland		0.60%	1.43%	1.46%				
All Britain		1.09%	0.88%	0.88%				

Table 25 **Scenario S3Hb: Model prediction of average wage costs 2031-2071**

Changes in wage costs 2011 = 100	2011	2031	2051	2071
London & WSE	100	116	140	176
Midlands	100	110	136	188
South West	100	107	129	175
N England	100	105	128	181
Wales	100	105	127	177
Scotland	100	106	131	188
All Britain	100	111	135	182

Table 26 **Scenario S3Hb: Model prediction of the volume of commuting within and between local authority districts (or equivalent) 2031-2071**

	Commuting travel - within LAD/UA only				% change			
	2011	2031	2051	2071	2011-31	2031-51	2051-71	2011-71
London and WSE	4.3	5.4	5.4	5.3	25.7%	-0.8%	-2.4%	21.6%
Midlands	2.3	2.7	3.0	3.5	14.3%	14.4%	13.8%	48.9%
South West	1.6	1.8	2.1	2.5	10.4%	19.9%	19.8%	58.6%
N England	4.0	4.1	5.0	6.0	2.8%	22.0%	20.5%	51.0%
Wales	0.8	0.9	1.1	1.3	4.3%	23.0%	23.1%	57.9%
Scotland	1.7	1.8	2.2	2.6	6.2%	21.1%	21.6%	56.4%
All Britain	14.8	16.6	18.8	21.3	12.6%	13.0%	13.0%	43.9%
	Commuters from outside LAD/UA				% change			
	2011	2031	2051	2071	2011-31	2031-51	2051-71	2011-71
London and WSE	6.4	8.4	8.4	8.3	29.9%	0.5%	-1.2%	29.1%
Midlands	2.1	2.4	2.9	3.4	18.1%	17.1%	17.8%	62.9%
South West	0.8	0.9	1.1	1.4	12.0%	21.2%	22.2%	65.9%
N England	2.5	2.7	3.3	4.0	7.0%	23.7%	22.4%	62.0%
Wales	0.4	0.5	0.6	0.7	10.1%	20.8%	21.2%	61.2%
Scotland	0.7	0.8	0.9	1.2	8.5%	22.6%	23.1%	63.7%
All Britain	13.0	15.6	17.2	18.9	20.6%	10.0%	10.1%	46.1%

Table 27 **Scenario S3Hc: higher rates of job growth outside London and WSE, spread from the core cities**

Jobs (million)	**1981***	**1991***	**2001**	**2011**	**2031**	**2051**	**2071**
London & WSE	7.6	8.7	9.9	11.2	14.0	13.8	13.6
Midlands	3.4	3.9	4.1	4.6	4.7	5.7	6.8
South West	1.6	2.0	2.3	2.5	2.6	3.2	3.9
N England	5.4	5.7	6.1	6.8	7.0	8.4	10.1
Wales	0.9	1.1	1.2	1.3	1.4	1.7	2.0
Scotland	2.1	2.1	2.3	2.5	2.6	3.2	3.8
All Britain	19.2	23.4	27.3	28.9	32.3	36.0	40.2

% change per year	**1981-91**	**1991-01**	**2001-11**	**2011-31**	**2031-51**	**2051-71**
London & WSE	1.36%	1.31%	1.27%	1.12%	-0.07%	-0.08%
Midlands	1.26%	0.64%	0.98%	0.16%	0.96%	0.90%
South West	2.45%	1.27%	1.16%	0.13%	1.04%	1.02%
N England	0.52%	0.60%	1.07%	0.14%	0.95%	0.90%
Wales	1.36%	0.76%	1.41%	0.27%	0.95%	0.90%
Scotland	-0.24%	1.04%	0.94%	0.23%	1.00%	0.84%
All Britain	2.02%	1.53%	0.59%	0.55%	0.55%	0.55%

Table 28 **Scenario S3Hc: Extrapolation of recent trends of house-building since 1991**

Dwellings (million)	**2011**	**2031**	**2051**	**2071**
London & WSE	9.6	10.8	12.1	13.6
Midlands	4.3	4.8	5.4	6.0
South West	2.4	2.7	3.1	3.5
N England	6.6	7.3	8.0	8.8
Wales	1.4	1.5	1.7	1.9
Scotland	2.5	2.7	3.0	3.3
All Britain	26.8	29.9	33.4	37.2
% change per year		**2011-31**	**2031-51**	**2051-71**
London & WSE		0.60%	0.59%	0.59%
Midlands		0.54%	0.54%	0.54%
South West		0.66%	0.65%	0.64%
N England		0.47%	0.47%	0.48%
Wales		0.57%	0.57%	0.56%
Scotland		0.49%	0.50%	0.50%
All Britain		0.55%	0.55%	0.55%

Table 29 **Scenario S3Hc: Model prediction of average dwelling rents 2031-2071**

	Dwelling rents (£(2011) per unit per year)				**Change (2011 = 100)**			
	2011	**2031**	**2051**	**2071**	**2011**	**2031**	**2051**	**2071**
London & WSE	11200	15116	16351	17654	100	135	146	158
Midlands	6359	7177	9322	12002	100	113	147	189
South West	7841	8625	11125	14355	100	110	142	183
N England	6201	6997	9328	12300	100	113	150	198
Wales	4839	5467	7203	9413	100	113	149	195
Scotland	5519	6374	8532	11043	100	115	155	200
All Britain	8027	9968	11867	14146	100	124	148	176
Average Earnings Trend	8027	9602	11486	13741	100	120	143	171
% change per year		**2011-31**	**2031-51**	**2051-71**				
London & WSE		1.51%	0.39%	0.38%				
Midlands		0.61%	1.32%	1.27%				
South West		0.48%	1.28%	1.28%				
N England		0.61%	1.45%	1.39%				
Wales		0.61%	1.39%	1.35%				
Scotland		0.72%	1.47%	1.30%				
All Britain		1.09%	0.88%	0.88%				

Table 30 **Scenario S3Hc: Model prediction of average wage costs 2031-2071**

Change in wage costs				
2011 = 100	**2011**	**2031**	**2051**	**2071**
London & WSE	100	116	140	177
Midlands	100	106	129	179
South West	100	105	125	171
N England	100	106	131	184
Wales	100	106	130	181
Scotland	100	108	135	193
All Britain	100	111	135	182

Table 31 **Scenario S3Hc: Model prediction of the volume of commuting within and between local authority districts (or equivalent) 2031-2071**

	Commute within LAD/UA only (m)				% change			
	2011	2031	2051	2071	2011-31	2031-51	2051-71	2011-71
London and WSE	4.3	5.5	5.4	5.3	27.4%	-2.2%	-2.4%	21.6%
Midlands	2.3	2.5	2.9	3.5	6.1%	19.4%	17.5%	48.9%
South West	1.6	1.7	2.1	2.5	6.4%	22.6%	21.6%	58.6%
N England	4.0	4.2	5.1	6.0	5.7%	20.2%	18.9%	51.0%
Wales	0.8	0.9	1.1	1.3	8.1%	21.5%	20.2%	57.9%
Scotland	1.7	1.8	2.2	2.6	9.1%	21.7%	17.8%	56.4%
All Britain	14.8	16.6	18.8	21.3	12.7%	13.2%	12.8%	43.9%
	Commuters from outside LAD/UA (m)				% change			
	2011	2031	2051	2071	2011-31	2031-51	2051-71	2011-71
London and WSE	6.4	8.5	8.4	8.3	31.9%	-0.9%	-1.2%	29.1%
Midlands	2.1	2.3	2.8	3.4	9.0%	22.7%	21.8%	62.9%
South West	0.8	0.9	1.1	1.4	7.7%	24.0%	24.2%	65.9%
N England	2.5	2.7	3.3	4.0	10.1%	21.8%	20.8%	62.0%
Wales	0.4	0.5	0.6	0.7	14.2%	19.3%	18.3%	61.2%
Scotland	0.7	0.8	1.0	1.2	11.5%	23.1%	19.2%	63.7%
All Britain	13.0	15.7	17.2	18.9	20.8%	9.7%	10.2%	46.1%

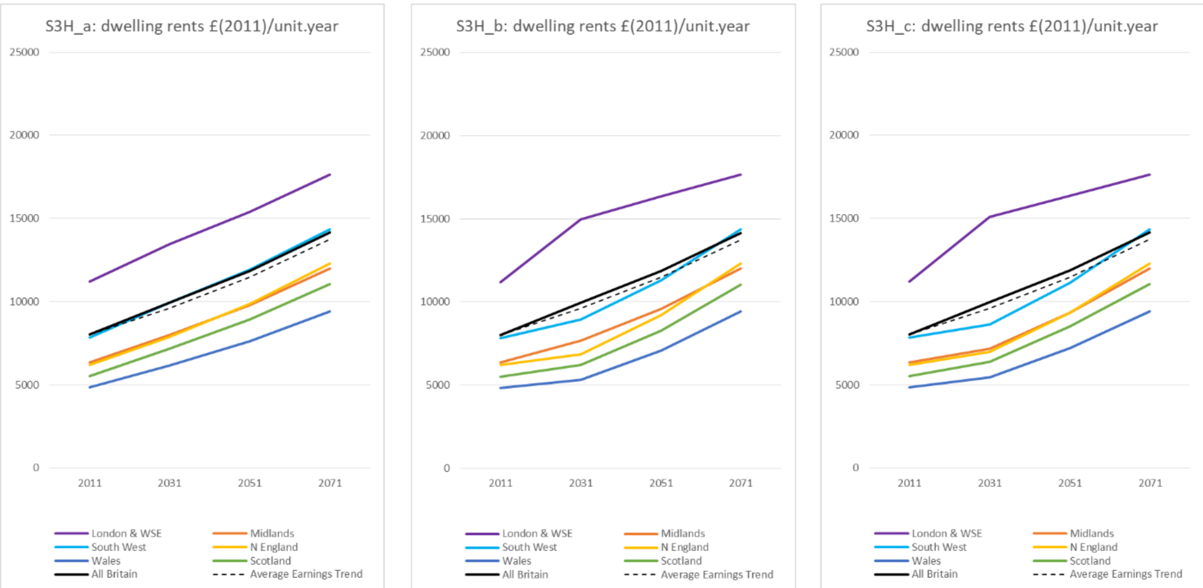

FIGURE 4 COMPARISON OF DWELLING RENTS: SCENARIOS S3H VARIANTS

Table 32 **Net land take for new housing: a comparison among scenarios**

		Land (km2)	Net land take (km2)				% change relative to 2005 base			
		Dwellings & gardens 2005	2011-2031	2031-2051	2051-2071	2011-2071	2011-2031	2031-2051	2051-2071	2011-2071
S1L	1. London and WSE	2,964	302	216	228	**745**	10%	7%	8%	**25%**
	2. Midlands	1,482	107	93	100	**300**	7%	6%	7%	**20%**
	3. South West	931	95	66	69	**230**	10%	7%	7%	**25%**
	4. N England	1,776	102	95	100	**298**	6%	5%	6%	**17%**
	5. Wales	546	36	30	31	**97**	7%	6%	6%	**18%**
	6. Scotland	940	74	56	58	**188**	8%	6%	6%	**20%**
	All Britain	**8,639**	**716**	**556**	**586**	**1859**	**8%**	**6%**	**7%**	**22%**
S1H	1. London and WSE	2,964	595	525	598	**1718**	20%	18%	20%	**58%**
	2. Midlands	1,482	220	190	217	**626**	15%	13%	15%	**42%**
	3. South West	931	184	170	190	**544**	20%	18%	20%	**58%**
	4. N England	1,776	207	149	150	**506**	12%	8%	8%	**28%**
	5. Wales	546	80	66	68	**213**	15%	12%	12%	**39%**
	6. Scotland	940	147	116	123	**386**	16%	12%	13%	**41%**
	All Britain	**8,639**	**1432**	**1216**	**1346**	**3993**	**17%**	**14%**	**16%**	**46%**
S2H	1. London and WSE	2,964	537	397	441	**1375**	18%	13%	15%	**46%**
	2. Midlands	1,482	242	228	255	**725**	16%	15%	17%	**49%**
	3. South West	931	169	138	153	**460**	18%	15%	16%	**49%**
	4. N England	1,776	245	234	262	**742**	14%	13%	15%	**42%**
	5. Wales	546	81	72	80	**234**	15%	13%	15%	**43%**
	6. Scotland	940	155	137	154	**446**	16%	15%	16%	**47%**
	All Britain	**8,639**	**1430**	**1207**	**1345**	**3982**	**17%**	**14%**	**16%**	**46%**
S3Ha	1. London and WSE	2,964	355	254	271	**880**	12%	9%	9%	**30%**
	2. Midlands	1,482	289	275	311	**875**	20%	19%	21%	**59%**
	3. South West	931	201	170	191	**563**	22%	18%	21%	**60%**
	4. N England	1,776	311	300	345	**956**	18%	17%	19%	**54%**
	5. Wales	546	101	92	105	**298**	19%	17%	19%	**55%**
	6. Scotland	940	192	173	197	**562**	20%	18%	21%	**60%**
	All Britain	**8,639**	**1450**	**1264**	**1420**	**4134**	**17%**	**15%**	**16%**	**48%**
S3Hb	1. London and WSE	2,964	799	217	220	**1235**	27%	7%	7%	**42%**
	2. Midlands	1,482	270	280	324	**874**	18%	19%	22%	**59%**
	3. South West	931	120	199	243	**562**	13%	21%	26%	**60%**
	4. N England	1,776	131	368	456	**955**	7%	21%	26%	**54%**
	5. Wales	546	42	113	144	**298**	8%	21%	26%	**55%**
	6. Scotland	940	90	204	264	**559**	10%	22%	28%	**59%**
	All Britain	**8,639**	**1452**	**1381**	**1651**	**4484**	**17%**	**16%**	**19%**	**52%**
S3Hc	1. London and WSE	2,964	845	213	223	**1280**	28%	7%	8%	**43%**
	2. Midlands	1,482	181	320	372	**873**	12%	22%	25%	**59%**
	3. South West	931	91	211	260	**562**	10%	23%	28%	**60%**
	4. N England	1,776	160	363	433	**955**	9%	20%	24%	**54%**
	5. Wales	546	54	113	132	**298**	10%	21%	24%	**55%**
	6. Scotland	940	109	219	231	**559**	12%	23%	25%	**59%**
	All Britain	**8,639**	**1439**	**1437**	**1651**	**4528**	**17%**	**17%**	**19%**	**52%**

Table 33 **Net increases in jobs in neighbourhoods - by quintile of relative multiple deprivation**

	Average rank of Local Authority/Unitary Authority 0-20%: most deprived 60-100%: least deprived	**Million of new jobs** 2011-2031	2031-2051	2051-2071	**% share by quintile** 2011-2031	2031-2051	2051-2071
S1L	0-20%	0.25	0.20	0.19	14%	8%	7%
	20-40%	0.27	0.21	0.14	15%	9%	5%
	40-60%	0.29	0.35	0.38	16%	15%	13%
	60-100%	0.97	1.60	2.26	55%	68%	76%
	All Britain	**1.77**	**2.37**	**2.98**	**100%**	**100%**	**100%**
S1H	0-20%	0.96	1.68	2.51	21%	20%	20%
	20-40%	0.95	1.62	2.33	21%	20%	19%
	40-60%	0.75	1.33	1.93	17%	16%	15%
	60-100%	1.89	3.66	5.69	42%	44%	46%
	All Britain	**4.54**	**8.28**	**12.46**	**100%**	**100%**	**100%**
S2H	0-20%	0.96	1.65	2.39	21%	20%	19%
	20-40%	0.98	1.74	2.56	21%	21%	21%
	40-60%	0.76	1.38	2.06	17%	17%	17%
	60-100%	1.84	3.52	5.45	41%	43%	44%
	All Britain	**4.54**	**8.28**	**12.46**	**100%**	**100%**	**100%**
S3Ha	0-20%	0.96	1.62	2.30	21%	20%	18%
	20-40%	1.10	1.98	2.94	24%	24%	24%
	40-60%	0.79	1.44	2.17	17%	17%	17%
	60-100%	1.70	3.25	5.04	37%	39%	40%
	All Britain	**4.54**	**8.28**	**12.46**	**100%**	**100%**	**100%**
S3Hb	0-20%	0.96	1.63	2.30	21%	20%	18%
	20-40%	0.73	1.77	2.94	16%	21%	24%
	40-60%	0.75	1.40	2.17	17%	17%	17%
	60-100%	2.10	3.47	5.04	46%	42%	40%
	All Britain	**4.54**	**8.27**	**12.46**	**100%**	**100%**	**100%**
S3Hc	0-20%	0.99	1.65	2.30	22%	20%	18%
	20-40%	0.79	1.82	2.94	17%	22%	24%
	40-60%	0.73	1.40	2.17	16%	17%	17%
	60-100%	2.05	3.41	5.04	45%	41%	40%
	All Britain	**4.57**	**8.28**	**12.46**	**100%**	**100%**	**100%**

4. Commentary on Output from Model Tests

In summary the outcomes from the scenario tests are as follows:

Scenario Group 1 shows that even under low growth, average housing costs in London and its region are expected to rise well above average earnings. Job growth would be concentrated in the least deprived areas.

Scenario Group 2 see a significant reduction in cross boundary commuting and a reduction in the rate of housing cost inflation in London and the WSE.

Scenario Group 3 implies that four million additional jobs in the rest of the UK, whilst 2.4 million in London and WSE. As a result, there would be a significant reduction in cross boundary commuting, in housing and labour costs and in the pressure on housing land take in London and the WSE.

In summary, unless there is a change in policy direction economic inequalities will grow and London and the wider south east will experience increased problems of housing affordability and pressure on infrastructure, with increasing need for more commuting into dense urban areas, requiring further investment to maintain current levels of access and mobility. Higher growth rates driven elsewhere in the UK would lead to better job access, better balanced migration and housing demand, reduced commuting pressures and new land take for housing. However, all scenarios demonstrate the importance of complementary local policies if economic growth is to reach out beyond the areas that are doing well in each country/region.

The main insights from the model tests could be summarised as follows.

First, there is a real need to consider a sufficiently wide range of growth trajectories, rather than just marginally different spatial rebalancing scenarios. The three groups of scenarios presented above are a good start in exploring a possible range of possibilities, and they already highlight the scale of the task if the UK would be to pursue a more economically, socially and environmentally sustainable development.

Secondly, even at a modest rate of employment growth, which is considered low relative to historic means and common expectations, the housing and transport needs in London and the WSE would significantly exceed the current trends of provision by the 2050s, if not before.

Thirdly, the scenarios that coordinate jobs and housing growth would reduce the strains of growth. This insight should help inspire a wide range of interventions that would tackle persistent long-term issues such as housing unaffordability, transport bottlenecks as well as lack of business vitality. It would appear that these problems are intrinsically connected and may need to be considered together rather than in policy silos.

More specifically, the model results show that:
Employment Growth: By their very nature these scenarios describe a changed balance in the pattern of economic development. All still involve substantial economic growth of over 10m jobs, of which between 2.4- 4.3m jobs would be located in London and the WSE region whilst the scale of job growth elsewhere could be doubled.

Housing Costs: There would be related changes in the pattern of housing costs and commuting volumes. With a substantially higher rate of job growth outside London and the WSE, average housing costs across the UK might rise at similar rates to UK average earning rates. The historic patterns of housing delivery which underlies the housing growth assumptions would start to be in balance with job growth if there were a more balanced pattern of economic development.

Disadvantaged Communities: A scenario of low economic growth has least benefit to disadvantage communities not only in terms of available jobs but also their regional distribution. However, under all scenarios the full benefit would only be realised only with supporting locally tailored inclusive employment growth strategies.

Commuting Levels: With a rebalancing of the economy under Scenario Group 3, the pressures of increased commuting would ease substantially in the London and the WSE, with rates of around 6% over 2031-2051 and 2051-2071. By contrast, the rates of commuting increases in the rest of the UK would rise to around 15% for a twenty-year period.

Net land Take for house-building: The overall land take for housing is proportional to the assumptions of growth in population. Therefore, the sooner the nations and regions in the north achieve higher growth, the less land take that would be needed in the wider south east, and the greater potential to decrease the pressure for greenfield development

Labour Costs: In line with the housing cost variations, the labour costs across the three scenarios also indicate divergence under Scenario Group 1 with High Growth assumptions (i.e. with current trends of spatial polarisation continuing into the future, and high demographic and economic growth) – London and the WSE are expected to face rapid rises in per hour wage costs. This rise is modestly ameliorated under Scenario 2, but it is under Scenario Group 3 that the all the UK countries and regions start to converge in terms of wage costs.

5. Conclusions

The overarching finding from the scenario tests is that the employment growth hotspots which are mostly in the southern areas of England and the relatively low growth elsewhere are related to one another. If the countries and regions are better connected economically and via transport and telecommunications, it would be possible to shape a better rebalanced spatial economy which may provide the local communities in both the south and the north of the UK improved prospects to pursue their aspirations in quality of life, nature conservation and economic growth.

High quality jobs, business investment and supply chain development could spread from the current growth hotspots through better transport connections, complemented by investment in telecommunications. Historically, this has been how such jobs, investments and supply chains spread from London to the WSE. It would seem that the current transport investment programme to connect the core cities outside London and the WSE are not ambitious enough in its impact to facilitate a similar level of access, and this issue should not be confused with the separate issue of cost control since it is accepted that transport investment should show its value through sustainable accessibility and mobility it generates for those core cities, not merely by the money spent or budget planned.

The new growth model where all areas of the UK complement each other could distinguish itself through a vision for channeling growth pressures via corridors of growth.

The strategic implications of the findings from this study are that:

- Continuing with existing policy frameworks (i.e. Business as Usual) will exacerbate the problems of housing affordability, pressure on transport infrastructure and commuting into dense urban areas, even if investment is made to maintain the current levels of access and mobility in London and the WSE. It looks very unlikely that we could build our way out of the problems.
- There is every reason to believe from other high growth areas (e.g. Manhattan in New York City and the San Francisco Bay Area) that areas of high growth run the risk of being stifled by the scale of housing and labour cost rises and demands for major infrastructure investment.
- An increased level of job creation in the rest of the UK would lead to a better balance of development in terms of not only access to jobs, internal migration but also house prices and commuting levels.
- An increase in the scales of growth in Scenario Group 3 are more consistent with observed housing development capacities, for example as set out in the current local plans in London and the WSE, and the Great North Plan.
- The higher growth rates in Scenario 3 (Attacking the Problem) represent the most desirable basis for creating a new narrative for the UK. It delivers the scale of change needed to have a significant impact on housing and wage costs – moderating rates of growth where it is problematic. It reduces the sole dependency on London for sustaining the levels of growth of the UK and creates ambition across the UK.

In the UK2070 Commission modelling project the number of variables being considered is necessarily large and the relationships among them are necessarily complex. This means that it will be possible to improve the scenario variables beyond this first iteration. As we move forward, we may find that the range of variability of a scenario assumption need to be readjusted. What is presented here is the first analyses on this complex research question.

6. Project Team, Focus Group and Sponsors

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Appendix A The LUISA Model and Its Application to the UK2070 Futures Modelling Study

This model appendix is organized as follows. Section A1 introduces the formal structure of the LUISA2.03 model. Section A2 discusses the model solving algorithm in a step-by-step manner. Section A3 summarizes the zoning system in the model. Lists of model variables and behavioural parameters are provided in Section A4. Further technical details are available from the Martin Centre team at University of Cambridge.

A1 Structure of the LUISA2.02 Model

Suppose that the city region is divided into $\mathfrak{I}$ core zones plus $\wp$ peripheral zones. Core zones represent the core study area where detailed policy analyses are conducted with relatively fine spatial granularity; while the peripheral zones represent the wider region outside the core study area which exchanges production factors (e.g. labour) and trades goods & services with the core zones. $\mathbb{N} = \mathfrak{I} + \wp$ thus denotes all modelled zones. Each of the model zones has $r = 1, \dots, \mathcal{R}$ basic industries and $f = 1, \dots, F$ consumer types. Table 34 summarizes the model segmentations in the model.

TABLE 34 SEGMENTATIONS IN THE MODEL

	Industry types	Consumer types	Residential floorspace types	Commercial floorspace types
Core zones	$r = 1, \dots, \mathcal{R}$	$f = 1, \dots, F$	$m = 1, \dots, \aleph_1$	$k = 1, \dots, \aleph_2$
Peripheral zones	$r = 1, \dots, \mathcal{R}$	$f = 1, \dots, F$	$m = 1, \dots, \aleph_1$	$k = 1, \dots, \aleph_2$

We introduce the following model components in turn: producers, final consumers, location choices, stock constraints and equilibrium conditions.

A1.1 Producers

The producers are represented by a set of production functions that define how they use capital, labour, floorspace and intermediate inputs (raw materials and services). A nested Cobb-Douglas CES (CD-CES) function has been broadly accepted as a standard for this purpose in spatial general equilibrium analyses since Krugman (1991) and Fujita et al. (1999). We follow Anas and Liu (2007) and Jin et al. (2013), and define the production function as a variant of the CD-CES specification.

$$X_{rj} = E_{rj} A_{rj} (K_r)^{\nu_r} \left(\sum\nolimits_f \kappa_{rfj} L_{fj}^{\theta_r} \right)^{\frac{\delta_r}{\theta_r}} \left(\sum\nolimits_k \chi_{rkj} B_{kj}^{\zeta_r} \right)^{\frac{\mu_r}{\zeta_r}} \prod\nolimits_s (Y_{rsj})^{\gamma_{rs}} \quad (1)$$

where X_{rj} is the production output of industry r in zone j; K_r, L_{fj}, B_{kj} and Y_{rsj} are the capital, labour, business floorspace and intermediate input, respectively; ν_r, δ_r, μ_r and γ_{rs} are cost share parameters for the respective input group. This function is Cobb-Douglas and is constant returns to scale by $\nu_r + \delta_r + \mu_r + \sum_s \gamma_{rs} = 1$. The elasticity of substitution between any two labour and building floorspace varieties is $1/(1-\theta_r)$ and $1/(1-\zeta_r)$, respectively. $\kappa_{rfj}, \chi_{rkj} \geq 0$ are input-specific constants for labour and business floorspace varieties, respectively. These constants allow us to specify input-specific preference within each input bundle. A_{rj} is a function of the economic mass for industry r in zone j that represents Hicksian-neutral Total Factor Productivity (TFP) effects resulting from learning and transfer of tacit knowledge (Graham & Kim, 2008; Rice, Venables, & Patacchini, 2006), which is an important component of urban agglomeration effects. E_{rj} is a constant scalar representing any additional zonal effects on total factor productivity. We define $A_{rj} = \underline{A}_{rj}(M_j/\underline{M}_j)^{\pi}$, where $\underline{A}_{rj}$ is a constant representing the baseline agglomeration effects, M_j is a function of the economic mass of zone j, $\underline{M}_j$ is a constant representing the baseline economic mass in j; π is a scale parameter. The function of economic mass builds on the concept of effective density (Graham, Gibbons, & Martin, 2009).

$$M_j = \sum\nolimits_f \sum\nolimits_i \frac{L_{fi}}{\chi_{fij}} \quad (2)$$

where L_{fi} is the total size of labour type f in zone i (including zone j) that is relevant to production zone j, and χ_{fij} is the travel time from location i to j for labour type f.

We assume that each firm minimizes the cost subject to the production demand and the price of each input variety. The *conditional input demand* (given target output X_{rj}) of each input factor can be derived as follows:

$$K_r = \frac{1}{\rho}\nu_r p_{rj} X_{rj} \tag{3}$$

$$L_{rfj} = \frac{\kappa_{rfj}^{\frac{1}{1-\theta_r}} w_{fj}^{\frac{1}{\theta_r-1}}}{\sum_s \kappa_{rsj}^{\frac{1}{1-\theta_r}} w_{sj}^{\frac{\theta_f}{\theta_r-1}}} \delta_r p_{rj} X_{rj} \tag{4}$$

$$B_{rkj} = \frac{\chi_{rkj}^{\frac{1}{1-\zeta_r}} R_{kj}^{\frac{1}{\zeta_r-1}}}{\sum_s \chi_{rsj}^{\frac{1}{1-\zeta_r}} R_{sj}^{\frac{\zeta_r}{\zeta_r-1}}} \mu_r p_{rj} X_{rj} \tag{5}$$

$$Y_{rsj} = \frac{\gamma_{rs} p_{rj} X_{rj}}{p_{rs|j}^*} \tag{6}$$

where p_{rj} is the unit production price of industry r in zone j; ρ is the exogenous price of business capital (i.e. the real interest rate); w_{fj} is the hourly wage of labour type f; R_{kj} is the average rent for business floorspace type k; and $p_{rs|j}^*$ is the average delivered price of intermediate input type s for producing product type r in zone j.
The minimized production price can then be calculated by substituting the above conditional demands into the production function. As zero profit is assumed at any level of output, the minimized price equals the average and the marginal cost, which takes the form:

$$p_{rj} = \frac{\rho^{\nu_r}\left(\sum_f \kappa_{rfj}^{\frac{1}{1-\theta_r}} w_{fj}^{\frac{\theta_r}{\theta_r-1}}\right)^{\frac{\delta_r\theta_r-1}{\theta_r}} \left(\sum_k \chi_{rkj}^{\frac{1}{1-\zeta_r}} R_{kj}^{\frac{\zeta_r}{\zeta_r-1}}\right)^{\frac{\mu_r\zeta_r-1}{\zeta_r}} \prod_m {p_{rs|j}^*}^{\gamma_{rs}}}{E_{rj} A_j \nu_r^{\nu_r} {\delta_r}^{\delta_r} \mu_r^{\mu_r} \prod_s \gamma_{rs}^{\gamma_{rs}}} \tag{7}$$

A1.2 Final Consumers

Final consumers are categorized into $f = 1, \dots, F$ types according to their employment status and socio-economic level. H_f is the exogenous number of consumers in group f. Consumers in socio-economic group f receive both wage and nonwage income, except group $f = F$ denoting the non-employed consumers who do not have wage income but receive nonwage income through social welfare transfer. The wage income is modelled endogenously subject to equilibrium conditions, while the nonwage income is subject to the *a priori* welfare transfer scheme.
Each consumer makes a set of discrete and continuous choices. For discrete choices, the employed residents decide where to work and where to live jointly from $j = 1, \dots, \mathbb{N}$ employment zones and $i = 1, \dots, \mathbb{N}$ residence zones; the non-employed residents choose their residence location from $i = 1, \dots, \mathbb{N}$ residence zones. Both the employed and non-employed consumers choose where to source goods & services from $z = 1, \dots, \mathbb{N}$ production zones. The remaining choices entail continues variables and are conditional on the above discrete location choices. Consumers then decide on: 1) the annual consumption of each goods & services variety; 2) the quantity of type m housing floorspace to rent; 3) the use of time between work and leisure in the case of employed consumers. All consumers are assumed to maximize their utility from the mixed discrete-continuous choice.

Following the random utility framework (McFadden, 1973), the utility of consumer type f living in zone i and working in zone j takes the form $U_{fij}^* = U_{fij} + e_{fij}$ where U_{fij} is the observable quantity-based utility and e_{fij} is the error term which measures the unobservable utility variance among consumers. The observable utility U_{fij} is given by:

$$U_{fij} = \alpha_f \ln\left(\sum_r \sum_z \xi_{rfz}\left(Z_{rz|fij}\right)^{\eta_f}\right)^{\frac{1}{\eta_f}} + \beta_f \ln\left(\sum_m \iota_{mfi}\left(b_{m|fij}\right)^{\sigma_f}\right)^{\frac{1}{\sigma_f}} + \gamma_f \ln l_{fij} \quad (8)$$

$$\textit{subject to budget constraint}: \sum_{r,z}(p_{rz} + c_f 2g_{fiz})Z_{rz|fij} + \sum_m r_{mi}b_{m|fij} + \Delta_f 2Dg_{fij}$$
$$= \Delta_f w_{fj}\left(N - 2DG_{fij} - \sum_{r,z} c_f Z_{rz|fij}2G_{fiz} - l_{fij}\right) + \mathcal{M}_{fi}$$
$$\textit{and time constraint}: \quad N - \sum_{r,z} c_f Z_{rz|fij}2G_{fiz} - \Delta_f\left(l_{fij} + 2DG_{fij}\right) \geq 0$$

In equation (8), we assume Cobb-Douglas preference between goods & services $Z_{rz|fij}$, housing $b_{m|fij}$ and leisure time l_{fij}. $\alpha_f + \beta_f + \gamma_f = 1$ are the expenditure coefficients for each consumption bundle. The varieties of goods & services and housing are assumed to be imperfect substitutes (Dixit & Stiglitz, 1977), and the elasticity of substitution is governed by η_f and σ_f for goods & services and housing, respectively. $\xi_{rfz}, \iota_{mfi} > 0$ are the input-specific constants measuring the inherent attractiveness of the goods & services, and housing varieties for consumers type f, which is calibrated empirically.
For the budget constraint in equation (8), the right-hand side of the function is the total income and the left-hand side is the total expenditure. Specifically, p_{rz} is the mill price for goods & services type r produced in zone z; g_{fiz} and G_{fiz} is the expected one-way monetary cost and travel time from i to z for customers type f, respectively[5]; c_f is an exogenous coefficient that measures the cost for delivering a unit of goods & services as percentage of the normal trip cost. r_{mi} is the housing rent of type m in zone i; w_{fj} is the hourly wage rate for labour type f working in zone j. Δ_f is the employment status of the consumer type f. For all employed consumers $\Delta_f = 1$; otherwise $\Delta_f = 0$. $\mathcal{M}_{fi}$ is the nonwage income of consumer type f in zone i. It consists of normal investment returns on real estate in the city region (endogenous in the model) as well as the individual share of social welfare transfer and amenity gains (subject to *a priori* scheme). As for the time constraint, D is the exogenous number of working days per annum; $N = 24D$ is the exoge*n*ous total annual time endowment. For the non-employed consumers ($\Delta_f = 0$), the model only accounts for the time for shopping, as they do not commute and have zero value of time for leisure time.
We can rewrite the budget constraint in equation (8) to consider the value of time for shopping travel as a part of the delivered price. The new constraint function is equivalent to equation (8).

$$\sum_{r,z} p^*_{rz|fij} Z_{rz|fij} + \sum_m r_{mi} b_{m|fi} + \Delta_f 2Dg_{ij} \quad (9)$$
$$= \Delta_f w_{fj}\left(N - 2DG_{ij} - l_{fij}\right) + \mathcal{M}_{fi}$$

where $p^*_{rz|fij}$ is the full delivered price of a unit of goods & services type r produced in zone z purchased by consumer type f living in zone i and working in zone j. We use the subscript z to denote the production location of goods & services and j as the employment location for employed workers. The full delivered price for final consumers $p^*_{rz|fij}$ is given by:

$$p^*_{rz|fij} = p_{rz} + c_f 2\left(g_{iz} + \Delta_f G_{iz} w_{fj}\right) \quad (10)$$

Accordingly, the full disposable income of the consumer type (fij) net of commuting costs is given by:

$$\Omega_{fij} = \Delta_f w_{fj}\left(N - 2DG_{ij} - l_{fij}\right) - \Delta_f 2Dg_{ij} + \mathcal{M}_{fi} \quad (11)$$

Under the above budget and time constraint, we can then derive the *Marshallian* demand for goods & services, housing and leisure time in Eq. 3.12, Eq. 3.13 and Eq. 3.14, respectively.

[5] The monetary cost and travel time is composite over all available travel modes. For the moment, we do not consider the time-of-day and purpose variations in travel time and cost.

$$\bar{Z}_{r|fij} = \frac{\xi_{rfz}^{\frac{1}{1-\eta_f}} \bar{p}_{r|fij}^{\frac{1}{\eta_f-1}}}{\sum_s \xi_{rfz}^{\frac{1}{1-\eta_f}} \bar{p}_{s|fij}^{\frac{\eta_f}{\eta_f-1}}} \alpha_f \Omega_{fij} \tag{12}$$

$$b_{m|fij} = \frac{\iota_{mfi}^{\frac{1}{1-\sigma_f}} r_{mi}^{\frac{1}{\sigma_f-1}}}{\sum_s \iota_{si}^{\frac{1}{1-\sigma_f}} r_{si}^{\frac{\sigma_f}{\sigma_f-1}}} \beta_f \Omega_{fij} \tag{13}$$

$$l_{fij} = \frac{\gamma_f \Omega_{fij}}{w_{fj}} \tag{14}$$

where $\bar{Z}_{r|fij}$ is the aggregate demand for product type r for consumer type (fij); $\bar{p}_{r|fij}$ is the probability-weighted average price of product type r faced by consumer type (fij). The formulation of $\bar{p}_{r|fij}$ and $\bar{Z}_{r|fij}$ and the associated discrete-choice probability function will be introduced shortly.

In addition to the *Marshallian* utility function (maximizing utility subject to budget constraints), which is used in base-year model calibration, the model employs the *Hicksian* utility function in forecasts. The Hicksian utility function differs from the Marshallian utility function in that it minimizes the expenditure given fixed utility. The use of Hicksian utility function in forecast mode implies that consumers are assumed to maintain, if not increase, their base-year utility level in future years by altering their locational and consumption choices. Under the same Nested-CES configuration and parameterization, the Marshallian and Hicksian utility functions are consistent in base-year model calibration, in the sense that the derived Marshallian demands (given observed budget constraint) are identical to the Hicksian demands (given the Marshallian utility). In forecast mode, the Hicksian utility function will replace the Marshallian utility function. The implication is that consumers will have to raise the income if the cost of living (i.e. prices of goods & services and housing rents) goes up, in order to maintain the same utility level. The need for increasing income will then be represented by an upward pressure on labour wage. In case the cost of living goes down (e.g. abundance of housing supply), the model assumes that the local wage level would not decrease subject to global price adjustment. Nonetheless the resulting extra utility gain will be competed out in spatial equilibrium as more residents move into the area, which in turn drives up the cost of living.

For the Hicksian utility function, the minimized expenditure given the utility U_{fij} is defined as:

$$\Omega_{fij}^{Hicksian} = \alpha_f^{-\alpha_f} \beta_f^{-\beta_f} \gamma_f^{-\gamma_f} \left[\left(\sum_r \sum_z \xi_{rfz}^{\frac{1}{1-\eta_f}} \bar{p}_{r|fij}^{\frac{\eta_f}{\eta_f-1}} \right)^{\frac{\eta_{f-1}}{\eta_f}} \right]^{\alpha_f} \left[\left(\sum_m \iota_{mfi}^{\frac{1}{1-\sigma_f}} r_{mi}^{\frac{\sigma_f}{\sigma_f-1}} \right)^{\frac{\sigma_f-1}{\sigma_f}} \right]^{\beta_f} (w_{fj})^{\gamma_f} U_{fij} \tag{15}$$

The total annual labour working time N_{fij} for the employed consumer type (fij) is thus determined by subtracting the total travel time for commuting and shopping, and the annual leisure time from the annual time endowment N.

$$N_{fij} = N - 2DG_{ij} - \sum_{r,z} c_f Z_{rz|fij} 2G_{iz} - l_{fij} \geq 0 \tag{16}$$

The next step is to evaluate the direct utility function (8) to get the price-based indirect utility function $\widetilde{U}_{fij}$, which is given by:

$$\widetilde{U}_{fij} = \ln \Omega_{fij} - \alpha_f \frac{\eta_f - 1}{\eta_f} \ln \left(\sum_r \sum_z \xi_{rfz}^{\frac{1}{1-\eta_f}} \bar{p}_{r|fij}^{\frac{\eta_f}{\eta_f-1}} \right) - \beta_f \frac{\sigma_f - 1}{\sigma_f} \ln \left(\sum_m \iota_{mfi}^{\frac{1}{1-\sigma_f}} r_{mi}^{\frac{\sigma_f}{\sigma_f-1}} \right) - \gamma_f \ln w_{fj} \tag{17}$$

Note that the quantity-based and the price-based utility functions are mathematically equivalent in static equilibrium. However, for the purpose of welfare evaluation over time, particularly in long-term forecast that involves macroeconomic changes (e.g. price-level changes due to growth, inflation or deflation), the quantity-based direct utility function offers a more intuitive and straightforward measure than the price-based counterpart. Therefore, we use the price-based utility in static equilibria and the quantity-based utility for welfare analysis.

A1.3 Location Choices

The location choices in the model include: 1) sourcing goods & services for final consumers; 2) the employment-residence choice (or residence location choice if employment is exogenous) for the employed residents. Both location choices are modelled in the spatial equilibrium framework. Another important aspect of location choice modelling is the articulation of travel disutility. We summarize the measure of travel disutility in the model by the end of this section.

A1.3.1 Sourcing goods and services

In the model, consumers do not only decide the quantity of each product to purchase, but also where to source them. The former decision is based on average delivered price of each product thus is continuous in nature; while the latter choice is discrete involving limited number of location alternatives. We represent this mixed discrete-continuous choice problem by combining two different choice models. For the continuous choice on quantities, a nested CES function is applied to consider the substitution effects within the consumption bundle. For the discrete location choice, the sourcing pattern is modelled with a multinomial logit probabilistic model. The probability of obtaining product type r from zone z to consumer type f living in zone i (and working in zone j, if employed) is given by:

$$P_{rz|fij} = \frac{S_z \exp(-\lambda_{f|r}(p_{rz} + c_f \chi_{fiz} + \psi_{riz} - E_{rfz}))}{\sum_n S_n \exp(-\lambda_{f|r}(p_{rn} + c_f \chi_{fin} + \psi_{rin} - E_{rfn}))} \quad (18)$$

where S_z is a size term that corrects for the bias introduced by the uneven sizes of zones in the model (Ben-Akiva & Lerman, 1985); $\lambda_{f|r}$ is the dispersion parameter. c_f is a coefficient measuring the cost for delivering a unit of goods & services as percentage of normal trip cost; χ_{fiz} is a travel disutility function; ψ_{riz} are observable non-monetary barriers for trading between zone i and zone z; E_{rfz} is the residual attractiveness term which is calibrated empirically. In the model, consumers will shop to all potential production zones, rather than the zone with the cheapest delivered price only[6]. A similar probability function can be applied to model the sourcing of intermediate inputs for producers.

With the above probability, we can derive the weighted average price of product type r faced by consumer type (fij). Note that this weighted average price considers the consumption inputs from all possible production locations, thus the dimension is $[r]$.

$$\bar{p}_{r|fij} = \sum_z p^*_{rz|fij} P_{rz|fij} \quad (19)$$

where $p^*_{rz|fij}$ is the full delivered price including the value of time for travel. The purpose of deriving $\bar{p}_{r|fij}$ is to link the discrete location choice with the continuous choice of consumption quantities. For residents living in zone i, they first choose how much to consume for each product type ($\bar{Z}_{r|fij}$), regardless of the their production locations. This continuous choice is made based on the weighted average price $\bar{p}_{r|fij}$ through CES functions. The discrete-choice probability in Eq. 3.17 then distributes the aggregate demand $\bar{Z}_{r|fij}$ to each production location z. This distribution process is given by:

$$Z_{rz|fij} = P_{rz|fij} \bar{Z}_{r|fij} \quad (20)$$

This function is used to derive the total production demand for product type r in zone z.

A1.3.2 Employment/residence location choice

In the model, we differentiate the location choice of employed residents and the non-employed. For employed residents we assume that they respond quickly to the utility changes and are mobile in terms of employment-residence relocation in static equilibria. By contrast, the relocation of non-employed residents is inertia-prone, i.e. there may be a lag of many years between a utility change and household relocation. We thus deal the relocation of non-employed households outside the equilibrium framework through recursive dynamic model or model assumptions. This section first introduces the discrete choice model for employment-residence joint choice. The residence location choice model as an abridged version the former model will be discussed afterwards.

For the employment-residence choice of employed residents, a multinomial logit model is developed. The probability of consumer f working in zone j choosing to live in zone i is defined as:

[6] By "shop" we refer to any non-work trip that involves the purchase of goods and services. We ignore trip chains and travels that do not originate from home.

$$P_{fij} = \frac{S_{ij}\exp(\lambda_f \upsilon_{fij})}{\sum_{m,n} S_{mn}\exp(\lambda_{fI}\upsilon_{fmn})} \quad (21)$$

where

$$\upsilon_{fij} = \widetilde{U}_{fij} - d_{fij} + \psi_{fij} + E_{fij} + e_{fij} \quad (22)$$

S_{ij} is the a size term that addresses the size of residence/employment opportunities in zone i/j; $\lambda_{f|I}$ is the dispersion parameter; $\widetilde{U}_{fij}$ is the consumption utility of consumer f living in zone i and working in zone j; d_{fij} is the travel disutility of travelling from zone i to j; E_{fij} is the residual attractiveness of location pair (i, j), and e_{fij} is the unobserved error term.

For the residence choice of employed residents, the probability of consumer f choosing to live in zone i, given the employment location j, is defined as:

$$P_{fi|j} = \frac{S_i\exp(\lambda_{f|I}\upsilon_{fi|j})}{\sum_m S_m\exp(\lambda_{f|I}\upsilon_{fm|j})} \quad (23)$$

where

$$\upsilon_{fi|j} = \widetilde{U}_{fi|j} - d_{fi|j} + \psi_{fi|j} + E_{fi|j} + e_{fi|j} \quad (24)$$

$\upsilon_{fi|j}$ is the residence location utility of zone i for resident type f, given the chosen workplace j; $\lambda_{f|I}$ is the dispersion parameter. The other variables follow the same definitions as in function υ_{fij}, except that the employment location j is given.

A1.3.3 Travel disutility

In the model, the χ_{fij} function is introduced to represent the attributes of travel for traveller type f from i to j. We differentiate the χ_{fij} function for different uses throughout the model. In this section, we summarize the use of the χ_{fij} function. For measuring the economic mass (as in Eq. 2), we define $\chi_{fij} = 2G_{fiz}$, which is the round-trip travel time (in hourly term) between zone i and j for traveller type f.

For sourcing goods & services (as in Eq. 18), we define $\chi_{fiz} = 2(g_{fiz}/\varsigma_f \overline{w}_{fi} + G_{fiz})$, where $\overline{w}_{fi}$ is the average hourly wage of type-f employed residents living in zone i[7], and $\varsigma_f \in (0,1]$ is a decay coefficient, implying that the shopping trip being partly voluntary thus its value of time is not fully valued by the traveller. The front multiplier transforms the one-way cost into round-trip cost (de Dios OrtÃozar & Willumsen, 2011). The above formulation adopts the time unit (hour), and considers both the travel time and the monetary cost. The monetary cost is transformed into time unit by dividing it by the value of time $\varsigma_f \overline{w}_{fi}$. Note that this time-based travel disutility is only used for modelling location choices. The actual transport costs, including the value of time, are measured in monetary unit in the equilibrating process.

For the employment-residence location choice, it is important to consider the realistic commuting patterns within a large city region. City regions with reasonably self-contained commuting catchment today tend to have a radius of 50km or more. At this metropolitan scale, extensive analyses of travel choices data show that a d_{ij} function (as in Eq. 22) that is linear to travel costs and times will have great difficulties in representing realistic demand elasticity throughout (Jin et al., 2013); a non-linear transformation of utilities is required (Gaudry & Laferriére, 1989). Fox et al (2009) devise a log-linear transformation that is a close equivalent to the Box-Cox function whilst being easier to calibrate. This function is given by:

$$d_{fij} = a_{f|d}\chi_{fij} + (1 - a_{f|d})\ln\chi_{fij} - a_{f|d} \quad (25)$$

where $\chi_{fij} = 2DG_{fiz}$, i.e. the annual total commuting time between zone i and j for labour type f, and $a_{f|d}$ is a log-linear parameter. The reason why we do not account for the monetary cost is that the monetary cost is already accounted for in the consumption utility function (see the budget constraint in Eq. 8). To avoid double counting, we thus only consider the travel time in the χ_{fij} function.

To demonstrate the non-linear feature of the above function, we plot the log-linear travel disutility versus the linear counterpart in **Error! Reference source not found.**. It shows that the modelled elasticity of the l og-linear function varies for different distance ranges. Specifically, the elasticity of disutility with regard to distance is higher for short-distance range (approx. 0-15 km), and becomes lower for long-distance range (approx. > 15 km).

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[7] To distinguish $\overline{w}_{fi}$ and w_{fj}, the latter is the hourly wage of labour type f at production zone j, while the former is the average wage for labour type-f living in residence zone i, weighted by the modelled labour distribution to all employment locations.

A1.4 Stock Constraints

We define stock constraints to cover land/floorspace and transport infrastructure which may evolve or "churn" slowly. In the model, the stock constraints include: 1) the zonal supply of housing floorspace varieties ($\hat{b}_{mi}$) and business floorspace varieties ($\hat{B}_{ki}$); 2) the expected transport monetary cost (g_{fij}) and travel time (G_{fij}) for consumer type f; 3) the zonal number of non-employed residents (H_F).

In the model, such stock constraints remain exogenous for any static period and will be updated periodically in a non-equilibrium manner. The underlying assumption is that land/floorspace and transport infrastructure respond to demand slowly and indivisibly, subject to regulation, planning, construction, commission and decommission (Jin et al., 2013). User-defined supply scenarios are likely to be the most appropriate in order to reflect policy targets and background changes. As for the relocation of non-employed residents, it is assumed that there is a time lag between a utility change and household relocation.

A1.5 Equilibrium Conditions

The general equilibrium structure of the model requires three sets of equilibrium conditions to be satisfied simultaneously, conditional on the transport conditions $\boldsymbol{g}$ and $\boldsymbol{G}$.

1) All consumers maximize utility subject to budget and time constraint, or minimise expenditure subject to given utility target.
2) All producers minimize cost subject to supply constraint of input factors and technology. Producers are competitive and operate under constant returns to scale. The minimized production price equals the average and marginal cost, implying zero economic profit.
3) All markets clear with zero excess demands. This applies to: a) the residential and business floorspace markets; b) the labour market for each socio-economic group at each production zone; c) the product market of each product type at each production zone.

The above equilibrium conditions are formulated in the model as follows:

A1.5.1 Product markets

The market clearance condition in both zonal and regional product markets prescribes that in each of the $j = 1, \dots, \mathbb{N}$ production zone, the production output of each industry should equal the total production demand plus net export. Let $Y_{rj|sn}$ be the intermediate demand for industry r in zone j for producing product s in zone n and Ξ_{rj} be the exogenous net export for industry r in zone j. The zero excess demands in product markets require:

$$\sum_{f,z} H_{fi} P_{rz|fij} \bar{z}_{r|fij} + \sum_{s,n} Y_{rj|sn} + \Xi_{rj} = X_{rj} \qquad (26)$$

A1.5.2 Labour Markets

In each of the $j = 1, \dots, \mathbb{N}$ production zone, the annual labour demand in hourly term for each of the $f = 1, \dots, F-1$ labour group must equal the working hours supplied by the respective labour group, net of the time for commuting, shopping and leisure.

$$\sum_{r} L_{rfj} = \sum_{i} H_{fi} P_{fij} \left(N - 2DG_{fij} - \sum_{r,z} c_f Z_{rz|fij} 2G_{fiz} - l_{fij} \right) \qquad (27)$$

A1.5.3 Floorspace Markets

We treat the zonal building floorspace as exogenous supply constraints in static equilibria, and update them through Recursive Dynamic models. The market clearance in floorspace markets requires that in static equilibrium, the zonal demand for each type of residential and business floorspace must equal the corresponding zonal supply constraint.

$$\sum_{f,j} b_{m|fij} = \hat{b}_{mi} \qquad (28)$$

$$\sum_{r} B_{rkj} = \hat{B}_{kj} \qquad (29)$$

where $\hat{b}_{mi}$ and $\hat{B}_{kj}$ is the zonal supply constraint for housing and business floorspace, respectively.

As a summary, the aforementioned equilibrium conditions define the aggregate behavioural rules of agents, and specify how they interact with each other in respective market. In fact, the equilibrium conditions constitute the economic foundation of general equilibrium models, and it is a theoretical necessity to satisfy such conditions in equilibrium analysis.

A2 Model Algorithm

In the previous section, we present the formal structure of the Spatial Equilibrium model. Given the exogenous stock constraints (building floorspace supply, transport infrastructure and non-employed households), the aforementioned equations and variables complete the spatial general equilibrium of the model. Following the convention of spatial equilibrium models, we solve the static equilibrium in a sequential manner, which is specified in Figure 5.

The solving algorithm for the Spatial Equilibrium model is as follows:

STEP 0 (Initialization). Arbitrary exogenous vectors of rents $(\boldsymbol{R}, \boldsymbol{r})$, wages $(\boldsymbol{w})$ serve as initial inputs. Given the guessed values, as well as the given transport conditions $\boldsymbol{G}$ and $\boldsymbol{g}$ and all parameters, the following sequentially arranged steps complete a single iteration of the SE model.

STEP 1 (Production prices). The zero economic profit equation (7) is solved for the equilibrium production price $\boldsymbol{p}$, given wages $\mathbf{w}$ and business floorspace rents $\mathbf{R}$.

STEP 2 (Location choices). Residents make discrete location choice for sourcing goods & services with equation (18). Employed residents make joint location choices with Equation 21 or 23.

STEP 3 (Outputs). Given the production price $\boldsymbol{p}$ from STEP 1 and the location choices from STEP 2, the final demand for production $\boldsymbol{F}$ can be solved with the *Marshallian* demand function (12) and the zero-excess-demand equation (26). The total production demand $\boldsymbol{X}$, including the intermediate demand, can be derived with the classical input-output solution $\boldsymbol{X} = (\boldsymbol{I} - \boldsymbol{A})^{-\mathbf{1}}\boldsymbol{F}$, where $\boldsymbol{A} = [\gamma_{rs}]$ is the matrix of input-output coefficients.

STEP 4 (Rents). Given the production price $\boldsymbol{p}$ from STEP 1 and the production outputs $\boldsymbol{X}$ from STEP 3, the equilibrium rents for business floorspace $\mathbf{R}$ can be solved with the floorspace demand function (3.5) subject to the stock constraints $\widehat{\boldsymbol{B}}$. Similarly, the housing rents $\mathbf{r}$ are solved with the *Marshallian* or *Hicksian* demand function subject to the housing stock constraints $\widehat{\boldsymbol{b}}$.

STEP 5 (Wages). Given the production price $\boldsymbol{p}$ from STEP 1, the location choices from STEP 2, and the production outputs $\boldsymbol{X}$ from STEP 3, the equilibrium wages $\mathbf{w}$ can be solved with the labour market zero-excess-demand equation.

STEP 6 (Updating). Gathering the results of STEP 1 to STEP 5, the algorithm has determined vectors $\boldsymbol{p}, \boldsymbol{w}, \boldsymbol{R}, \boldsymbol{r}$ conditional on transport matrices $\boldsymbol{G}$ and $\boldsymbol{g}$ and all exogenous variables, constraints and parameters. The algorithm will then check whether these updated prices and the associated quantities are converged and whether they simultaneously satisfy all equilibrium conditions to a desired level of accuracy that is discussed below. If not, then the next iteration is started by returning to STEP 1 with these updated vectors. If all equilibrium conditions and converging criteria are satisfied simultaneously, model iteration stops and writes output files.

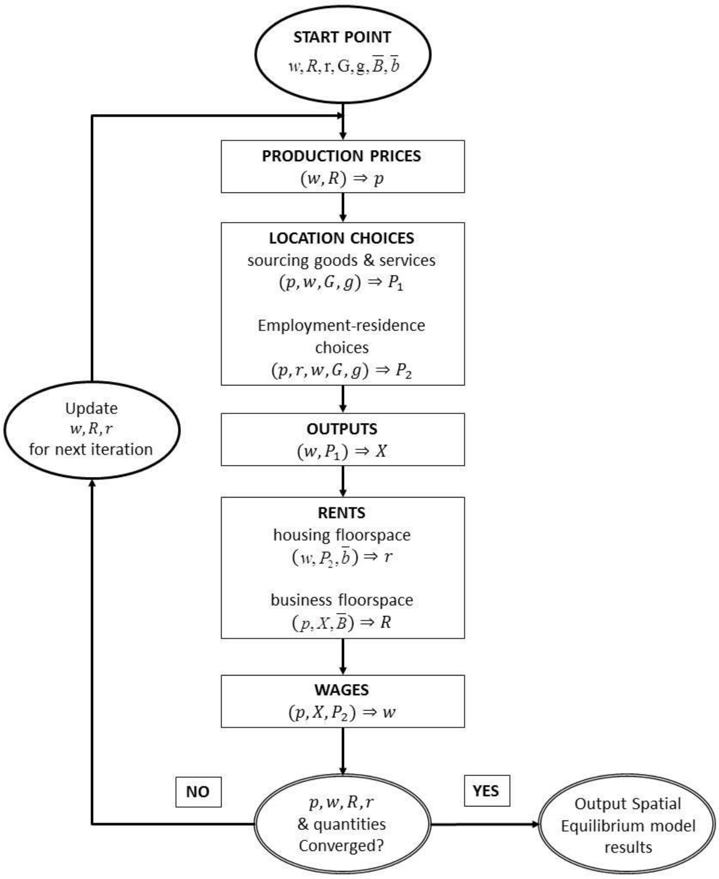

FIGURE 5 SOLVING ALGORITHM FOR SPATIAL EQUILIBRIUM MODEL

We define the level of converging accuracy by setting a maximum relative error condition. The Spatial Equilibrium model is considered converged in the *n*th iteration when the following inequality condition is satisfied simultaneously for all prices and quantities concerned:

$$\max_{\forall i}\left(\left|\frac{x_{i|n} - x_{i|n-1}}{\frac{1}{2}\left(x_{i|n} + x_{i|n-1}\right)}\right|\right) < ITERTOL \qquad (30)$$

where vectors $x_{i|n}$ include zonal prices $\boldsymbol{p}, \boldsymbol{w}, \boldsymbol{R}, \boldsymbol{r}$ and all the associated excess demands in iteration n, and $ITERTOL$ is a user-specified maximum iteration tolerance. When the Spatial Equilibrium model is initiated with guesstimated starting values, large relative errors between iterations may occur. As the model approaches the equilibrium solution, the relative errors are expected to reduce gradually, yet not necessarily monotonically.

In order to stabilize the equilibrating process and avoid the model from divergence, we need to define how the variables are updated between iterations. Let $Current(X_n)$ be the variable value in iteration n and $New(X_{n+1})$ be the updated value from the solving algorithm for iteration $n + 1$, we set:

$$Current(x_{n+1}) = \varpi(n)New(x_n) + [1 - \varpi(n)]Current(x_n) \qquad (31)$$

where coefficient $\varpi(n) \in [0,1]$ is a monotonically increasing function with respect to the iteration number $n \in [1, MAXITER]$. The $\varpi(n)$ function represents a smoothing technique for updating variables between iterations. A smaller step change of $\varpi(n)$ helps to stabilize the equilibrating process but incurs more iterations.

Summary of the geographic zones of the model

List of Variables in the Model

INDICES FOR DIMENSIONS OF THE MODEL	
$\Im$	Number of core zones
$\wp$	Number of peripheral zones
$\mathbb{N} = \Im + \wp$	Total number of model zones
F	Number of social-economic groups
$\mathcal{R}$	Number of industry types
$\aleph_1$	Number of residential floorspace types
$\aleph_2$	Number of business floorspace types
D	Exogenous number of annual working days
$N = 24D$	Exoge*n*ous total annual time endowment
VARIABLES IN SPATIAL EQUILIBRIUM MODEL	
X_{rj}	Aggregate production output of industry r in zone j
E_{rj}	Constant scalar representing any additional zonal effects on Total Factor Productivity (TFP)
A_{rj}	An economic mass function for industry r in zone j that represents the agglomeration effects on TFP
K_r	Capital input for industry r
L_{fj}	Labour input of type f for industry r in zone j
B_{kj}	Business floorspace input of type k for industry r in zone j
Y_{rsj}	Intermediate input of type s for industry r in zone j
M_j	Economic mass of zone j
S_i	Geographic area of zone j
χ_{fij}	Travel disutility function for socio-economic group type f travelling from i to j
p_{rj}	Unit production price of industry r in zone j
ρ	Real interest rate
w_{fj}	Hourly wage of labour type f in zone j
R_{kj}	Average rent for business floorspace type k in zone j
$p^*_{rs\|j}$	Average delivered price of intermediate input type s for producing product type r in zone j
U_{fij}	Observable utility of resident type f living in zone i and working in zone j
$Z_{rz\|fij}$	Aggregate consumption volume for industry r in zone z, given resident type f living in zone i and working in zone j
$b_{m\|fij}$	Consumption volume for housing type m in zone i, given resident type f living in zone i and working in zone j
l_{fij}	Leisure time of resident type f living in zone i and working in zone j
g_{fiz}	Expected one-way monetary cost from i to z for customers type f
G_{fiz}	Expected one-way travel time from i to z for customers type f
$\mathcal{M}_{fi}$	Nonwage income of consumer type f in zone i
r_{mi}	Housing rent of type m in zone i
Δ_f	Employment status of the consumer type f (For all employed consumers $\Delta_f = 1$; otherwise $\Delta_f = 0$)
$p^*_{rz\|fij}$	Full delivered price of a unit of goods & services type r produced in zone z purchased by consumer type f living in zone i and working in zone j

Ω_{fij}	Full disposable income of the consumer type (fij) net of commuting costs
$\bar{Z}_{r\|fij}$	Aggregate demand for product type r for consumer type (fij)
$\bar{p}_{r\|fij}$	Probability-weighted average price of product type r faced by consumer type (fij)
N_{fij}	Total annual labour working time for labour type (fij)
$\widetilde{U}_{fij}$	Price-based indirect utility of resident type f living in zone i and working in zone j
$P_{rz\|fij}$	Probability of obtaining product type r from zone z to consumer type f living in zone i (and working in zone j, if employed)
S_z	Size term that corrects for the bias introduced by the uneven sizes of zones in the model
P_{fij}	Probability of employed resident type f choosing to live in zone i and work in zone j
υ_{fj}	Employment location utility of zone j for labour type f
$\upsilon_{fi\|j}$	Residence location utility of zone i for resident type f, given the chosen workplace j
$V_{f\|j}$	*Log-sum* or *inclusive utility* representing the expected utility that employed worker type f in zone j would receive from all residence location choices
$\bar{w}_{fi}$	Average hourly wage of type-f employed residents living in zone i
d_{fij}	Travel disutility after Box-Cox transformation for commuter type f travelling from i to j
$\hat{b}_{mi}$	Stock constraints of housing floorspace type m in zone i
$\hat{B}_{ki}$	Stock constraints of business floorspace type k in zone j
H_{fi}	Number of type f residents in zone i
Θ	Exogenous nonwage income from other sources
Ξ_{rj}	Exogenous net export for industry r in zone j
VARIABLES IN RECURSIVE DYNAMIC MODELS	
$\hat{B}_{ki}^{t+1}$	Zonal business floorspace stock of type k at zone i for period $t+1$
$\vec{B}_{k}^{t\|t+1}$	Regional aggregate stock change of business floorspace type k from period t to $t+1$
$V_{i\|B}$	Locational utility of zone j for business floorspace growth
$\hat{b}_{mi}^{t+1}$	Zonal housing floorspace stock of type m at zone i for period $t+1$
$\vec{b}_{m}^{t\|t+1}$	Regional aggregate stock change of housing floorspace type m from period t to $t+1$
$V_{i\|b}$	Locational utility of zone j for housing floorspace growth
$\bar{R}_i^t$	Zonal average business floorspace rent at zone i for period t
$\bar{R}_D^t$	Municipal/provincial average business floorspace rents at D for period t
$\mathcal{D}_i^t$	Zonal building floorspace density at zone i for period t
$\beth_{i\|B}$	Dummy variable indicating zonal policy trend for business floorspace growth
$\bar{r}_i^t$	Zonal average housing floorspace rent at zone i for period t
$\bar{r}_D^t$	Municipal/provincial average housing floorspace rents at D for period t
$\beth_{i\|b}$	Dummy variable indicating zonal positive policy trend for housing floorspace growth
$\lambda_{i\|b}$	Dummy variable indicating zonal negative policy trend for housing floorspace growth
$H_{i\|F}^{t+1}$	Zonal number of non-employed residents in zone i at period $t+1$
$\vec{H}_F^{t\|t+1}$	Regional aggregate change of non-employed households from period t to $t+1$
J_{fj}^t	Number of labour type f in zone j for period t

List of Parameters in the Model

PARAMETERS IN SPATIAL EQUILIBRIUM MODEL	
δ_r	Labour cost share
μ_r	Business floorspace cost share
ν_r	Capital cost share
γ_{rn}	Intermediate cost share
ζ_r	Elasticity of substitution for business floorspace varieties
θ_r	Elasticity of substitution for labour varieties
σ_f	Elasticity of substitution for housing varieties
$a_{f\|\kappa}$	Coefficient for determining the input-specific parameters for labour varieties
κ_{rfj}	Input-specific parameters for labour varieties
$a_{f\|\iota}$	Coefficient for determining the input-specific parameters for housing varieties
ξ_{rfz}	Input-specific parameters for goods & services varieties
ι_{mfi}	Input-specific parameters for housing varieties
E_j	Additional total factor productivity multiplier
π	Economic mass effects on productivity
c_f	Cost for delivering a unit of local services as percentage of commuting trip cost
α_f	Utility coefficient for goods & services
β_f	Utility coefficient for housing
γ_f	Utility coefficient for leisure time
$a_{f\|d}$	Log-linear travel cost function parameter
ς_f	Decay coefficient for value of time (non-commuting travels)
$\lambda_{f\|r}$	Dispersion parameter for sourcing goods & services
$\lambda_{f\|J}$	Dispersion parameter for employment location choices
$\lambda_{f\|I}$	Dispersion parameter for residence location choices
$\psi_{iz}, \psi_{fi\|j}, \psi_{fj}$	Observable non-monetary barriers for spatial interaction
E_{fz}	Residual attractiveness for sourcing goods & services
$E_{fj}, E_{fi\|j}$	Residual attractiveness for residence-employment location choices