

Zhu, Jie; Jin, Ying; Echenique, Marcial

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Application of a new spatial computable general equilibrium model for assessing strategic transport and land use development options in London and surrounding regions

by
Jie Zhu^{*}, Ying Jin^{} and Marcial Echenique^{***}**

The Martin Centre for Architectural and Urban Studies,
University of Cambridge

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ABSTRACT: This paper reports the application of a new spatial computable general equilibrium (SCGE) model at the city region level for analyzing the wider economic impacts of strategic transport and land use development options. We start from a static computable general equilibrium model for an open economy, and extend it to incorporate (1) agglomeration effects on productivity that arise from urbanization and transport improvements, (2) labour mobility across the study area with both commuting and migration, (3) short run and long run counterfactual equilibrium to allow for different rates of change in economic activities and residential location, (4) land as an explicit factor input to production, and (5) concave transport cost functions with respect to travel distance that are consistent with realistic transport costs. These extensions are built on the Dixit-Stiglitz model of monopolistic competition among producers, random utility theory of residents' behaviour, the concept of spatial economic mass, interregional trade pooling, and the Armington specification regarding product varieties. Data from London and surrounding regions is used to calibrate and validate the model. We report its applications in studying a new high speed rail link, dualing of a rural highway, and increased suburban and exurban land supply for business use. The model results obtained are in line with theoretical expectations and provide new quantification of the costs and benefits that may feed into the assessment of those strategies. All results reported in this paper are provisional although no major changes are expected.

JEL Classification: C68, F12, F16, F17, O18, R13, R42

Key words: computable general equilibrium models; land use and transport modelling, agglomeration; land; infrastructure investment appraisal

* mail to: jz286@cam.ac.uk

** mail to: yj242@cam.ac.uk

*** mail to: me15@cam.ac.uk

¹ See Appendix D for derivation

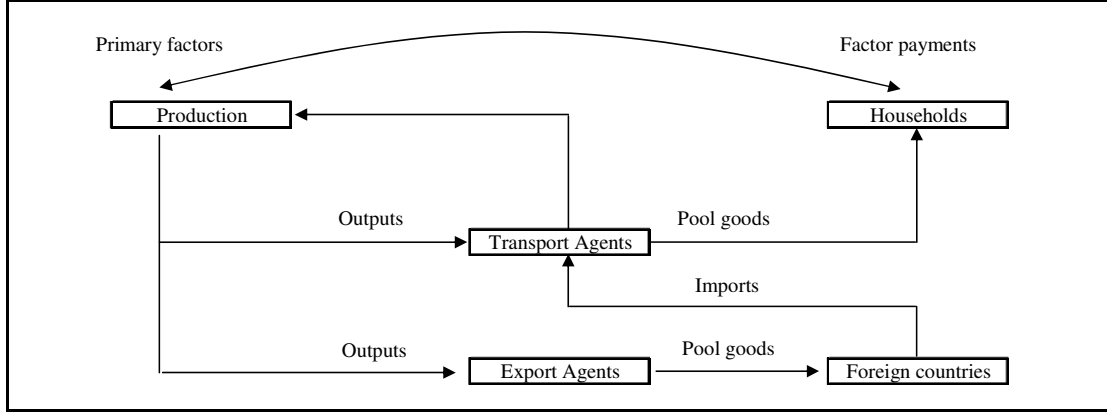
1. Introduction

This paper reports the application of a new spatial computable general equilibrium (SCGE) model which aims to assess city region level development options, particularly those related to land use and transport strategies. Our model is a further development and implementation of the models of Bröcker^[2], Bröcker^[3], Bröcker et al.^[5], Bröcker and Schneider^[4] and Schneider^[13]. The plan of the paper is as follows. In section 2, we outline the basic structure of the model. In section 3 and 4, we discuss data and solve the model, then interpret the model simulation results. Finally, in section 5, we draw the main conclusions from the applications. In this paper, we have included the main formulae of the models but not the detailed derivations. Detailed explanation and verification of the equations are found in draft Chapter 3 of Jie Zhu's dissertation (forthcoming) which is available upon request.

2. Model Structure

Our model is a static computable general equilibrium model for the UK as an open economy with geographical disaggregation of production and residential locations at the subregional level. The model consists of 3 broad industry sectors (primary, secondary and tertiary), 2 foreign country groups (EU and non-EU) and 62 UK zones with the majority representing London and its surrounding regions. For each UK zone, the model classifies economic activities into four broad sectors: production carried out by firms of the 3 types of industries, with the total number of firms being determined endogenously; a transport agent, who has an Armington preference^[1] on products from different origins and is responsible for aggregating commodities from all relevant zones in a pool^[11], from where deliveries are made to both intermediate and final consumers; final demand by households, who earn income by selling primary production factors (labour, capital and land) to firms then spend the income on pool goods, subject to their perception of consumption utility; and an export agent whose behaviour is analogous to the transport agent for commodities exported from the UK. Figure 1 shows the circular flow of the model. A brief description of the model follows from Section 2.1 to 2.5.

Figure 1. Overview of the model structure



2.1 Production

Following Bröcker^[3] and Bröcker et al.^[5], we design the firms' production process with two stages as shown in Figure 2 and Figure 3. In the first stage, the firms produce a homogenous raw output I by means of a two level NCES linear-homogenous production technology under perfect competition with constant returns to scale, using intermediate inputs $i=1, \dots, I$, taken from the pool in zone s at the upper level, and using primary factor inputs $k=1, \dots, K$ at the lower level. To keep the model simple, it is assumed that within each sector firms in all zones produce using a same Leontief technology at the upper level and a zonal specific external increasing returns to scale CES technology at the lower level. According to Shephard's lemma, cost-minimization behaviour yields the technology coefficients in terms of intermediate goods and the value-added coefficients as the first derivatives of the nested CES unit-cost functions, cf_j , with respect to individual prices.

$$a_{ij,s} = \frac{\partial cf_j(q_s, w_s; \alpha_j, \gamma_{j,s})}{\partial q_{i,s}} = \alpha_{ij} \quad (1)$$

$$c_{kj,s} = \frac{\partial cf_j(q_s, w_s; \alpha_j, \gamma_{j,s})}{\partial w_{k,s}} = \left(\sum_{k=1}^K (w_{k,s}^{(1-\sigma_{j,P})}) \frac{\gamma_{kj,s}}{\sum_{k=1}^K \gamma_{kj,s}} \right)^{\frac{1}{(1-\sigma_{j,P})-1}} w_{k,s}^{-\sigma_{j,P}} \gamma_{kj,s} \quad (2)$$

where α_{ij} and $\gamma_{kj,s}$ are known as position parameters. $a_{ij,s}$ and $c_{kj,s}$ are the intermediate and value added coefficients in zone s . $q_{i,s}$ and $w_{k,s}$ are the prices for pool goods and primary factors. Our external increasing returns to scale effect is assumed to be Hicks neutral here and is measured with spatial economic mass or

effective density^[8] which is formulated as

$$ED_s = \frac{LD_s}{d_{ss}} + \sum_r^{s \neq r} \left(\frac{LD_r}{d_{sr}} \right) \quad (3)$$

where LD_s and LD_r are the total labour demand at zone s and r ; d_{ss} is the intrazonal distance within zone s ; and d_{sr} is the interzonal distance between zone s and r . This means that $\gamma_{kj,s}$ takes the form of:

$$\gamma_{kj,s} = \gamma_{kj} \left(\frac{ED_s}{ED_B} \right)^{-\sigma_{j,ED}} \quad (4)$$

where position parameter γ_{kj} is associated with the national average technology used to produce value added; \overline{ED}_B is a national base level effective density to be chosen for normalization and can be set equal to one arbitrary zone's ED_s ; $\sigma_{j,ED}$ is the elasticity of effective density on productivity for sector j .

In the second stage, the firm takes the raw output as the only input required to produce varieties of final output under monopolistic competition in the Dixit-Stiglitz^[6] style and a fixed amount of that raw output per variety plus a constant marginal amount per unit of final output is required for producing final goods. Under this specification, each variety is monopolistically supplied by one firm. If the price is a fixed mark-up over marginal costs and profits are driven to zero by free market entry, then output per variety is also fixed so the total final output of diversified goods is proportional to the amount of raw output used for producing them. With an appropriate choice of units the factor of proportionality can be chosen to be unity, such that the zonal raw output quantity $X_{i,r}$ is the same as the zonal final diversified output $X'_{i,r}$, and the raw output price $p_{i,r}$ equals the final diversified output price $p'_{i,r}$. The composite of zonal varieties therefore has the price¹

$$v_{i,r} = \left[\frac{X_{i,r}}{X_{i,B}} (p_{i,r})^{1-\varepsilon_{i,r}} \right]^{\frac{1}{1-\varepsilon_{i,r}}} \quad (5)$$

where $X_{i,B}$ is the total supply for sector i at national level in the base year benchmark. $\varepsilon_{i,r}$ is the elasticity of substitution between varieties for sector i within each production origin r and is assumed to be the same across all domestic zones in

the model.

We assume foreign country producers also use raw output to produce final goods under Dixit-Stiglitz type of monopolistic competition. Similarly, the price of composite of varieties for sector i from foreign country z takes the form of

$$v_{i,z} = \left[\frac{M_{i,z}}{X_{i,B}} (p_{Mi,z})^{1-\varepsilon_{i,z}} \right]^{\frac{1}{1-\varepsilon_{i,z}}} \quad (6)$$

where $p_{Mi,z}$ is the import price for sector i from foreign country z . For simplicity, $\varepsilon_{i,z}$, the elasticity of substitution between varieties for sector i within each foreign country z is also assumed to be the same across all foreign countries.

Figure 2. Nested Leontief-CES production functions

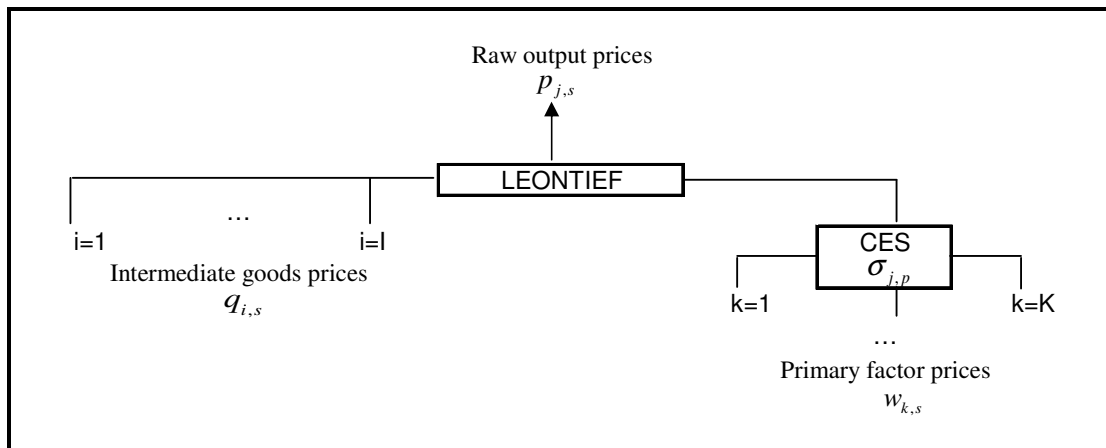
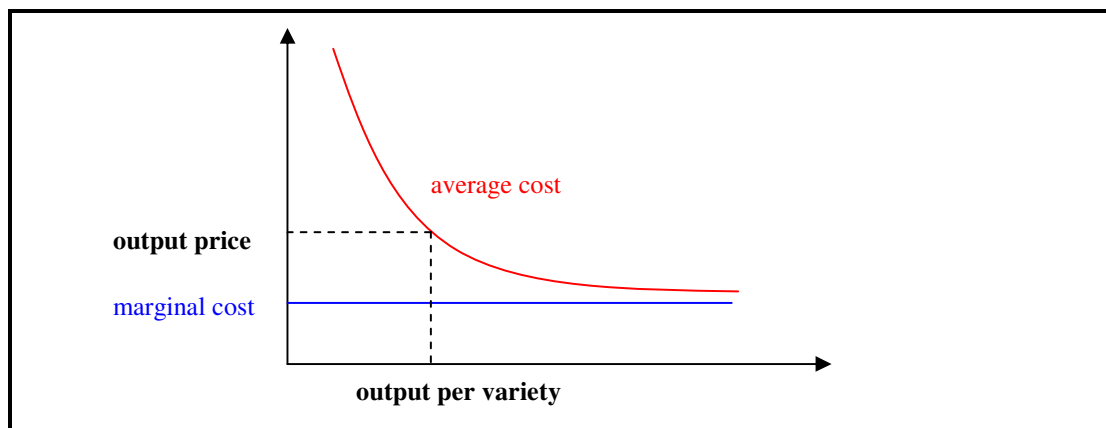


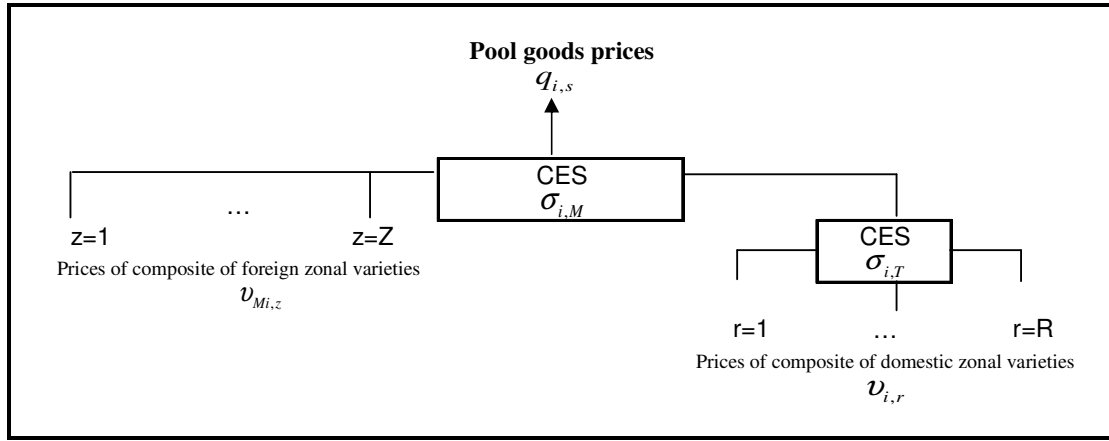
Figure 3. Production of final diversified output



2.2 Transportation

Transportation technology is modelled using the “pool-concept”^[11] of interzonal trade. According to this concept, all final diversified outputs produced by sector i in various zones including foreign countries are aggregated in a pool of the commodity i in zone s ; from this pool, deliveries are made to intermediate and final consumers. The transport technology is described by a linear homogenous NCES unit-cost function (Figure 4). The degree of homogeneity at this upper level within a sector is reflected by the elasticity of substitution $\sigma_{i,T}$. This approach for handling interzonal substitution of imperfectly substitutable goods is called the Armington specification.

Figure 4. Nested CES unit-cost functions of transportation



The specification of the transportation technology has to take into account that transportation uses up resources, the amount of which depends on economic distance. In the present paper, we have kept a simple fashion of representing the transport sector by adopting Samuelson's^[12] iceberg approach. Following McCann^[9], we assume transport cost to be concave shaped with respect to distance such that:

$$q_{i,rs} = v_{i,r} (1 + \eta_i d_{rs}^{\sigma_{i,d}}) \quad (7)$$

$$q_{i,zs} = v_{i,z} (1 + \eta_i d_{zs}^{\sigma_{i,d}}) \quad (8)$$

where $q_{i,rs}$ is the price of one unit of pool good of sector i transported from zone r to zone s ; $q_{i,zs}$ is the price of one unit of pool good of sector i transported from foreign country z to zone s ; η_i is a transport scale parameter for sector i ; d_{rs} is the distance

between zone r and s and $\sigma_{i,d}$ is a transport shape parameter with $0 < \sigma_{i,d} < 1$ to incorporate transport economies of scale. Therefore, the pool good price of sector i in zone s takes the form of

$$q_{i,s} = ct_{i,s}(p_i, p; \vartheta_i^d, \vartheta_{Mi}^d) = \left[p_i^{(1-\sigma_{i,M})} \phi_{ir,T} + \sum_{z=1}^Z \left(\frac{M_{i,z}}{X_{i,B}} \right) \pi_{i,z} (p_{Mi,z} (1 + \eta_i d_{zs}^{\sigma_{i,d}}))^{(1-\sigma_{i,M})} \phi_{iz,M} \right]^{\frac{1}{1-\sigma_{i,M}}} \left(\sum_{r=1}^R \vartheta_{i,r} + \sum_{z=1}^Z \vartheta_{Mi,z} \right) \quad (9)$$

with

$$\phi_{ir,T} = \frac{\sum_{r=1}^R \vartheta_{i,r}}{\left(\sum_{r=1}^R \vartheta_{i,r} + \sum_{z=1}^Z \vartheta_{Mi,z} \right)}, \phi_{iz,M} = \frac{\vartheta_{Mi,z}}{\left(\sum_{r=1}^R \vartheta_{i,r} + \sum_{z=1}^Z \vartheta_{Mi,z} \right)} \text{ and}$$

$$p_i = \left(\sum_{r=1}^R \left(\frac{X_{i,r}}{X_{i,B}} \right) \pi_{i,r} (p_{i,r} (1 + \eta_i d_{rs}^{\sigma_{i,d}}))^{(1-\sigma_{i,T})} \frac{\vartheta_{i,r}}{\sum_{r=1}^R \vartheta_{i,r}} \right)^{\frac{1}{(1-\sigma_{i,T})}}$$

$$\pi_{i,r} = \frac{1 - \sigma_{i,T}}{1 - \varepsilon_{i,r}}, \pi_{i,z} = \frac{1 - \sigma_{i,M}}{1 - \varepsilon_{i,z}}$$

where $\sigma_{i,M}$ is the sector specific elasticity of substitution between domestic and foreign goods. $\vartheta_{i,r}$ and $\vartheta_{Mi,z}$ are sector specific Armington preference factors for domestic goods produced in zone r and imported goods from foreign country z . It is assumed that both $\vartheta_{i,r}$ and $\vartheta_{Mi,z}$ only varies over origin zones but not over destination zones; the competition parameter $\pi_{i,r}$ and $\pi_{i,z}$ controls the position of locational and sectoral specific market form between perfect competition ($\pi = 0$) and pure Dixit-Stiglitz ($\pi = 1$) monopolistic competition for domestic zones and foreign countries respectively. By introducing π , we introduce a supply market size effect on pool goods price $q_{i,s}$. As π goes to zero, the supply market size effect vanishes and we approach perfect competition. For $\varepsilon_i > \sigma_i > 1$, we have $\pi < 1$.

2.3 Households

On the households side, each zone s consists of a set of homogenous households and each household produces one labour. Following Thissen *et al*^[15], we specify a multiplicative utility (u_s) function (Figure 5) consisting of utilities derived from both consumption $u_{c,s}$ and living $u_{l,s}$. On the one hand, the households in zone s earn its

income by selling its production factors to firms. For distribution of income, we assume wage income follows commuters and is equally redistributed among households within each residential zone while capital and land rental are modelled as a national dividend. The households spend their full income on the consumption of pool goods $i=1, \dots, I$ and derive utility from this consumption. This part of the household behaviour is described by a linear-homogeneous utility function and a CES expenditure function. On the other hand, the households also obtain utility from living in a zone and this zone related utility is specified by a logarithmic decreasing returns function including zonal housing stock (H_s), zonal labour supply (L_s) and living attractiveness constant F_s according to equation (11). To release the restriction on interzonal labour mobility of commuting and migration, we define a commuting utility $u_{com, sr}$ with a log linear function^[10] consisting of workplace and residential wages ($w_{1,r}$ and $w_{1,s}$), commuting cost² (ϕd_{rs}) and zonal pair specific commuting constant v_{sr} inside of a multinomial logit function, and adopt the utility equalization assumption to classify three types of equilibrium including: 1) Benchmark; 2) counterfactual short run (SR); and 3) counterfactual long run (LR) where both benchmark and LR represent a respective situation of utility equalization and labour migration is only allowed in LR.

$$u_s = u_{c,s} u_{l,s} \quad (10)$$

$$u_{l,s} = \ln\left(F_s \frac{H_s}{L_s}\right) \quad (11)$$

$$u_{com, sr} = \ln w_{1,r} - \ln w_{1,s} - \ln(\phi d_{sr}) - \ln v_{sr} + \zeta_{sr} \quad (12)$$

where ζ_{sr} is a double exponential stochastic random term capturing individual heterogeneity in commuting preferences.

² The commuting cost is assumed to be internal to labour as all household's income is fully spent on consumption.

Figure 5. Household's personal utility function

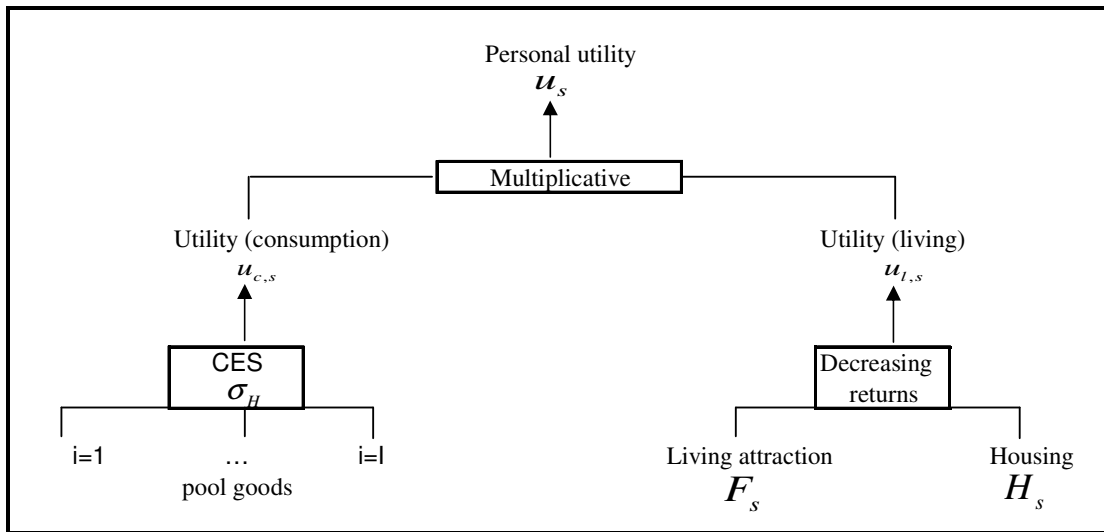
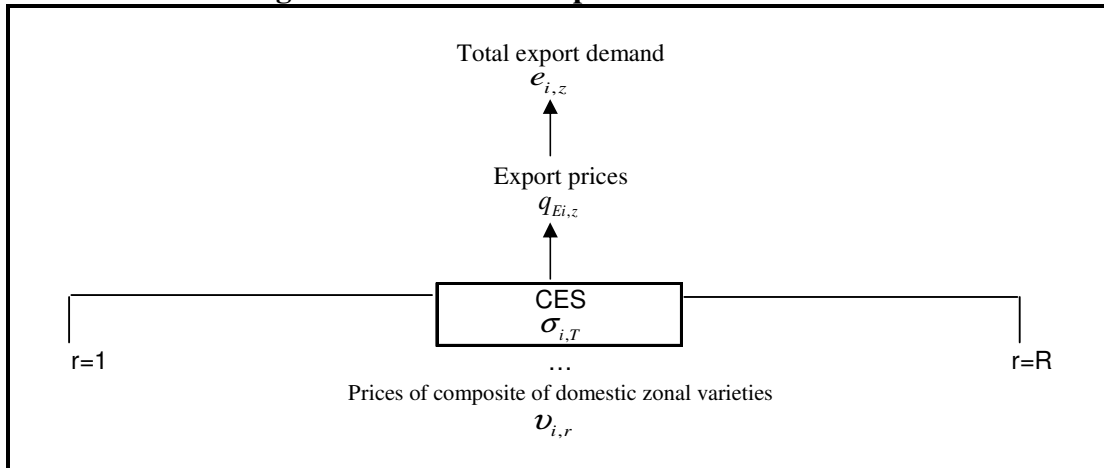


Figure 6: A two-level export demand function



2.4 Foreign trade

The apportionment of exports and imports to domestic zones follows the same principles as inter-zonal trade between domestic zones. Import supply $M_{i,z}$ is assumed to be perfectly elastic with $p_{M_{i,z}}$ exogenously specified. Total export demand $e_{i,z}$ is determined by a constant elasticity of export demand function according to export prices $q_{Ei,z}$ and the export agent's behaviour is assumed to be similar to the domestic transport agents and the export activity is carried out by means of a CES linear-homogenous technology (Figure 6).

2.5 Equilibrium conditions

Equilibrium is characterized by a set of goods and factor prices for which excess demands for both goods and factors vanish. The set of equilibrium conditions consists of

$$X_{i,r} = \sum_{s=1}^S t_{i,rs} (FD_{i,s} + \sum_{j=1}^J a_{ij,s} X_{j,s}) + \sum_{z=1}^Z t_{Ei,rz} e_{i,z} \quad (13)$$

$$M_{i,z} = \sum_{s=1}^S t_{Mi,zs} (FD_{i,s} + \sum_{j=1}^J a_{ij,s} X_{j,s}) \quad (14)$$

$$\sum_{s=1}^S f_{k,rs} = fd_{k,r}(\mathbf{w}) = \sum_{i=1}^I X_{i,r} c_{ki,r} \quad (15)$$

with

$$t_{i,rs} = \frac{\partial q_{i,s}}{\partial p_{i,r}}, t_{Ei,rz} = \frac{\partial q_{Ei,z}}{\partial p_{i,r}}, t_{Mi,zs} = \frac{\partial q_{i,s}}{\partial p_{Mi,z}}$$

where $t_{i,rs}$, $t_{Ei,rz}$ and $t_{Mi,zs}$ are domestic, export and import trade coefficients; $d_{i,s}$ is the sector specific zonal final demand; $fd_{k,r}(\mathbf{w})$ denotes factor demand given factor price vector \mathbf{w} and $f_{k,rs}$ denotes factor supply flow.

3. Data and Model Calibration

The model is calibrated based on the following data sources:

- A Social Accounting Matrix (SAM) for the UK (*OECD, 2000*)
- Employment data by sector at NUTS4 level (*ABI, 2000*)
- Factor prices³ (*ASHE, 2000 and VOA, 2000*)
- Crow-fly distance matrix (*UKBORDERS, 2000*)
- Labour commuting matrix (*CENSUS, 2001*)

The calibration and solving techniques follow Schneider^[13] with extension to labour commuting and migration modelling and is programmed within MATLAB. The calibration is accomplished such that the values of modelled values of interindustry flows and primary inputs, when aggregated over model zones for the benchmark equilibrium, exactly add up to the values observed in the SAM. When calibrating

³ Capital price is set to 1 everywhere.

benchmark equilibrium, external information is required for fixing those exogenous parameters (e.g. elasticity of substitution and transport rates). So far, we have consulted an extensive literature where a majority comes from the UK sources and all remained parameters are experimental based on regional available evidence. Those parameter values are reported in Table 1 and 2. The main outputs obtained from calibration contain position parameters as well as estimated capital and land stocks, both of which can be used to define policy changes and simulate counterfactual equilibriums. We specify full employment of labour and land due to the assumption of perfect price flexibility⁴ and the general solving algorithm for finding updated factor prices to clear factor markets in the respective counterfactual equilibrium is based on the Levenberg-Marquardt method as offered by MATLAB's optimization toolbox as an alternative to the common Newton-Raphson method.

Table 1: Transport and competition parameter values

Industry Sector	Scale Parameter η_i (per km)	Shape Parameter $\sigma_{i,d}$
Primary	0.0019	0.75
Secondary	0.0014	0.75
Tertiary	0.0014	0.75

⁴ Capital price is fixed from base year benchmark and capital supply is assumed to be perfectly elastic.

Table 2: Main exogenous parameter values specified in the model

Type	Elasticity of substitution				Concentration parameter for commuting
	Production	Transport	Import	Consumption	
	$\sigma_{j,p}$	$\sigma_{i,T}$	$\sigma_{i,M}$	σ_H	
Primary	0.3	6.0	4.0	-	-
Secondary	0.4	6.0	4.0	-	-
Tertiary	0.8	6.0	4.0	-	-
Household	-	-	-	0.5	2.0
Type	Elasticity of productivity with respect to effective density		Price elasticity of export demand		
			EU excluding UK	ROW (Rest of the World)	
	$\sigma_{i,ED}$		$\zeta_{i,z}$	$\zeta_{i,z}$	
Primary	0.1		1.0	1.0	
Secondary	0.1		1.0	1.0	
Tertiary	0.2		1.2	1.2	
Type	Competition parameter				
	UK	EU excluding UK	ROW		
	$\pi_{i,r}$	$\pi_{i,z}$	$\pi_{i,z}$		
Primary	0.10	0.10	0.10		
Secondary	0.30	0.30	0.30		
Tertiary	0.50	0.50	0.50		

4. Results and Discussion

4.1 Base year benchmark

For the base year (2000) benchmark model, we first present one of the distinctive features in our model, namely the spatial distribution of effective density as calculated by equation (3). As shown in Figure 7, such a kind of distribution reflects the pattern of the London-centric urban agglomeration.

Because zonal factor stock other than labour is calibrated in the model, we make a comparison on the distribution of zonal business land stock between the modelled and the observed. Figure 8 below shows a good match between the two.

Figure 7: Spatial distribution of effective density, Benchmark Model for 2000

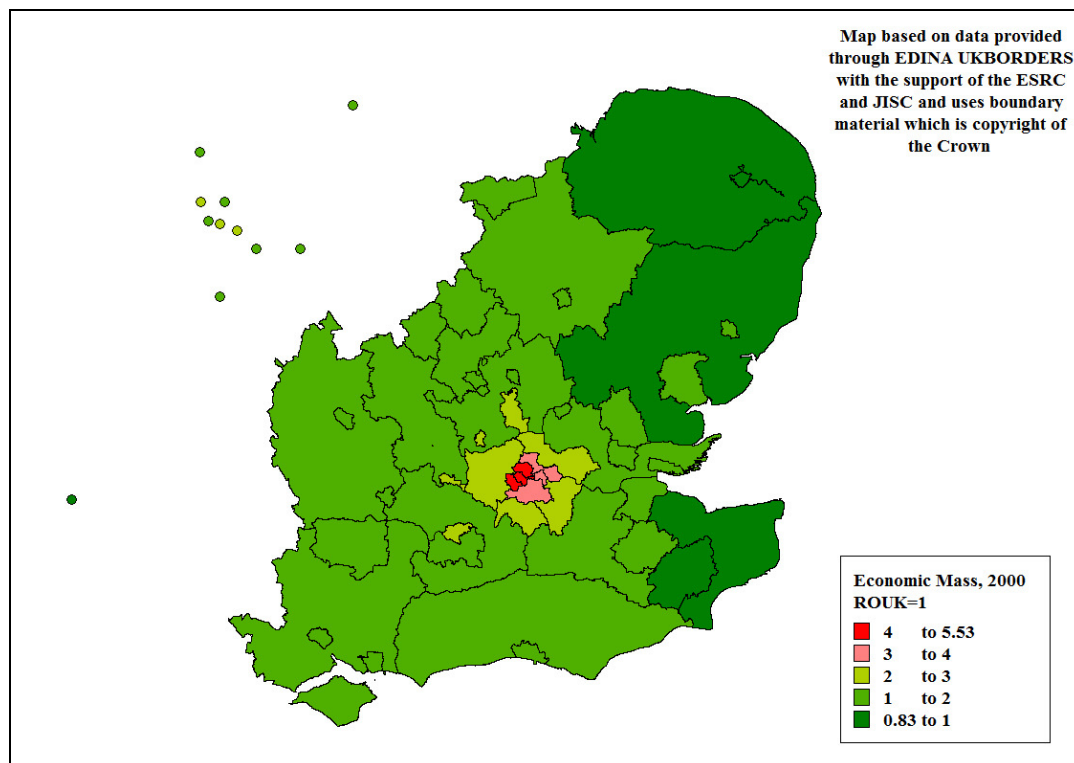
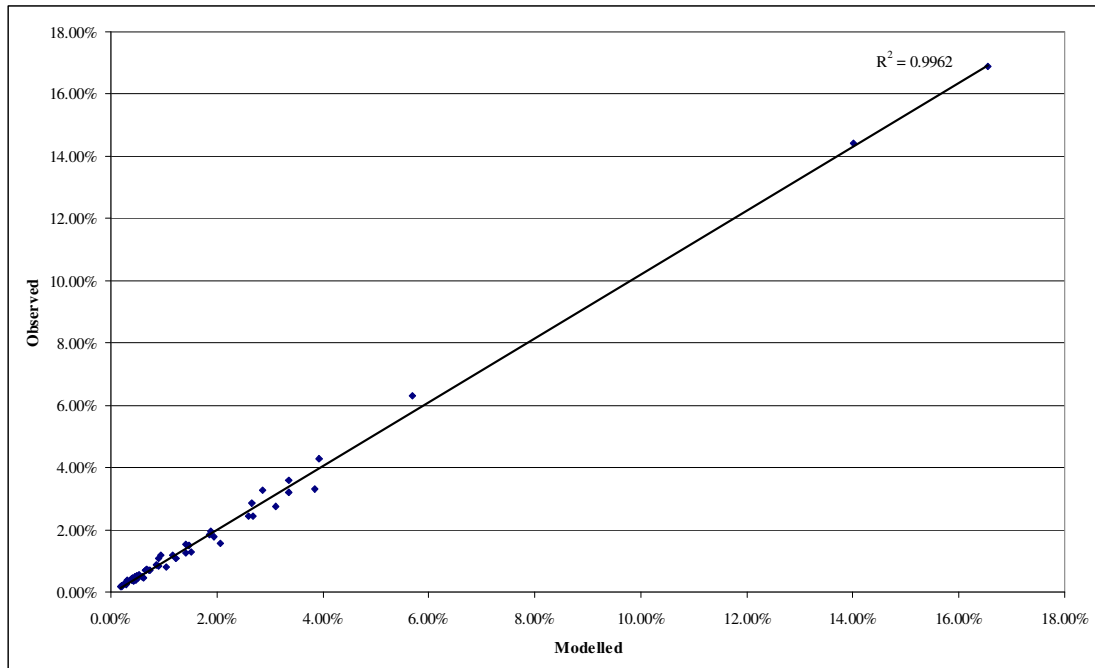
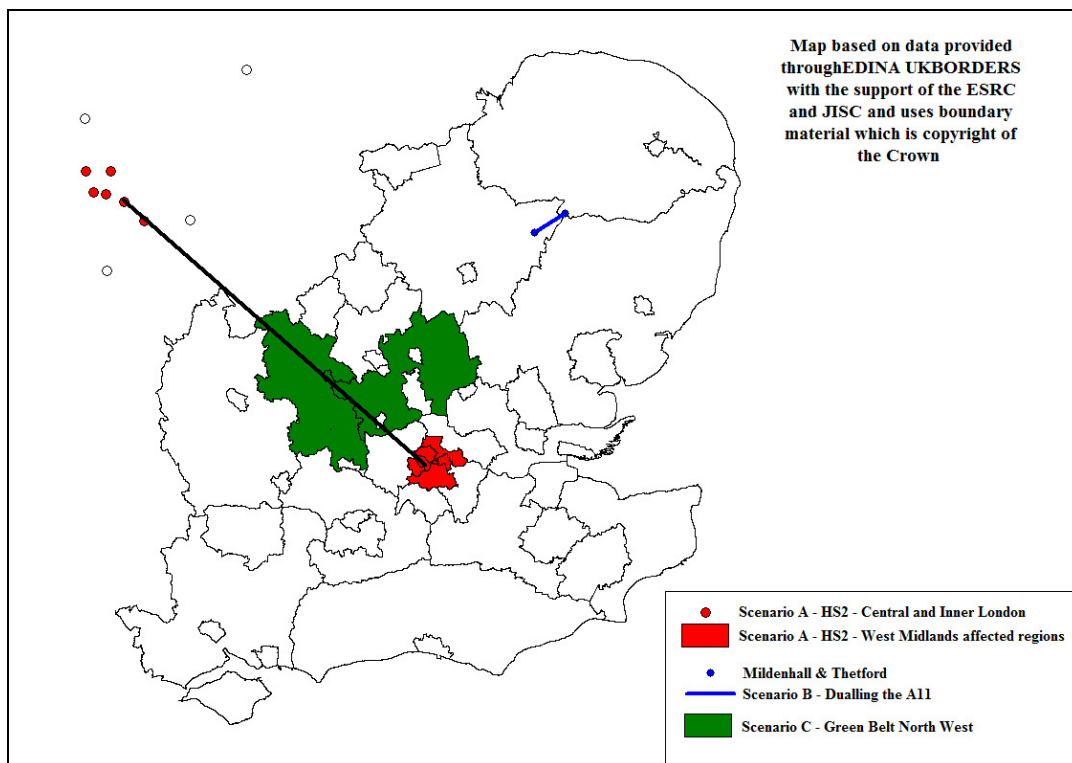


Figure 8: Zonal share of business land, modelled versus observed, base year benchmark



*The percentage distribution above are calculated based on the exclusion of Wales, Scotland and Northern Ireland because observed business land stock for those regions are not available from Generalised Land Use Database (2001) in the UK.

Figure 9: Summary of counterfactual equilibrium scenarios



4.2 Overview of the simulation scenarios

Before introducing the counterfactual equilibrium scenarios, we first classify two sets of benchmark equilibrium: base year and future year. Our base year benchmark equilibrium is calibrated for the year 2000, whereas the future year (2030) benchmark is obtained from the base year model through a long run counterfactual simulation run by applying growth factors on exogenous variables including total labour supply, dwellings stock and export demand while assuming all other inputs (such as zonal business land supply) and calibrated parameters from the base year benchmark remain constant. We then carry out three further counterfactual scenario runs from the 2030 benchmark model. These scenarios (as shown in Figure 9 above) are: A) the first stage of the proposed UK High Speed 2 (HS2) railway project between central London and Birmingham; B) dualing the 14 km single carriageway section of the A11 trunk road between Mildenhall and Thetford in the County of Norfolk to the Northeast of London; and C) business land supply to increase by 20% for London's Green Belt North West. The transport schemes are represented by readjusting the distance matrix used by the model for each type of activity as appropriate. For instance, the High Speed Rail project in Scenario A causes economic distances to change for the tertiary sector (because of business travel), but not for the primary and secondary industry sectors.

We perform a comparative analysis first on the results of future year benchmark with respect to the base year benchmark for 2000, and then on the counterfactual scenarios with respect to the future year benchmark for 2030. The model outputs four main types of variables: quantities (production, pool goods, factors, interzonal trade flows, final demands, imports and exports), prices (production prices, pool goods prices, factor prices), values (production, final demand, imports and exports, factor income) and the utilities (personal utility and commuting utility). Our analysis here is focused on the values of production, imports and exports, factor demand and price, as well as personal utility. All results are measured as percentage changes from the respective benchmark equilibrium.

4.3 Future year benchmark

As mentioned above, our future year benchmark for 2030 is not calibrated but derived from a base year counterfactual long run. Therefore, it is equivalent to an export demand driven scenario and the results at national level in Table 4 below can be understood as follows. The exogenously specified growth of exports leads to increased demand on both commodity markets and factor markets. Given those specified factor supply changes and due to the assumption of perfect price flexibility, the new equilibrium factor prices of labour and land indicates a rise in order to clear their markets. This increase of factor prices has two consequences. First, it leads to an increase of domestic production prices and therefore a decline of relative import prices (due to import prices being fixed from the base year). This in turn leads to an increase of imports, which dampens the increase on pool goods prices due to increase on domestic production prices. Second, the increased factor stock and their prices lead to an increase of personal income. Our results show that the increase on national average personal income outweighs the increase on price index⁵ and hence leads to an increase of personal utility from consumption. This part of the utility increase is combined with the change of utility derived from living and finally leads to a net increase of national average personal utility.

Table 4: Relative changes (%) from base year benchmark (2000), future year benchmark (2030)

Type	Sector	Relative Changes (%) for UK as a whole
Production value	Primary	22.0
	Secondary	26.3
	Tertiary	29.7
Production price	Primary	14.7
	Secondary	16.9
	Tertiary	19.7
Pool goods price	Primary	10.3
	Secondary	6.4
	Tertiary	13.6
Export value	Primary	129.0
	Secondary	157.0
	Tertiary	191.8

⁵ Price index is defined as the expenditure needed to reach one unit of utility. This is also known as the zonal price index^[2]. In this model, a national average price index can be calculated by summing up all zonal price indices weighted with zonal personal utility from consumption.

Type	Sector	Relative Changes (%) for UK as a whole
Import value	Primary	117.6
	Secondary	124.7
	Tertiary	422.4
Factor demand	Labour	17.0
	Capital	49.9
Factor price	Labour	44.2
	Land	80.8
Personal income		39.5
Price index		10.8
Personal utility		25.6

4.4 Counterfactual scenario analysis

For all three counterfactual scenarios, it should be noted that the following three causal chain effects together with the interplay between all markets in the economy determine the new equilibrium results. The first is a direct effect resulting from the change of transport cost or factor endowment, which generates a shock on both commodity markets and factor markets. The second is an indirect effect resulting from an increase in zonal production, which generates a stronger supply market size effect on pool goods price and its related trade and therefore also leads to secondary shocks. The third effect is related to productivity improvements as a result of a change in effective density, which again generates some additional shocks. Those three causal chain effects are valid across all sectors and all zones in the model. Obviously, the magnitude of the effects also depends on underlying assumptions such as exogenously given parameters and elasticities.

As seen from Table 5, variations on the level of sector production changes are predicted across all regions and scenarios. Those variations, either positive or negative, are fully determined by the three causal chain effects, the relative changes on factor prices and the inter-industry relations stated in the SAM table. In general, those regions that directly benefit from the shocks show an increase in total production and labour demand whereas most other regions show various degrees of reductions because they suffer from zonal excess supply of factor inputs. In order to pinpoint these effects and examine them in detail, we have deliberately chosen simple scenarios where the directly affected areas can be clearly identified: the transport improvement in Scenario A only affects the two ends of the new transport link,

whereas the business land supply increase under Scenario C is only applied to one zone. As expected, for all scenarios those zones that directly benefit from the shocks show an increase in personal utility in the short run, which then induces a net inflow of migrants in the long run.

Table 5: Relative changes (%) from future year benchmark at regional Level

	Short Run			Long Run								
	Personal Utility			Production Value			Labour Demand			Labour Migration		
Region\Scenario	A	B	C	A	B	C	A	B	C	A	B	C
Central London	0.09	0.004	0.02	0.23	0.00	-0.16	0.20	0.00	-0.18	0.09	0.00	0.00
Inner London	0.09	0.004	0.02	0.23	0.00	-0.09	0.20	0.00	-0.09	0.09	0.00	-0.02
Outer London	0.07	0.005	0.03	-0.14	0.00	-0.08	-0.15	0.00	-0.10	-0.01	0.00	0.03
Green Belt	0.04	0.005	0.17	-0.16	0.01	1.69	-0.18	0.00	1.47	-0.12	0.00	0.58
Urban East	0.04	0.022	0.09	-0.16	0.07	-0.09	-0.18	0.07	-0.13	-0.14	0.07	0.26
Urban South East	0.03	0.005	0.03	-0.18	0.00	-0.05	-0.20	0.00	-0.06	-0.16	0.00	0.03
Rural East	0.03	0.071	0.05	-0.14	0.26	-0.02	-0.17	0.27	-0.03	-0.16	0.23	0.14
Rural South East	0.03	0.005	0.02	-0.16	0.00	-0.03	-0.19	0.00	-0.04	-0.18	0.00	0.00
South West	0.02	0.005	0.00	-0.13	0.00	-0.06	-0.16	-0.01	-0.07	-0.15	-0.01	-0.06
East Midlands	0.04	0.002	0.01	-0.10	-0.01	-0.07	-0.13	-0.02	-0.08	-0.10	-0.01	-0.06
West Midlands	0.39	0.002	0.00	1.53	-0.02	-0.08	1.31	-0.02	-0.08	1.24	-0.02	-0.08
REST OF THE UK	0.02	0.001	0.00	-0.13	-0.02	-0.10	-0.17	-0.02	-0.11	-0.16	-0.02	-0.10
UK	0.067	0.006	0.023	0.054	0.003	0.028	-	-	-	-	-	-

4.5 Comparison with perfect competition and homogenous productivity

In this model, we have introduced effects of both external increasing returns to scale (i.e. urban agglomeration) and Dixit Stiglitz monopolistic competition for firms (i.e. product varieties). To isolate their effects on counterfactual scenario results, we have recalibrated a set of alternative base year benchmarks by excluding those model features as defined in Table 6 below. This is equivalent to set the elasticity of productivity with respect economic mass $\sigma_{i,ED}$ or competition parameters $\pi_{i,r}$ and $\pi_{i,z}$ to zero and basically leaves all firms to operate under constant returns to scale, no product variety or both, which are the typical assumptions held by most traditional LUTI (Land Use and Transport Interaction) and SCGE models. We then also derive a

corresponding future year benchmark with the same growth factors and rerun scenario A, B and C for the long run counterfactual equilibrium. Therefore, we would expect such change of specifications would provide us a good understanding of those effects' influence on the magnitude of the model results.

Table 6: Inclusion of agglomeration and zonal variety effects for additional runs

Run	1a	1b	2	3a	3b	4
Agglomeration effect	Yes	Yes	Yes	No	No	No
Zonal variety effect with zonal total number of variety $n_{i,r}$ specified as $X_{i,r} / X_{i,B}$	Yes	-	No	Yes	-	No
Zonal variety effect with zonal total number of variety $n_{i,r}$ specified as $X_{i,r}$	-	Yes	No	-	Yes	No

Table 7 below shows the net differences in total production values at regional level between the long run counterfactuals and the future year benchmark for each respective run. The results show models that do not consider urban agglomeration and product variety effects tend to report much lower output increases in areas directly affected by the policy interventions, and at the same time report lower output decreases in the rest of the study area.

In this model, we have taken Tavassy et.al (2002)^[15]'s suggestion to define the zonal number of varieties $n_{i,r}$ as its share of zonal production in the production of all varieties within a sector in the base year. To see the influence of this specification on the model results, we reset $\chi_{i,r}\epsilon_{i,r}$ equal to one as an alternative and this basically leaves the zonal number of varieties being directly equal to the total zonal raw output $X_{i,r}$. The result differences between run 1a and 1b, as well as run 3a and 3b indicate that a lower level specification for the zonal number of varieties from the base year could generate a stronger impact on the zonal output for both directly affected and indirectly affected regions, given the same policy interventions. This is because the supply market size effect takes a concave shape due to the specification of

competition parameters between 0 and 1.

As a further comparison, we adopt the current Department for Transport (DfT)'s approach (DfT, 2005)^[7] based on model results obtained from Run 4 to calculate the wider economic benefits of agglomeration. The DfT's approach is a partial approach and is defined as:

$$WB_{j,r} = \sigma_{j,ED} \left(\frac{ED_{r,1} - ED_{r,0}}{ED_{r,0}} \right) * X_{j,r,0} \quad (16)$$

where $WB_{j,r}$ is the wider economic benefits of agglomeration, measured as change of output value for sector j in zone r ; $ED_{r,0}$ and $ED_{r,1}$ are the respective economic mass (effective density) for zone r before and after the economic shock; $X_{j,r,0}$ is the output value for sector j at zone r before the economic shock.

The corresponding results are reported as Run 5. Interestingly, as compared to our central case (Run 1a) results and for scenario A and B, the DfT's approach predicts a similar level of change on total national output. However, the internal distributions of the total output change at regional level are very different. It seems to us that the DfT's approach is likely to underestimate both the positive effect (for directly affected areas) and negative effect (for indirectly affected areas) on output changes across the board. This is because only zonal output $X_{j,r,0}$ before the economic shock is taken into account when calculating wide economic benefits according to equation (16) above. For scenario C, because the economic shock is induced from change of business land supply, it does not have a strong impact on zonal economic mass as the distance matrix remains constant from benchmark. As a result, the positive and negative changes of regional output across the board cancel out with each other and leave the net change of output at national level almost unchanged. This suggests that the DfT's approach might not be appropriate to evaluate the wide impacts of policy interventions which are not transport related.

Table 7: Net differences on modelled total production value from future year benchmarks for additional runs, scenario A, B and C

	Scenario A						
Region\Run**	1a	1b	2	3a	3b	4	5
Central London	320	291	224	187	140	140	71
Inner London	373	327	262	222	157	160	88
Outer London	-255	-206	-169	-36	-55	-43	8
Green Belt	-280	-153	-164	-43	-32	-41	3
Urban East	-164	-89	-94	-26	-18	-23	1
Urban South East	-215	-108	-120	-35	-21	-30	0
Rural East	-123	-58	-67	-23	-13	-18	0
Rural South East	-257	-121	-143	-46	-25	-38	1
South West	-257	-138	-159	-69	-37	-52	1
East Midlands	-187	-118	-122	-56	-30	-42	1
West Midlands	3854	2347	2368	414	239	311	1018
ROUK	-1304	-692	-777	-341	-172	-244	-2
UK	1504	1282	1039	147	132	79	1190
	Scenario B						
Region\Run**	1a	1b	2	3a	3b	4	5
Central London	-3	-4	-1	4	3	3	2
Inner London	-1	1	1	2	4	2	3
Outer London	5	7	5	4	4	3	4
Green Belt	10	10	8	3	4	3	6
Urban East	74	33	48	19	1	14	19
Urban South East	4	4	3	2	2	1	3
Rural East	233	153	161	108	71	80	47
Rural South East	6	5	4	2	2	2	4
South West	-9	-2	-4	-1	1	0	3
East Midlands	-28	-16	-18	-14	-8	-10	-1
West Midlands	-43	-21	-25	-18	-9	-13	-1
ROUK	-170	-84	-103	-81	-40	-53	-5
UK	77	87	79	31	34	33	85
	Scenario C						
Region\Run**	1a	1b	2	3a	3b	4	5
Central London	-223	-260	-122	-142	-163	-92	-8
Inner London	-143	-166	-84	-108	-112	-72	-3
Outer London	-144	-219	-97	-166	-203	-107	7
Green Belt	2953	2450	2081	2765	2353	1993	18
Urban East	-93	-228	-75	-154	-246	-98	13
Urban South East	-54	-96	-47	-88	-102	-59	6
Rural East	-16	-67	-26	-45	-77	-37	6
Rural South East	-49	-66	-49	-90	-79	-63	7
South West	-132	-74	-89	-142	-82	-91	0
East Midlands	-142	-77	-88	-121	-75	-80	-4
West Midlands	-204	-100	-122	-166	-95	-107	-7
ROUK	-990	-451	-566	-819	-437	-502	-33
UK	764	646	715	725	683	684	1

*All values are measured in million pounds at 2000 prices.

4.6 Separating the influence of economic distance reduction on sectoral production

The specification of iceberg transport cost generates two effects when economic distances reduce. The first is price effect and it leads to a reduction of transport cost (therefore pool goods prices) which could increase the demand from consumers. The second is volume effect as reducing iceberg transport cost implies that producers could produce less to satisfy one unit of demand. The latter effect would dampen the increase on production resulted from the price effect and in an extreme case where the reduction in transport cost leads to an increase of consumption but the actual production declines. This is reason why some SCGE modellers intend to explicitly model the transport sector using alternative methods. In this model, due to the inclusion of effective density, we perform an additional test (Run 1c) for the HS2 scenario based on Run 1a above by assuming that the iceberg transport cost does not change so that economic shock is fully due to the change of effective density (therefore productivity). Table 8 shows the absolute change on tertiary sector's supply and demand from future year benchmark between the two runs and the results comparison suggest that although remaining iceberg transport cost unaffected might reduce the volume effect, the price effect is actually much stronger when iceberg transport cost reduces and therefore leads to a higher increase on both demand and output at national level.

Table 8: Absolute changes on tertiary sector's supply and demand in long run from future year benchmark between Run 1a and Run 1c*****

Region	Domestic output	Intermediate Demand	Final Demand	Export Demand
Run 1a				
Central and Inner London	724	308	364	52
West Midlands	3680	1464	1751	467
ROUK	-3292	-1294	-1497	-501
UK	1113	477	618	18
Run 1c				
Central and Inner London	-126	-38	-58	-31
West Midlands	2994	1165	1428	401
ROUK	-2098	-740	-999	-358
UK	770	386	371	12

*All values are measured in million pounds at 2000 prices; **Run 1a: with economic distance changes being applied to both effective density and iceberg transport cost; ***Run 1c: with economic distance only being applied to effective density;

4.7 Sensitivity Analysis

It is well known that in applied general equilibrium models, the degree of model responses largely depends on the values of exogenously chosen parameters, in particular with respect to e.g. price and substitution elasticities. For this model, although we have carried out an exhaustive search in the econometric literature with a focus on UK sources to inform the choice of the model parameters, a level of arbitrariness on the results still exists. To test how the choice of model parameters affects model results, we have carried out a series of sensitivity tests by rerunning both the base year and future year benchmarks with different level of exogenous parameters. This improves our understanding of the model responses. Our selection of parameters includes elasticity of productivity with respect to economic mass ($\sigma_{j,ED}$), transport substitution parameter ($\sigma_{i,T}$), elasticity of substitution for production ($\sigma_{j,p}$), price elasticity of export demand ($\zeta_{i,z}$) and domestic competition parameter ($\pi_{i,r}$). We test each parameter by multiplying its base value with a set of factors in the range of 0 and 2 while keeping the rest of the parameters fixed and investigate their individual impact on the model results, particularly changes in overall welfare.

It is clear from Table 9 below that the magnitude of overall welfare gains is highly influenced by most of the elasticities and parameters mentioned above, with the exception of transport substitution parameter ($\sigma_{i,T}$) which seems to have very little impact within our test range. For the elasticity of effective density ($\sigma_{j,ED}$), it follows that the higher the elasticity, the stronger the productivity is increasing, given the same change on effective density. The results on price elasticity of export demand ($\zeta_{i,z}$) is a confirmation of what is well-known in the literature. The influence of elasticity of substitution for production ($\sigma_{j,p}$) is specific to this model as we assume perfectly elastic on capital supply so that the higher the $\sigma_{j,p}$ is, the more increase on capital demand will be. The impact of domestic competition parameter ($\pi_{i,r}$) is a natural consequence due to the specification of supply market size effect on the pool goods prices.

Table 9: Sensitivity of relative changes (%) at national level on personal utility with respect to the variation of exogenous parameters, Future Year Benchmark

Parameters	Weights on base values					
	0	0.5	0.75	1	1.5	2
$\sigma_{j,ED}$	21.8	23.6	24.6	25.6	27.7	30.0
$\sigma_{i,T}$	-	-	25.7	25.6	25.0	-
$\sigma_{j,p}$	-	20.1	22.8	25.6	32.2	40.2
$\zeta_{i,z}$	-	28.5	26.9	25.6	23.4	21.6
$\pi_{i,r}$	20.2	22.9	24.2	25.6	28.2	30.6

Note: The choice of parameter values are subject to the hierarchical structure of the CES function as well as the definition of the parameters where hyphen (-) indicates that the parameter value cannot be adopted.

Based on the above results and as a further sensitivity analysis, we now rerun scenario A in the long run. As usual, we first test each parameter by multiplying its base value with a set of factors as specified in the range above while keeping the rest of the parameters fixed and investigate their individual impact on the model results. We then simultaneously change all those parameters by $\pm 25\%$ to see their cumulative effects on the model results. We again report net difference on total production value at regional level as shown in Table 10 below. As compared to our central run (with weights of 1.00), it is clear to see that the magnitude of total national output change as well as the internal distribution of regional output changes are closely related to the magnitude of each specified exogenous parameter. Among all those parameters, the value choice on elasticity of productivity with respect to economic mass causes the highest variation on the results of HS2 scenario and the extent of influence from remaining parameters are much less significant.

Table 10: Net differences on total production value at regional level from respective future year benchmark, sensitivity analysis of exogenous parameters, scenario A (HS2)

	Central	Productivity elasticity					Transport elasticity		
Region\Weights on base values	1.00	0.00	0.50	0.75	1.50	2.00	0.75	1.25	
Central London	320	187	261	296	284	-186	230	435	
Inner London	373	222	311	349	331	-141	277	479	
Outer London	-255	-36	-115	-174	-534	-1234	-152	-379	
Green Belt	-280	-43	-135	-198	-533	-1068	-160	-437	
Urban East	-164	-26	-81	-118	-298	-550	-91	-263	
Urban South East	-215	-35	-106	-155	-392	-722	-118	-349	
Rural East	-123	-23	-65	-92	-208	-350	-66	-200	
Rural South East	-257	-46	-132	-188	-453	-810	-141	-413	
South West	-257	-69	-160	-208	-354	-420	-148	-387	
East Midlands	-187	-56	-125	-158	-220	-132	-110	-276	
West Midlands	3854	414	1897	2805	6497	10202	2527	5610	
ROUK	-1304	-341	-823	-1070	-1649	-1277	-733	-2049	
UK	1504	147	725	1089	2472	3313	1313	1770	
	Central	Transport scale				Production elasticity			
Region\Weights on base values	1.00	0.50	0.75	1.50	2.00	0.50	0.75	1.50	2.00
Central London	320	164	244	464	585	154	224	609	880
Inner London	373	213	295	522	649	246	311	496	547
Outer London	-255	-236	-246	-267	-286	-184	-225	-294	-369
Green Belt	-280	-245	-263	-310	-344	-195	-242	-336	-403
Urban East	-164	-140	-152	-184	-205	-109	-139	-200	-232
Urban South East	-215	-181	-199	-246	-277	-139	-181	-268	-314
Rural East	-123	-104	-114	-141	-158	-93	-111	-136	-145
Rural South East	-257	-216	-237	-295	-335	-180	-224	-301	-336
South West	-257	-216	-237	-295	-331	-186	-228	-300	-319
East Midlands	-187	-159	-174	-213	-230	-138	-166	-223	-233
West Midlands	3854	3487	3672	4202	4534	2904	3449	4450	4906
ROUK	-1304	-1053	-1178	-1562	-1786	-919	-1138	-1581	-1660
UK	1504	1314	1412	1674	1816	1162	1329	1917	2321
	Central	Export demand elasticity				Domestic competition parameter			
Region\Weights on base values	1.00	0.50	0.75	1.50	2.00	0.00	0.50	0.75	1.50
Central London	320	317	319	323	325	209	252	283	449
Inner London	373	371	372	375	376	244	295	331	510
Outer London	-255	-274	-264	-240	-229	-133	-178	-209	-423
Green Belt	-280	-297	-288	-267	-256	-136	-187	-225	-505
Urban East	-164	-173	-168	-157	-151	-78	-108	-131	-306
Urban South East	-215	-227	-221	-206	-198	-100	-140	-170	-408
Rural East	-123	-131	-127	-117	-113	-58	-80	-98	-232
Rural South East	-257	-273	-265	-245	-236	-121	-168	-205	-482
South West	-257	-272	-264	-246	-237	-131	-177	-211	-435
East Midlands	-187	-198	-192	-179	-173	-100	-133	-156	-306
West Midlands	3854	3952	3900	3776	3713	2172	2781	3229	6478
ROUK	-1304	-1352	-1326	-1264	-1232	-641	-880	-1059	-2355
UK	1504	1443	1476	1552	1590	1129	1278	1377	1987
	Central	All parameters							
Region\Weights on base values	1.00	0.75	1.25						
Central London	320	131	918						
Inner London	373	188	651						
Outer London	-255	-123	-627						
Green Belt	-280	-127	-693						
Urban East	-164	-73	-406						
Urban South East	-215	-92	-560						
Rural East	-123	-57	-271						
Rural South East	-257	-116	-620						
South West	-257	-133	-475						
East Midlands	-187	-103	-281						
West Midlands	3854	1864	7630						
ROUK	-1304	-641	-2277						
UK	1504	717	2990						

*All values are measured with 2000 prices

5. Conclusions

In this paper, we have demonstrated that it is feasible to develop a SCGE model at city region level with existing data sources in the UK. The resulting model shows that it is capable of testing a wider set of policy impacts than existing land use/transport models and SCGE models, and the test results are often qualitatively different from those from the existing models.

As compared with traditional land use and transport models, our model differs due to the inclusion of Dixit-Stiglitz model of monopolistic competition among producers, elasticity of substitution on production factors, interregional trade pooling, and the Armington specification regarding product varieties from producers in different locations. Relative to existing SCGE models, our extensions incorporate (1) a specification of Hicks neutral agglomeration effects on productivity, which arise from external increasing returns to scale induced from urbanization and transport improvements, (2) labour mobility across the study area with both commuting and migration, (3) counterfactual equilibrium in both short run and long run to allow for different rates of change in the spatial distribution of economic activities and residential location, (4) land as an explicit factor input to production, and (5) concave transport cost functions with respect to travel distance to be consistent with realistic transport costs.

The model results obtained are in line with theoretical expectations and provide new quantification of the costs and benefits that feed into the assessment of those strategies. In both transport related scenarios (A and B), the model shows how transport improvements can lead to both shifts of production and residential population, and net overall welfare changes. Under the business land supply increase scenario (C), the model suggests that releasing a moderate proportion of Green Belt for development can help boost economic growth.

To identify the sensitivity of the model results, we have carried out additional model tests to isolate the effects of introducing agglomeration and product variety effects. The model results indicate that it is important to incorporate both model features if one wishes to quantify wider economic impacts. In addition to this, we have also tested for the range of uncertainties associated with the choice of model parameter and

elasticity values, which provide an in-depth understanding of the results and should inform future empirical determination of the parameter values.

In view of the findings above, we suggest following areas as possible research tasks for the near future. First, it is preferable to replace the current iceberg representation of transport costs with a better approach that separate the price and volume effects . Secondly, it would be desirable to have a more detailed sectoral disaggregation for the model's practical implementation. A straightforward disaggregation is to introduce different types of labour by skills or socioeconomic status or a combination of them. Thirdly, it is desirable to extend the model with a true dynamic structure for studying intertemporal decisions of savings and investment decisions.

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Appendix A: Production sectors used in the model

The UK IO table is aggregated in the following way

Production Sector	ISIC Rev.3 Code
Primary	A-B
Secondary	C-F
Tertiary	G-Q

Appendix B: ISIC of all economic activities, Rev.3

Category	Economic Activities
A	Agriculture, hunting and forestry
B	Fishing
C	Mining and quarrying
D	Manufacturing
E	Electricity, gas and water supply
F	Construction
G	Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods
H	Hotels and restaurants
I	Transport, storage and communications
J	Financial intermediation
K	Real estate, renting and business activities
L	Public administration and defence; compulsory social security
M	Education
N	Health and social work
O	Other community, social and personal service activities
P	Private households with employed persons
Q	Extra territorial organizations and bodies

Appendix C: List of Acronyms

ABI	Annual Business Inquiry
ASHE	The Annual Survey of Hours and Earnings
NCES	Nested Constant Elasticity of Substitution
HMRC	Her Majesty's Revenue and Customs
ISIC	International Standard Industrial Classification of All Economic Activities
SAM	Social Accounting Matrix
OECD	Organisation for Economic Co-operation and Development
VOA	Valuation Office Agency

Appendix D: Derivation of price for the composite of zonal varieties

As mentioned in section 2.1, firms use the raw output $X_{i,r}$ as the only input to produce the variety of final output $X'_{i,r}$ under monopolistic competition in the style of Dixit-Stiglitz. For production of each variety under each sector i and zone r , it is assumed that the firm uses a fixed amount χ_i of raw output plus a constant marginal amount κ_i per unit of final output such that

$$x_{i,r} = \chi_{i,r} + \kappa_{i,r} x'_{i,r} \quad (\text{D.1})$$

The firm sets its final output price $p'_{i,r}$ as a constant fixed mark-up over marginal cost $p_{i,r}$

$$p'_{i,r} = \frac{\varepsilon_{i,r}}{\varepsilon_{i,r} - 1} \kappa_{i,r} p_{i,r} \quad (\text{D.2})$$

The output per variety is fixed in equilibrium, which takes the form of

$$x'_{i,r} = \frac{\chi_{i,r}}{\kappa_{i,r}} (\varepsilon_{i,r} - 1) \quad (\text{D.3})$$

By inserting (D.3) into (D.1), the amount of raw output used to produce each variety is equivalent to

$$x_{i,r} = \chi_{i,r} \varepsilon_{i,r} \quad (\text{D.4})$$

The total number of varieties $n_{i,r}$ produced in each zone r is equivalent to

$$n_{i,r} = \frac{X_{i,r}}{\chi_{i,r} \varepsilon_{i,r}} \quad (\text{D.5})$$

The total output of final goods $X'_{i,r}$ produced in zone r can be calculated as

$$X'_{i,r} = n_{i,r} x'_{i,r} = \frac{X_{i,r}}{\chi_{i,r} \varepsilon_{i,r}} \frac{\chi_{i,r}}{\kappa_{i,r}} (\varepsilon_{i,r} - 1) = X_{i,r} \frac{\varepsilon_{i,r} - 1}{\varepsilon_{i,r} \kappa_{i,r}} \quad (\text{D.6})$$

If we set the unit of final output as $\frac{\varepsilon_{i,r} - 1}{\kappa_{i,r} \varepsilon_{i,r}}$, we can have $X'_{i,r} = X_{i,r}$ and $p'_{i,r} = p_{i,r}$

The composite of the zonal varieties has the unit cost $v_{i,r}$ in the CES form of

$$v_{i,r} = \left[\sum_{n=1}^N p_{i,r}^{1-\varepsilon_{i,r}} \right]^{\frac{1}{1-\varepsilon_{i,r}}} = [n_{i,r} p_{i,r}^{1-\varepsilon_{i,r}}]^{\frac{1}{1-\varepsilon_{i,r}}} \quad (\text{D.7})$$

By inserting (D.5) into (D.7), we can rewrite (D.7) as

$$v_{i,r} = \left[\frac{X_{i,r}}{\chi_{i,r} \varepsilon_{i,r}} p_{i,r}^{1-\varepsilon_{i,r}} \right]^{\frac{1}{1-\varepsilon_{i,r}}} \quad (\text{D.8})$$

In general, $n_{i,r}$ (or the combination of $\chi_{i,r} \varepsilon_{i,r}$) is estimated based on interzonal trade flows and it is a common practice to set both $\chi_{i,r}$ and $\varepsilon_{i,r}$ only sector specific but not zonal specific. Following Tavasszy et.al (2002)^[15], $n_{i,r}$ might be better understood as the share of zonal production in the production of all varieties within a sector rather than being interpreted as the number of firms or varieties in a zone because in the empirical case, it is likely that a variety is made by many firms.

Therefore, in this model, we set $n_{i,r} = \frac{X_{i,r}}{X_{i,B}}$.