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A Land Use and Spatial Interaction Model based on Random Utility Theory and Social Accounting Matrices

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Abstract

Random utility modelling has been established as one of the main paradigms for the implementation of land use and transport interaction (LUTI) models. Despite widespread application of such models, the respective literature provides relatively little detail on the theoretical consistency of the overall formal framework of the random utility based LUTI models. We present a detailed formal description of a land use and spatial interaction model that adheres to the random utility paradigm through the explicit distinction between utility and cost across all processes that represent the behaviour of agents. The model is rooted in an extended input-output table, with the workforce and households accounts being disaggregated by socio-economic type. Similarly, the land account is broken down by domestic and non-domestic land use types. The model is developed around two processes. Firstly, the generation of demand for inputs required by established production; the estimation of the level of demand between industrial sectors, households and land use types is supported by social accounting techniques. When appropriate the implicit production functions are assumed depending on costs of inputs, which give rise to price-elastic demands. Secondly, the spatial assignment of demanded inputs (industrial activity, workforce, land) to locations of production; here sequences of decisions are used to distribute demand (both

spatially and, when necessary, a-spatially) and to propagate costs and utilities of production and consumption that emerge from imbalances between supply and demand. The implementation of this generic model is discussed in relation to the case of the Greater South East region of the UK, including London, the South East and the East of England. We present the calibration process, data requirements, necessary assumptions and resulting implications. We discuss outputs under various land use strategies, such as regulated versus competing land uses, constrained versus unconstrained densities.

1. Introduction

Land use and transport interaction (LUTI) models can be grouped into three broad classes, such as (1) aggregate spatial interaction models based on gravitation and entropy maximisation principles (Lowry, 1963 and 1964; Crecine, 1964 and 1968; Garin, 1966; Wilson, 1970 and 1974; Goldner, 1971; Putman, 1974, 1983 and 2001; Mackett, 1983, 1990 and 1991; Wegener, 1982a, 1982b, 1983; Wegener et al., 1991, among others), (2) aggregate spatial econometric models based on random utility maximisation (Echenique, 1985 and 2004; de la Barra, 1989; Hunt and Abraham, 2005; Anas, 1982; Anas and Arnott, 1994; Simmonds, 1999; Waddell, 2002, among others) and, finally, (3) disaggregate, activity-based, micro-simulation models (Miller et al., 2004; Veldhuisen et al., 2000; Batty et al., 1997, among others)¹.

In this paper we discuss a LUTI model² which belongs to the second modelling stream as outlined above. The developed generic LUTI model is capable of capturing complex socio-economic relationships between key economic actors, such as firms, households and the

¹ For a detailed overview of these and other relevant models, please see Timmermans (2003), Wegener (2004) and Iacono et al. (2008)

² The model has been developed as part of a research project on Regional Visions of Integrated Sustainable Infrastructure Optimised for Neighbourhoods (ReVISIONS), conducted at the University of Cambridge in collaboration with the University of Leeds, University of Exeter, University of Surrey, University of Aberdeen, Newcastle University and University of Aberystwyth. The academic research is funded by the UK Engineering and Physical Sciences Research Council (EPSRC), as part of the Sustainable Urban Environments research programme; grant reference number is GR/S90874/01. The development of the integrated economic and spatial modelling tool and application to the East of England case study areas is funded by the East of England Development Agency.

government, and their spatial dimension. As a starting point, it uses a specifically designed social accounting matrix to reflect the aggregate patterns of demand for goods, services, transport, labour, floorspace and land by groups of economic actors. The model then capitalises on random utility theory to spatially distribute that demand across the economy (Domencich and McFadden, 1975). It, therefore, makes it possible to establish a clear link between the development of the socio-economic system at the macro-level and the behaviour of economic agents driven by micro-economic incentives (de la Barra, 1989).

In terms of the modelling approach used, its most immediate antecedents are studies by Echenique (1985, 2004), Echenique and Williams (1980), Echenique et al. (1990). These and some other related studies generated a reputed family of fully operational models, which have been successfully tested and applied in the policy context in different countries across the world (de la Barra et al., 1975; Flowerdew, 1977; Hirton and Echenique, 1978; Williams and Echenique, 1978; Geraldles et al., 1978; Hunt and Simmonds, 1993; Williams, 1994; Hunt, 1994; Echenique et al., 1995). These utility maximisation models are formally equivalent to the entropy-maximising type of models pioneered by Wilson (1970), indicating, at least in the mathematical sense, the convergence and mutual acceptance of the two main paradigms of the aggregate LUTI models (Anas, 1983; de la Barra, 1989; Wegener, 2004). At the same time, it is often argued that random utility conceptualisation provides substantial advantages in terms of its ability to explain the causal mechanisms involved in the formation and evolution of particular spatial structures, whereas the entropy maximisation approach is less concerned with the causality issues and more oriented towards efficient model building (Gordon, 2010).

Despite a relatively long and very successful history of practical application of the utility maximising type of the LUTI models, the relevant literature remains fragmented when it comes to the analysis of the theoretical consistency of their overall formal framework (Oosterhaven, 1999). One possible reason is that the focus of academics and practitioners is often on incremental developments introduced in the respective models, rather than extensive and systematic discussion on the modelling processes involved and underlying theoretical assumptions (DETR, 1999).

Therefore, our primary aim is to present a systematic and critical analysis of a formal generic framework of random utility based LUTI models. This will also help to address some of the

criticisms towards this type of models resulting from fragmented codified knowledge about their formal structure and capabilities. We then proceed to discuss the implementation of this generic model in relation to the case of the Greater South East region of the UK, including London, the South East and the East of England. We discuss the model outputs under alternative land use strategies, such as regulated versus competing land uses and constrained versus unconstrained densities.

2. Theoretical Framework

2.1. Spatial equilibrium

The model we present here assumes spatial equilibrium. Spatial equilibrium is a very important concept in urban and regional economics (Glaeser, 2008; Takayama and Labys, 1986; Glaeser and Gottlieb, 2008). It is based on the observation that, since similar people, firms and activities are located in different places, we must assume that the combinations of advantages and disadvantages (wages, prices, resources, amenities) that any of these places offers are equal. If this were not the case, the market would adjust either by the relocation of entities to locations with more favourable conditions, or by exploiting any competitive advantage to generate profit (e.g. increase in land rent rates). The spatial equilibrium assumption may be formally expressed as a necessary and sufficient condition, a principle of spatial invariance, which states that the spatial assignment of any quantity should be such that all chosen locations offer equal benefit to the assigning agent. In the case of household location, this may be translated to equal satisfaction; in the case of acquiring goods, to invariance of acquirement benefit across space.

This principle is used here to establish a framework that can explain the spatial variation of prices and densities. The proposed model treats these variations as the result of the interactions of the agents of a spatially aware economic system. The main agents of this system are households, representing different socio-economic classes, and firms, representing different industrial sectors, while government and developers (builders), have implicit effects. The core processes of the model are based on the underlying behavioural assumptions about these agents and their interactions.

2.2. Behaviour of households – living costs and demand for goods and services

In accordance with the invariance principle, it is assumed that households of a specific socioeconomic class will maintain the same level of satisfaction in any location. In order to accommodate the respective behaviour we resort to the concept of utility. Utility is commonly used in economics as a measure of the level of satisfaction of a consumer. In most basic terms, it is often presented as a set of indifference curves, depicting different combinations of goods and services that consumers are willing to accept for a set of given utility levels.

The simplest utility function is the one of eq.1.

$$U_i^n = U^n \cdot \prod_m f_m(a_i^{mn}), \text{ where } f_m(a_i^{mn}) = \begin{cases} 0 & \text{if } a_i^{mn} < a_{min}^{mn} \\ 1 & \text{if } a_i^{mn} \geq a_{min}^{mn} \end{cases} \quad (1)$$

Where U^n is targeted utility, m is a specific good or service, a_i^{mn} is the amount of m consumed in location i and a_{min}^{mn} is a minimum threshold level for m . Eq. 1 states that to maintain U^n a household needs at least a certain amount from a series of goods and services. In this case, the minimum cost for reaching U^n in i is given by eq. 2.

$$c_i^n = \sum_m a_{min}^{mn} \times p_i^m \quad (2)$$

Where p_i^m is the price of m in i . Equation 1 implies that the goods and services demanded by a household to reach the required level of utility cannot be substituted by others. Some times it may be useful to allow consumption of goods or services of one type to compensate for the lack of consumption of another type. A typical way to model the resulting substitution effect is to model household utility using a Cobb-Douglas function (eq. 3).

$$U^n = \prod_m (a_i^{mn} - a_{min}^{mn})^{a^{mn}}, \quad \sum_m a^{mn} = 1 \quad (3)$$

Where, a_i^{mn} is the consumed amount of m in location i , a_{min}^{mn} is a minimum demanded amount, a^{mn} is the respective utility elasticity for m . Since the sum of the a^{mn} for all inputs is equal to 1, the utility function has a constant return to scale; i.e. an increase of all inputs by 10% will

result in a 10% increase of the utility. It can be shown that by minimising cost, eq. 3 leads to the demanded amounts of eq. 4.

$$c_i^n = \min \left[\sum_m a_i^{mn} \times p_i^m \right] \quad a_i^{mn} = a_{\min}^{mn} + U^n \times \left(\frac{a^{mn}}{p_i^m} \right) / \prod_{m'} \left(\frac{a^{m'n}}{p_i^{m'}} \right)^{a^{m'n}} \quad (4)$$

Where c_i^n is the minimum expenditure needed to reach the targeted utility, and p_i^m is the price of m in i . This, for example, suggests that if the value of a specific good in location i is increasing, households will be inclined to consume less of this good and compensate by consuming larger amounts of other goods or services that contribute to their utility U^n . Moreover, assuming prices of other products remain constant, the cost of living in i will increase.

2.3. Behaviour of firms – generating the prices of goods and services

In equations 2 and 4, we describe p_i^m as the price of m in i ; or, more formally, the cost of consuming one unit of m in location i . Next, we discuss how these prices are generated, by focusing on the underlying behaviour of firms.

It is assumed that firms of a specific industrial sector maintain a constant level of profit per unit of output across space; i.e. the selling price of one unit of output of this sector minus the cost of its production does not vary with location. It is, therefore, the cost of production³ in a given location, that determines the selling price of the outputs of an industrial sector in this location. Correspondingly, the costs of producing and transporting the outputs to the places they are demanded determine the relative competitiveness of a given location for the production of outputs of this sector. Cheap inputs and labour⁴, and low land prices translate into low selling prices; proximity to the markets (i.e. locations where the outputs of the sector are demanded) and high accessibility translate into low transport costs.

³ After taking into account indirect taxes paid by producers, reduced by producer subsidies received.

⁴ Note that the real cost of labour in an area is a function of both wages and labour productivity in this area.

More formally, the cost of producing one unit of output of a sector n in location j is equal to the sum of the costs of consuming the needed amount of each of the inputs that are required for its production plus the assumed - sector-specific - constant level of profit. The needed amounts of each input may or may not vary across space. They may be elastic to price or fixed.

$$c_i^n = \sum_m a_i^{mn} \times p_i^m \quad (5)$$

Where c_i^n is the production cost⁵ of n in location i , p_i^m is the consumption price of m , and a_i^{mn} is the needed amount of input m . Typically, the needed amount is inelastic to price and not variable in space for intermediate demands (i.e. the demanded amount of input of one sector to produce one unit of output of a specific sector) due to lack of empirical data on such variations. This in effect implies that the technology used for the production of outputs of any sector is the same in any location in the modelled economic system. However, the needed amount of labour differs across space, representing varying productivity levels; similarly, the amount of land is elastic to price and follows a power function (eq. 6).

$$a_i^{mn} = a_{min}^{mn} + \beta^{mn} \cdot (p_i^m)^{-\gamma^{mn}} \quad (6)$$

2.4. Costs and disutilities – towards a bi-modal accounting track

In the previous section we discuss how the prices of the needed inputs determine the demanded amounts and the costs of the products of a specific sector in a location i . In doing so, we assume that all costs induced during the production of the outputs of a given sector in location i , are passed to the consumers of these outputs. Moreover, we implicitly assume that non-money costs induced during the production of the outputs are not translated to costs for their consumers.

⁵ The assumed fixed profit can be treated as one more input m where $a_i^{mn} = a^{mn}$ is the fixed profit per unit of output of sector n and $p_i^m = p^m = 1$. Therefore, for the rest of the paper production cost will refer to the cost of all inputs plus profit.

These simplifications may, in certain cases, be too restrictive. Consider, for example, the case of a location where production of a specific sector generates considerable risk or great discomfort. It is conceivable that the respective firms will charge the consumer of their goods with a charge that compensates for resulting discomfort or potential loss. In order to address such modelling restrictions we introduce disutility, a second mode of, non-monetary, accounting. As a result, eq. 5 is replaced by equations 7 and 8.

Eq. 7 states that the cost of production of one unit of sector m in zone j is equal to the sum of the demanded amounts for each input multiplied by the fractions of its consumption cost that are passed to the consumers plus the fractions of its consumption disutility that are passed as costs.

$$c_i^n = \sum_m \left[a_i^{mm} \cdot (a_m \cdot p_i^m + \beta_m \cdot u_i^m / \mu^m) \right] \quad (7)$$

Where c_i^n is the production cost, u_i^m is the consumption disutility of m in i , p_i^m is the consumption cost, μ^m is the marginal utility of money⁶, a_m and β_m are the parameters that determine the fraction of costs passed to the consumers and the fraction of the disutility passed to the consumer as monetary cost respectively.

Eq. 8 expresses the amount of consumption disutility that is passed to the consumer as production disutility of n . It states that the disutility of production of one unit of sector m in zone i is equal to the sum of the fraction of disutility of consumed input m that passes to the consumers multiplied by the demanded amount of the input.

$$w_i^n = \sum_m \left[a_i^{mm} \cdot \gamma_m \cdot u_i^m \right] \quad (8)$$

Where w_i^n is the production disutility, u_i^m is the consumption disutility of m in i , and γ_m is the parameter that determines the fraction of disutility passed to the consumers.

⁶ This is a transformation factor that reflects the value that the agents associated with the specific sector attach to the disutility unit (typically unit of time).

In accordance with this, bi-modal, accounting system, eq. 6 may be transformed in a consistent manner to reflect elasticity of a composite metric that reflects both costs and disutilities (eq. 9).

$$a_i^{mn} = a_{min}^{mn} + \beta^{mn} \cdot (q_i^m)^{-\gamma^{mn}}, \text{ where } q_i^m = f(p_i^m, u_i^m) \quad (9)$$

Similarly, p_i^m may be replaced in equations 2 and 4 with a composite metric. This would suggest that households are assumed to determine their required inputs by minimising the combined disutility of these inputs that is passed on to them.

2.5. Deciding where to buy from – discrete choices and the random utility model

The fixed profit assumption means that, under spatial equilibrium, the total production of an industrial sector in a location will be determined by the total amount that is demanded in all locations where its selling price plus cost of transportation is competitive and by the access of such locations to other potential production sites. This satisfies the equilibrium condition that requires invariance of acquirement benefit across space.

Formally, the total demand for m in location j is equal to the sum of the demands from all sectors n that require input m.

$$Y_j^m = \sum_n (a_j^{mn} \times X_j^n) + {}^X Y_j^m \quad (10)$$

Where Y_j^m is the total demand for m in zone j, X_j^n is the production of n in j, a_j^{mn} is the demand coefficient of n for m in j and ${}^X Y_j^m$ is the exogenous demand for m in j.

The total demand for m in j is distributed in the production zones of m based on the assignment coefficients. Each production zone i is assigned production of m equal to the demand of m in zone j multiplied by the assignment coefficient of sector m from zone i to zone j.

$$T_{ij}^m = Y_j^m \times b_{ij}^m \quad (11)$$

$$b_{ij}^m = \frac{s_i^m \times \exp(-\lambda^m \times U_{ij}^m)}{\sum_{i'} s_{i'}^m \times \exp(-\lambda^m \times U_{i'j}^m)} \quad (12)$$

Where T_{ij}^m represents the assignment of sector m from zone i to zone j , Y_j^m the demand in j , b_{ij}^m is the assignment coefficient between zone i and j , U_{ij}^m is the modelled disutility of sector m from zone i to zone j , λ^m represents the size of the random element of disutility, and s_i^m is the weighting factor for zone i that represents the sector-specific size of the zone and reflects the number of opportunities or alternative production sources in the zone.

The modelled part of disutility U_{ij}^m is equal to the sum of production costs (in utility units) and disutilities of the input sector in its production zone and transport costs (in utility units) and disutilities between production and consumption zone (Equation 4).

$$U_{ij}^m = \mu^m \times {}^M p_i^m + {}^M u_i^m + {}^T u_{ij}^m + {}^T z_{ij}^m \quad (13)$$

Where ${}^T u_{ij}^m$ and ${}^T z_{ij}^m$ are transport disutilities and exogenous transport disutilities, ${}^M u_i^m$ is the production disutility, ${}^M p_i^m$ is production cost and μ^m is the marginal utility of money.

The total production of sector m in production zone i is calculated by summing the assigned productions of m from demand generated in all consumption zones and adding to the total endogenous production any exogenous production specified by the user.

$$X_i^n = \sum_j T_{ij}^n \quad (14)$$

Where T_{ij}^n represents the assignment of factor n from zone i to zone j , X_i^n is the production in i

The cost of consumption of one unit of sector m in zone j is equal to the weighted average of the cost of consumption from each production zone i .

$${}^N p_j^m = \sum_i b_{ij}^m \times ({}^M p_i^m + {}^T c_{ij}^m) \quad (15)$$

Where ${}^N p_j^m$ represents the consumption cost of a unit of factor m in zone j , b_{ij}^m is the assignment coefficient of factor m from zone i to zone j , and ${}^M p_i^m$ and ${}^T c_{ij}^m$ are the production and transport costs.

The disutility of consumption of one unit of sector m in zone j is equal to the minimum subjective disutility of consumption that the set of the available production zones provides.

$${}^N d_j^m = -\frac{1}{\lambda^m} \times \log \sum_i s_i^m \times \exp\left(-\lambda^m \times (\mu^m \times {}^M p_i^m + {}^M u_i^m + {}^T u_{ij}^m + {}^T z_{ij}^m)\right) \quad (16)$$

Where ${}^N d_j^m$ is the consumption disutility of a factor m in a consumption zone j , ${}^T u_{ij}^m$ is the transport disutility, ${}^M u_i^m$ is the production disutility, ${}^M p_i^m$ is the production cost, and μ^m is the marginal utility of money.

2.6. Constraints and rents

Production is subject to minimum and maximum production constraints. To match demand to supply, production costs and disutilities for each sector and production zone are adjusted based on the demanded production and the production constraints.

$${}^i p_i^m = p_i^m + \frac{1}{\lambda^m} \times \log\left(\frac{X_i^m}{K_i^m}\right) \quad (17)$$

Where ${}^i p_i^m$ is the at-the-gate consumption cost of sector m in zone i , λ^m represents the size of the random element of disutility, X_i^m is the production in i , and K_i^m is the production constraint of sector m in zone i .

2.7. Linking the model components

This section describes the overall structure and flow of the model and how this allocates the location of activities and the flows of agents. A causal chain is used to model the interrelated impact of exogenously input and endogenously generated production and consumption. The process is repeated until equilibrium between supply and demand is reached, subject to exogenously set constraints.

Typically the process is triggered by inputting export estimates, estimated government expenditure and investment, and inactive household. The implemented causal chain follows the flowchart of figure 1. Red boxes indicate exogenous inputs, green boxes generation of demand (consumption) and orange boxes assignment into production locations.

Exports are exogenous consumption inputs, and government spending and investment are exogenous production inputs. They are spatially assigned in external consumption locations

(exports), and internal production locations (government spending, investment and inactive households). The respective productions generate demand for all other sectors. New consumption is repeatedly assigned into zones of production, and respective production is generating more consumption. The iterative process is terminated when new consumption for all sectors reaches a minimum threshold.

Figure 1 focuses on the consumption-production sequence of industries, labour, household and land. Industrial production demands consumption of labour. Labour is spatially assigned from the locations of consumption (workplace location) to production locations (residence locations). Persons in employment (labour) and inactive and unemployed persons form households. Households of different socioeconomic classes consume different amounts of outputs of firms. Finally, both firms and households demand land, the supply of which is exogenously constrained.

[Figure 1 about here]

3. Empirical Framework

3.1 Geographical and temporal dimensions

The generic model described in the previous section(s) is designed to predict land-use and spatial interaction patterns across the UK. In terms of geographical disaggregation, the modelled output for a given region of interest is generated at the level of local authority. Correspondingly, the same level of geographic detail is applied to the underlying empirical data inputs used in the calibration of the model. For the case study of the Greater South East (GSE) of England the model generates output for 192 spatial zones (Map 1). For the GSE regions such as London, the East of England, and the South East each zone corresponds to a local authority district. For regions that share borders with the GSE (the East Midlands, the West Midlands and the South West) each zone corresponds to an administrative county. Each of the remaining UK regions (such as the North East, the North West, and devolved administrations of Wales, Scotland and Northern Ireland) represents a separate zone too.

[Map 1 about here]

As for temporal dimension, we choose 2001 as a base year of the model. To no small degree this is driven by data related considerations. Much of the required data inputs on spatial patterns of interactions between economic agents can be obtained from census data only. The most recent census data publicly available in the UK refer to 2001. For consistency reasons, the other relevant data inputs used in the model are also dated 2001. In few specifically defined cases, where 2001 data are not directly available, we use data sources nearest to 2001.

3.2 The Input-Output Core

An empirical framework of the model is built up around a social accounting matrix which is specifically constructed for the modelling purposes. At the core of this matrix is a symmetric industry-by-industry input-output table which captures macroeconomic linkages between firms and households. More specifically, the input-output table provides two important sets of inter-related economic information. One is about the market structure (or the composition of revenues) for a given group of firms. This shows how much of output of this group of firms is demanded by other economic agents such as other firms, households, the government,

investment and exports sectors. Another important set of information relates to the cost structure for a given group of firms. This specifies all inputs which are used by firms of this group in their production process, such as intermediates, labour, capital and land. The underlying principle behind the input-output table is interdependence of production processes, i.e. the output of a given group of firms can be used as intermediate input for another group of firms, while the output of the latter may be used by many more other groups of firms.

In our model both firms and households are aggregated into groups. The most common way to aggregate firms is to use their industrial classification. For the purposes of the model we also need to take account of potential differences in the pattern of spatial location between different industrial sectors and their interface with households. For instance, it is critical for us to distinguish between retail and wholesale firms to spatially capture the flows of manufacturing goods to the residential population represented by households. Based on the UK Standard Industrial classification 1992 (SIC92), we, therefore, group all UK firms into the following seven broad industrial sectors: (1) agriculture and mining, (2) manufacturing, energy and water supply, and construction, (3) wholesale and automotive sales, (4) retail and hotels and restaurants, (5) real estate, (6) transport and business services excluding real estate, and (7) public administration, defence, education, social work and other social services.

As far as households are concerned, our primary concern is to allow for differences in the consumption power across different segments of population. To address it, we use the UK National Statistics Socio-Economic Classification (NS-SEC). Based on the so called Goldthorpe Schema (Goldthorpe and Llevellyn, 1987), this classification takes into account information on both occupation and employment status of a given person. By applying NS-SEC codes to household reference persons (HRP)⁷, we are able to distinguish between four broad household groups. These include households where the HRP belongs to (1) senior and lower managerial staff and professionals, small employers, intermediate occupations and lower supervisory staff, (2) semi-routine and routine occupations and employed full-time

⁷ According to the Office for National Statistics, the Household Reference Person is “the person responsible for owning or renting or who is otherwise responsible for the accommodation. In the case of joint householders, the person with the highest income takes precedence and becomes the HRP. Where incomes are equal, the older is taken as the HRP” (please see <http://www.ons.gov.uk/about-statistics/classifications/current/ns-sec/household-level/index.html>).

students, (3) the unemployed and (4) the economically inactive and aged under 16 and over 75. It is assumed that this classification is sharp enough to capture differences in patterns of demand for goods, services, transport and housing across the household sector.

[Table 1 about here]

With seven groups of firms and four socio-economic classes of households, the input-output component of our modelling framework is presented in Table 1. From quadrants A, B and C of this table we derive demand coefficients for inter-firm transactions. For a given group of firms, these represent technical requirements for intermediate inputs (from quadrants A and B) to produce one unit of output (from quadrant D). Similarly, the relationship between households and firms are formalised via a set of demand coefficients derived from quadrants E, F and H. For a given socio-economic class of households, these represent fractions of total household consumption (from quadrant H) spent on goods and services provided by each of the groups of firms (from quadrants E and F).

The input-output table used in our modelling exercise is constructed based on a UK component of the Organisation for Economic Co-operation and Development (OECD) Input-Output Database for the year 2000 (Yamano and Ahmad, 2006). In order to decompose final consumption of the household sector by socio-economic class of households and product group consumed (quadrants E, F and G of Table 1), we use the results of the Expenditure and Food Survey conducted by the UK Office for National Statistics (EFS, 2001/02). In this survey the items of household expenditure are broken down according to the Classification of Individual Consumption by Purpose (COICOP). To make them consistent with our input-output framework we allocate each of the COICOP codes to the respective groups of firms. The derived matrix of household consumption is then updated via the RAS procedure (Miller and Blair, 2009) to make it possible to incorporate it into the OECD original input-output table.

3.3.Social Accounting Extensions

The input-output component of the modelling framework represents the relationship between firms and households in monetary units only. To model the spatial distribution of physical flows of people and factors of production, this component has to be complemented with a set

of physical accounts to form a social accounting matrix. Table 2 provides further details on socio-economic accounts specifically constructed for the purposes of our model. One set of such accounts deals with socio-economic disaggregation of demand for labour. (quadrant L). Based on census bespoke table C1148, these accounts present the composition of workforce by two broad NS-SEC classes (such as highly managerial, etc. and routine and semi-routine), as demanded by each group of firms. Having allocated labour to places of residence, the model also needs to be informed about local patterns of household formation. This is achieved by constructing a set of accounts representing allocation of residential population by socio-economic class across different socio-economic classes of households (quadrant O of Table 2). To estimate spatially specific labour demand for households by socio-economic class, we use specifically commissioned census table C1161 and a number of standard tables ST003, ST013, ST038 and ST043.

[Table 2 about here]

As different groups of firms compete for different type of floorspace, another important set of physical accounts relates to demand for floorspace (quadrant M). Based on the Valuation Office Agency data (VOA, 2001), we distinguish between four types of floorspace such as retail, offices, factories and warehouses. To derive demand coefficients for floorspace, we assume that all firms can compete to locate their employees in office space. Firms in retail, real estate and business services are assumed to compete for retail premises, with floorspace in factories and warehouses is directly allocated to manufacturing and wholesale firms, respectively. The floorspace accounts are closely interconnected with non-domestic land use accounts (quadrant N). Based on the VOA (2001) data on floorspace and rateable value and the Generalised Land Use Statistics (GLUD, 2001), these accounts are generated by estimating the plot ratio as a linear function of land value per square meter.

Similarly, the four household groups are assumed to compete for housing floorspace specified in terms of number of rooms. To create a set of accounts for demand for housing by size of dwelling and socio-economic class of household (quadrant P of Table 2), we use two customised census tables C1206 and C1209. Based on the local reference rent dataset by VOA (2007), we then proceed to add domestic land use accounts (quadrant Q). This is achieved by estimating land demand per room as function of land cost per square meter.

Finally, a set of transport related accounts is also part of our social accounting framework. These, essentially, replicate the quadrants A, B, E, and F of the input-output table, by converting them to physical flows of goods. The conversion volume per value ratio is introduced into the model using the estimates from secondary sources (WSP, 2003).

4. Calibration evaluation and control tests

4.1 Calibration Evaluation

The outputs of the calibration year replication exercise are considerably faithful to the original data. As illustrated by Graph 1, the modelled location of households perfectly correlates with their actual location.

[Graph 1 about here]

This level of correlation was expected since the discrepancy of the modelled spatial allocation totals and the total number of households provided by the data was externalised as an exogenous attractor for each zone. However, the correlation between data and model outputs continues to hold across the entirety of the sectoral hierarchy. Graphs 2 to 5 illustrate the correlation levels for different types of floorspace, such as domestic floorspace (in terms of total number of rooms in each zone), as well as retail, office and factory floorspace (all in terms of square meters per zone).

[Graphs 2 to 5 about here]

These outputs are very encouraging considering that they are the result of unconstrained competition between different types of land use⁸. The factors that determine the proportion of land to be used for each land-use are the elasticity functions that determine the relationship between floorspace of a particular type and the land it covers⁹, the relative availability of valid land in proximity, and the price of land in each of the zones. All these factors are

⁸ This applies to non-domestic land uses. In the particular configuration of the model that generates the presented outputs, domestic land is designated exogenously as valid for this sole use. This was done for simplification reasons with no loss of generality.

⁹ This includes the footprint of the buildings plus the private or public open area in the vicinity of the buildings that serve their functions (open parking spaces, courts, etc).

processed endogenously. Map 2, displays the total floorspace by type (non-domestic land-uses) for the modelled area.

[Map 2 about here]

The modelled living cost and employment compensation per year, for a working person of socio-economic group 1 (other than routine and semi-routine), are displayed by Maps 3 and 4, respectively. Map 5 displays the modelled total number of employed persons of socio-economic group 1; dots in magenta represent number of people living in each zone and dots in blue are number of people employed in each zone. The clustered pattern of employment is evident when compared against residence.

[Maps 3 to 5 about here]

The model is in the process of evaluating against control scenarios. The one presented in Maps 6 and 7 involves the increase of the supply of domestic land by 50% across the area displayed in Map 6.

[Maps 6 and 7 about here]

Map 7 shows the resulting impact of the scenario on the number of households of socio-economic group 1. Note that the increase in supply within the scenario area creates spill-over effects because of the increased demand that the extra households that are located within the scenario area generate.

5. Conclusions

The calibration process for the model has been successfully completed. The model provides a good representation of the Base year data and is providing the expected responses to control tests.

The next steps are to link the land use model to a transport model and develop the reference case scenarios for years 2011, 2031 and 2050 to represent the current policy trend. The model outputs will be systematically post-processed into urban form and spatial demands for energy, water and waste by the ReVISIONS research project. This wider project will aim to select appropriate sustainable infrastructure supply technologies according to demand and

urban form and feedback the supply characteristics and costs to the land use model. The land use model will be used to estimate the impacts of these measures on reducing carbon emissions, water stress and waste and the costs to households and employers. A number of options will be designed and tested at the forecast year to investigate to what extent spatial planning policies affect the potential of green technologies to improve sustainability. The supply technologies will be combinations of building-scale, communal and centralised systems with emphasis on those that are affected by urban form. The spatial planning options range from the compact city, planned urban expansion, new settlements and market led dispersal, each combined with appropriate infrastructure technologies, regulations, and demand management measures.

The land use model will provide the capability to estimate the social, economic and environmental impacts on households, employers and wider economy over a wide range of future scenarios.

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C1206 Census Table. Dwelling type and accommodation type and tenure by household reference person's (HRPs) economic activity and NS-SeC by number of rooms.

C1209 Census Table. Accommodation type by tenure by household space type and number of rooms in dwelling.

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ST038 Census Table. Sex and industry by employment status and hours worked, CASWEB.

ST043 Census Table. Sex and NS-SeC by economic activity, CASWEB.

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Figure 1 Overall modelling Framework

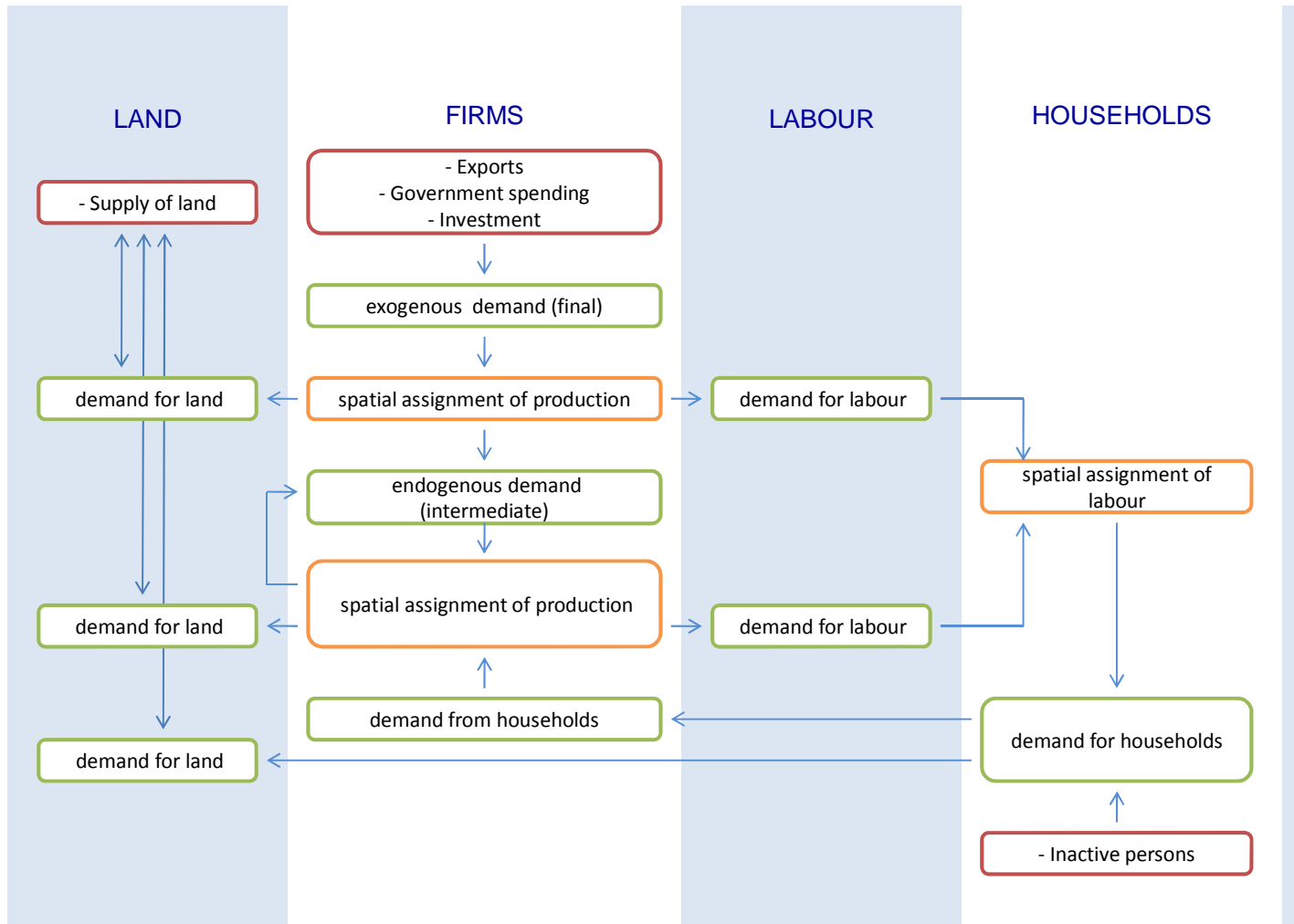


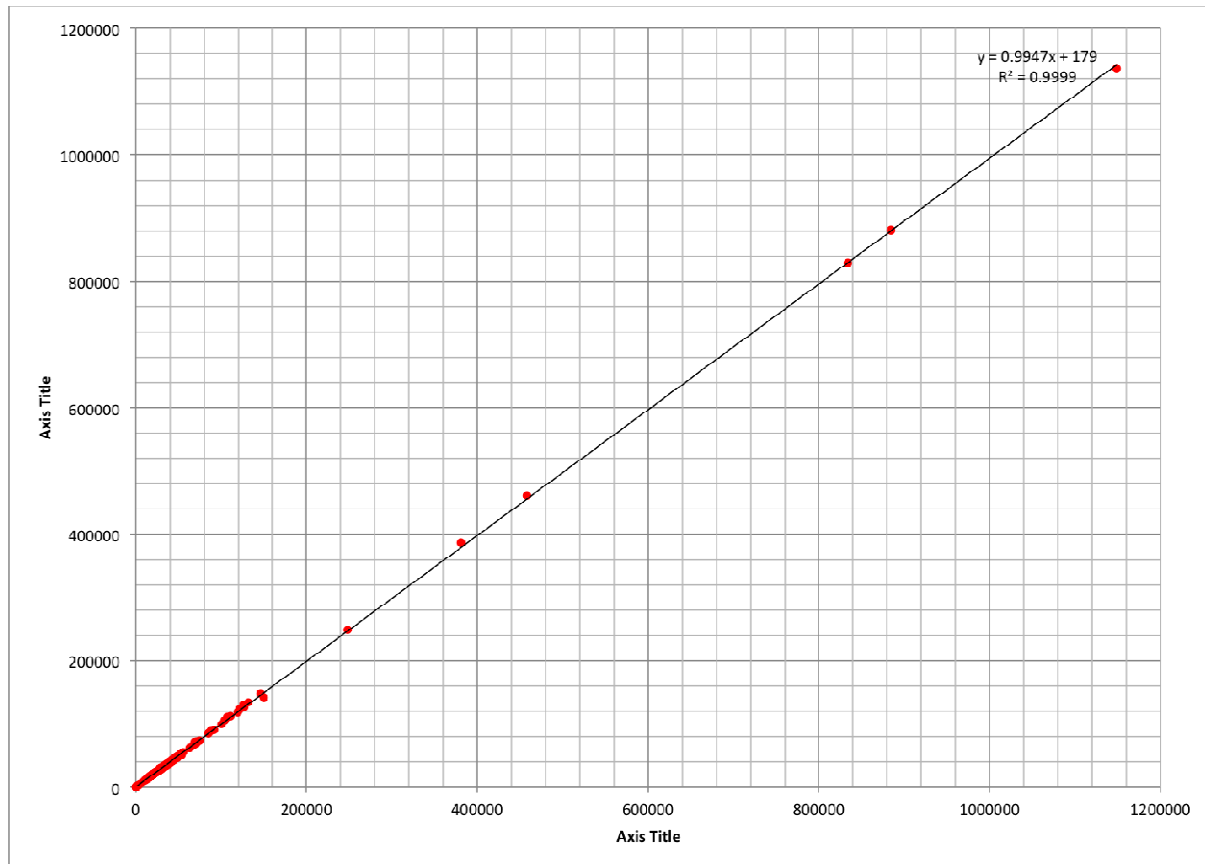
Table 1 The input-output component of the modelling framework

Sector		Firms							Households				Government consumption	Investment	Exports	Total use
		1	2	3	4	5	6	7	1	2	3	4				
		Agriculture and mining	Manufacturing, etc.	Wholesale, etc.	Retail, etc.	Real estate	Business services and transport	Defence, education, health, etc.	Higher managerial, etc.	Routine and semi-routine	Unemployed	Economically inactive				
Domestic Firms	1 Agriculture and mining	A							E				I			A+E+I = D
	2 Manufacturing, etc.															
	3 Wholesale, etc.															
	4 Retail, etc.															
	5 Real estate															
	6 Business services and transport															
	7 Defence, education, health, etc.															
Foreign Firms	1 Agriculture and Mining	B							F				J			
	2 Manufacturing, etc.															
	3 Wholesale, etc.															
	4 Retail, etc.															
	5 Real estate															
	6 Business services and transport															
	7 Defence, education, health, etc.															
	Net taxes on products	C							G				K			
	Value Added															
	Total Output	D = A+B+C							H = E+F+G							

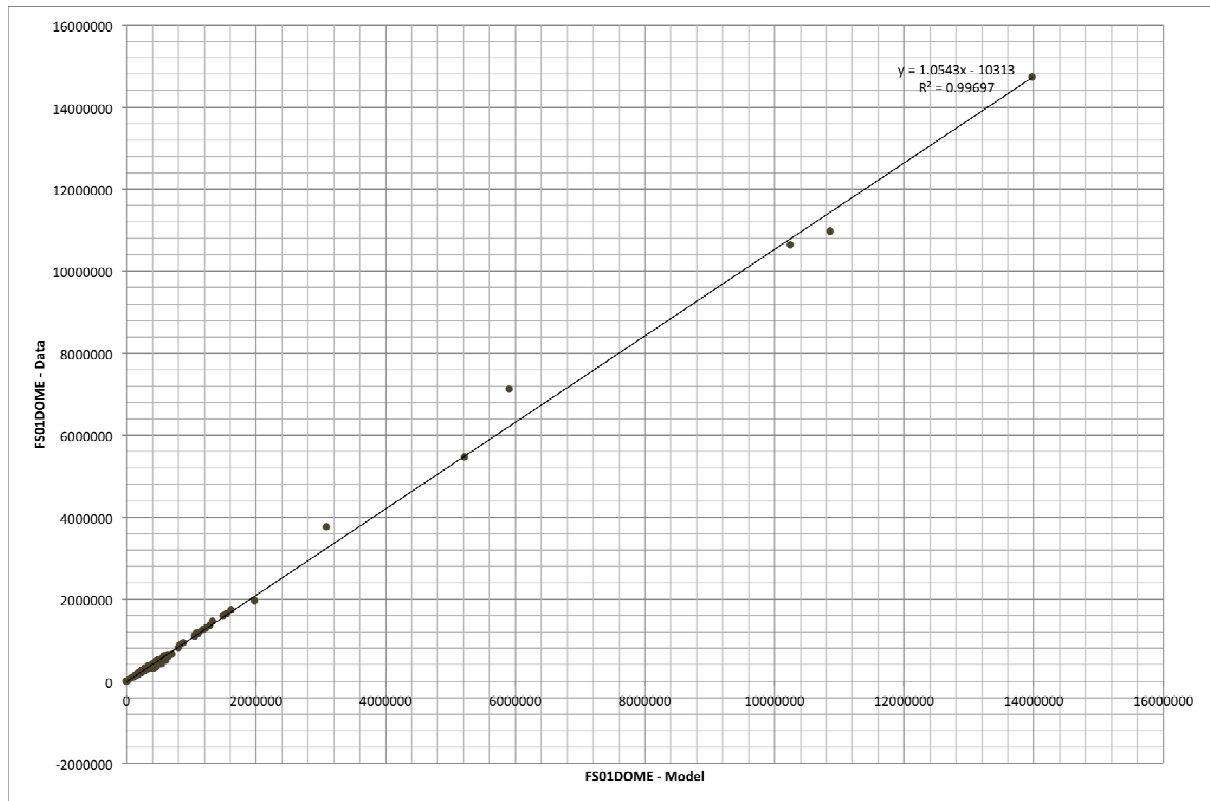
Table 2 Social Accounting Extensions of the Modelling Framework

Sector		Firms							Households			
		1	2	3	4	5	6	7	1	2	3	4
		Agriculture and mining Manufacturing, etc. Wholesale, etc. Retail, etc. Real estate Business services and transport Defence, education, health, etc.							Higher managerial, etc. Routine and semi-routine Unemployed Economically inactive			
Input-Output Component		A							E			
		B							F			
		C							G			
Workplace labour	1 Higher managerial, etc. 2 Routine and semi-routine	L										
Non-domestic floorspace	1 Retail premises 2 Offices 3 Factories 4 Warehouses	M										
Non-domestic land	1 Retail premises 2 Offices 3 Factories 4 Warehouses 5 Agricultural	N										
Residential population	1 Higher managerial, etc. 2 Routine and semi-routine 3 Unemployed 4 Economically inactive								O			
Domestic Floorspace									P			
Domestic land									Q			

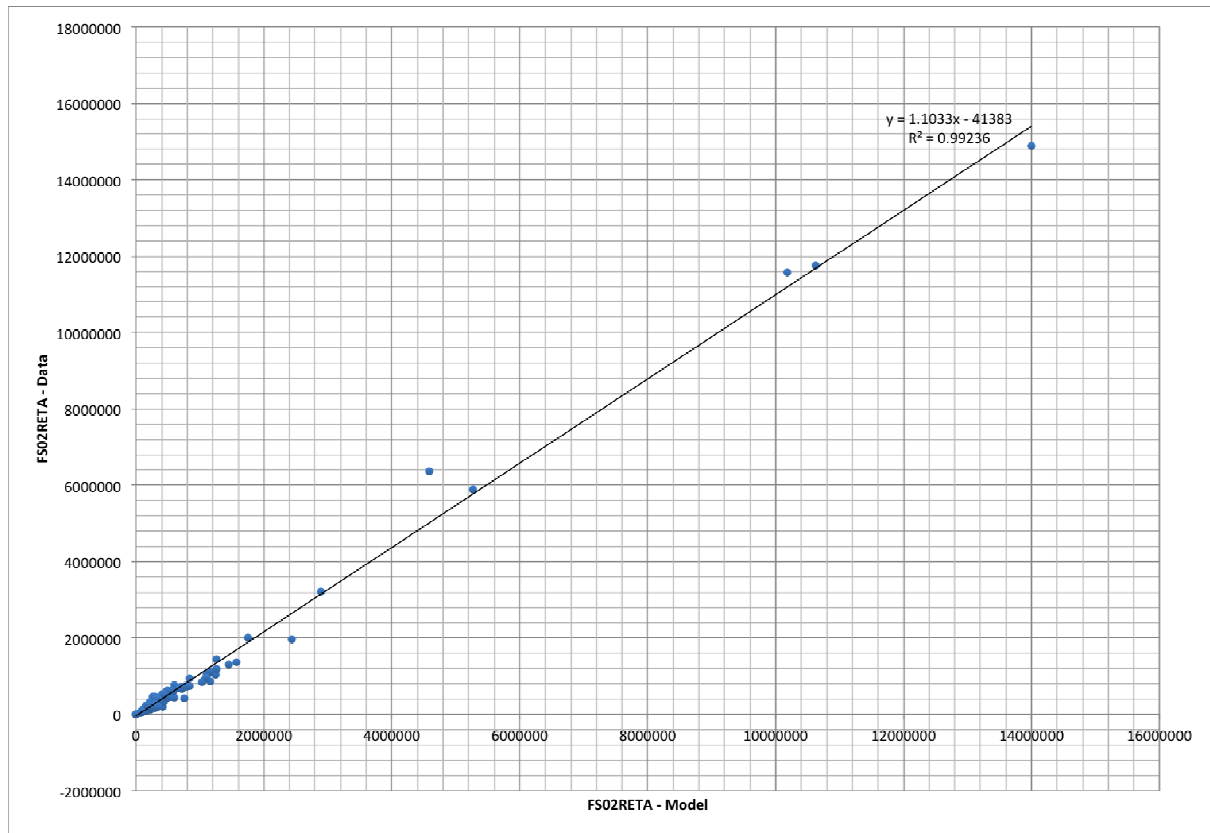
Graph 1 Correlation between model (x-axis) and data (y-axis) values for number of households of socio-economic group 1.



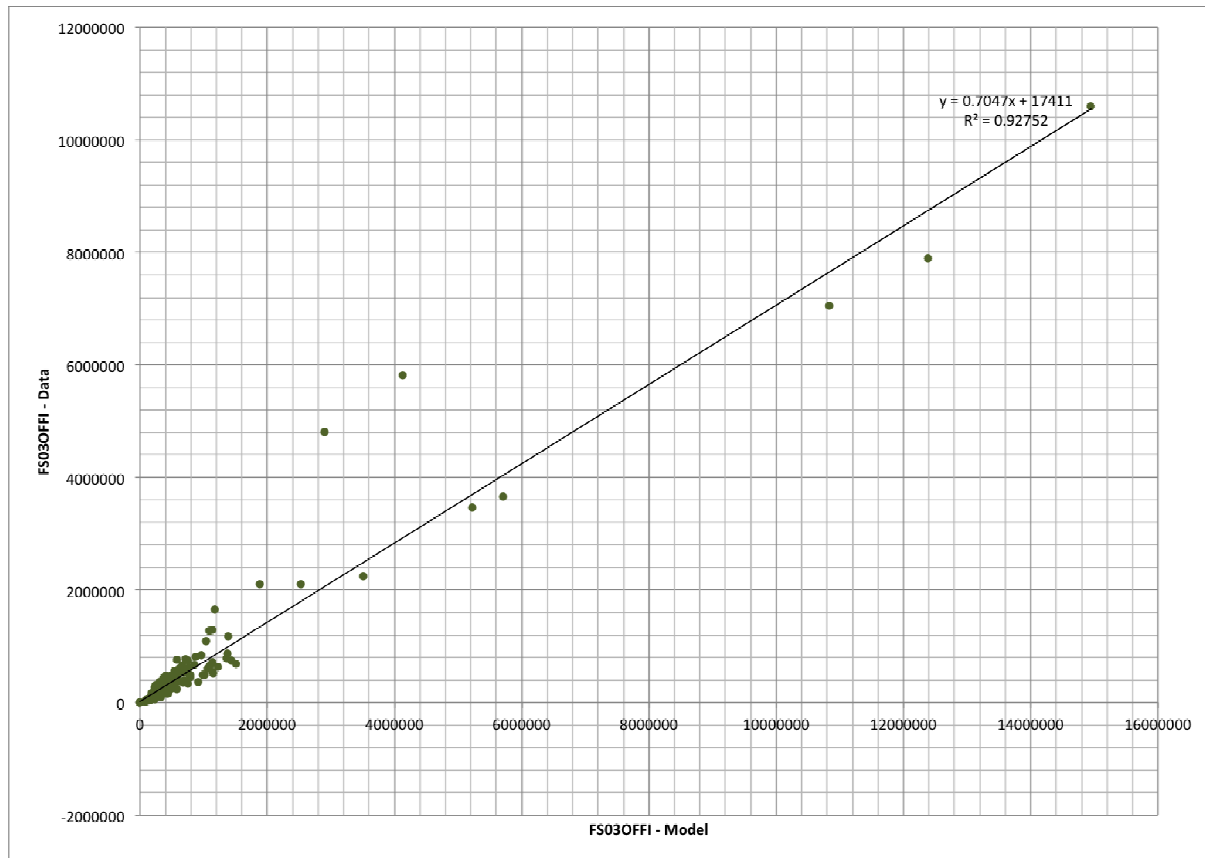
Graph 2 Correlation between model (x-axis) and data (y-axis) values of total number of rooms for domestic use.



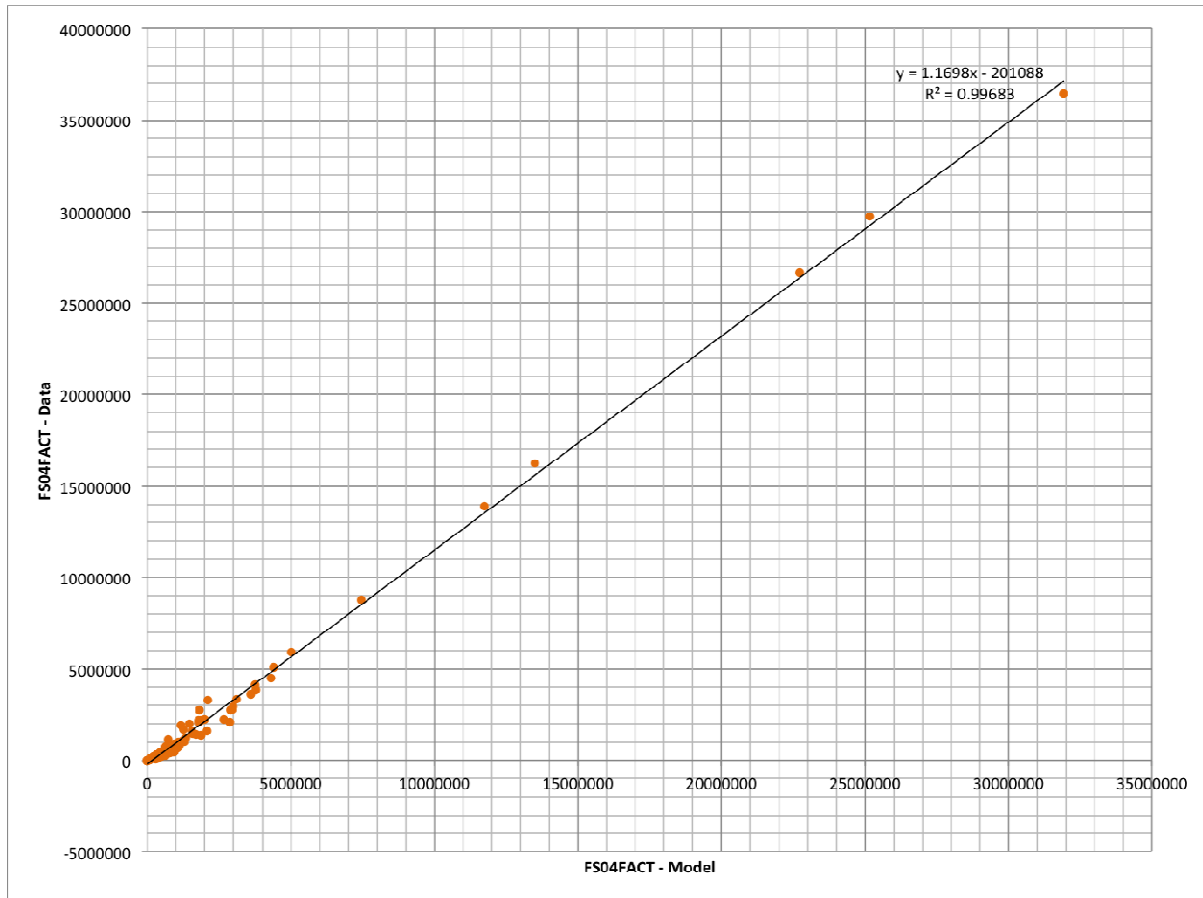
Graph 3 Correlation between model (x-axis) and data (y-axis) values of total retail floorspace in square metres.



Graph 4 Correlation between model (x-axis) and data (y-axis) values of total office floorspace in square metres.



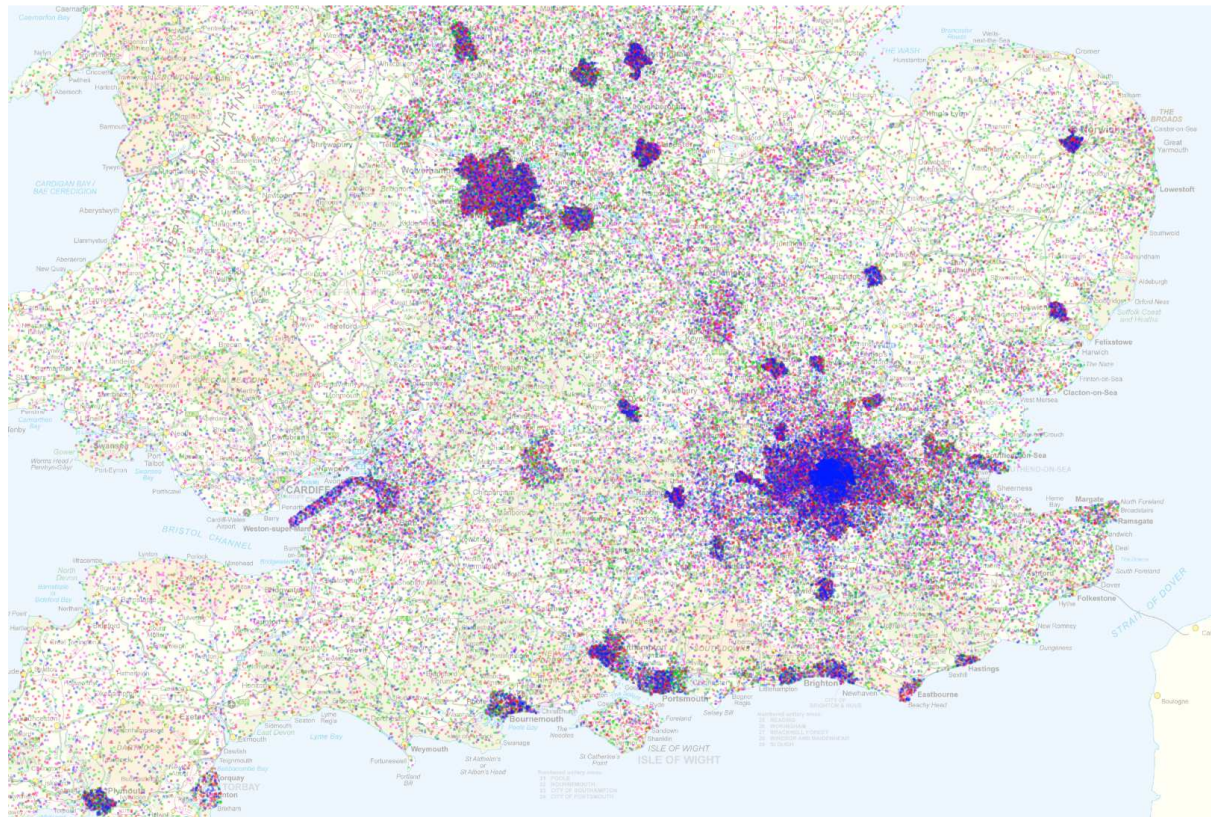
Graph 5 Correlation between model (x-axis) and data (y-axis) values of total factory floorspace in square metres.



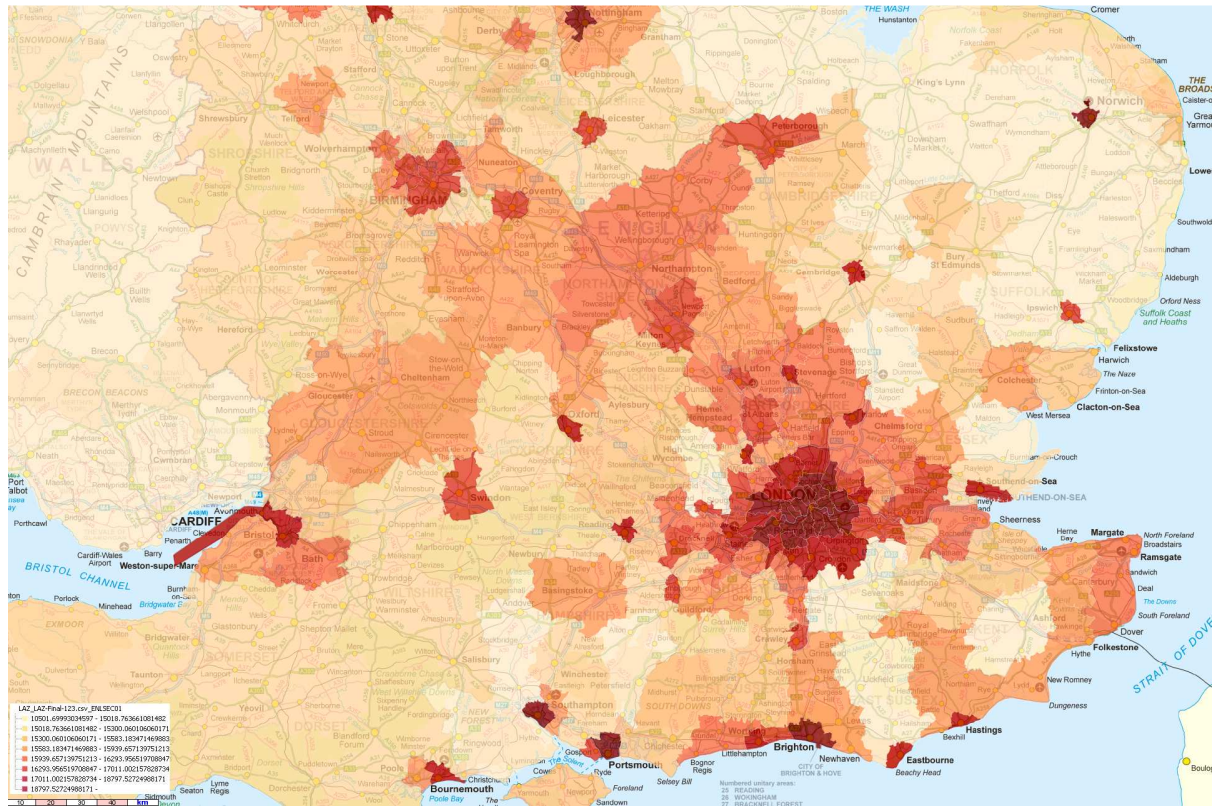
Map 1 Land use zones



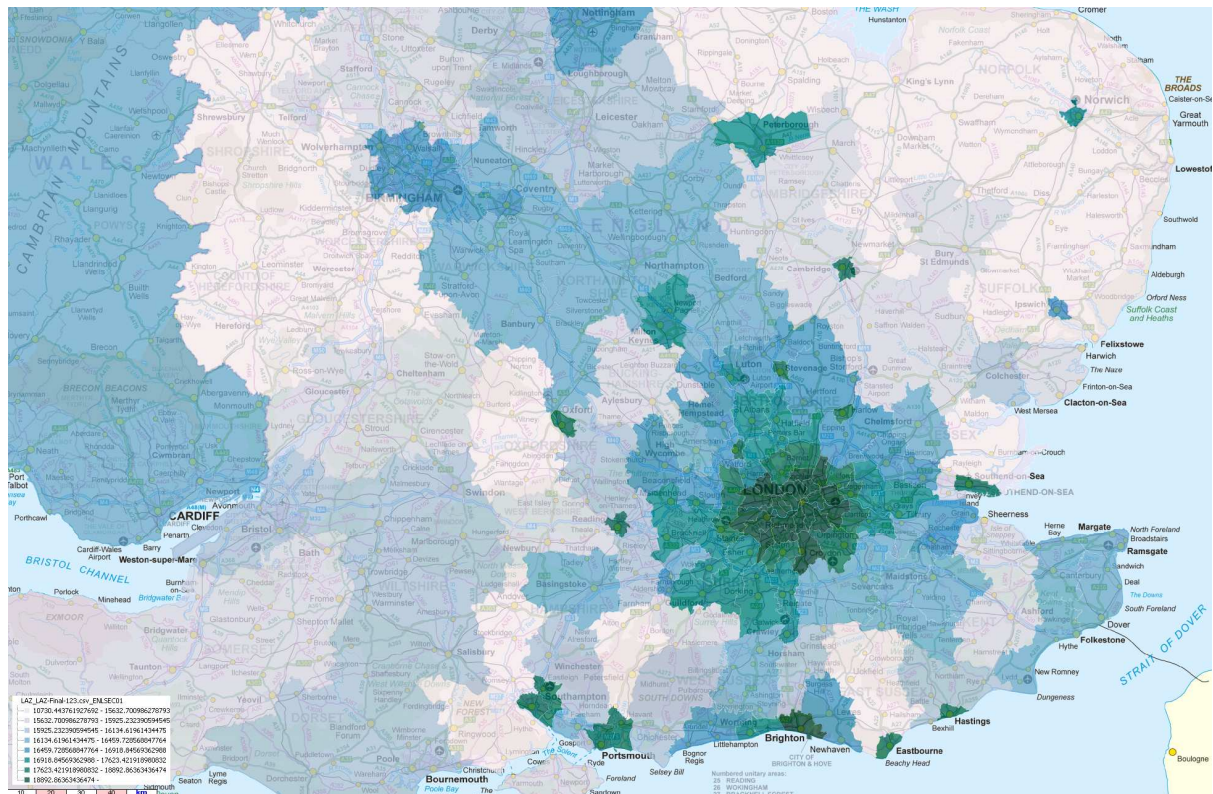
Map 2 Distribution of floorspace by type (each dot represents 5000 square metres of floorspace); red – retail, blue – office, green – factory, magenta – warehouse [modelled].



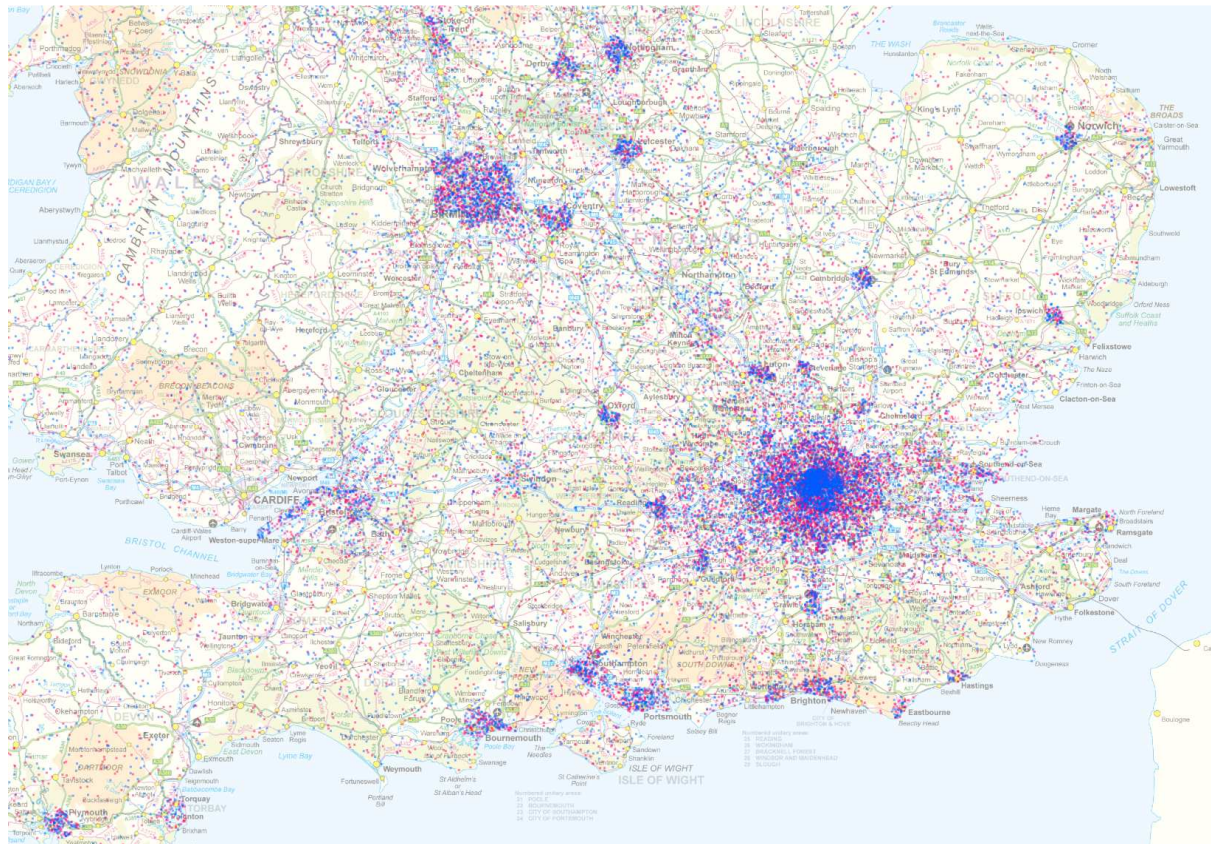
Map 3 Living cost of person of socioeconomic group 1 (other than routine or semi routine) for 2001 [modelled].



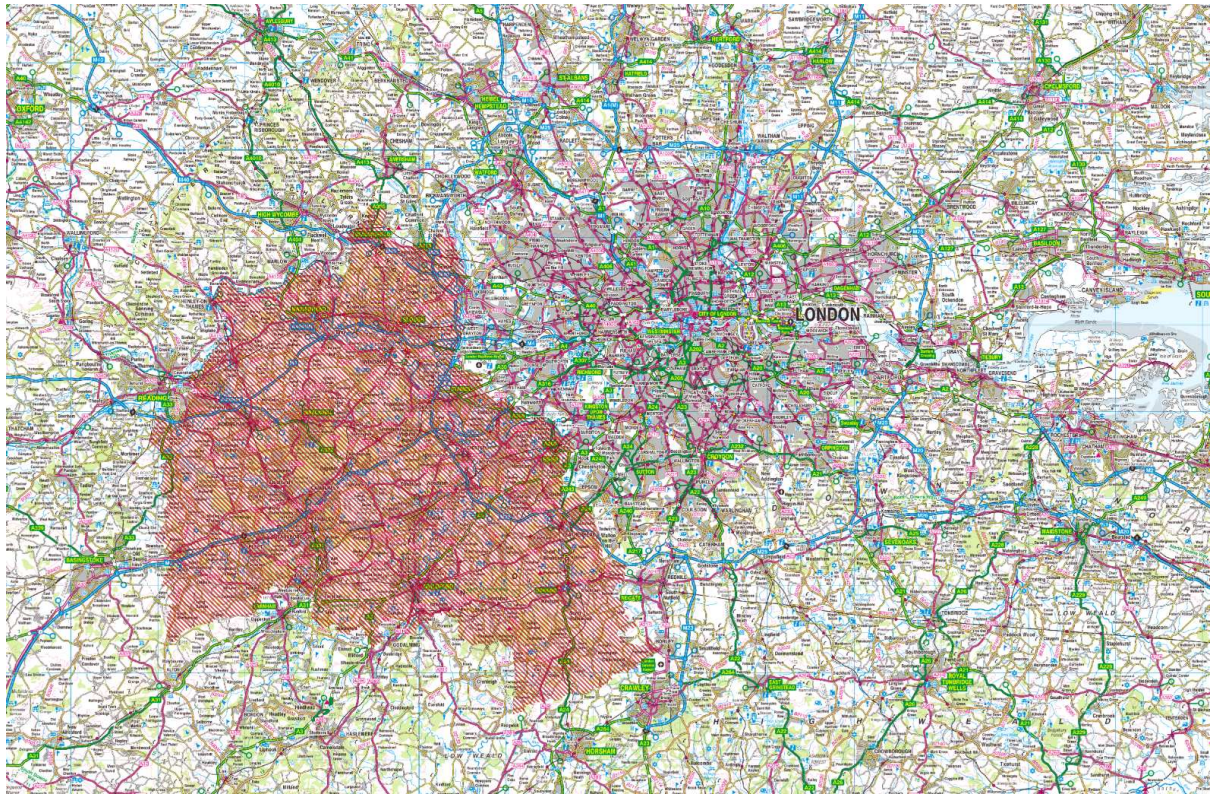
Map 4 Employment Compensation of person of socioeconomic group 1 (other than routine or semi routine) for 2001 [modelled].



Map 5 Number of employed persons of socioeconomic group 1 (each dot represents 1000) persons; magenta represents location of residence and blue location of employment



Map 6 Control test area; total domestic land increased by 50%



Map 7 Difference in number of households of socioeconomic group 1 between base (year 2001) and control scenario.

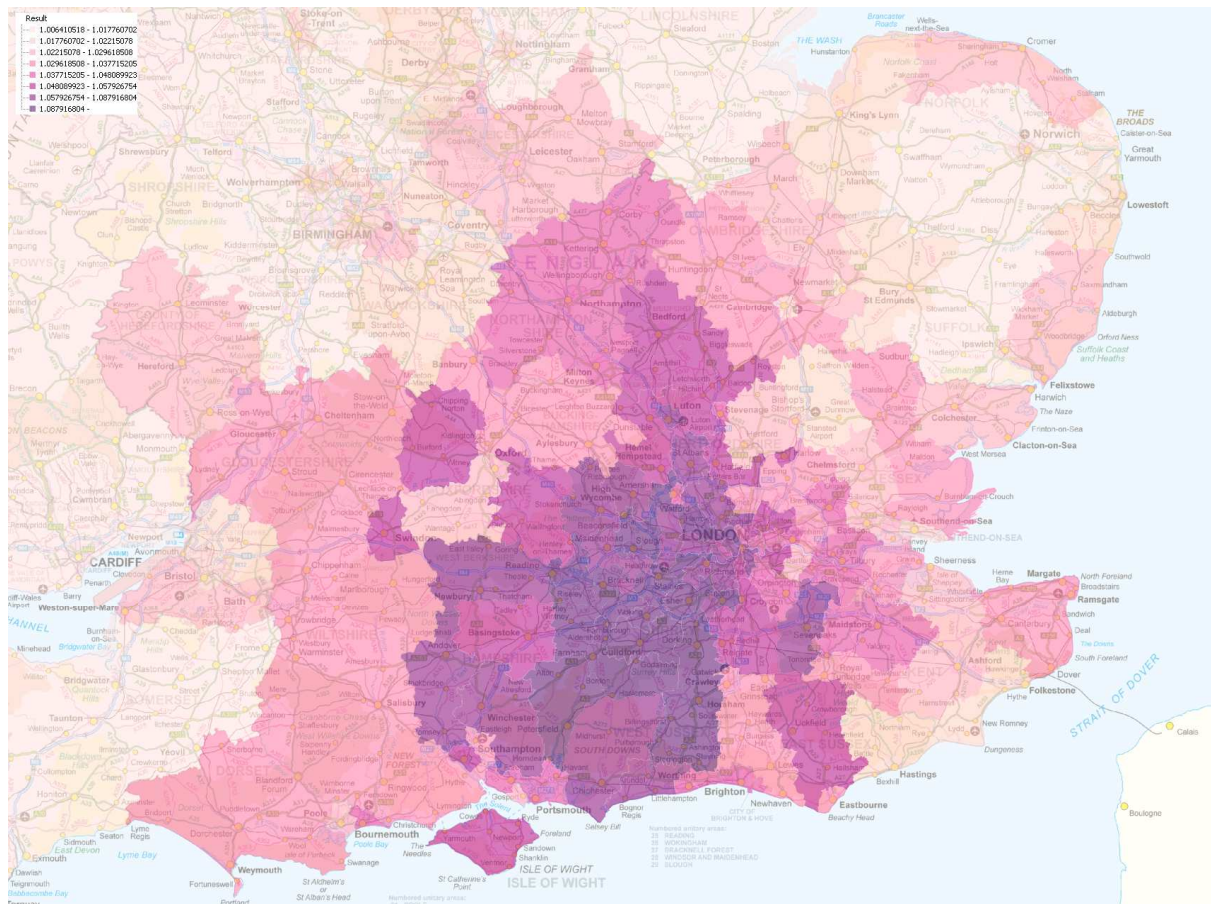


Table 3 – Industrial sectors, types of persons, households, land and floorspace.

Code	Legend	Units	Trans/able	Type
ENLSEC01	Endogenous Labour SEC01 HRP managerial, professional, Employers, supervisory	Person	T	Labour by SEC
ENLSEC02	Endogenous Labour SEC02 HRP semi-routine and routine, students	Person	T	Labour by SEC
ENM01AGR	Endogenous agriculture / mining	Pound	T	Endogenous Industry
ENM02MFG	Endogenous manufacturing	Pound	T	Endogenous Industry
ENM03WHO	Endogenous wholesale	Pound	T	Endogenous Industry
ENM04REA	Endogenous real estate	Pound	T	Endogenous Industry
ENM05SER	Endogenous services	Pound	T	Endogenous Industry
ENM06GOV	Endogenous goverment. NGO	Pound	T	Endogenous Industry
ENM07RET	Endogenous retail	Pound	T	Endogenous Industry
EXMGOVSP	Exogenous goverment spending	Pound	T	Exogenous Investment
EXMINVES	Exogenous investment	Pound	T	Exogenous Investment
ENMSTGVA	Endogenous GVA (statistics)	Pound	F	Statistics
ENMSTTAX	Endogenous Tax (statistics)	Pound	F	Statistics
ENHSEC01	Endogenous Household SEC02	Household	F	Household
ENHSEC02	Endogenous Household SEC04	Household	F	Household
ENHINACT	Endogenous Household Inactive	Household	F	Household
ENHUNEMP	Endogenous Household Unemployed	Household	F	Household
LD01DOME	Domestic Land	M2	F	Land
FS01DOME	Domestic Floorspace	Room	F	Floorspace
ENL01AGR	Labour - Endogenous agriculture / mining	Person	F	Labour by Industry
ENL02MFG	Labour - Endogenous manufacturing	Person	F	Labour by Industry
ENL03WHO	Labour - Endogenous wholesale	Person	F	Labour by Industry
ENL04REA	Labour - Endogenous real estate	Person	F	Labour by Industry
ENL05SER	Labour - Endogenous services	Person	F	Labour by Industry
ENL06GOV	Labour - Endogenous goverment. NGO	Person	F	Labour by Industry

ENL07RET	Labour - Endogenous retail	Person	F	Labour by Industry
ENL_OFF	Labour - Endogenous Office	Person	F	Labour by Floor Type
ENL_RET	Labour - Endogenous Retail	Person	F	Labour by Floor Type
ENL_FAC	Labour - Endogenous Factory	Person	F	Labour by Floor Type
ENL_WAR	Labour - Endogenous Warehouse	Person	F	Labour by Floor Type
ENL_FIE	Labour - Endogenous Field	Person	F	Labour by Floor Type
FS02RETA	Retail Floorspace	M2	F	Floorspace
FS03OFFI	Office Floorspace	M2	F	Floorspace
FS04FACT	Factory Floorspace	M2	F	Floorspace
FS05WARE	Warehouse Floorspace	M2	F	Floorspace
LD02NOND	Non Domestic Land	M2	F	Land
LD03AGRI	Agricultural Land	M2	F	Land
EXPINACT	Exogenous Person Inactive	Person	T	Person
EXPUNEMP	Exogenous Person Unemployed	Person	T	Person
FL01DOME	Domestic Floor	Room	F	Floor
FL02RETA	Retail Floor	M2	F	Floor
FL03OFFI	Office Floor	M2	F	Floor
FL04FACT	Factory Floor	M2	F	Floor
FL05WARE	Warehouse Floor	M2	F	Floor

Table 4 (continued)

	FS01DOME	FS02RETA	FS03OFFI	FS04FACT	FS05WARE	EXMGOVSP	EXMINVES	Internal	External
ENM01AGR	-	-	-	-	-	30	514	38,486	16,682
ENM02MFG	-	-	-	-	-	48	66,600	448,071	132,357
ENM03WHO	-	-	-	-	-	22	12,064	338,494	17,455
ENM04REA	-	-	-	-	-	0	2,458	98,395	24
ENM05SER	-	-	-	-	-	714	10,178	419,589	52,382
ENM06GOV	-	-	-	-	-	194,182	3,111	315,686	6,729
ENM07RET	-	-	-	-	-	10	391	344,233	29,611
EXMGOVSP	-	-	-	-	-	-	-	-	197,961
EXMINVES	-	-	-	-	-	-	-	-	120,589
ENMSTGVA	-	-	-	-	-	-	-	-	-
ENMSTTAX	-	-	-	-	-	1,396	7,009	-	-
ENHSEC01	-	-	-	-	-	-	-	-	-
ENHSEC02	-	-	-	-	-	-	-	-	-
ENHINACT	-	-	-	-	-	-	-	-	-
ENHUNEMP	-	-	-	-	-	-	-	-	-
ENL01AGR	-	-	-	-	-	-	-	-	-
ENL02MFG	-	-	-	-	-	-	-	-	-
ENL03WHO	-	-	-	-	-	-	-	-	-
ENL04REA	-	-	-	-	-	-	-	-	-
ENL05SER	-	-	-	-	-	-	-	-	-
ENL06GOV	-	-	-	-	-	-	-	-	-
ENL07RET	-	-	-	-	-	-	-	-	-
ENL_RET	-	-	-	-	-	-	-	-	-
ENL_OFF	-	-	-	-	-	-	-	-	-
ENL_FAC	-	-	-	-	-	-	-	-	-
ENL_WAR	-	-	-	-	-	-	-	-	-
ENL_FIE	-	-	-	-	-	-	-	-	-
FS01DOME	-	-	-	-	-	-	-	-	-
FS02RETA	-	-	-	-	-	-	-	-	-
FS03OFFI	-	-	-	-	-	-	-	-	-
FS04FACT	-	-	-	-	-	-	-	-	-
FS05WARE	-	-	-	-	-	-	-	-	-
LD01DOME	12,844,572,330	-	-	-	-	-	-	-	-
LD02NOND	-	511,369,177	321,776,324	542,399,638	260,627,500	-	-	-	-
LD03ARGI	-	-	-	-	-	-	-	-	-
ENLSEC01	-	-	-	-	-	-	-	18,688,311	-
ENLSEC02	-	-	-	-	-	-	-	7,778,738	-
EXPINACT	-	-	-	-	-	-	-	-	29,764,100
EXPUNEMP	-	-	-	-	-	-	-	-	1,582,622
Internal	-	-	-	-	-	-	-	-	-
External	-	-	-	-	-	-	-	-	-