# STUDI: A model to simulate the impacts of new metro lines on urban development in London

by

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# Declaration

I, Aris Christodoulou, confirm that the work presented in this dissertation is my own. Where information has been derived from other sources, I confirm that this has been indicated in the dissertation.

Aris Christodoulou

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# Abstract

Urban systems are complex and change as a result of the interactions between their main elements. In order to model urban systems effectively, the dynamics of the relationships between these elements need to be considered. This thesis investigates the interactions between transport and urban development, focusing on the impacts of new metro lines. A new model is developed for this purpose: the STUDI (Simulation of Transport and Urban Development Interactions) model.

The main concept underlying the STUDI model is that the impacts of new transport infrastructure on urban development are reflected in the interactions between the main agents involved in the process, which are authorities, developers, businesses and population. The STUDI model contains three main interrelated sub-models: the development, the business and the population sub-models.

The development sub-model is a regression model forecasting the number of new commercial and residential premises, and the business and population sub-models are microsimulation models. The business sub-model simulates business start-ups and closures and business location and relocation decisions. The population sub-model simulates in- and out-migration, demographic and employment change, and residential location decisions. The main results include changes in the spatial distributions of development, businesses and population over time under different transport supply scenarios.

The STUDI model has been developed for London in order to test the wider impacts of new metro lines. First it has been applied to evaluate the impacts of the Jubilee Line Extension (JLE) and then it was used to forecast the impacts of a line to open in the future: the East London Line Extension. Both cases indicate the positive impact of new transport infrastructure on urban development.

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# 1 Introduction

This study explores the interactions between transport and urban development focusing on the dynamics of the impact of new metro lines. For this purpose a new model has been developed: the STUDI (Simulation of Transport and Urban Development Interactions) model deals with the interactions in question in the context of urban systems modelling.

Urban systems are complex as are the interactions between transport and urban development and they involve dynamic relationships. New transport infrastructure can be the result of increasing demand for transit, but also the main policy-tool for the development of an area; it is expected to attract new development, and development of an area – which can be boosted by relevant policies – is expected to increase the demand for transport. Population is attracted by accessible housing and employment supply in one area increases as businesses move into that area or as accessibility to business areas increases. Businesses make location choices considering several factors, including accessibility to the workforce, other businesses and markets, and availability of premises. Developers, either by forecasting or by responding to the increased floorspace demand, make choices about new developments.

According to this brief description of location-related procedures of urban development, the four key agents (actors) involved in these procedures can be identified: authorities (i.e. government, local authorities, policy makers, transport authorities etc.), developers (i.e. construction companies, real-estate agents), businesses and population. The main concept of the STUDI model is that the procedures of urban development and the impact of new transport infrastructure on urban development are reflected in the interactions between the main agents of urban development. These interactions occur over time and hence they should be modelled in a dynamic framework.

Most models simulating the interrelation of transport and land-use focus on road networks, including public transport as a variable. Additionally, while travel demand models consider the impacts of land-use on transportation systems, most of them lack the ability to reflect the implications of transportation investments on the patterns of land development, except in a limited way (Zhao and Chung, 2003). In this study, the impacts of new public transportation on land use are modelled explicitly.

The STUDI model has been designed to be comprehensive in order to represent all the main factors of urban development. It simulates the interactions between developers, businesses and population and models the impacts of various factors – including transport – on their location decisions. Authorities are not included because their decision-making processes are affected by unmeasurable and subjective factors; decisions made by authorities (i.e. policies) are imported exogenously in the STUDI model in order to be tested. Location decisions of developers refer to decisions about where to develop new residential or commercial premises. Business location decisions refer to choices about where to locate their establishment. Population location decisions include residential and employment location choices. Location decisions involve behavioural factors and to be modelled realistically such factors should be considered.

A disaggregate model can address the behavioural characteristics of choices in more detail than an aggregate one. Also it can provide more flexibility and better monitoring of location changes, as the origin and destination of an agent who is relocating can be tracked, and it can represent the relationships between the agents of urban development in detail. The current form of the STUDI model is highly disaggregate at agent level, moderately disaggregate at sectoral level and aggregate at spatial level. Spatial aggregation at borough level was chosen for several reasons. One was that various datasets, specifically those on development were available only at borough level. Furthermore, the computational speed of the model was benefited by this decision as having fewer zones improves the running time of the model. In general, a model that runs relatively fast is needed, as speed is a key element of the operationality of the model.

The core aim of the STUDI model is the modelling of urban systems in order to understand, simulate and forecast the wider impacts of new public transport infrastructure in large cities, i.e. the impacts on the agents of urban development, on their interactions and on their location choices. The STUDI model has been developed for London and the Jubilee Line Extension (JLE) on London Underground is used to validate it. It is also applied to forecast the impacts of the opening of the first phase of the East London Line Extension (ELLX). The STUDI model was developed in order to be operational and these two applications are used to test its operational potentials. During its development, the potentials of more applications and wider use were also considered.

In accordance with the conceptual approach described earlier, the STUDI model consists of three sub-models: the development, the business and the population sub-models. The STUDI model runs over time simulating development, business and population processes for a number of simulation periods. The three sub-models are interconnected and exchange information dynamically. The development sub-model uses regression analysis to estimate the number of new commercial and residential premises to be added in each zone in every simulation period. The business sub-model is a microsimulation model, which simulates the decisions of each business separately. It simulates business start-ups and closures and relocation of existing businesses. It is applied to the total business population (individual business records) of London, which has been synthesized by using the Annual Business Inquiry data. The population sub-model is also a microsimulation model, which operates either at individual or at household level. It simulates demographic changes, migration, and employment and residential location decisions. It is applied to the raw LATS (London Area Transport Survey) data of 2001.

According to the discussion so far, the main features that were considered during the development of the STUDI model were:

- Dynamic representation
- Comprehensiveness
- Choice modelling
- Disaggregation
- Operationality
- Transport representation

- Modelling of large cities
- Transferability

In Chapter 2, the four agents of urban development are presented and the impacts of new transport infrastructure on each agent are examined. Methodologies and results of several studies that investigate the impacts of major transport investments on urban development are reviewed and the influence of JLE on each agent is discussed.

In Chapter 3, the most important models and methodologies on the interactions between transport and land use are reviewed in order to identify the ones that best comply with the key desired modelling elements. The preferred modelling methodology is chosen and justified.

In Chapter 4, the data used in the STUDI model are described and procedures followed in order to transform the data in the desirable forms are discussed.

In Chapter 5, a new model, the STUDI model, is presented. The various procedures followed in the development, business and population sub-models are described. This includes the commercial and residential development models, the modelling of business start-ups and closures, the simulation of business location and relocation decisions, the simulation of demographic changes, in- and out-migration, and the modelling of employment and residential location decisions. The links between the three sub-models representing the interactions between the agents of urban development over time are also discussed. In this context, reference to assumptions and areas that can be improved is also made.

In Chapter 6, the estimation, calibration and validation procedures of the STUDI model are presented. At first the equations used in the STUDI model are estimated and key indicators are determined. Then the results of the STUDI model are validated and the impacts of stochastic variation are examined. The forecast development, business and population distributions are compared to the real ones for two years, one in the middle of the whole simulation period and one at the end.

In Chapter 7 the STUDI model is applied to estimate the impacts of the JLE on urban development. Results presented include development, business and population distributions with and without the JLE in order to capture the impact of the new line, and relevant differences as forecast by the STUDI model. Moreover, results related to the distributions of employment positions and employed population with and without the JLE are shown.

In Chapter 8 the STUDI model is applied to estimate the impacts of the ELLX which is expected to open in the near future. Future business start-ups and closures and in- and out-migration are forecast based on economic growth. Results presented include distributions of commercial and residential development, businesses and population with and without the ELLX as forecast by the STUDI model.

In Chapter 9, issues raised during the conduct of the study and others that need to be further researched in the future are discussed.

In Chapter 10 a research summary in the form of conclusions is presented.

# 2 Agents of urban development

In order to model the interactions of the main agents of urban development (i.e. authorities, developers, businesses and population), the relationships between them and the impacts of transport infrastructure on their location decisions need to be understood. In this chapter, the agents of urban development are analytically presented and their relationship with transport infrastructure is discussed. Methodologies and results from several studies, which investigate the impacts of major transport investments on urban development, are reviewed. In this context the case of the Jubilee Line Extension on London Underground is also examined.

The JLE (Figure 2.1) opened in 1999 and starts from Westminster; towards the east it runs along the southern part of the Thames until Canada Water, it then crosses three times the river Thames before it turns to the North until Stratford. The JLE includes the following stations: Westminster, Waterloo, Southwark, London Bridge, Bermondsey, Canada Water, Canary Wharf, North Greenwich, Canning Town, West Ham and Stratford. It runs through an area which used to be among the most deprived in UK (mainly the eastern part of JLE), although neighbouring with highly developed areas of London. The JLE has contributed significantly to the improvement of the areas included in its corridor, especially the London Docklands area (i.e. the area around Canary Wharf station) where the most intense development occurred. The history of the development of the JLE is presented in Willis (1997).

New transport infrastructure affects urban functions in various ways. Moon (1990) argued that the primary positive impacts of rapid transit systems on economic development and land use are environmental and federal policies and regulations, demographic changes, changes in city functions and a rising demand for developable property. Two factors that continue influencing the relationship between transit systems, economic development and land use change are traffic congestion and the related commuting habits of individuals. He also argues that economic development is certainly occurring around the stations. Such impacts will be described through the interactions of the main actors of urban development.

Two general conclusions that came up from many studies on land use impacts of new urban rail transit investments are the following (Cervero and Landis, 1993):

- "Urban transportation investments will generate significant land-use impacts only if a region's economy is growing" and if
- "there are complementary development programs in place, such as zoning policies, which support higher densities or more intense land uses."

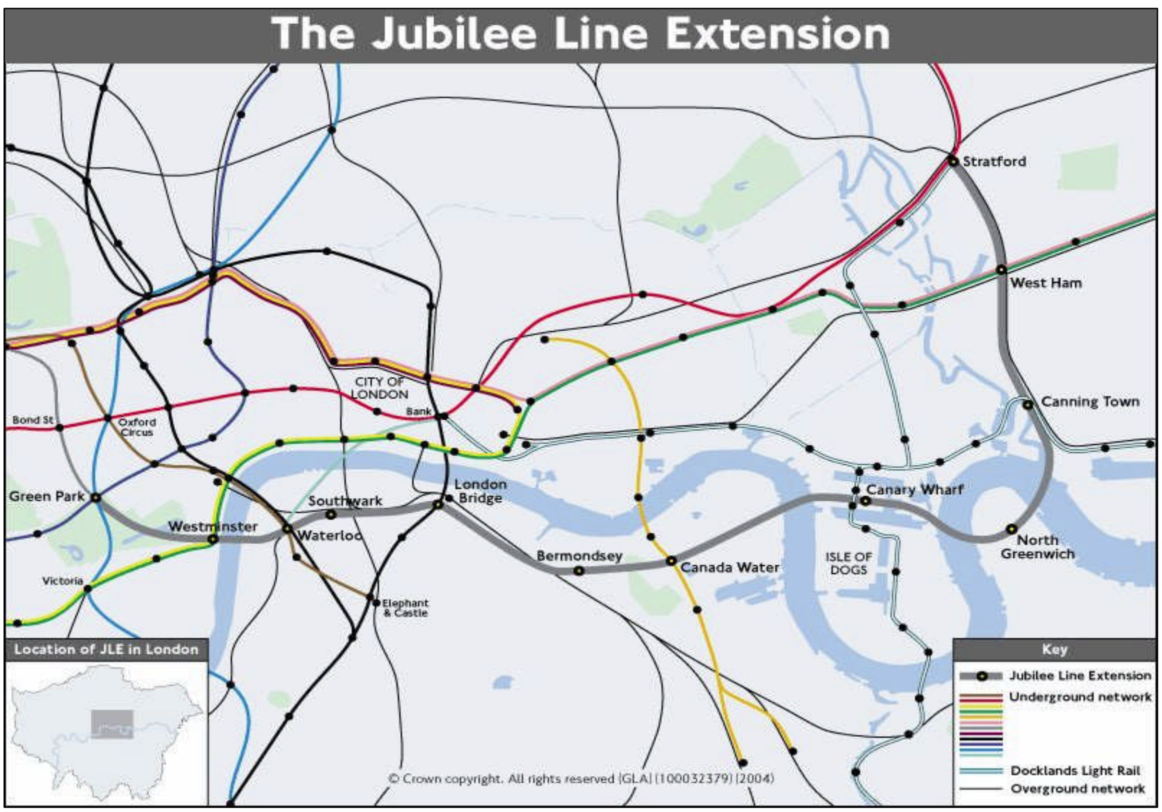


**Figure 2.1: Map of the JLE (taken from Transport Studies Group, 2004)**

## 2.1 Authorities

Authorities (e.g. municipalities, government etc.) are responsible for the legal environment in which population, developers and organisations function. They make development policies; for example they can make land available for development, they define land use, they can give incentives to attract development etc. Additionally, they make decisions about new transport infrastructure for various reasons including the attraction of development and the fulfilment of the needs of population. On the other hand, development of an area may have adverse impacts on incumbent residents; rapid development of an area can increase land and property values and as a result the incumbent population may be forced out of the area. For example, the development of Canary Wharf attracted thousands of new jobs, but it had little positive impact on the employment of local population, which suffered historically from high unemployment (Transport Studies Group, 2004).

Authorities interact with organisations. They try to attract big multinational companies in order to strengthen the national economy and the international position of the country and to reduce unemployment. The development of Canary Wharf attracted many multinational companies from the financial sector. Some of them might had gone to the City, but others might had chosen other cities within Europe to allocate their headquarters; this was a great benefit for London in both economic and employment terms.

In most cases, authorities expect to have long-term monetary (e.g. from taxes or fare revenue) or political benefits from new transport investments. The decision procedure for a new project involves the interaction of various governmental sectors with local authorities and developers. Authorities can take measures in order to promote development or in support of a new project (e.g. to support a new transit line they can give transit oriented development incentives), which will affect developers’ decisions. Economic growth of an area may increase the demand for transportation systems and new transport infrastructure is expected to attract development, but not without support. In the following, the role of authorities in the interactions between urban development and transport is discussed in the context of some major urban rail schemes.

In 1979 the first 13 stations of Atlanta's rail system called MARTA (Metropolitan Atlanta Rapid Transit Authority) opened. An early study of MARTA, called TIMP (Transit Impact Monitoring Program), was based on before-and-after comparisons of station catchment areas. The results showed that the impacts of MARTA on development were far smaller than expected and occurred at only some of the stations. No significant public policies – except rezoning – had been adopted by Atlanta's authorities to promote development in station areas (Bollinger and Ihlanfeldt, 1997).

The significance of the role of authorities in the wider success of new transport schemes becomes clearer from the comparison of two transport schemes that received different level of support: the SkyTrain in Vancouver (Babalik, 2002) and the South Yorkshire Supertram (Crocker et al, 2000), which opened in 1986 and 1994 respectively. The outcome of this comparison indicated that construction of a new transit system is not enough to attract development to an area and supportive policies are also needed (Babalik, 2002). The two rail systems together with some other rail systems in Europe and America have been analysed in Babalik (2002) from where the following information are extracted. The Vancouver SkyTrain was evaluated as a very successful rail system. It had a positive impact on urban growth; along its corridor significant development occurred, it affected positively the city centre and declining areas and around of some of its stations significant residential development occurred. On the other hand, the South Yorkshire Supertram did not perform very well; neither in patronage levels, nor in attracting development around the corridor. Although it is difficult to establish conclusions about the elements of success by comparing two different schemes, these two cases are probably two extremes in terms of the support they received.

In Vancouver, the municipalities located across the corridor of SkyTrain acted supportively towards the new rail by taking  actions such as redevelopment of industrial areas, adaptation of local plans to the transportation system, rezoning of station areas, joint development schemes, relocation of government buildings at the station areas and provision of development incentives (Transit-oriented development TOD incentives) e.g. development bonuses, tax reductions, reductions in car parking requirements (Babalik, 2002). Additionally, municipalities in Vancouver restricted major commercial development in areas far from the SkyTrain corridor.

In the case of South Yorkshire Supertram, there was poor coordination between the new rail project and the regeneration of the area project; some lines of Supertram were built to serve an area with high-density council flats (Babalik, 2002). However, these blocks of flats were demolished during the construction of the rail system. Furthermore, one route was designed to help in the regeneration of an ex-industrial area but the location of the line did not provide the best service to the new activity centres that were developed in this area. Other characteristics found to act supportively towards the use of new rail system are the following: security on board, parking supply in the station areas, economically strong CBDs (Central Business Districts), high frequency and the fare system.

In many cases authorities, respond to increasing development, which may increase demand for transport and often they work in cooperation with developers in order to promote a general plan of development as happened in Vancouver. Such cooperation is very important in the overall success of an urban rail scheme. Anyway, authorities affect directly location decisions of other agents, through development and transport policies. Many unmeasurable factors are included in these policies making their modelling very complex.

## 2.2 Developers

The category of developers includes constructors and real estate agents. Developers construct buildings to accommodate firms and residences for the population. Development location decisions are driven by the demands of businesses, and population and by location attributes; Swanson et al (2006) use land availability, property vacancy rates and smoothed historic business growth rates to estimate an attractiveness measure for developers. Developers may act independently, but some times – especially in big schemes – they form corporations. They are attracted by beneficial legislation (e.g.

building density) and supportive policies from the authorities. In the following, the key characteristics of development in the JLE corridor and the impacts of new transport infrastructure on development using the experience from other transit schemes will be discussed.

The most intensive development of the JLE corridor occurred in Canary Wharf. In fact, development started before the construction of JLE. Olympia and York signed a master building agreement with the LDDC (London Docklands Development Corporation) in October 1987 for a 1.1 million sq. meters development at Canary Wharf. The first tenants moved to Canary Wharf in 1991. However, LDDC recognized that the development of the area would not reach its maximum potential without major public transport infrastructure. The second phase of development did not begin until 1997 (Transport Studies Group, 2004). For the rest of the JLE corridor – besides Canary Wharf – the same report concluded that there is little evidence that the JLE has had significant impact on the rate of mixed use development or commercial development. However, the annual rate of residential dwelling construction in the corridor more than doubled from the three year period 1991-1993 to the seven year period 1994-2000. Additionally, the JLE helped to encourage major residential and commercial development in the JLE corridor including 130,000 sq.m of offices at London Bridge, 2000 residential units and commercial development at Canada Water, the additional 1.1 million sq.m of offices and 3,500 residential units at Canary Wharf, the Dome, 339,000 sq.m of offices and 10,000 residential units at North Greenwich and 465,000 sq m of offices, 150,000sq.m of retail space and 4,500 residential units in Stratford (Transport Studies Group, 2004).

A transport scheme that has extensively been examined is BART (Bay Area Rapid Transit) which opened in 1972 in San Francisco. Cervero and Landis (1997) argued that “BART had a modest though not inconsequential influence on land uses and urban development in the Bay Area. It did not create new growth, but rather acted to redistribute growth that would have taken place even without a rail investment”. BART affected land uses only where supportive conditions existed.

Cervero and Landis (1993) used quasi-experimental comparisons to assess the impacts of urban rail transit on local real estate markets; they compared similar cases which differ in one key dimension, i.e. a station area and its control area were chosen and compared. Comparisons were made on the basis of six measures of office market performance: average office rents, net absorption rates, vacancy rates, annual office space additions, average building size and percentage of new regional office floor space. T-statistics were computed based on the mean of paired differences between station areas and control areas for each of the six variables over the study period (matched pairs testing is regarded as less powerful than other comparative techniques such as multiple regression analysis; however, lack of systematic data covering other factors, which can influence office market performance precluded the use of regression analysis). Office buildings at some of the stations areas did command a slight rent premium over their freeway oriented competitors. For most of the real indicators no significant differences between the rail and non-rail areas occurred. In sum, the argument that transit service necessarily generates large capturable benefits for the owners of station area office buildings could not be supported. The authors concluded that transportation and land use changes occur simultaneously reinforcing each other and that transit investments by themselves are not sufficient to induce new growth.  Referring to the time when an impact study should be conducted Cervero and Landis (1993) argued that the study of land use impacts is best undertaken a decade or so after a new rail service begins; earlier the market may not have the time to respond to the new infrastructure.

In another study about the development impacts of BART, Cervero and Landis (1995) used hedonic price models in order to isolate the impact of distance from transportation on home prices, and thus to estimate the capitalization effects of proximity of households to BART. GIS was used for sale transactions to allocate housing units to computerized street maps and then to calculate the distance from each housing-unit to BART stations and highway interchanges. The regression results indicated that selling prices increase the closer a house unit is to the nearest BART station and decrease the closer a housing unit is to a highway access point, all else being equal. In terms of office rents the impacts of BART varied from station to station; there were stations the closer to which office rents increased and stations for which rents were higher as distance from the station increased.

BART affected residential densities, office development and the office rents. The impact of BART on office development is remarkable, particularly in downtown San Francisco, where many new offices were built within a quarter mile of BART. However, not all the BART stations attracted the development of new office buildings at the same density.

In summary, there are not arguments supporting the hypothesis that new transport infrastructure by itself can attract new development. In many cases it does but in general transport and development changes affect each other.

## 2.3 Organisations - Businesses

There are public and private organisations. Public organisations can have significant impacts on local development as in many cases they employ large numbers of people. They have different location criteria from private businesses and some times they operate as both authorities and firms in the urban "mechanism". The focus of the research will be will be on private businesses and firms.

Businesses interact directly with the other actors. They pay taxes to authorities, they operate within the legal framework set by the authorities, they may benefit from or be harmed by policies implemented by authorities and they purchase their establishments from developers. Population supplies organisations with employees and clients. Businesses interact with each other by competing or cooperating. Transport helps the interaction between firms and provides them with labour and customers; thus better transport infrastructure can improve firms' efficiency and performance and increase labour supply potentials.

Regarding the JLE case, the transformation of an industrial area – such as Canary Wharf – to an office area gave the opportunity to develop a large space in an aesthetically special area. However, to manage the transformation of a deprived area into an economic and employment centre, adequate transport infrastructure was needed. The development of the area of Docklands attracted many multinational companies mainly from the financial sector creating an alternative or an extension of City. This was beneficial not only for the particular area, but for London in general as big companies chose London –

instead of another European city – for the establishment of their headquarters. Although the first part of reconstruction of Canary Wharf was completed in 1992, general recession in the property market, as well as lack of good transportation did not allow the area to increase its development rate until the end of 1990s, when JLE opened (Transport Studies Group, 2004). In this section the interactions of organisations with the other actors of urban development and the impacts of transport infrastructure on businesses' location choices are discussed.

Businesses make location decisions, considering features such as accessibility, travel time, travel cost, land and property values, building space availability, labour costs, regional taxes etc. McQuaid et al (2004) note that the most important factors influencing business location decisions are (i) availability of suitable premises, (ii) accessibility to the workforce and (iii) accessibility to markets and other businesses. Location decisions depend also on the type and size of the business, e.g. for some businesses regular face-to-face contact is needed and thus transport cost increases; such businesses tend to concentrate in large agglomerations (Glaeser and Kohlhase, 2004). Other businesses require easy access to a main road network. De Bok and Sanders (2005) studied the location choices of firms in the Netherlands and they concluded that bigger office firms providing business services including lawyers, advertising agencies, accountants, economic consultants prefer locations close to highways and smaller firms seem to prefer locations with a railway station nearby; the same holds for the government and public sector (Glaeser and Kohlhase, 2004; Bollinger and Ihlanfeldt, 1997). Glaeser and Kohlhase (2004) observed a difference between big and small businesses, which consist mainly of retail and catering. Bigger firms showed preference in the urban business district or mixed urban locations and near railway stations. Small firms showed preferences in the urban business district and non-urban locations.

Attracting organisations to a newly developed area can mean the creation of new businesses, opening of new branches or complete business relocation. The most important theories explaining the location of business are the neo-classical, the behavioural and the institutional (Brouwer et al, 2002). The neo-classical theory is quite abstract and takes into account transportation and labour costs. The behavioural location theory assumes that managers may have multiple goals and seek to maximize their own utility. The institutional location theory considers firm's negotiations with suppliers, governments, labour unions and other institutions about prices, wages, taxes, subsidies, infrastructure and other factors in the production process. Other theoretical approaches on the location of business include economic base models that deal mainly with industries that export from a region, core-periphery models focusing on the relationship between core and peripheral regions, location theories taking into account regional features, agglomeration economies and other factors, industrial district models focusing on characteristics contributing to a successful regional economy, cumulative causation theory, the competitive advantage theory of Porter (1990) and innovative milieu models (McQuaid et al, 2004). In any case, transport infrastructure is expected to affect the location choice of firms either directly as so it can increase labour supply pool, and improve accessibility to customers, suppliers and other businesses, or indirectly by affecting other factors important for the location decisions of firms such as land values. Generally, the impact of public transport on the development of an area varies from case to case. New transport infrastructure can assist firms to relax location constraints allowing them to select from a wider range of locations and relocation of a firm can bring economic benefits if it helps the firm to improve productivity and operational efficiency (Holl, 2006). Furthermore, transport infrastructure improvement can affect organisations by affecting agglomeration economies. Transport improves interactions of economic agents, by reducing travel time and cost.  However, Haughwout (1999) argued that in US transport investment may have opposite effects on agglomeration economies by moving growth from areas having already dense employment to more undeveloped areas.

The influence of transport on firm location decisions is difficult to estimate. De Bok and Bliemer (2005) proposed a microsimulation modelling approach for the simulation of the interactions between transport infrastructure and firm location choices. Such a methodology increases heterogeneity in responses, it allows the use of accessibility measures as explanatory variables for events such as firm relocation, performance and dissolution and lastly it helps understanding of the path dependency between events, e.g. the relationship between new transport infrastructure, firm growth and firm relocation.

In an application of MEPLAN model in Sacramento, Abraham and Hunt (1999) evaluated various scenarios of major transport investments. They predicted that construction of rail in combination with some roadway projects and measures – to make the use of private vehicles unattractive to the population – would have forced businesses in the area of stations to move in order to avoid parking surcharge. On the other hand, the area gained residents, since absence of commercial activities made the area more attractive (and affordable) to residential activities. In the case of a more dramatic scenario including land use policy changes, land subsidies, investment in transit and higher transit frequencies, it was predicted that the land subsidies would have attracted development in large. Different kinds of activities bidding against each other will raise rents and attract developers.

In this section various issues related to business location decisions were discussed and important factors to be considered in the business modelling procedures were identified, such as the importance of the availability of suitable premises and the accessibility to workforce on the attractiveness of a location for businesses.

## 2.4 Population

The location choices of businesses are expected to affect population location choices. As mentioned above, people can be related to companies either as customers or as employees. Employment choices of people may affect residential choices through transportation supply. People are interacting directly with the rest of the actors. They vote for the election of the authorities and they pay taxes to authorities. On the other hand, authorities support development and they try to increase employment and to improve infrastructure. Developers construct and supply residential premises. People work in organisations. People are interacting with each other: in the property market they compete in order to buy residences and in the employment market they compete in order to get a job. Moreover, people with common characteristics (e.g. income) tend to concentrate in the same neighbourhoods. The impacts of new transport investment on residential infrastructure and house prices are discussed in the first part of this section and the impacts of transport on employment in the second.

### 2.4.1 Residence

New transport infrastructure can increase house prices in the areas close to the stations due to improved accessibility. However, increased noise and traffic might have adverse effects on the prices of properties, which are very close to the stations. Bowes and Ihlanfeldt (2001) estimated the impacts of rail transit stations on residential property values for the case of MARTA and they concluded that: "Properties within a quarter of a mile from a rail station are found to sell for 19% less than properties beyond three miles from a station. However, properties that are between one and three miles from a station have a significantly higher value compared to those farther away. These results suggest that houses that are very close to stations are affected by negative externalities, but those at an intermediate distance are beyond the externality effects and benefit from the transportation access provided by the stations".

It is important to see when impacts on house prices start to occur in the areas where a new transit line is being built, since in some cases the benefits of the new transit line begin to be capitalized into house prices before the opening of the new line. McMillen and Mcdonald (2004) estimated the reaction of house prices to Chicago's Midway Line – which opened in 1993 – and they found that the impacts of the new transit line on house prices began 6 years before the construction was completed (McMillen and Mcdonald 2004; McDonald and McMillen, 2000). The house price gradient with respect to distance from the nearest station rose from 4.2% before 1987 to 19.4% during 1991-1996. In an earlier study about the Chicago's Midway Line, McDonald and Osuji (1995) estimated the impact of the new line by using a generalized before-after method and they concluded: "Residential land values within one-half mile of the station sites were 17% higher than they otherwise would have been because of the future improvement in transportation service, and proximity to the right-of-way was regarded as a negative external effect".

The impact on house prices is certainly important because it reflects the demand for houses and hence attraction of population, but the impacts of new transport infrastructure on population can be seen directly by examining changes in population size and composition. To capture the impacts of MARTA on population and employment Bollinger and Ihlanfeldt (1997) compared station and non-station tracts and they concluded that MARTA had little effect on total population and employment in station areas but it had some effect on industry and population mix in these areas. In San Francisco Cervero and Landis (1995) estimated that residential population grew 20% faster in corridors not served by BART than in those served by BART.

The JLE appears to have affected the residential market in the JLE corridor (Transport Studies Group, 2004). Considerable residential development occurred in the Isle of Dogs by 2000 and the available land for new residential development has decreased significantly since then. Residential sales in Canary Wharf increased by 17.5% during the period 2000-2001, while for the same period residential sales in the prime Central London area as a whole increased by 12.7%. The catchment areas of Waterloo and London Bridge stations changed significantly after the JLE opened. They used to have limited commercial activity and residential development and now they have become important commercial and residential areas (Transport Studies Group, 2004). Moreover, the residential property market around the station of the JLE at Stratford has changed considerably.

Agents specialised in the area of JLE corridor suggested that residential property prices have risen very fast in the corridor, especially to the south of the river. The new residents moved to the area have definitely changed the previous population composition.

### 2.4.2 Employment

The opening of the JLE appeared to have been beneficial also for employment growth. In the JLE Summary Report (Transport Studies Group, 2004) employment growth was estimated using reference areas. Employment in the JLE corridor grew faster than in any of the reference areas. The total increase was estimated to be 52,000 representing the 53% of all employment growth in the Inner East London Area (IELA). A forecasting exercise indicated that the JLE under-performed in employment terms during the pre-opening period but over-performed during the post-opening period. Most of the growth happened to the east of London Bridge. The impacts of new transit lines on employment are examined below.

Cervero and Landis (1997) conducted a study about the land use and development impacts of BART. They used matched pairs analysis (i.e. comparison between station and non-station areas, which lie within a distance of 1 to 2.5 miles and connect with the same arterial). A logit model was used to predict the likelihood of land use conversion. The two primary data inputs used, were digital data of dominant land uses for hectare grid cells in 1990 and estimates of dominant land uses near BART stations in 1965 made from aerial photographs. The binomial logit model predicted the probability of each hectare grid-cell changing land-use from 1965 to 1990 as a function of distance to the nearest BART station. The rate of building construction during the post BART era was estimated using regression models. The models predicted growth rates in residential and non-residential floorspace as functions of parking supply, proximity to freeways, land use mixture, vacant land and how close a station is to the end of a line. Measuring employment growth for the period 1970-1990 in three counties, they estimated that employment grew 84.5% in the districts not served by BART compared to 38.9% growth in the districts served by BART. The largest difference between non-BART and BART areas occurred in the county of Alameda. They argued that the results mirror the trend of job decentralization that happened throughout the US. They also concluded that businesses near BART had high shares of executive, professional and technical workers and businesses benefiting from face-to-face contact and access to specialized labour that had been attracted to BART stations. Finally, the authors argued that to the degree that maintaining a dominant, primary commercial and employment centre has increased economic productivity in the region, BART has probably produced real, though immeasurable, economic benefits. The authors divided time in three periods: the pre-BART the early-BART and the recent-BART periods. Commercial and office development grew faster during the pre- and recent- BART periods.

Metro (Washington Metropolitan Area Transit) opened in 1976. A study comparing employment changes between station and non-station areas, showed significant differences in favour of station areas. It was estimated that station zones had 2.5 times more jobs and 2.5 times greater employment growth compared with non-station zones (Green and James, 1993). On the other hand, the opening of MARTA in Atlanta did not cause significant changes in total employment, but the composition of employment changed in favour of the public sector around the stations with higher levels of commercial activity (Bollinger and Ihnlanfeldt, 1997).

In summary, new transport infrastructure increases house prices and affects employment and population composition. The results about the impacts on size of population and employment vary from case to case: there are certainly strong regional effects and other factors such as authorities' decisions – as discussed in Section 2.1 – can cause an important variation in the impacts of new transport investments on population. Regarding the JLE case it seems that there were positive impacts on both size of population and employment.

## 2.5 Summary of impacts of new transport investments on urban development

Above, the impacts of new transport infrastructure on each category of agents and thus on urban development have been presented for various cases. Keeping in mind that every transport scheme is unique, the experience from other transport schemes reviewed above can help to underline some elements of success of a new project, as well as key characteristics of the impacts of transport investments on the actors of urban development. Key findings from the literature are:

- Transportation and land use changes occur simultaneously reinforcing each other. Transit investments by themselves are not sufficient to induce new growth.

- Integrated planning and supportive policies can provide significant assistance to the success of a project and to the promotion of urban development.

- Transport infrastructure may affect business location decisions directly (e.g. by improving accessibility) or indirectly (e.g. by affecting other factors such as land values). It can influence location decisions in various ways depending on size and type of business.

- The impacts of new transport infrastructure on employment vary from case to case. However, it appears that new transportation is affecting employment composition.

- New transportation can have positive impacts on residential dwelling prices.

- Most studies show that new transport infrastructure affects population composition.

## 2.6 Interactions between the agents of urban development

Various ways through which the main agents of urban development are interacting have been discussed in this section. These interactions can be expressed through flows of money, trips and information as shown in Table 2.1. However, not all of them can be modelled. For example authorities' decision-making processes are very complex and include immeasurable factors. In Figure 2.2, the procedures as they will be modelled are outlined abstractly.

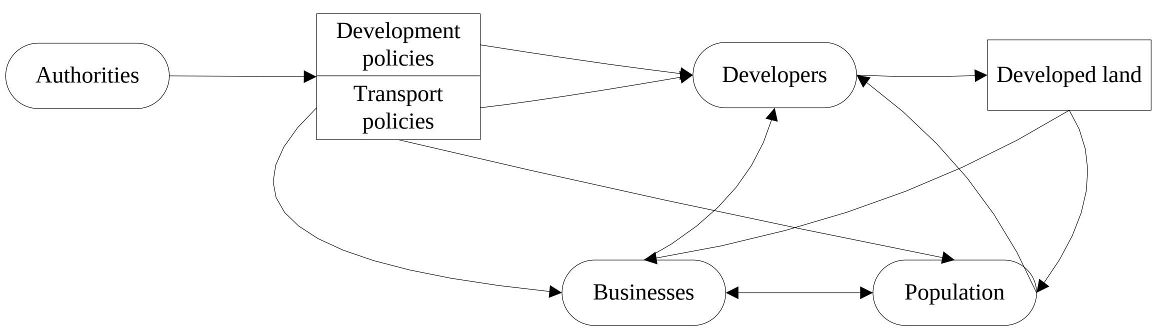


**Figure 2.2: Procedures of urban development**

Authorities affect the other agents' location decisions through development and transport policies. Developers make location decisions about developing premises taking into account the availability of developable land (affected by development policies) and demand for premises by businesses and population. Business and population location decisions are affected by the supply of premises.

| | | to | | | |
|---|---|---|---|---|---|
| | | Authorities | Developers | Organisations | Population |
| from | Authorities | Different public or governmental sectors interact in order to decide and to realize a new project (money flow, information flow). | Authorities assign projects to developers (money flow). They are responsible for legislation and they can give development incentives to developers (information flow). | Authorities can give incentives to attract organisations and are responsible for legislation (information flow). | Authorities correspond to people's needs for better transport infrastructure, employment and residence and are responsible for legislation (information flow). |
| | Developers | Developers try to achieve better deals, beneficial legislation and supportive policies for their projects. They pay taxes (money flow). | Developers construct infrastructure. They form corporations or compete in order to take the project (money flow, information flow). | Developers construct the buildings to accommodate firms. | Developers construct residences, working places and transport infrastructure to cover people's needs. |
| | Organisations | Big companies are attracted by incentives given by authorities (e.g. tax incentives). They pay taxes (money flow). | Organisations are attracted by major development. They buy their establishments from developers (money flow). | Organisations compete and concentrate in agglomerations in order to improve efficiency and exchange ability (money flow, information flow). | Organisations employ people (money flow), and have clients in the population. |
| | Population | People vote to elect authorities. They pay taxes (money flow). | People purchase their residences from developers (money flow). | People are employed by organisations and can be customers of firms (money flow). They travel to organisations as employees and as customers (trips flow). | Residents compete in the house market and employees in the job market. Employment location and residential location decisions interact (money flow, information flow). |

**Table 2.1: Interactions between the agents of urban development**

# 3 Review of land use – transport models

There is an interrelation between transport and land use and dynamic cyclical interactions between the two. Various models simulating these interactions have been developed over the years based on different concepts, approaches, methodologies and theories.

Lee (1973) in his Requiem for Large-Scale Models pointed out “the fundamental flaws in attempts to construct and use large models”. Some of the issues he pointed out remain valid, but others, mostly related to technology limitations that existed in the period when Lee wrote his critique, have disappeared according to a series of papers that were published in order to continue the discussion opened by Lee (Batty, 1994; Klosterman 1994; Wegener, 1994). These papers provide also a good and brief review of existing models. Regarding the desirable modelling features, Lee (1994) identified three key features necessary to make large-scale urban models scientific: transparency, replicability and pragmatic evolution and Wegener (1994) noticed the importance of comprehensivess and operationality of urban models.

Representative models of the main modelling approaches that have been used for the development of land use – transport models are reviewed in this chapter. The different modelling approaches will be evaluated according to their compliance with the following desirable elements of the model to simulate the interactions between transport and urban development for the case of JLE as identified in the Introduction:

- Dynamic: The interactions between transport and land use should be modeled over time.
- Behaviour and choice modelling: The choices of individuals and companies should be modelled and the behavioural attributes of these choices should be evaluated.
- Disaggregate: Location decisions of the agents of urban development should be modelled at individual level.

- Comprehensiveness. The essential processes of urban development must be integrated.

- Application oriented: An operational tool for real-world planning is needed.

- Transport representation: A model to represent the impacts of transport policies is needed.

The characteristics of transferability and ‘ability to model large cities’, which were also mentioned in the Introduction, although valued equivalently, are not included in the characteristics to be used in the evaluation of the modelling approaches because they depend on each model separately rather than on the modelling approach itself. The models are categorised according to Mackett (1985, 2006). The two main subcategories are the optimising and the forecasting models.

## 3.1 Optimising models (mathematical programming models)

These models produce an optimal allocation of a quantity, which is incorporated into an objective function, subject to a set of constraints. The latter make sure that the allocations are not negative, the supply side constraints are not violated and all the quantity being optimised is allocated.

Some examples of optimal allocation of quantities are the minimisation of cost of travel, maximisation of population income (or organisation’s profitability), maximisation of company’s, household’s, individual’s rent paying ability, minimisation of cost of development and minimisation of environmental impacts.

In the Herbert-Stevens model (Herbert and Stevens, 1960) the objective maximised is the aggregate rent-paying ability subject to the constraints that all households are allocated and the amount of land used does not exceed the amount of land available for residential use.

TOPAZ (Technique for Optimal Placement of Activities in Zones) was developed in Australia by Brotchie et al (1980). The model minimises the total cost of premises and travel, subject to the constraints that all activities are located and all zones are filled.

POLIS (Projective Optimization Land Use System) was developed initially at 1969 for the city of Cologne and is described in Prastacos (1985). The objective function to be optimised is derived from random utility theory and describes the choices of individuals that maximise their utility.

Optimising models are generally not used directly for the valuation of the impacts of transport and land use policies on urban development (Hunt et al, 2005). They are more suitable to explore alternative land uses than to capture behavioural responses to transportation and land use policies (Waddell and Ulfarsson, 2004). Hence they are not considered suitable for the purpose of this project.

## 3.2 Forecasting models

Forecasting models are divided in two categories according to the level of aggregation of the agents modelled. Aggregate models consider groups of agents, e.g. groups of households categorised according to household characteristics. Disaggregate models consider agents separately, e.g. in the case of population individuals or households.

### 3.2.1 Aggregate forecasting models

#### 3.2.1.1 Regression Models

Regression models consist of a relationship between the dependent variable and several independent variables. The general form is:

$$y = \alpha + \Sigma_k \beta_k x_k$$

The coefficients are estimated using appropriate statistical methods. The impact of transport on land use can be modelled by making population or housing the dependent variable and by including transport (or transport cost) in the independent variables. Thus, the coefficient of transport variable will be an estimator of the impact of transport on the dependent variable. The time factor can be included in the model by lagging the variables over time. Such a model is EMPIRIC (Hill et al, 1965). Regression models are aggregate and they do not model transport and land use explicitly.

#### 3.2.1.2 Spatial Interaction Models

In spatial interaction (gravity) models the study area is divided in several locations (zones) and the trips between each pair of zones are modelled. The spatial interactions are assumed to be proportional to the activity level of each location and inversely proportional to the transport impedance between zones. For this reason these models are also called gravity models.

The first model of this kind was the model developed by I.S. Lowry (Lowry, 1964). It combined the economic base multiplier model and the gravity model. The Lowry model divides employment in basic and non-basic employment. The place of basic employment determines the place of residence; residents demand services, which determine the place of non-basic employment; workers in non-basic employment are also allocated in the area according to another gravity model and their demands create additional non-basic employment.

ITLUP (Integrated Land Use Transportation Package) was developed by Putman initially in the early 1970's (Putman, 1983). It has been calibrated for several metropolitan regions in US and it is still used by many of them. It contains DRAM (Disaggregate Residential Allocation Model) and EMPAL (Employment Allocation Model). DRAM forecasts the number of households by household categories defined by income. EMPAL forecasts employment size by employment sectors.

LILT (Leeds Integrated Land use Transport) was developed by Mackett (1983a). It links the Lowry type model with a four-stage aggregate transport model and with a car ownership model to describe the relation between transport supply and the spatial distribution of households, employment, shopping and land utilization (Wegener et al, 1991). Taking into account the existing land use pattern, travel cost and constraints on land use, it allocates population, new housing and jobs. It was developed for Leeds and has been applied to Dortmund and Tokyo (Mackett 1990a, 1991a, 1991b). It has also been applied to forecast the impacts of the then still proposed Crossrail link (Mackett, 1994).

Some limitations of these models include the non-representation of behavioural factors influencing location choices, the fact that real estate markets and prices are not considered and the lack of detailed spatial representation (Zhao and Chung, 2006). Furthermore, they are not dynamic. As two of the key elements of the model to be applied in London are to model the behaviour of the agents of urban development and to consider the dynamics of their interactions, spatial interaction models are considered in general to be unsuitable.

#### 3.2.1.3 Spatial Input – Output Models

Spatial input-output models are based on the framework of economic input-output models. They convert economic flows by economic sectors to travel demand. Different economic sectors and the spatial patterns of their interactions within regions, as well as the movement of goods and people between zones are described. Real estate and labour markets are considered.

MEPLAN was developed by Echenique (1984). It is based on microeconomic theory and on welfare economics providing detailed economic evaluations of the predictions (Wegener et al, 1991). In the following the procedures of the model according to Echenique et al (1990) are described. The land use model consists of factors such as the location of economic activities in terms of households and employment, and the location of properties in terms of housing units or floorspace. The output of one factor is related to the inputs of other factors. Each factor has a spatial definition. For transportable factors, such as labour, the inputs can be purchased from any relevant zones. For not transportable factors, such as land and properties, the demand must be satisfied within the same place. The model iterates, generating demands of inputs to produce outputs, until the system reaches an equilibrium. Additionally, it estimates the location from which the factor obtains its inputs, considering variations in prices. Initially the production and consumption of at least one factor in one zone is defined exogenously to start the process. When the model reaches an equilibrium, the resulting trades of labour, goods and services are transformed into flows of different kinds of trips. After this, modal split and route split can be calculated considering capacity constraints. MEPLAN consists of four interrelated modules:

i. The land use module, which models the spatial location of employment and population and produces trades between zones.

ii. The land use transport interface module, which converts the matrices of flows of trade from (i) into trip matrices disaggregated by trip purposes.

iii. The transport module, which assigns the flow matrices to different modes and routes.

iv. The evaluation module, which is responsible for the cost-benefit analysis based on consumer surpluses, producer surpluses and government benefits on land and transport changes of a policy compared to a base case.

Lastly, it contains the graphic option to provide a graphical form of the results (plots, maps, charts etc).

MEPLAN has been applied to cities and wider areas of many countries around the world including UK, Finland, Sweden, Italy, Spain, Japan, US, Chile, Brazil, Venezuela, Colombia (Hunt and Simmonds, 1993; Zhao and Chung, 2006).

Another model based on the spatial input-output framework is TRANUS (de la Barra, 1989). It is available freely from Modelistica (2009).

Two issues about spatial input – output models, are their over-reliance on equilibrium and scale of spatial aggregation of the area where the input – output approach is applied (Hunt et al, 2005). For the case examined in the current study, a non-equilibrium and dynamic model is needed. Spatial input – output models are applied in closed systems and hence impacts from out of these systems are not modelled (e.g. business or population in-migration). Migration is an important factor of urban development and it has to be taken into account in order to measure the real dimensions of the interactions between transport and urban development. Spatial input – output models do not consider factors related to the location behaviour of the agents of urban development.

#### 3.2.1.4 Activity Based Models

The activity based models focus on the creation and changes of activities instead of the optimal allocation of activities over time. In contrast to most of the other model categories they do not seek to reach an equilibrium in every simulation period but they allow for disequilibrium and allocation of excess activities in the next simulation periods. Relocation decisions are modeled in two phases: at first the decision of whether to move is simulated and then the search for a new location (DETR, 1999). Behavioural characteristics can be considered in detail

Activity based models are strongly related to microsimulation models (Section 3.2.2.4), as the microsimulation models are basically activity based models that operate at an individual level.

DELTA has been developed by the David Simmonds Consultancy (Simmonds, 1999). It can be linked to a transport model and the overall structure of a model based on DELTA as described in Simmonds and Feldman (2007):

- The transport model uses activity related inputs to forecast travel by car and by public transport and hence to forecast travel times and costs.
- The economic model forecasts economic growth considering transport cost, consumer demand and commercial rents
- The urban land-use model forecasts locations of households and jobs and is described more extensively in the next paragraph.
- The migration model forecasts migration between areas.

According to its initial development for the Lothian area, the urban land-use model consists of sub-models considering the following processes:

- Transitions and the growth of households and employment which refer to demographic and employment changes which are imported exogenously.
- Development changes such as new development considering relevant constraints.
- Location and relocation of households in response to changes in accessibility, development supply, changing demands from employment and environment and area quality changes.
- Changes in employment status in response to labour demands.
- Area quality changes regarding the income level of the residents and property vacancies.

The sub-models are connected over time, meaning that the changes in one sub-model can affect another after one or more simulation periods. The DELTA model has been applied in several areas including Greater Manchester (Dobson et al 2009), the Trans-Pennine Corridor, Scotland (Bosredon et al 2009), Auckland, New Zealand (Feldman et al 2009), Sardina, Italy and Uruguay.

UrbanSim started as an activity based model but has been developed further as a microsimulation model. Hence it is described in the next section.

### 3.2.2 Disaggregate forecasting models

#### 3.2.2.1 Discrete Choice Models (Random Utility Models)

Discrete choice models describe the choices made by a person (e.g. resident, employee) or by an organisation (e.g. company) considering the characteristics of these choices. These models focus on individuals and on choice characteristics and they are based on Random Utility Theory. Changes over time can be considered by introducing time lags.

METROSIM was developed by Anas (1982) and NYMTC is a later version (Anas, 1998). METROSIM is based on economic theory and forecasts industrial, commercial, residential and land distributions, employment changes, households, travel flows, rents and market prices and vacancy rates for several types of real estate, new development of residential and commercial buildings and land use changes. It does not represent firms explicitly. METROSIM iterates between three major market sectors (labour market, housing market and commercial floorspace) and transportation until land use and transportation reach equilibrium (Zhao and Chung, 2006). It contains seven modules:

i. Basic industry. Production targets are fed exogenously into the model to determine labour demands, floorspace utilisation and land requirements of the basic industry, wages and rent prices

ii. Non-basic industry. After the pattern of location is determined from (i) the procedure is similar to that of basic industry.

iii. Property. Construction and demolition of residential units, vacancies, rents and market values are determined in each zone.

iv. Vacant land. The amount and market value of developable vacant land in each zone are determined.

v. Households. The distribution of households in each zone according to type of residence, workplace of family head, income and mode of commuting to work of the family head is determined.

vi. Travel. The travel demand matrix is calculated.

vii. Traffic assignment. Car matrices are assigned to road network. Travel times are updated taking congestion into to reach equilibrium state.

One weakness of this method is that a person does not consider all the potential choices when choosing residential location; personal preferences exist and these cannot be adequately modelled. Some other problems as reported in Mackett (1983b) are the actual impact of travel cost on decision making, the interrelationship between decisions, the influence of other activities on travel and the definition of the decision unit.

Discrete choice theory is promising; choices of the agents are modelled considering behavioural attributes. Some weaknesses it has could be addressed by combining discrete choice models with microsimulation, which is discussed in a following sub-section (Section 3.2.2.4).

#### 3.2.2.2 Random Bid Models

Random bid models (or bid – rent models) describe the behaviour of decision-makers (bid) and landowners (rent). A number of decision-makers are bidding for a certain property or land and landowners will sell or rent to the highest bidder. These models are divided into deterministic and stochastic types. Deterministic bid-rent models produce all-or-nothing land-use patterns and stochastic bid-rent models produce probabilistic variations in land-uses (Chang, 2006).

MUSSA is a highly disaggregate land use model, based on Bid-Choice theory. It was developed by Martinez (1996) to interact with ESTRAUS, a four stage transport model that was applied in Santiago, Chile. The two models exchange outputs: MUSSA provides to ESTRAUS land use outputs so that ESTRAUS calculates trip frequencies and trip purposes, and ESTRAUS provides to MUSSA outputs about accessibility and attractiveness. MUSSA is an equilibrium model, where demand for building stock is based on the willingness to pay. The equilibrium equation is derived considering that consumers try to maximize consumer surplus (willingness to pay minus price) and owners try to obtain the maximum price for a property (sell to the maximum bidder). The probability that a consumer makes the highest bid is given by the multinomial logit model. Market equilibrium is constrained by three conditions: (a) every household and firm should find a location, (b) land should not exceed land availability and (c) dwelling supply must comply with developers' behaviour.

So far, MUSSA is the only operational model of this category. It has a robust theoretical background of economics and it relies on equilibrium. The equilibrium constraint make the methodology unattractive as a non-equilibrium approach seems more realistic for the issues being considered in this thesis.

#### 3.2.2.3 Cellular Automaton Models

Cellular automaton models have their basis in sciences such as physics and biology. They deal with the interaction among cells considering the distances between them and they simulate the change in the state of individual cells. Temporal changes in a system are represented through local activities in cells located in the immediate proximity of the system. Cellular automaton models are based on reaction-diffusion equations; 'reaction' refers to the reaction of a function upon which depends a cell, and to what is already in the cell, and 'diffusion' refers to the function relating the cell of interest, and to what is happening to its immediate neighbourhood (Batty et al, 1999). In the case of urban models, cells simulate four types of settlements including trade, industrial, residential and empty areas (Zhao and Chung, 2006). They are not based on economic theories and they do not focus on agents' decisions, individuals' behaviour and on the economic impacts on land-use change. Most applications are not developed for operational planning (Zhao and Chung, 2006; Waddell and Ulfarsson, 2004). For these reasons they are not considered suitable to serve the purposes of this project.

The cellular automata approach was used in the development of TRANSIMS (Transportation Analysis and Simulation System) an open source model used for regional system transportation analyses (TRANSIMS, 2009). Cellular automaton models and complexity theory have been used extensively at the CASA (Centre for Advanced Spatial Analysis), UCL (CASA, 2009) to study urban dynamics (Batty, 2005).

#### 3.2.2.4 Microsimulation Models

Microsimulation models are highly disaggregate models, which simulate the behaviour of individuals either of the total or of a representative population over time. Aggregation of the results obtained leads to the overall behaviour of the system. The decision processes of individuals are simulated using Monte Carlo simulation.

*Monte Carlo method*

Before presenting some microsimulation models a reference to the Monte Carlo method needs to be made. Monte Carlo simulation is used to determine the final output of a procedure for one individual, household or business, when the probability of the output is known. Monte Carlo is used to simulate binary or multiple choices. In the case of a binary choice the probability that something can happen is estimated. Then a pseudorandom number in the range zero to one is generated. If the random number is equal or smaller than the probability, the event for which the probability was estimated happens.

In symbols, event *e* happens to an 'entity' *n* (this can be person, household or business) with characteristics $x_{1n}, x_{2n}, \ldots, x_{kn}$ (these can represent characteristics of a person, e.g. age, employment status etc, household, e.g. income etc, or business, e.g. industrial sector, size etc) if the random number *R* is equal or smaller than the probability $P^e(x_{1n}, x_{2n}, \ldots, x_{kn})$ (this is the probability for 'entity' with characteristics $x_{1n}, x_{2n}, \ldots, x_{kn}$):

$$R(n \mid x_{1n}, x_{2n}, \ldots, x_{kn}) \leq P^e(x_{1n}, x_{2n}, \ldots, x_{kn}) \quad (3.1)$$

In the case of choosing between more than two alternative events (i.e. multiple choice), the cumulative probability for each event is calculated. For the probabilities of each event:

$$\sum_{e=1}^{m} P_e = 1 \quad (3.2)$$

where $P_e$ is the probability that event *e* will happen and *m* is the number of possible events.

Hence an event $e_k$ will happen if:

$$P^{e_{k-1}}(x_{1n}, x_{2n}, \ldots, x_{kn}) < R(n \mid x_{1n}, x_{2n}, \ldots, x_{kn}) \leq P^{e_k}(x_{1n}, x_{2n}, \ldots, x_{kn}) \quad (3.3)$$

Proceeding to some microsimulation models, the IRPUD (Institut für Raumplanung, Technische Universität Dortmund) or Dortmund model was developed by Wegener (1982) and it is described in IRPUD (2009). It has been applied to Dortmund, Germany. It consists of six main sub-models:

- The transport sub-model
- The aging sub-model
- The public programs sub-model
- The private construction sub-model
- The labour market sub-model
- The housing market sub-model

These sub-models simulate the interactions between the major stock variables which are employment, population, residential buildings and non-residential buildings and interact through competitive choices or markets: population and employment are interacting through the transport market and the labour market, population and residential buildings interact through the housing market, employment and non-residential buildings interact through the market for commercial buildings and residential and non residential buildings interact through the land and construction market. Choice in the markets is constrained by supply and guided by attractiveness. Exogenous inputs include forecasts of regional employment and population, transport policy, housing policy, land use control policy and industrial development policy.

In a more comprehensive approach aiming to consider the environmental impacts of land-use and transport policies, the ILLUMASS (Integrated Land-Use Modelling and Transport System Simulation) project combined part of the IRPUD model with a dynamic simulation model on urban traffic flows and environmental impact models (Moeckel et al, 2007; Wagner and Wegener, 2007; ILUMASS 2009). Furthermore, the IRPUD model was implemented in Dortmund (Germany) in the framework of the EU project PROPOLIS (Planning and Research of Policies for Land-Use and Transport for Increasing Urban Sustainability) for the assessment of urban strategies. In the same project the MEPLAN model was implemented in Bilbao (Spain), Helsinki (Finland), Naples and Vicenza (Italy) and the TRANUS model was implemented in Brussels

(Belgium) and Inverness (Scotland) (Lautso et al, 2004; Spiekermann and Wegener, 2003).

The MASTER (Micro-Analytical Simulation of Transport Employment and Residence) model has been developed by Mackett (1984, 1988, 1990b, 1992, 1993) and has been applied to Leeds. It uses microsimulation to represent the processes affecting members of the population and to model choices. It is highly disaggregate in the representation of population characteristics as it operates at the household level and it considers demographical changes such as births, ageing, deaths, marriages, divorces and migration to model population growth. Employment, retirement, education level, sex, social groups, job vacancies and income are modelled among others. Monte Carlo simulation is used to model potential zone of residence, employment choice and travel mode. The key stages for the transport process are the following:

- Four components determine the mode of transport to work: the ability to drive, household car ownership, car availability for the individual and the actual choice of mode on the basis of generalised cost of using the available ones.
- The main modes for transport are car, public transport and walk.
- The probability of a mode being chosen is determined considering the generalised cost of travel by the alternative modes.
- Monte Carlo simulation uses these probabilities to determine the potential mode.

Job and residential location decisions are modelled in two steps: at first the decision of whether to consider relocation is simulated and then the location choice. Regarding employment, the potential of redundancy is taken into account. New development and the demolition of existing dwellings are simulated. Tenure and changes in tenure and household income and expenditure are modelled so that tenure changes and property purchases can be forecasted. Property prices are also modelled considering market, location and property characteristics.

A household location modelling project commissioned by the Department of Transport was based on the integration of DELTA with concepts from MASTER. Household and individual components of the land use modelling package DELTA have been replaced with microsimulation components based on MASTER. The new model is called SimDELTA and it has been applied to a part of South and West Yorkshire and it is discussed in Feldman et al (2007).

UrbanSim has been developed by the Urban Planning Department and Computer Science Department at the University of Washington. It consists of the following core sub-models (Waddell, 2002; Waddell et al, 2003):

i. Accessibility model. The accessibility model creates accessibility indices to model business and population location choices.

ii. Demographic and economic transition models. The demographic transition model simulates births and deaths in the population. The number of households created or deleted is determined by iterative proportional fitting; the newly created households are placed in housing by the household location model. The economic transition model simulates job creation and loss.

iii. Household and employment mobility models. The household and employment mobility models estimate households and jobs deciding to move from their current locations based on historical data.

iv. Household and employment location models. The household and employment location models choose the location for each household and job that has no current location. In the household location model, each alternative is evaluated for its desirability to the household using multinomial logit model and variables such as price, age, neighbourhood characteristics and regional accessibility to jobs. In the employment location model for each job without current location a sample of locations is randomly selected from the set of all possible alternatives using variables such as real estate characteristics, neighbourhood characteristics and regional accessibility to population.

v. Real estate development model. The real estate development model simulates developer choices about the kind and the location of new developments or the redevelopment of existing structures. A list of potential alternatives is created every year including no development. The probability for each alternative is calculated using multinomial logit model.

vi. Land price model. The land price model is based on urban economic theory, which states that the value of location is capitalized into the price of land. Historical data are used and hedonic regression helps to include the effect of several attributes on land prices.

UrbanSim has been validated for Eugene-Springfield, Oregon, U.S. and it has been applied to various areas in U.S. including Salt Lake City and Honolulu (Zhao and Chung, 2006). It is available for download under a General Public License and according to UrbanSim (2009) it has been been adopted for operational planning use in the U.S.

The ILUTE model is under development at the Department of Civil Engineering, University of Toronto. It is at experimental stage focusing in the area of Greater Toronto and other Canadian urban areas (ILUTE, 2009). It consists of four sub-models: Land Development, Location Choice, Activity/Travel, Car Ownership.

The RAMBLAS (Regional Planning Model Based on the Microsimulation of Daily Activity Patterns) model (Veldhuisen et al, 2000) has been designed to simulate the impacts of land-use and transport policies on the total population of Netherlands focusing on activities and traffic flows and it is less comprehensive than the other models of this category (Iacono et al, 2008).

Wegener (2004) after a review of twenty urban models concludes that microsimulation is the most promising technique for modelling activity-based land use and transport: it allows the reproduction of complex spatial behaviour of individuals on a individual basis.

## 3.3 Summary

Several types of models describing the interactions between land use and transport were reviewed above. Over the years, different methodologies have been developed for different areas, based on various theoretical backgrounds, on qualitative and quantitative elements of data and on different conceptual approaches. In Table 3.1 the main modelling approaches are evaluated in relation to the desirable elements of the model presented in this study, as identified at the beginning of this section. Activity based models are not included because they are represented by the microsimulation models, which represent their natural evolution. In many cases the evaluation is based on the most important models of each type, and not on the methodology followed by the type of model. Agents' representation refers to the comprehensiveness of the model, i.e. the representation of all the agents of urban development as presented in Chapter 2 and the level at which the agents are modelled (i.e. individual, aggregate).

Microsimulation fulfills better the criteria set up at the beginning of this section and especially the dynamic non-equilibrium allocation and the detail in which it represents the agents of urban development and the behavioural characteristics of their choices. Microsimulation offers more flexibility and the potential to model urban systems realistically as modelling is conducted at individual level and focuses on understanding and explaining individual behaviour. Furthermore, it can be combined with some of the other methodologies, for example with discrete choice models to simulate location choices, or with cellular automaton models. In the STUDI model microsimulation is used to model businesses and population. Their location choices are driven by location attractiveness which is also reflecting the interaction with other agents. The MASTER model predominantly and the IRPUD model have been used as an inspiration for the design of the STUDI model.

| Criteria<br>Models | Allocation of quantities in time (dynamic-static) | Behaviour representation | Choice modelling | Agents' representation (comprehensiveness) | Operational applications | Transport representation |
|---|---|---|---|---|---|---|
| **Optimising** | static equilibrium | no | no | limited | yes | detailed |
| **Regression** | lagged | no | no | limited | limited | limited |
| **Spatial Interaction** | static equilibrium | no | no | limited | yes | detailed |
| **Cellular Automaton** | static equilibrium | no | no | limited | limited | detailed |
| **Spatial Input – Output** | equilibrium | aggregate | no | detailed | yes | detailed |
| **Random - Bid** | static equilibrium | disaggregate | yes | detailed | yes | depends* |
| **Discrete Choice** | static equilibrium | disaggregate | yes | detailed | yes | depends* |
| **Microsimulation** | dynamic disequilibrium | disaggregate | yes | very detailed | yes | depends* |

**Table 3.1: Land use - transport modelling methodologies**

* It depends on the transport model the land use model is integrated with. It varies from very detailed to detailed.

# 4 Data

The STUDI model uses a large amount of data from various data sources. In order to combine them efficiently in an integrated model, some of the datasets have been reformed and restructured. In this chapter the data used are presented and the processes followed to reform them are described.

The STUDI model divides London in 33 zones according to the 33 boroughs. The choice of this spatial aggregation level was guided by the availability of data and by the need to develop a model that will run relatively fast.

## 4.1 Travel time estimates

Transport supply is represented in the model by travel time. New metro lines have an impact on travel time and this impact is captured by the travel time estimates. Two datasets are used:

- CAPITAL
- Railplan

Both of them were obtained from Transport for London (TfL). The monetary cost is not considered. Due to the zoning system of TfL in London and the extensive use of travel-cards, there is not change in the monetary cost for the user as a result of the new metro lines.

### 4.1.1 CAPITAL

The CAPITAL data are travel time estimates (in minutes) for public transport. London is divided into 15,366 zones. The dataset obtained included travel time estimates from each of the 15,366 zones to the JLE stations, i.e. Westminster, Waterloo, Southwark, London Bridge, Bermondsey, Canada Water, Canary Wharf, North Greenwich, Canning Town, West Ham and Stratford. The travel times are estimated with and without the JLE.

The boroughs of London are presented in Figure 4.1.The boroughs with JLE stations and the boroughs with stations of the Jubilee line before the extension are highlighted.

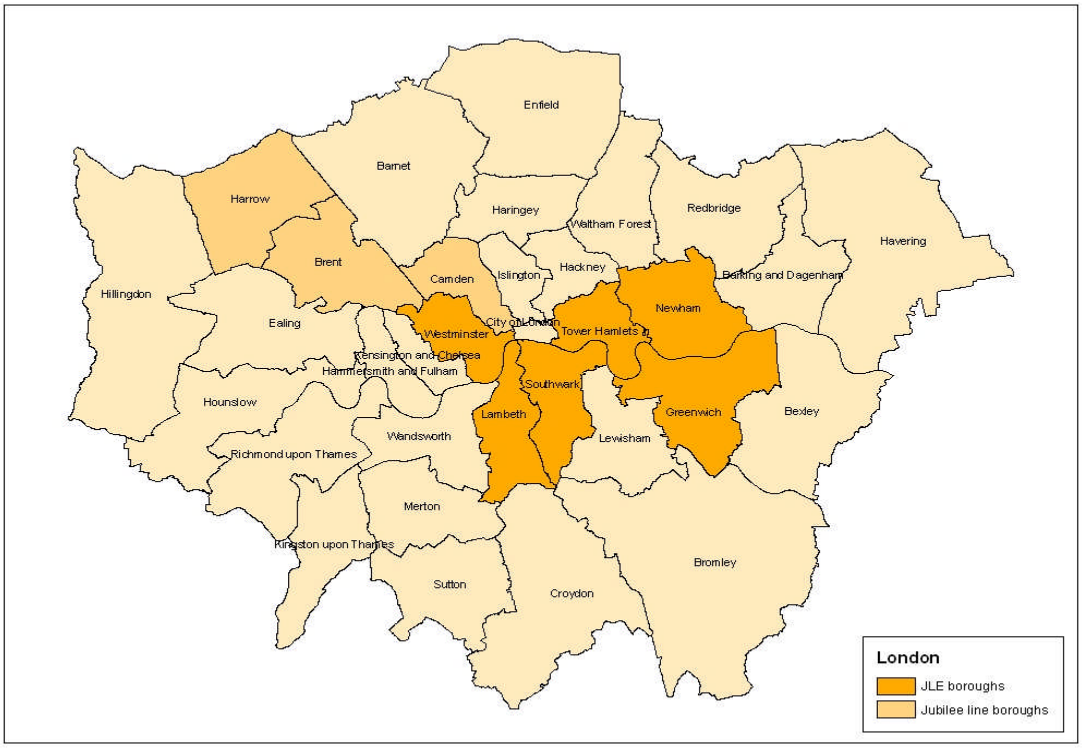


**Figure 4.1: Boroughs of London**

To find the travel time from each STUDI zone to the zones with JLE stations, the mathematical average of the travel times from all the CAPITAL zones included in each STUDI zone was estimated. Hence the travel times from each STUDI zone to the JLE stations with and without the JLE are calculated. If spatial data on CAPITAL zones had been available, the travel time from the centroid of each STUDI zone to the JLE stations would have been calculated, but unfortunately GIS data on the CAPITAL zones were not available.

### 4.1.2 Railplan

The Railplan data provide estimates of travel time (in minutes). UK is divided into 9,864 zones out of which 1,551 zones cover the Greater London area. The data used are travel times in vehicle. In-vehicle time can be broken down in travel time by mode (i.e. bus, DLR, tram, rail, underground). Railplan also provides estimates of walking time, waiting time and boarding time.

The aim was to obtain travel time estimates between the 33 zones into which London is divided according to the STUDI model. Using GIS, first the centroid of each borough was found. Then the zone of the Railplan database that contains this centroid was identified. Hence the Railplan zone that represents each STUDI zone was identified. Knowing the travel time between each pair of Railplan zones, a table with the travel times between all STUDI zones was formed. This is a 33x33 table.

### 4.1.3 Combination of CAPITAL and Railplan data

Using the CAPITAL data, the travel times from each STUDI zone to each JLE station, with and without the JLE, are estimated. Using the Railplan data, the travel times with the JLE between all the STUDI zones are estimated. Hence the two datasets are combined in order to obtain travel time estimates between all STUDI zones with and without the JLE.

From the CAPITAL data, the difference in travel time from all STUDI zones to the JLE stations due to JLE is calculated. Then the differences due to JLE to each STUDI zone including JLE stations is estimated, by calculating the mathematical average of the differences of travel time to all JLE stations included in the STUDI zone. The latter is added to the Railplan travel time estimates in order to find the travel time estimates without the JLE. The impacts of JLE on travel times are illustrated in Figures 4.2 to 4.7 (the data used to produce these figures can be found in Table A.1, Appendix).

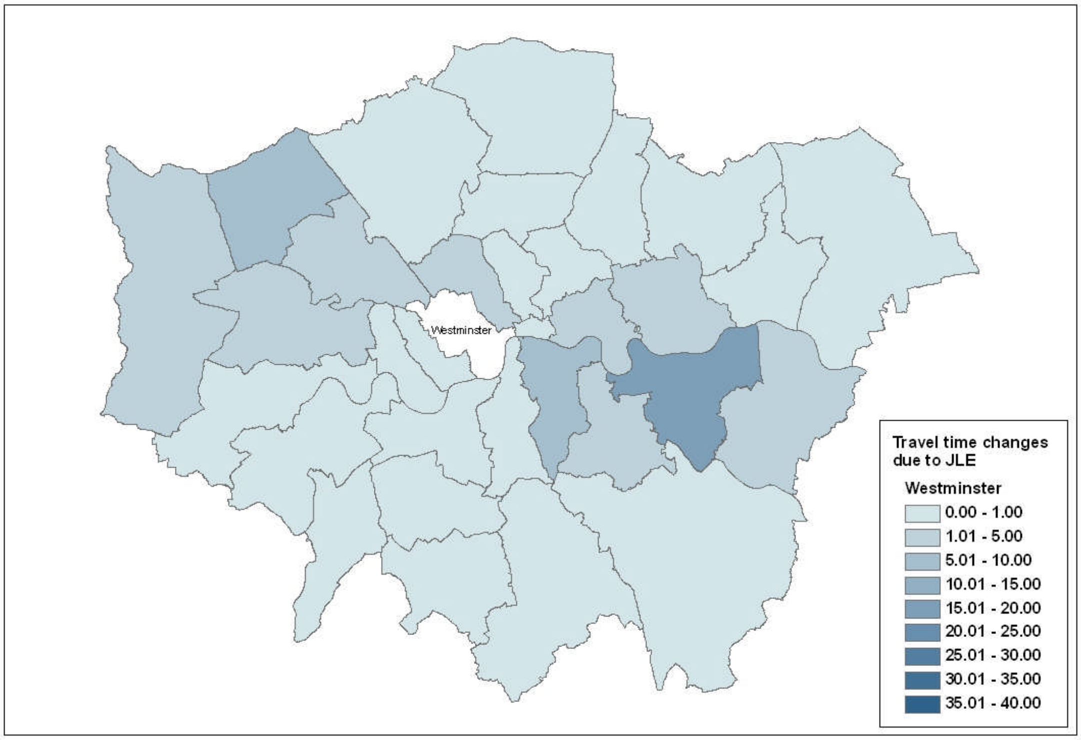


**Figure 4.2: Changes in travel times from Westminster due to JLE**

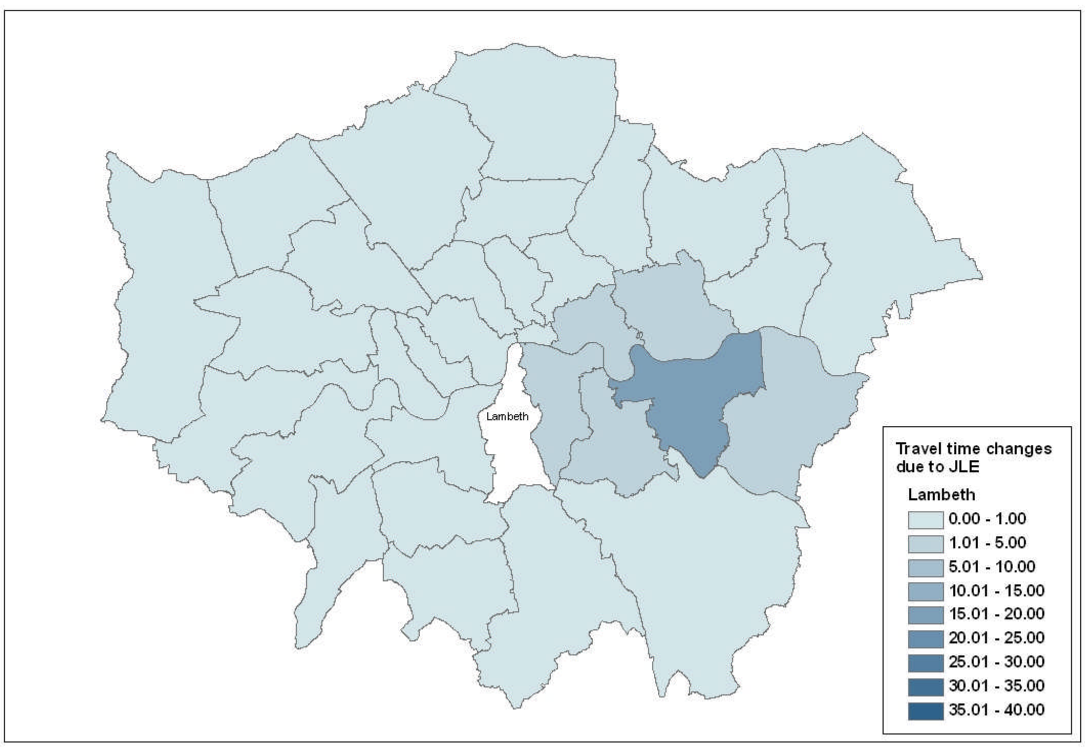


**Figure 4.3: Changes in travel times from Lambeth due to JLE**

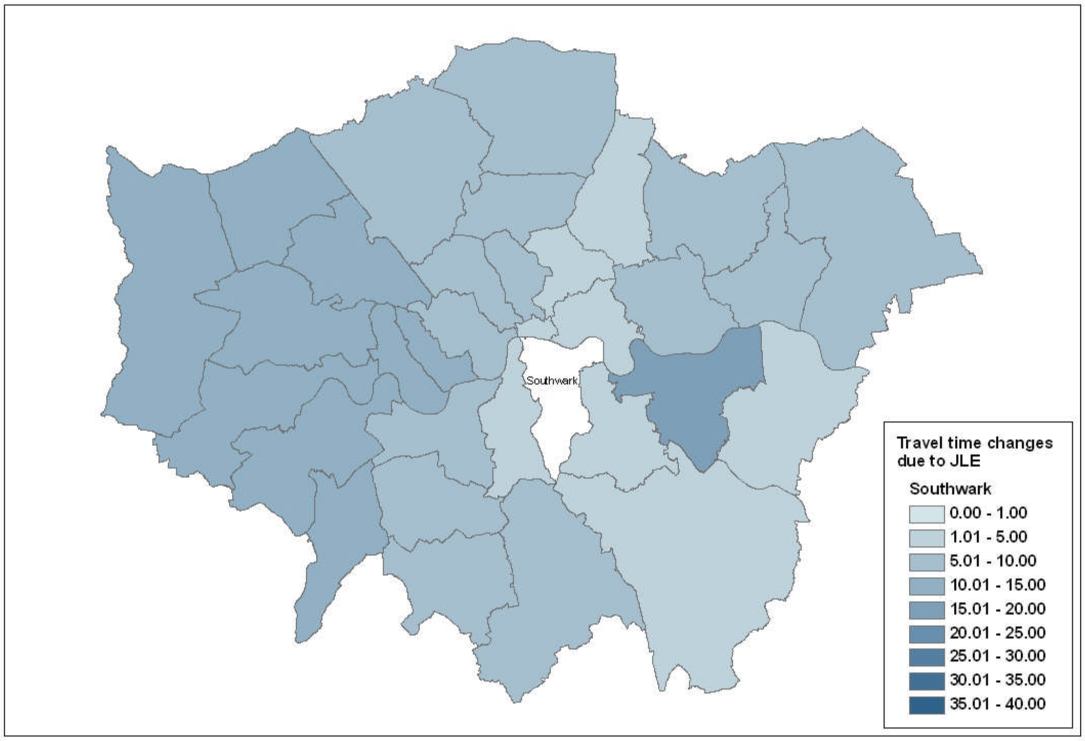


**Figure 4.4: Changes in travel times from Southwark due to JLE**

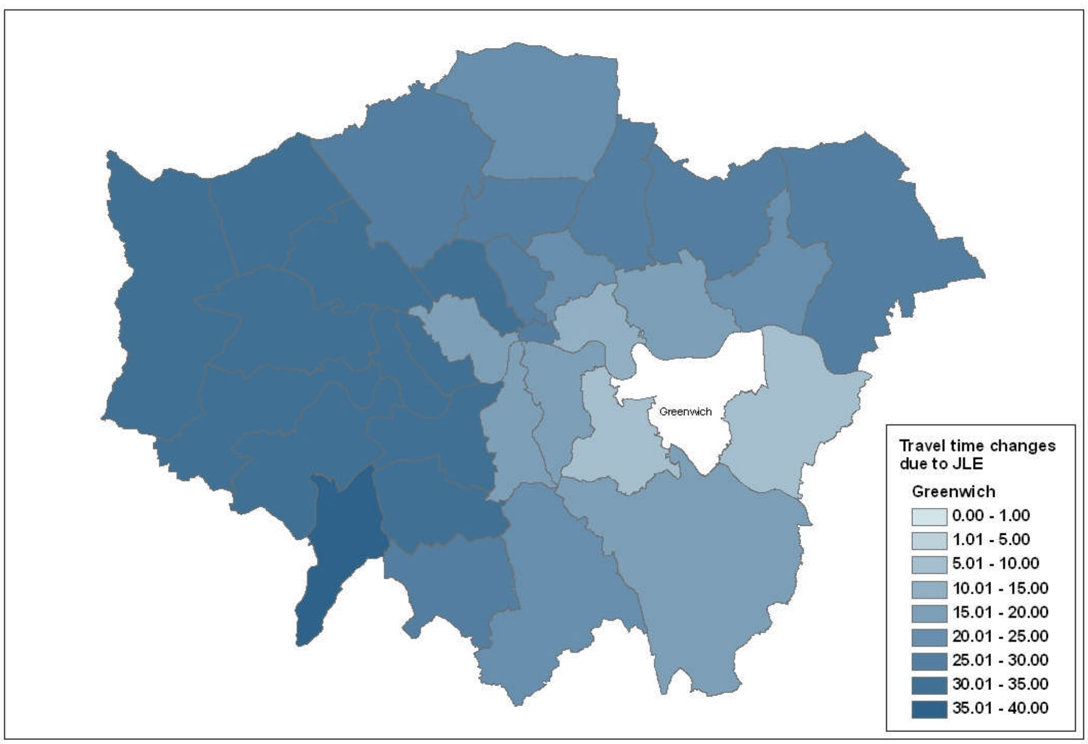


**Figure 4.5: Changes in travel times from Greenwich due to JLE**

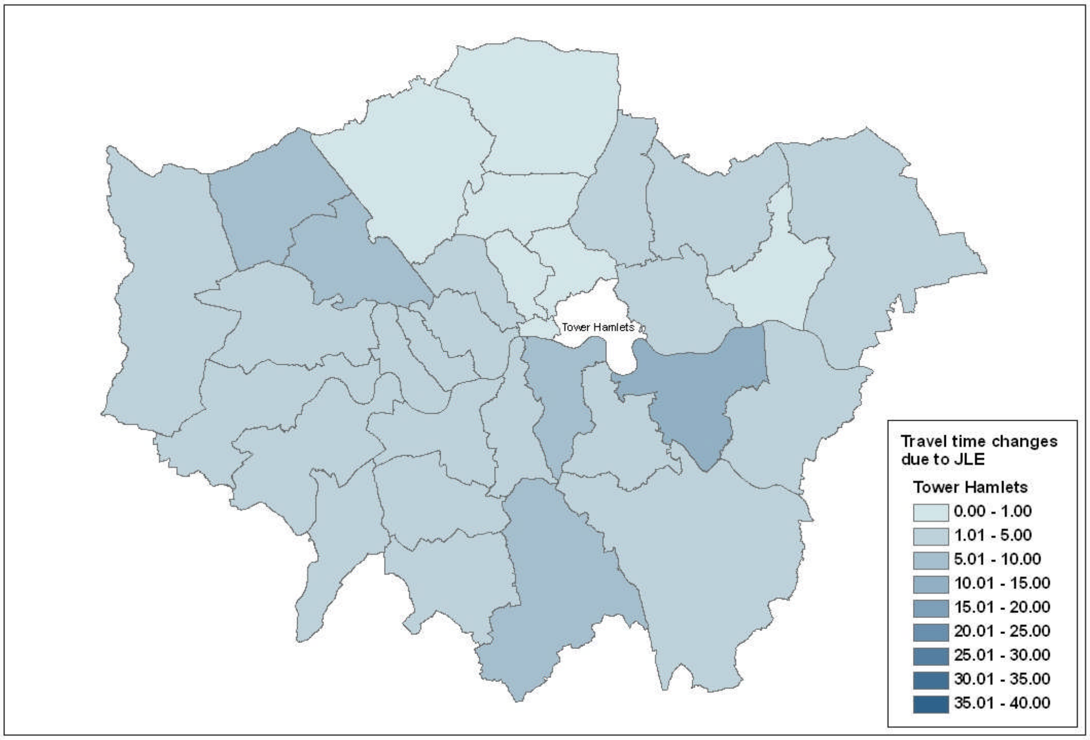


**Figure 4.6: Changes in travel times from Tower Hamlets due to JLE**

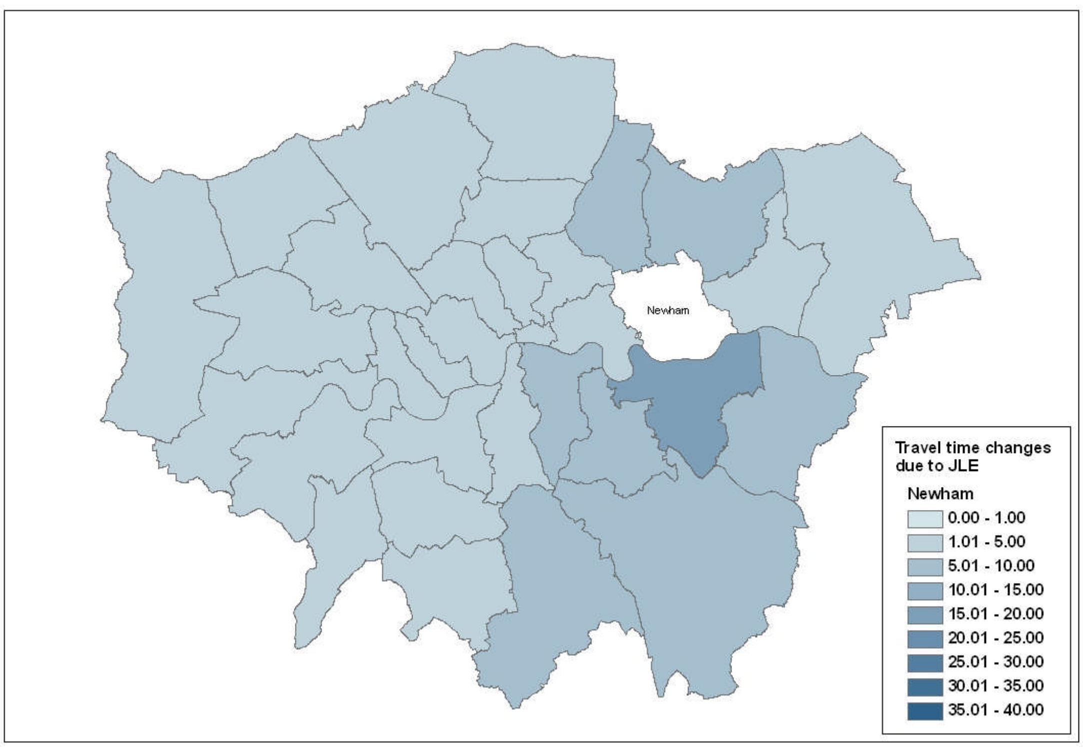


**Figure 4.7: Changes in travel times from Newham due to JLE**

## 4.2 Development data

Data on planning applications, dwelling stock and vacancies, property sales and house prices were taken from the Department of Communities and Local Government (Communities, 2009). More specifically the number of planning applications decided by district planning authority by the type of development, were obtained from the Development Control Statistics of the Planning, Building and the Environment section of the Department of Communities and Local Government. Dwelling and stock vacancies, property sales and house prices were obtained from the Local Level Statistics of the Housing section of the Department of Communities and Local Government. Land use statistics were obtained from the Generalised Land Use Database from the Planning, Building and the Environment section of the Department of Communities and Local Government. Data on new dwellings were obtained from the Land Use Change statistics of the Planning, Building and the Environment section of the Department of Communities and Local Government.

Data on land available for development including previously developed land, derelict land and buildings, vacant buildings, land with planning allocation and planning permission and other land with known potential – were obtained from the National Land Use Database (NLUD, 2009).

Data on Commercial and Industrial Floorspace, Ratable Value Statistics and Commercial and Industrial Property Vacancy Statistics were found in the Physical Environment section of the Neighbourhood Statistics of the Office for National Statistics (Neighbourhood Statistics, 2009).

In Table 4.1 the main variables used in the development model are presented.

| **Variable** | **From** | **To** | **Source** | **Spatial aggregation level** | **Units** |
|---|---|---|---|---|---|
| Planning applications received by district planning authority | 2000/01 | 2006/07 | http://www.communities.gov.uk/ | Local Authority/ Districts | Number |
| Commercial and Industrial Property Vacancy Statistics | 1998/99 | 2004/05 | http://www.neighbourhood.statistics.gov.uk | Local Authority/ Districts | Percentage |
| Previously developed land that may be available for redevelopment by type of land | 2001 | 2006 | http://www.nlud.org.uk | Local Authority/ Districts | Hectares |
| Ratable Value Statistics | 1998 | 2007 | http://www.neighbourhood.statistics.gov.uk | Middle Layer Super Output Area, Local Authority/ District | Ratable Value per $m^2$ |
| Commercial and Industrial Floorspace | 1998 | 2007 | http://www.neighbourhood.statistics.gov.uk | Middle Layer Super Output Area, Local Authority/ District | Square meters ($m^2$) (thousands) |
| Planning applications decided by district planning authority | 1999/00 | 2006/07 | http://www.communities.gov.uk/ | Local Authority/ District | Number |
| Stock of dwellings | 1994 | 2007 | http://www.communities.gov.uk/ | Local Authority/ District | Number |
| Mean house prices | 1996 | 2008 | http://www.communities.gov.uk/ | Local Authority/ District | Sterling |
| Vacant dwellings | 1995 | 2008 | http://www.communities.gov.uk/ | Local Authority/ District | Number |

**Table 4.1: Data sources of the development sub-model**

## 4.3 Business data

The ABI (Annual Business Inquiry) data from the Office for National Statistics provide information on the number of businesses in each zone categorised by industrial sector and size (i.e. number of employees). The Annual Employment Survey includes data for the years 1991, 1993 and 1995-1997 and the ABI includes data for the years 1998-2006. The categorisation of business according to industrial sector is presented in Table 4.2 and according to size is presented in Table 4.3.

| **Industrial sectors** | **Label** |
|---|---|
| Agriculture and fishing | 1 |
| Energy and water | 2 |
| Manufacturing | 3 |
| Construction | 4 |
| Distribution, hotels and restaurants | 5 |
| Transport and communications | 6 |
| Banking, finance and insurance, etc | 7 |
| Public administration, education, health and other services | 8 |

**Table 4.2: Industrial sectors**

| **Size (number of employees)** | **Label** |
|---|---|
| 1-10 | 1 |
| 11-49 | 2 |
| 50-199 | 3 |
| 200 or more | 4 |

**Table 4.3: Size of businesses**

The problem with the aggregate business data is that only net changes in number of firms can be observed. Hence a specific firm cannot be tracked and followed over time in order to observe, understand and explain location changes, and the birth and death of businesses cannot be identified.

To perform analysis at a micro level, the ABI data have been used to synthesize a database including individual business records for the base year. The number of businesses – provided by the ABI data – of certain industrial sector and size in one zone will equal the number of individual business records of this sector and size to be synthesized in the particular zone.

A value of growth is also assigned to each business, although it was decided not be used at this stage. Growth is a categorical variable created using the net change of the number of businesses (initially taken from the VAT registration-deregistration database) of industrial sector *s*, in zone *i* and in period *T* under the assumption that the change in the number of businesses of sector *s*, in zone *i* and in period *T* represents the growth or decline of the industrial sector *s*, in zone *i* and in period *T*. Growth varies between -3 and 5 according to the number of new business added in one industrial sector in one year as shown in Table 4.4. Another measure of business growth (e.g. based on turnovers) could be more realistic, but the one used is an acceptable indicator given the data limitations.

| **Annual change in the number of businesses** | **Label** |
|---|---|
| -99 to -60 | -3 |
| -59 to -30 | -2 |
| -29 to -1 | -1 |
| 0 | 0 |
| 1 to 30 | 1 |
| 31 to 60 | 2 |
| 61 to 100 | 3 |
| 101 to 150 | 4 |
| 151 and more | 5 |

**Table 4.4: Business Growth**

For the start-ups of businesses, the number of new businesses is used to synthesize the database to include the individual records of the new businesses to be added in every simulation period (i.e. every year).

With the following example the construction of a synthetic database – containing individual records – from the available data is outlined. Table 4.5 shows how the synthesized database of businesses is structured.

If, according to the data, in zone *i* (e.g. borough of Barking and Dagenham, $i = 1$) there are $n = 3$ business units of industrial sector $s = 5$ (i.e. 'Distribution, hotels and restaurants') with 50 – 199 employees, i.e. of size category $m = 3$ (e.g. one business with 151, one with 89 and one with 123 employees) and growth factor $g = -2$, three business records will be created: 530100001, 530100002, 530100003. Similarly, if in the same zone there are $n = 2$ business units of the industrial sector 'Banking, finance and insurance', i.e. $s$ = 7 with 10 – 49 employees, i.e. of size category $m$ = 2 (e.g. one with 35 and one with 23 employees) and growth factor $g$ = 3, two business records will be created: 720100001, 720100001. The database including these businesses will look as follows:

| Reference number | Borough | Industrial sector | Size | Growth |
|---|---|---|---|---|
| 10530100001 | 1 | 5 | 3 | -2 |
| 10530100002 | 1 | 5 | 3 | -2 |
| 10530100003 | 1 | 5 | 3 | -2 |
| 10720100001 | 1 | 7 | 2 | 3 |
| 10720100002 | 1 | 7 | 2 | 3 |
| …. | …. | …. | …. | …. |
| ref no | *i* | *s* | *m* | *g* |

**Table 4.5: Business database (individual business records)**

The reference number is analysed as follows: The third digit represents the industrial sector, the fourth the size, the fifth and the sixth the zone and the last five digits are given so that each firm has a unique reference number. The two digits at the beginning of the reference number, i.e. before the sector digit, represent the simulation period in which the firm was added to the database: '10' is the number of the existing businesses at 1995 when the simulation starts.

To model business closures and start ups, the VAT registration and deregistration data were used. They were obtained from Nomis: official labour market statistics provided by the Office for National Statistics (Nomis, 2009). They provided information on the number of the annual VAT registrations and deregistrations in each zone (i.e. local authority) categorized by industrial sector.

To forecast business closures and start ups UK GDP at current prices (YBEU) was used. GDP rates were obtained from the Time Series Data, Office for National Statistics (ONS, 2009a).

## 4.4 Population data

The 2001 LATS (London Area Transport Survey) individual records were used to model persons and households. Unfortunately, it was not possible to obtain the 1991 LATS data. Statistics on demographic changes were obtained from Census of Population.

The LATS data provide a wide range of information for households and individuals. For each individual the variables presented in Table 4.6 are used.

| **Variable** | Household's income |
|---|---|
| **Symbol** | hincomei |
| **Income levels** | **Label** |
| less than 5000 | 1 |
| 5000-9999 | 2 |
| 10000-14999 | 3 |
| 15000-19999 | 4 |
| 20000-24999 | 5 |
| 25000-34999 | 6 |
| 35000-49999 | 7 |
| 50000-74999 | 8 |
| 75000 or more | 9 |

| **Variable** | Household's structure |
|---|---|
| **Symbol** | hhstruct |
| **Household categories** | **Label** |
| Single person - pensioner | 1 |
| Single person - other | 2 |
| Single parent: dependent children | 3 |
| All pensioner household | 4 |
| Married/cohabiting: no children | 5 |
| Married/cohabiting: dependent children | 6 |
| All other households | 7 |

| **Variable** | Relationship with the other members of the household |
|---|---|
| **symbol** | rlsp |
| **Relatioship** | **Label** |
| Not asked | -1 |
| Spouse/Partner | 1 |
| Son/Daughter | 2 |
| Mother/Father | 3 |
| Grandparent | 4 |
| Grandchild | 5 |
| Other relative | 6 |
| Not related | 7 |

| **Variable** | Employment status |
|---|---|
| **symbol** | pwkstat |
| **Employment status** | **Label** |
| Not asked (aged under 16) | -1 |
| FT paid employment | 1 |
| PT paid employment | 2 |
| FT self-employment | 3 |
| PT self-employment | 4 |
| Student/school pupil | 5 |
| Waiting to take up a job | 6 |
| Unemployed | 7 |
| Unable to work | 8 |
| Retired | 9 |
| Looking after home/family | 10 |
| Other | 11 |

| **Variable** | Gender |
|---|---|
| **symbol** | psexi |
| **Gender** | **Label** |
| Male | 1 |
| Female | 2 |

| **Variable** | **Symbol** |
|---|---|
| Individual's id | pid |
| Household's id | hid |
| Age | pagei |
| Members of the household | hresnon |

**Table 4.6: Variables of the population database**

The 2001 LATS data include information for 67,252 individuals and 29,973 households in Greater London and surroundings. The districts that have been sampled are shown inTable 4.7.

| Variables | Borough of residence, Borough of employment | | |
|---|---|---|---|
| symbols | hhaboro, pwsaboro | | |
| **Borough** | **Label** | **Borough** | **Label** |
| Barking and Dagenham | 1 | Redbridge | 26 |
| Barnet | 2 | Richmond upon Thames | 27 |
| Bexley | 3 | Southwark | 28 |
| Brent | 4 | Sutton | 29 |
| Bromley | 5 | Tower Hamlets | 30 |
| Camden | 6 | Waltham Forest | 31 |
| City of London | 7 | Wandsworth | 32 |
| Croydon | 8 | Westminster | 33 |
| Ealing | 9 | Dartford | 34 |
| Enfield | 10 | Elmbridge | 35 |
| Greenwich | 11 | Epping Forest | 36 |
| Hackney | 12 | Epsom and Ewell | 37 |
| Hammersmith and Fulham | 13 | Hertsmere | 38 |
| Haringey | 14 | Mole Valley | 39 |
| Harrow | 15 | Reigate and Banstead | 40 |
| Havering | 16 | Runneymead | 41 |
| Hillingdon | 17 | Sevenoaks | 42 |
| Hounslow | 18 | South Bucks | 43 |
| Islington | 19 | Spelthorne | 44 |
| Kensington and Chelsea | 20 | St Albans | 45 |
| Kingston upon Thames | 21 | Tandridge | 46 |
| Lambeth | 22 | Three Rivers | 47 |
| Lewisham | 23 | Thurrock | 48 |
| Merton | 24 | Watford | 49 |
| Newham | 25 | Woking | 50 |

**Table 4.7: Boroughs in LATS data**

For the purposes of this research, only the households and individuals that live in one of the 33 London boroughs are used. The rest are combined in one zone from which the in-migrants are selected and to which the out-migrants are added when migration is simulated. The sample population that is used includes 60,854 individuals and 27,272 households. The population model runs using the sample population and the results are aggregated at the end using the interim expansion factor which is explained below.

The 2001 LATS data include an interim expansion factor for each entry. Applying all the interim expansion factors produces the equivalent of the total population of London. According to the LATS data the total population of London is 6,993,645 which is rather smaller than the population as given by Census. In Table 4.8 the population for 2001 of each borough of London according to LATS, Census and mid-year ONS estimates is shown. Moreover, the population of 1991 according to Census and the population of 2006 according to ONS mid-year population estimates are presented. Census is conducted every ten years and involves data collection from the total population. ONS mid-year estimates are based on aggregated sample data collected annually and hence they are less precise than the Census data. The simulation should start well before 2000 when the JLE opened (more precisely it opened at the end of 1999). 1995 has been chosen. One reason for this is that only after 1995 are the business data continuously available (section 4.3). The other reason has to do with the 2001 LATS data: looking at Table 4.8 it can be observed that the population according to the 2001 LATS data lies somewhere between the population of 1991 and 2001 according to the Census data; it is assumed that the population given by the 2001 LATS is a good approximation of the 1995 population.

## 4.5 Total-sample population compatibility

Using the total business population in the business sub-model and the sample human population in the population sub-model model creates a compatibility issue, when the two models exchange information (e.g. when the new jobs created by the opening of new businesses are added in the stock of available jobs). To overcome this problem a weighting factor is used. This and a similar issue that occurs for the connection between the development and the population sub-models are discussed further in Section 6.1.4.

| | LATS 2001 | Census data | | ONS mid-year population estimates | |
|---|---|---|---|---|---|
| **Borough** | **LATS 2001** | **Census 2001** | **Census 1991** | **ONS 2001** | **ONS 2006** |
| **Barking and Dagenham** | 165,560 | 163,936 | 143,658 | 165,700 | 165,700 |
| **Barnet** | 308,036 | 314,566 | 293,559 | 319,500 | 328,600 |
| **Bexley** | 218,652 | 218,317 | 215,633 | 218,800 | 221,600 |
| **Brent** | 252,920 | 263,464 | 243,031 | 269,600 | 271,400 |
| **Bromley** | 291,935 | 295,530 | 290,597 | 296,200 | 299,100 |
| **Camden** | 180,921 | 198,015 | 170,467 | 202,600 | 227,500 |
| **City of London** | 6,476 | 7,175 | 4,141 | 7,400 | 7,800 |
| **Croydon** | 325,195 | 330,581 | 313,523 | 335,100 | 337,000 |
| **Ealing** | 290,038 | 300,950 | 275,267 | 307,300 | 306,400 |
| **Enfield** | 270,773 | 273,567 | 257,411 | 277,300 | 285,300 |
| **Greenwich** | 215,169 | 214,408 | 207,669 | 217,500 | 222,600 |
| **Hackney** | 187,413 | 202,826 | 181,262 | 207,200 | 208,400 |
| **Hammersmith and Fulham** | 161,832 | 165,248 | 148,495 | 169,400 | 171,400 |
| **Haringey** | 203,488 | 216,505 | 202,193 | 221,300 | 225,700 |
| **Harrow** | 205,601 | 206,811 | 200,096 | 210,000 | 214,600 |
| **Havering** | 222,801 | 224,241 | 229,524 | 224,700 | 227,300 |
| **Hillingdon** | 240,507 | 243,000 | 231,612 | 245,600 | 250,000 |
| **Hounslow** | 205,918 | 212,344 | 204,401 | 216,000 | 218,600 |
| **Islington** | 169,932 | 175,804 | 164,692 | 179,400 | 185,500 |
| **Kensington and Chelsea** | 152,743 | 158,929 | 138,406 | 162,200 | 178,000 |
| **Kingston Upon Thames** | 145,559 | 147,274 | 133,018 | 149,000 | 155,900 |
| **Lambeth** | 260,937 | 266,167 | 244,812 | 273,400 | 272,000 |
| **Lewisham** | 236,915 | 248,918 | 230,979 | 254,300 | 255,700 |
| **Merton** | 187,495 | 187,918 | 168,479 | 191,100 | 197,700 |
| **Newham** | 233,411 | 243,884 | 212,180 | 249,400 | 248,400 |
| **Redbridge** | 234,002 | 238,638 | 226,225 | 241,900 | 251,900 |
| **Richmond Upon Thames** | 175,084 | 172,341 | 160,729 | 174,300 | 179,500 |
| **Southwark** | 228,618 | 244,868 | 218,530 | 256,700 | 269,200 |
| **Sutton** | 178,548 | 179,765 | 168,880 | 181,500 | 184,400 |
| **Tower Hamlets** | 197,498 | 196,099 | 161,050 | 201,100 | 212,800 |
| **Waltham Forest** | 213,996 | 218,346 | 212,081 | 222,000 | 221,700 |
| **Wandsworth** | 252,901 | 260,382 | 252,409 | 271,700 | 279,000 |
| **Westminster** | 172,771 | 181,290 | 174,825 | 203,300 | 231,900 |
| **Column Total** | **6,993,645** | **7,172,107** | **6,679,834** | **7,322,500** | **7,512,600** |

**Table 4.8: Population data**

# 5 STUDI model – Theoretical description

The STUDI model simulates the interactions between transport and urban development over time. The main concept underlying the model is that the procedures of urban development are reflected in the location decisions made by the main agents involved in urban development which are: authorities, developers, businesses and population. When modelling the location decisions of each agent, the impact of the other agents and of transport supply on these decisions is considered. The STUDI model focuses on the dynamics of the interactions between all the factors (i.e. agents of urban development and transport) involved in urban development. Authorities' decisions, such as extensions of metro lines, are imported exogenously into the model. Hence the STUDI model contains three main sub-models: the development, the business and the population sub-models as presented in Figure 5.1. The model runs in one-year steps meaning that each sub-model runs once in each simulation period, i.e. every year.

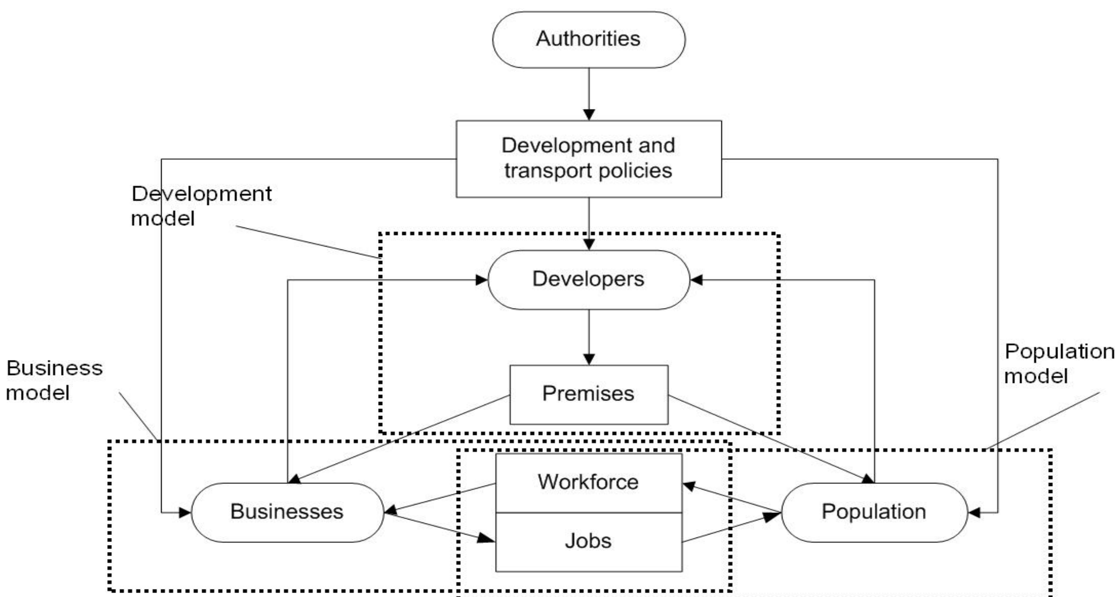


**Figure 5.1: Agents of urban development – Sub-models of the STUDI model**

The STUDI model is programmed in Python, and MySQL is used for database management. Python is an object oriented language with a General Public License. In general, object oriented languages such as JAVA, C++ and Python are more suitable for microsimulation modelling and for integrated models, as their structure allows them to analyze different systems better. Python has good support and it can be used in ArcGIS. UrbanSim changed from JAVA to Python in order to improve development and computation time, to make the model more modular and because Python is a more accessible language for modellers (Borning et al, 2008). The use of a database was decided on the grounds that it increases flexibility and it allows fast execution of specific procedures. MySQL is available under a General Public License and has good support. Python can be connected to MySQL as can ArcGIS, which is a big advantage as aim for the future is the integration of the STUDI model with ArcGIS. The STUDI model was developed considering the potentials of more applications and wider use. Although it has not been developed to this level yet, the choice of Python and MySQL was significantly affected by the fact that they are openly accessible.

Monte Carlo is used in various procedures in the STUDI model to simulate either binary choices (e.g. determine for a business or a household if it will consider relocation or not) or choices between more than two possible outputs (e.g. size of a newly added business).

Before proceeding to the description of the model it is important to mention that there are several parts of the STUDI model that can be improved and the version presented here is not the final one. However, considering the academic purposes of this research, this model can be seen as a solid base for an integrated urban development - transport model.

Transport supply is represented by travel time between zones and new metro lines are modelled using their impact on travel time. The travel time estimates used are described in Section 4.1.

The development sub-model is a regression model estimating the number of commercial and residential premises to be added to the relevant stock in each zone in each simulation period. The data used in the development sub-model are described in Section 4.2. The outputs of the model are the number of new and total commercial and residential premises.

The business sub-model is a microsimulation model, simulating business start-ups and closures and relocation of existing businesses. The sub-model is applied to the total business population (individual business records) as described in Section 4.3. To model relocation decisions of existing businesses, the businesses considering relocation are identified first. Final location decisions of businesses are based on attractiveness of the zones. The main outputs of the business sub-model are number of businesses in each zone categorised by industrial sector, size and employment distribution.

The population sub-model is a microsimulation model, simulating demographic changes, migration, and employment and residential location decisions. The sub-model is applied to a sample population as described in Section 4.4. The main outputs are number of people or households in each zone, which can be categorised according to household structure or income, age distribution and employment status distribution.

Each of the sub-models can run independently using inputs from the other two. The inputs have to do with the supply and demand of factors provided by one sub-model and received by another, such as jobs, premises and workforce. The interconnections between the sub-models capture the dynamics of their relationship and are realized using the following stocks: the stocks of total and vacant commercial premises, the stock of labour, the stocks of total and vacant dwellings, the stock of available jobs, and the stock of businesses. They are shown in Figure 5.2 which illustrates the interactions between the three main sub-models. The dotted arrows represent inputs from the stock at the previous period *T*-1.

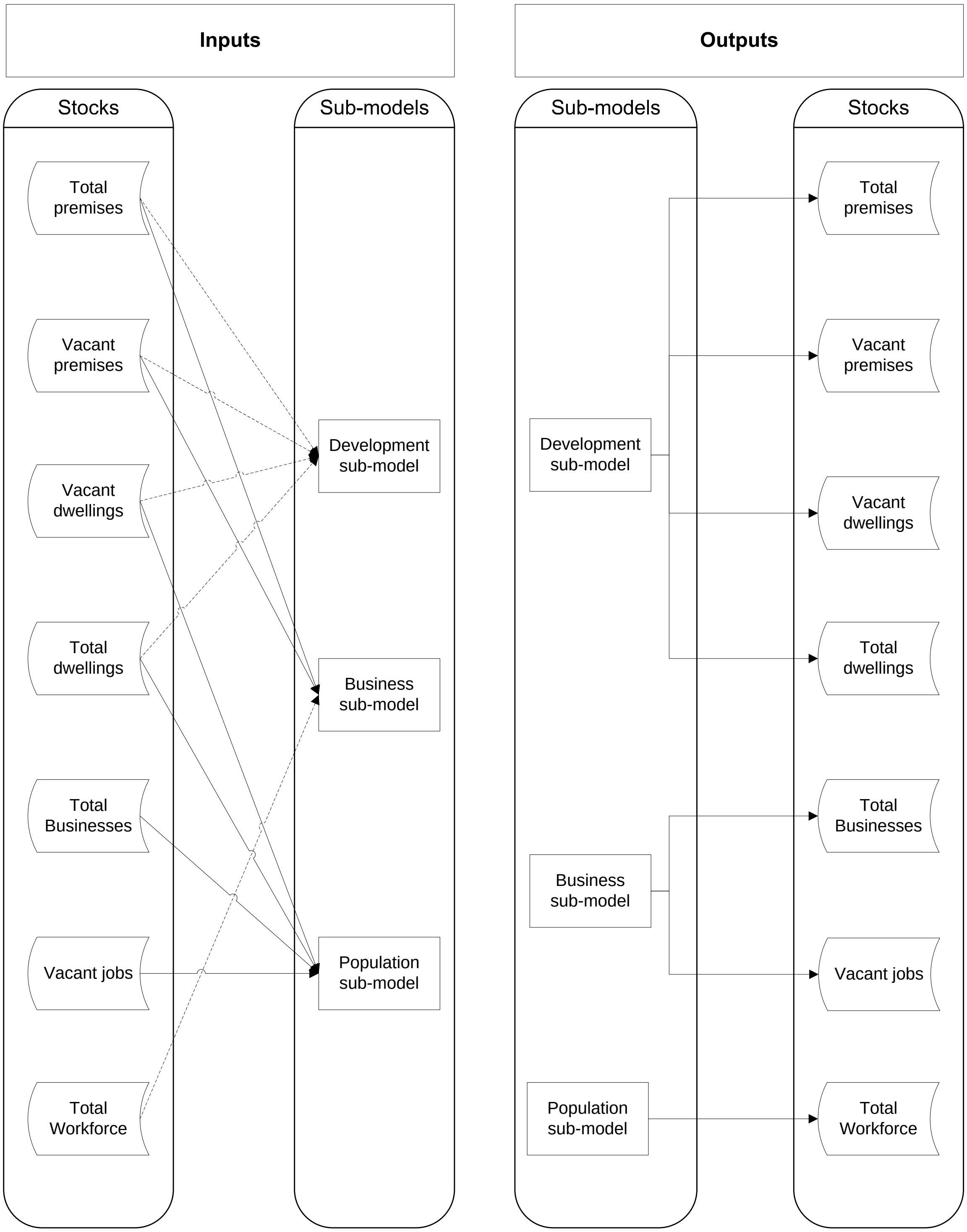


**Figure 5.2: The main sub-models of the STUDI model**

The various processes of the three sub-models are described analytically in this chapter. For every simulation period the various processes are run in the following order:

I. Development sub-model

II. Business sub-model

   i. Forecast of business closures and start-ups.

   ii. Connection with development and population sub-models.

   iii. Business closures.

   iv. Business start-ups.

   v. Business relocation – Selection of businesses to look for new location.

   vi. Business relocation – Location choices of businesses considering relocation.

   vii. Formation of the new business database.

III. Population sub-model

   i. Out-migration. Out-migration is simulated first for two reasons: the first one is to update the stocks of dwellings and jobs as households move out and the second one is to avoid simulation of demographics or location decisions of people that might be deleted from the population database.

   ii. Ageing.

   iii. Deaths.

   iv. Births.

   v. Household dissolution.

   vi. Connection to development and business sub-models.

vii. Employment – Changes in working status, decisions whether to change employment location.

viii. Employment location decisions.

ix. Household formation. After the new households have been formed, some of them will look for new residences. At this point the residential part of the population sub-model begins. This mixture of the four main parts of the population sub-model – demographics, migration, employment location and residence location – is used in order to achieve a more realistic representation of choices made by population. Household formation comes after dissolution in order to consider individuals from couples that have separated.

x. Residential allocation of separated people who did not find a partner.

xi. Search for dwelling by newly formed couples.

xii. Update attractiveness: attractiveness is recalculated after in-migration and household formation in order to capture the reduction of vacant dwellings.

xiii. In-migration: in-migration follows household formation in order to give priority in the vacant dwellings to the newly formed households in London.

xiv. Residential location decisions.

## 5.1 Development sub-model

The development sub-model contains two regression models in order to estimate the number of new commercial premises and new dwellings to be added to the stocks of total and available commercial premises and total and available dwellings in zone $i$ in period $T$. Attributes significant for development location decisions as identified in Section 2.2 such as land availability and property vacancy rates are included in the independent variables.

Two major assumptions are made in the development sub-model: The first one is that the new buildings are added immediately to the relevant stock (this can be the stock of either the commercial or the residential premises), but realistically some time is needed before a new building becomes available. In the estimation of the regression models to calculate the number of new commercial premises and dwellings to be added in the current year, the number of applications granted by local authorities is used and not the number of new buildings. Unfortunately, no data on the latter could be obtained. The second assumption has to do with the developed space. No information on the size of new buildings is available, so it is assumed that one new commercial building will accommodate one business and one new dwelling will accommodate one household. One business is referring to one individual business record created using the Annual Business Inquiry data as described in Section 4.3.

The following equations give the number of new dwellings *d* and new commercial premises *p* built in zone *i* in time *T*.

$$d_{iT}^{new} = At_{iT}^{b_1} d_{iT-1}^{total\,b_2} l_{iT-1}^{b_3} d_{iT-1}^{vacant\,b_4} \quad (5.1)$$

$$p_{iT}^{new} = b_1 t_{iT} + b_2 p_{iT-1}^{total} + b_3 p_{iT-1}^{vacant} \quad (5.2)$$

where $t_{iT}$ is travel time from zone *i* to the city centre in simulation period *T*. It is the CAPITAL estimate of travel time to the station of Westminster (as described in Section 4.1.1) and it takes account of the JLE impact; hence when the simulation with the JLE runs, travel times before 2000 are estimated without the JLE but after 2000, the impact of JLE on travel times is taken into account,

$d_{iT-1}^{total}$ is the total number of dwellings in zone *i* in simulation period *T*-1. It is the number of dwellings at the starting year plus the number of new dwellings added in each period until *T*-1. The model is developed to forecast the number of new dwellings. If the forecast number is negative, this will lead to subtraction of number equal to the absolute value of the forecasted number of dwellings from the total number of dwellings,

$p_{iT-1}^{total}$ is the total number of commercial premises in zone *i* in period *T*-1,

$d_{iT-1}^{vacant}$ and $p_{iT-1}^{vacant}$ are the number of vacant dwellings and vacant commercial premises respectively in zone *i* in period *T*-1. They are updated by the population and business sub-models according to the location changes of households and businesses – e.g., when a business moves to another zone, one commercial premises unit becomes available and is added to the stock of vacant commercial premises of the zone where the business was previously located, and one commercial premises unit is subtracted from the number of vacant commercial premises in the zone where the business moves in. As mentioned earlier in this section, it is assumed that each business, irrespective of size, occupies one unit of commercial premises; this assumption is necessary as no information on the size of new developments could be obtained. The same assumption applies for dwellings and households,

$l_{iT-1}$ is the land available for development in zone *i* in period *T*-1. It includes previously developed vacant land, derelict land and buildings, land occupied by vacant buildings and land currently in use with planning allocation or planning permission,

*A* is a constant and $b_1$, $b_2$, $b_3$ and $b_4$ are the estimated coefficients.

At the end of the run of the development sub-model the total number of dwellings and the total number of commercial premises is updated by adding the new dwellings and the new commercial premises to the existing stocks respectively.

## 5.2 Business sub-model

In the business sub-model the following processes are simulated:

- ‘Birth’ of new businesses
- ‘Death’ of businesses
- Location choices of new businesses
- Relocation of existing businesses

### 5.2.1 Connection with development and population sub-models

The stock of vacant commercial premises is updated by adding in the stock of each zone the number of newly built commercial premises as estimated in the development sub-model.

The stock of labour is updated by receiving information from the population sub-model. The number of people that moved from/to a zone is subtracted/added from/to the stock of labour of the zone. No distinction between different job categories is made. More specifically, the updates described below are executed.

The stock of labour is updated by adding labour units to the new zone where a household has moved to and by subtracting labour units from the zone, which the household has left. For the newly formed households two labour units are added to the stock of labour of the zone in which a newly formed couple moves. One labour unit is deleted from each zone from which the members of the formed couples are moving out. These procedures refer to newly formed couples that move into a new household after they form a couple. One labour unit is deleted from the stock of labour of the old zone and added to the stock of labour of the new zone, for every individual that is moving into the home of the other member of the newly formed couple.

If a separated man (it is assumed that he is the one leaving the household as discussed in Section 5.3.3.4) does not form a couple, then he will form a single household. So in this case, one unit is added in the zone where he moves to and subtracted from the zone where he moves from. If he does not find an appropriate dwelling he is deleted from the population database, which can be interpreted as moving out of London.

### 5.2.2 Forecast of business closures and start-ups

Business closures and start ups are forecast in relation to GDP change. GDP change is the annual percentage change of GDP and it can take positive as well as negative values. GDP in year t is given by the following:

$$GDP_T = GDP_{T-1}(1+C_T) \tag{5.3}$$

where $GDP_T$ is the value of GDP in period $T$ and

$C_T$ is the percentage change of GDP from period $T-1$ to period $T$. $C_T$ is specified exogenously.

The estimated GDP value is used to estimate the number of new businesses. The total number of businesses in period $T$ is given by:

$$B_T^{total} = a + bGDP_T \tag{5.4}$$

where $B_T^{total}$ is the total number of businesses in London in period $T$

The total number of businesses in the previous year is given by:

$$B_{T-1}^{total} = B_{T^{initial}} + \sum_{T^{initial}+1}^{T-1} B_T^{new} \tag{5.5}$$

where $B_{T^{initial}}$ is the number of businesses in the first period of the simulation $T^{initial}$.

Hence the new businesses to be added in year t are given by:

$$B_T^{new} = B_T^{total} - B_{T-1}^{total} \tag{5.6}$$

New businesses are spatially allocated following the spatial distribution of new businesses of the previous year, $T$-1. The first distribution of new businesses is derived from the VAT data as described in Section 4.3. Knowing the number of new businesses added in the current and in the previous year, the ratio $r$, which is calculated as follows, is multiplied by the number of new businesses of each sector in each borough of the previous year in order to give the number of new businesses of each sector:

$$\text{If } B_T^{new} > 0 \text{ and } B_{T-1}^{new} > 0 \text{ then } r = \frac{B_T^{new}}{B_{T-1}^{new}} \tag{5.7}$$

If $B_T^{new} < 0$ and $B_{T-1}^{new} > 0$ then $r = \frac{\left| B_T^{new} + B_{T-1}^{new} \right|}{B_{T-1}^{new}}$ (5.8)

If $B_T^{new} > 0$ and $B_{T-1}^{new} < 0$ then $r = \frac{B_T^{new} - B_{T-1}^{new}}{\left| B_{T-1}^{new} \right|}$ (5.9)

If $B_T^{new} < 0$ and $B_{T-1}^{new} < 0$ and $\frac{B_T^{new}}{B_{T-1}^{new}} < 1$ then $r = \frac{B_T^{new}}{B_{T-1}^{new}}$ (5.10)

If $B_T^{new} < 0$ and $B_{T-1}^{new} < 0$ and $\frac{B_T^{new}}{B_{T-1}^{new}} > 1$ then $r = \frac{B_{T-1}^{new}}{B_T^{new}}$ (5.11)

The number of new businesses in each borough for each sector is known until 2006 from the VAT registration-deregistration data. So a 33(boroughs)x8(sectors) matrix can be formed for this year. Multiplying this matrix by *r* for new businesses and by 1/r for the closure probabilities, the distribution of the new entries or new closures for 2007 can be found. Similarly the distribution of the next years is estimated. This way it is assumed that the distribution of one year (of 2006 in this case) is followed in the next years. This is methodology currently used to allocate new businesses.

An alternative method for the spatial allocation of new businesses is to use the attractiveness of zones and Monte Carlo simulation. The calculation of the attractiveness of zones is described in Section 5.2.5.2. The second methodology does have some weaknesses regarding the deletion of businesses, as attractiveness cannot be used to decide from which zones to delete the closing businesses, because location attractiveness depends only on location characteristics and not on economy or business growth estimates, which may indicate decline in business activity in one zone. Hence it needs further investigation before being implementing. The process to add new businesses according to the second methodology is presented in Figure 5.3.

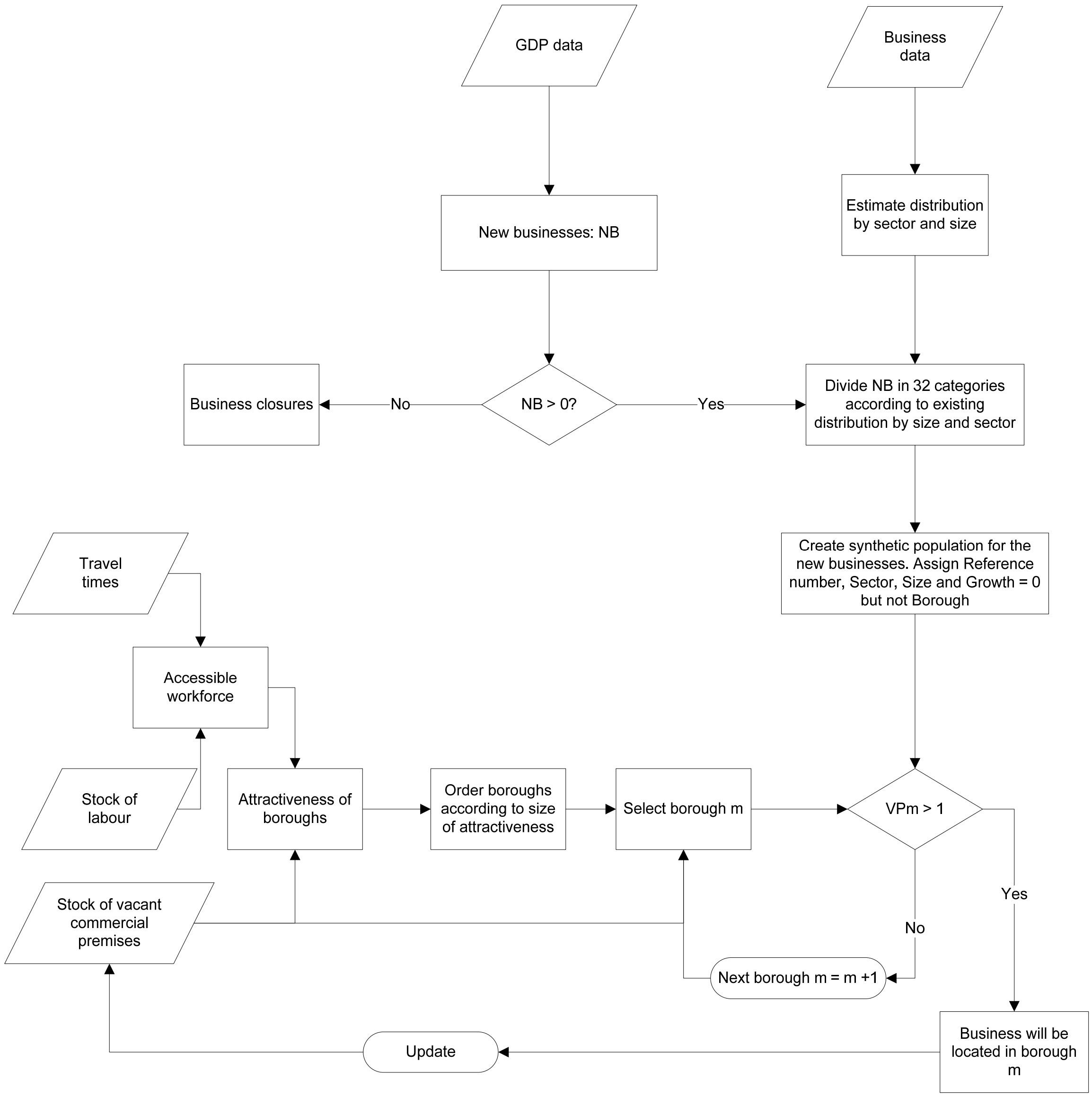


**Figure 5.3: Adding new businesses using zone attractiveness**

### 5.2.3 Business closures

Businesses closures are modelled either exogenously – until 2006 when data are available – using the VAT registration-deregistration data, or endogenously by predicting first the change in the number of businesses as described in Section 5.2.2. The VAT registration-deregistration data provide information on annual change of the number of businesses by zone and industrial sector. When negative change occurs in zone *i* for industrial sector *s*, a number of businesses of sector *s* equal to the absolute value of the change will close down in zone *i*; these businesses will be deleted from the database of businesses. When the change is positive then new businesses open and they will be added to the database of businesses.

In order to identify the businesses that will close down, Monte Carlo simulation is used. At first using the absolute value of the negative change in the number of businesses and the total number of businesses in one year, the probability that a business of sector *s* in zone *i* during the period *T* will close down is:

$$P_{iTs} = \frac{V_{iTs}^{decrease}}{B_{iTs}} \tag{5.12}$$

where $V_{iTs}^{decrease}$ is the negative change in number of businesses of sector s in zone i in year T resulted by subtracting the VAT deregistrations from the VAT registrations, and

$B_{iTs}$ is the total number of businesses of sector s in zone *i* in period T.

Then Monte Carlo simulation is applied. For every business in zone *i* of sector *s*, a random number is generated and compared to the probability that a business of sector *s* in zone *i* will close down; when the random number is smaller than the probability then the business record is deleted from the database. When a business is deleted, one unit of commercial premises is added to the stock of vacant commercial premises. The procedure is shown in Figure 5.4 .

When a business closes then some people will become unemployed. The number of the people that will become unemployed can be approximated as the size of each business is known. Unfortunately it is not possible to use this information to update the population database and make some people unemployed because the population and business databases are not interconnected, i.e. is not known in which business every person works. The interconnection of the two databases becomes complicated because the business sub-model is applied to the total number of businesses and the population sub-model is applied to a sample population. One aim of this study was to use the data which best represent the dynamics of business and population behaviour. The available datasets were independent of one another and the population dataset was a sample and the business dataset was at the 100% of the real (that had to be disaggregated). This meant that the relevant sub-models were not connected directly.


**Figure 5.4: Business closures and start-ups**

### 5.2.4 Business start-ups

New businesses are added annually. As in the case of closures, the annual change in the number of businesses of sector *s* in zone *i* is used. For every new business a new business record is added to the database. When a new business is added in zone *i*, one unit is deleted from stock of vacant commercial premises of zone *i*. All new businesses are assumed to have zero growth for the first year (growth = 0).

In order to avoid getting negative values in the stock of commercial premises, if there are fewer vacant premises in the zone of interest, the number of new businesses is modified accordingly (i.e., reduced in order to allow enough space for all the new businesses and to leave space for internal moving).

The VAT registration-deregistration data do not provide information on size of businesses, so in order to assign a size value to each new business the distribution of sizes of the existing businesses for each sector is used. The probability for each size category is calculated as follows:

$$P_{ms} = \frac{B_{ms}}{B_s} \tag{5.13}$$

where $B_{ms}$ is the number of businesses of sector s with size m and

$B_s$ is the number of businesses of sector s

so that:

$$\sum_{m=1}^{4} P_{ms} = 1 \tag{5.14}$$

Then the cumulative probability of the sizes is calculated.

When the new businesses have been added, Monte Carlo simulation is used to assign a value for the size of each business. The simulation of business start-ups is presented in Figure 5.4.

### 5.2.5 Business relocation

#### 5.2.5.1 Selection of businesses to look for new location

In this section the procedures to model relocation of existing businesses are described. First, the businesses willing to look for new location are identified. They are chosen randomly using a fixed probability without distinguishing according to size or sector.

Then Monte Carlo simulation is used to decide whether or not the business will look for a new location: The probability is compared to a random number, and if larger, then the business is considered as willing to look for a new location.

An alternative method is to choose businesses considering relocation according to their growth. It is not used at this stage because it needs further investigation but it is described below and it is illustrated in Figure 5.5. In this case the probability for a business of industrial sector *s* to consider moving home is estimated using binomial logit model:

$$P_s = \frac{1}{1 + \exp(-U_s)} \tag{5.15}$$

The utility function of sector *s* $U_s$, depends only on the growth category $G_s$ and the coefficients *a* and *b* can vary for different industrial sectors.

$$U_s = a + bG_s \tag{5.16}$$

where $G_s$ is the growth category of sector *s*

and *a* and *b* are the estimated coefficients.

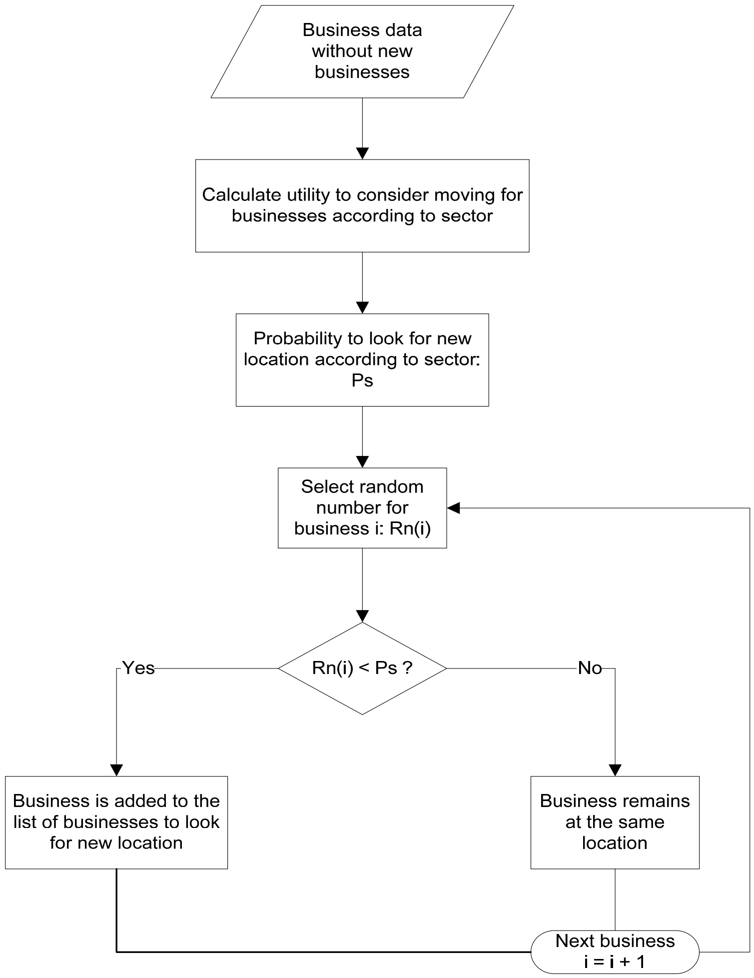


**Figure 5.5: Selection of businesses considering relocation**

### 5.2.5.2 Location choices of businesses

The location choice of the businesses considering relocation is based on the comparison of the attractiveness of the current zone to that of the alternative zones. In Section 2.3, where the impacts of new transport infrastructure on business location choices (Section 2.3.) are discussed, some important factors such as availability of suitable premises and accessibility to workforce were identified. These variables are included in the attractiveness functions of locations.

Before discussing the estimation of attractiveness, a short reference to the alternative locations considered by businesses willing to relocate will be made. Each business is assumed to look for a new location considering all zones in order of proximity: First it will look for an establishment in the zone closest to its current one; the attractiveness of the current zone is compared to that of the closest zone; if the attractiveness of the new zone is larger than that of the current zone and there is available space, then the business will move into the new zone. Otherwise, it will look for commercial premises in the next closest zone and so forth. If the attractiveness of the current zone is larger than all alternatives, then the business will remain in the current zone and will not move. The distance between zones that is used to order them by proximity in the set of alternative locations is the distance between the centroids of the zones. Hence each zone will have a different ranking of alternatives, i.e. the set of alternatives will contain the same zones but in a different order.

The attractiveness or utility is the key factor in the final location decisions. The attractiveness function has the following form:

$$A_{iT} = b_1 P_{iT}^{vacant} + b_2 W_{iT}^{accessible} \tag{5.17}$$

where $P_{iT}^{vacant}$ is the number of vacant commercial premises in zone *i*, in period *T*. This variable represents the connection to the development model and it is updated every year as the new commercial premises are added to the stock of vacant commercial premises and

$W_{iT}^{accessible}$ is the size of accessible workforce in zone *i*, in period *T*.

The accessible workforce $W_{iT}^{accessible}$ for zone *i* in period *T* is the summation of workforce of each zone *j* weighted by the travel time $t_{jiT}$ from *j* to *i* in period *T*:

$$W_{iT}^{accessible} = \sum_{j=1}^{33} \frac{W_{jT}}{t_{jiT}} \tag{5.18}$$

This variable represents firstly the impact of travel time on attractiveness and secondly the connection of the business model to the population model. The workforce is the amount of economically active people living in one zone. It is the vector stock of labour which is updated every year in connection to the population model. For the zone of interest $i$, $t_{iiT} = 10$.

The attractiveness is calculated using the number of vacant premises as updated by the development sub-model but it does not change as vacant premises are occupied during one simulation period, because it is assumed that the attractiveness of one zone does not change within one year.

When a business moves, one unit is added to the stock of vacant commercial premises of the current zone and one is subtracted from the stock of vacant commercial premises of the new zone. The number of businesses moving out of every zone and the number of businesses moving in are counted.

The procedure is presented in Figure 5.6.

### 5.2.6 Formation of the new business database

In the final stage of the business sub-model, the new database to be used in the next simulation period is formed by adding the new businesses (business start-ups), the businesses that did not choose to relocate, the businesses that considered changing location but did not, and the businesses that changed location. The businesses closed down have already been deleted from the business database.

The stock of vacant jobs is updated according to the moves that have been completed. New vacancies are created as a result of a business changing location. The number of new vacant jobs depends on the size of business and on whether it is a new or relocating business. This number is used to update the stock of vacant jobs. Due to lack of relevant data, judgment is used to determine the number of new job vacancies and the following assumptions are made.

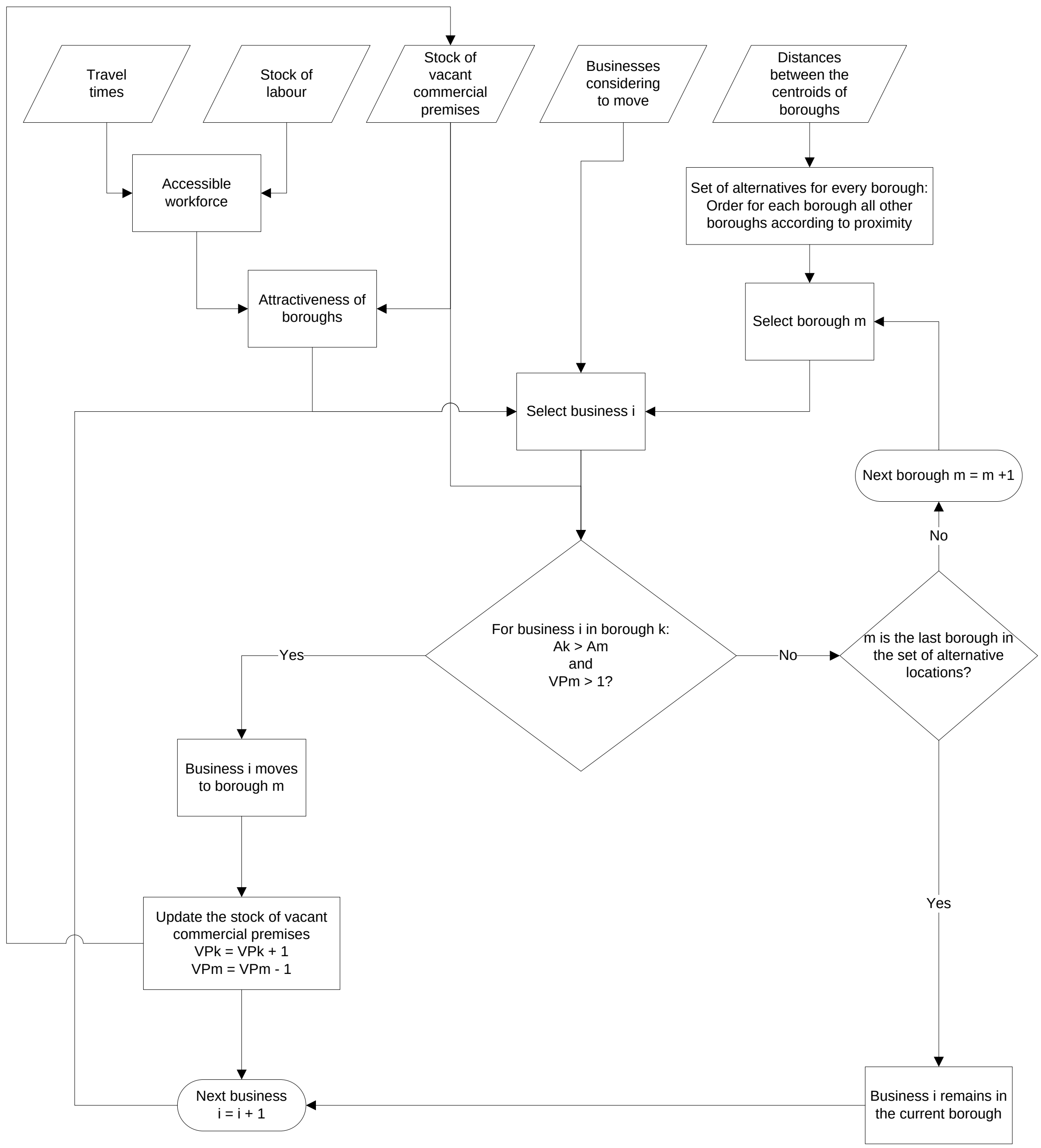


**Figure 5.6: Modelling of business location decisions**

It is assumed that for a new business moving to a zone, a number (integer) of new jobs approximately equal to the median of the range of the size category of the business, are added to the stock of vacant jobs of the zone (e.g. for a business of size 1, which employs 1-10 employees, 5 units will be added to the stock of vacant jobs). I.e. it is assumed that moving businesses are expanding. The main purpose of this is to represent employment growth in areas where businesses are moving to. As the business and population databases are not interconnected, the opposite process – hence the impacts of the decline in employment on population in the zones where businesses are moving from – can not be represented. For a relocating – within London – business, the number of new jobs to be added to the stock of vacant jobs of the zone where the business is moving to, is set equal to the 10% of the maximum limit of the range of the size category of the business (e.g. for a relocating business of size category 1 – which employs 1-10 employees as shown in Table 4.3 – one unit will be added to the stock of vacant jobs, because the maximum limit of the range of the size category of the business is 10). These jobs are considered as new jobs and do not have an impact on the borough the business is leaving from. For new businesses that belong to the largest size category (size 4, Table 4.3), 250 new jobs are added to the stock of vacant jobs. For relocating businesses of the largest size category, 20 new jobs are added to the stock of vacant jobs. The number of new vacancies to be created due to a business according to business size and type of move (i.e. new or relocating business) are shown below:

| size | Vacancies for new business | Vacancies for relocating business |
|---|---|---|
| 1 | 5 | 1 |
| 2 | 35 | 5 |
| 3 | 125 | 10 |
| 4 | 250 | 20 |

The sizes of businesses are known and the probability for each business to be of a certain size can be calculated. As most moves occur in industrial sector 7, i.e. banking, finance and insurance etc (Table 4.2), the size distribution of this sector is used. The number of new vacancies to be added to the stock of vacancies of each zone equals to:

$$J_i = \sum_{m=1}^{4} B_i P_m J_m^{size} \tag{5.19}$$

where

$B_i$ is the number of businesses that moved into zone $i$

$P_m$ is the probability for a business to be of size $m$

$J_m^{size}$ is the number of vacancies according to size, different for new and relocating businesses.

### 5.2.7 Aggregate results

At the end of the procedure the results are copied into four tables. There are two aggregate tables summing up the results of all the years of the simulation: one includes the number of businesses that moved from each zone; the other, the number of businesses that moved to each zone. There are also two tables that include the results from every simulation period, so for a 10-year simulation there will be 10 sets of result in each table. Similarly as in the previous case, one includes the number of businesses that moved from each zone and the other the number of businesses that moved to each zone.

## 5.3 Population sub-model

The population sub-model is the largest and most complex part of the STUDI model. The processes simulated include:

- Demographic changes
- In- and out-migration
- Employment location decisions
- Residential location decisions

### 5.3.1 Connection to development and business sub-models

The population sub-model is connected to the development and business sub-models in order to receive relevant updates. Then, the attractiveness of zones as residential locations is calculated.

By connecting the population to the business model, the stock of businesses of each zone is updated. New businesses and relocating businesses in one zone are added to the stock of businesses of that zone. Businesses that closed down and businesses that moved out of the zone are subtracted from the stock of businesses of the zone.

Then the stock of vacant dwelling is updated by connecting to the development model. The number of new dwellings that were built in every zone – divided by 100 in order to make it compatible to the sample population that is used in the population model, as explained in Section 6.1.4 – is added to the stock of vacant dwellings of the zone.

Finally the attractiveness of each zone as residential location is calculated according to the following equation:

$$A_{iT} = aD_{iT}^{vacant} + bB_{iT}^{accessible} \tag{5.20}$$

where $D_{iT}^{vacant}$ is the number of vacant dwellings in zone *i*, in period *T* and

$B_{iT}^{accessible}$ is the amount of accessible businesses in zone *i*, in period *T*

'Accessible businesses' – similarly to 'accessible workforce' in the business sub-model – for one zone is the summation of businesses in every zone weighted by the travel time to the zone of interest.

Hence 'accessible businesses' $B_{iT}^{accessible}$ for zone *i* in period *T* is the summation of businesses of each zone *j* weighted by the travel time $t_{jiT}$ from *j* to *i* in period *T*:

$$B_{iT}^{accessible} = \sum_{j=1}^{33} \frac{B_{jT}}{t_{jiT}} \tag{5.21}$$

The variable 'vacant dwellings' represents the relation with the development model and is updated in every simulation period by adding the new dwellings estimated by the development sub-model. It is also updated every time a household changes location. Interzonal times travel times are assumed to be 10 minutes: $t_{iiT} = 10$.

### 5.3.2 Migration

Migration depends on the change in the number of businesses. The STUDI model has been developed and calibrated using data from a period of economic growth, during which the total number of businesses increased annually. Hence the number of new businesses each year of the whole simulation period was positive. The model has not been run under a scenario of decline in the number of businesses. The impacts of such a decline need further investigation.

#### 5.3.2.1 Out-migration

The number of new out-migrants every year depends on the total number of new businesses that were estimated in the business sub-model. Thus, migration can be controlled endogenously under the assumption that migration is related to economic and businesses activity.

Using the total number of businesses that were added in London – which is positive – the probability for one household to move out is estimated. The probability for a household of household structure *s* to leave London in period *T* is:

$$P_{sT} = C_s \frac{1}{B_T^{new}} \tag{5.22}$$

where $B_T^{new}$ is the number of new businesses added in London in period *T* as estimated by the business sub-model and

$C_s$ is a constant different for every household structure *s*, representing the fact that for some household categories it is more possible to move out of London than for others.

Instead of using businesses $B_T^{new}$, the number of employment positions could have been used. However, since at this stage the number of employment positions is not affecting location decisions and for new businesses the size distribution of existing businesses is used to estimate the number of new employment positions, it would not make any difference. In the future this can be modified.

Having the probability for every household to out-migrate, Monte Carlo simulation is used to decide which households will move out. When the households to migrate out of London are identified, they are deleted from the London database and added to the table with the households located out of Greater London.

Then the stock of available dwellings is updated. One unit is added to the stock of vacant dwellings of one zone for every household that is out-migrating. Finally the stock of vacant jobs is updated. This update is based on the assumption that all the working members of every household that out-migrates from London will leave their job in London. For every member – that is working within London – of one household that is moving out of London, one unit is added to the stock of vacant jobs of the zone where the member's job was.

#### 5.3.2.2 In-migration

##### 5.3.2.2.1 Identify households to migrate in London

Similarly to the case of out-migration, in order to model in-migration endogenously it is assumed that migration is related to economic and businesses activity. The number of people moving to London is estimated in relation to the number of new businesses that were added earlier in the current simulation period *T*. New migrants are divided in two broad categories. The first one, which is larger, includes single households or couples the chief economic supporter of which is relatively young (e.g. 45 years old). The second category includes all other household structures and the age limit for the chief economic supporter is higher (e.g. 60). The main purpose for making this distinction is to represent the observation that most of the in-migrants in London belong in the first category. The chief economic supporter of the household is chosen randomly from the economic active members of the household.

The number of new households that belong in the first category $M_T^{[1]}$ is given by:

$$M_T^{[1]} = \frac{B_T^{new}}{C^{[1]}} \qquad (5.23)$$

The number of new households that belong in the second category is given by:

$$M_T^{[2]} = \frac{B_T^{new}}{C^{[2]}} \tag{5.24}$$

where $B_T^{new}$ is the number of new businesses and

$C^{[1]}$ and $C^{[2]}$ are constants. They are determined as explained in Section 6.1.3.1

The households to be added to London are chosen from a zone including all the zones out side the 33 London zones. The sample size of people moving in and out of London is the sample size of the LATS data (Section 4.4). To avoid adding the people that were subtracted in the previous period, the deleted households are imported at the bottom of the list and the new households are taken from the top of the list.

In order to be able to identify the number of new households or people added at every simulation period, the year they were added appears at the beginning of the reference number of the individual and the household.

#### 5.3.2.2.2 Job allocation

The next step is to allocate a job to the chief economic supporter of each household. The chief economic supporter is not necessarily the same as in the previous process; he or she is chosen randomly from the economic active member of the household. Only the chief economic supporter is looking for a job in London at this stage.

The job allocation is based on the distribution of new businesses. The zones are ordered according to the number of new businesses added – alternatively zones can be ordered according to the number of new job positions. The cumulative probability for the zones in which the number of businesses increases is assumed so that in the first zone the probability is higher than in the second, in the second higher than in the third, and so forth. According to this more in-migrants will look for a job first in the borough where the most new businesses were added and so forth. Using the cumulative probability and Monte Carlo simulation the job location zone of the head of each in-migrating household is selected. If there are no vacant jobs in the chosen zone, then another random number is selected and the procedure is repeated. If there is no vacant job in any of the zones, then the household is not added in London. When a job is taken by the chief economic supporter of the household, the job is deleted from the stock of vacant jobs. The procedure is shown in Figure 5.7.

#### 5.3.2.2.3 Residence allocation

Finally, the in-migrating households will search for a residence. The search will be based on the employment location of the chief economic supporter of the household. The set of alternative locations is formed in a similar way as in the case of businesses, by ordering all London zones according to proximity to the job location of the chief economic supporter of the household as chosen in the previous process.

It is assumed that the migrating household is looking at first in the zone where the job of the chief economic supporter of the household is; if there are more than twenty vacant dwellings in the zone, the household moves there and the stock of vacant dwellings is updated. If not, the household continues looking in the next zone of the set of alternatives and so forth. The limit of twenty vacant dwellings was specified using judgment. The logic of not using one is to leave vacant dwellings for inter-London relocations which are simulated later in the model.

The moves of the people are recorded in order to keep track of the changes of population. Also the stock of labour is updated by subtracting and adding the members of the couple to the stocks of the zones where they move from and to respectively. Finally the stock of vacant dwellings is updated. The procedure is presented in Figure 5.7.

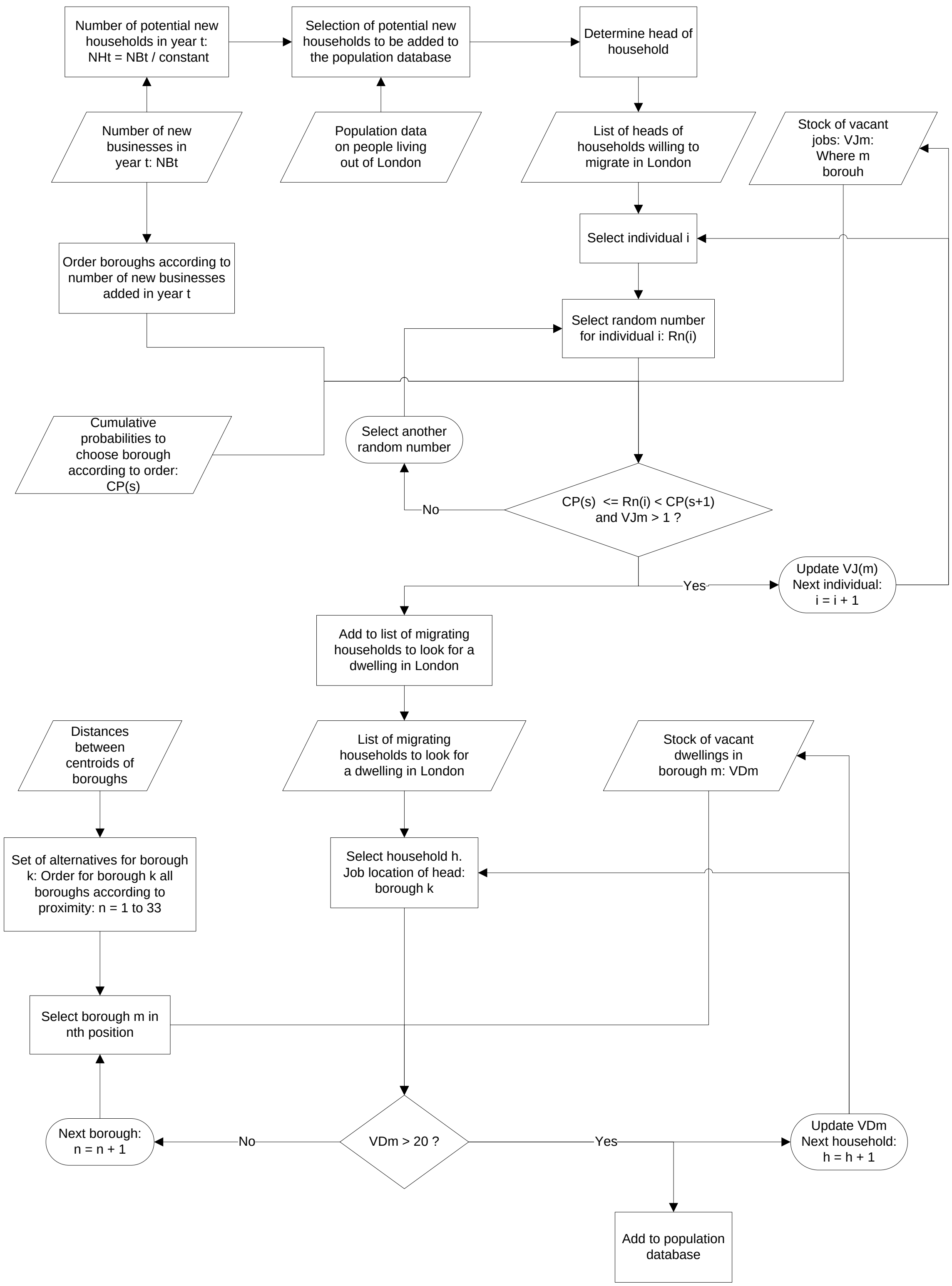


**Figure 5.7: In-migration**

### 5.3.3 Population demographics

For the description of population terms such as household, marriage and divorce have been avoided as much as possible, because they are restrictive regarding more unconventional household structures such as couples living together without being married. For this reason, terms like couple separation and formation and household formation or dissolution are used. The term ‘household’ could be substituted by ‘collection of people’. Another complication related to these unconventional structures is that detailed relevant statistics do not exist: accurate statistics exist only for deaths, births, marriages and divorces. The demographic processes to be simulated in this section are:

- Ageing
- Deaths
- Births
- Dissolution of households (e.g. divorces)
- Formation of households (e.g. couples)

#### 5.3.3.1 Ageing

Ageing is simulated by adding one year to the age of every individual as a one-year simulation period is used.

Then the working status of older people is changed. For people above 65 who are working, the working status is changed from employed (pwkstat = 1, 2, 3, 4, Table 4.6) to pensioner (pwkstat = 9) and the zone of job location (pwsaboro, Table 4.7) is set equal to -1. The job positions that open after retirement in every zone are added to the stock of vacant jobs of the zone. Finally the household structure is updated: households in which all the members are pensioners become all pensioner households (hhstruct = 4, Table 4.6) and single households where the single member is a pensioner become single pensioner households (hhstruct = 1).

#### 5.3.3.2 Deaths

Then deaths are simulated using the probabilities of death according to gender and age as given by the ONS (ONS, 2009b). The probabilities for death remain the same during the whole simulation period. Knowing the death probabilities, Monte Carlo simulation is used to identify the people that die. These people are deleted from the population database. The final stage of this process is to update the variables 'number of persons in the household' (hresnon), 'household structure' (hhstruct) and 'relationship of one household member with the other members' (rlsp), as presented in Table 4.6, of the rest of the household members where death occurred. Household income is not updated, as it is assumed that the remaining members will continue receiving the pension of the dead person. This is quite crude assumption but there are cases with life insurance or in pension schemes which allow the partner to continue receiving at least a percentage of the pension.

#### 5.3.3.3 Births

For the simulation of births, only women are considered. The probabilities for women to give birth according to age group are taken from the ONS (ONS, 2009c). As in the case of deaths, these probabilities remain constant over time.

In order to avoid ending up with too many large families a restriction rule is imposed and only women in households with fewer than 7 people are considered as potential mothers. In the future, probabilities to give birth should consider the number of dependent children in the household.

Monte Carlo simulation is used to identify which women will give birth. Currently the possibility of a woman having twins is not considered.

Then the new born children are added to the population database. The household-related variables of the newborn children are set equal to that of the mother. The assigned reference number contains the core of the household reference number and the last two digits show the simulation period in which the newborn was added. The age of the newborn will be 0, it will not have working status and job location (pwkstat = -1, pwsaboro = -1, Table 4.6), and the relationship with the other members will be son or daughter, i.e. rlsp = 2, Table 4.6. Gender is defined using a constant probability and Monte Carlo simulation.

At the end of the process the household structure and the number of persons of the household where the birth occurred are updated. The procedure simulating births is illustrated in Figure 5.8.

#### 5.3.3.4 Household dissolution

Monte Carlo simulation is used to model couples' separation. As mentioned earlier the term "divorce" is not used, as the focus is on people (either married or not) separating, so that one of them will move out and look for another home.

Only males are considered in the separation simulation, in order to avoid double counting, and it is assumed that the man is the one who will move out of the household after the separation. Additionally, it is assumed that the children – if there are any – will remain with the mother. Only individuals with rlsp = 1 (which represents spouse/partner) are considered, in order to be sure that the individual has a partner to separate from. The separation probabilities are based on divorce statistics, taken from the Office for National Statistics (ONS).

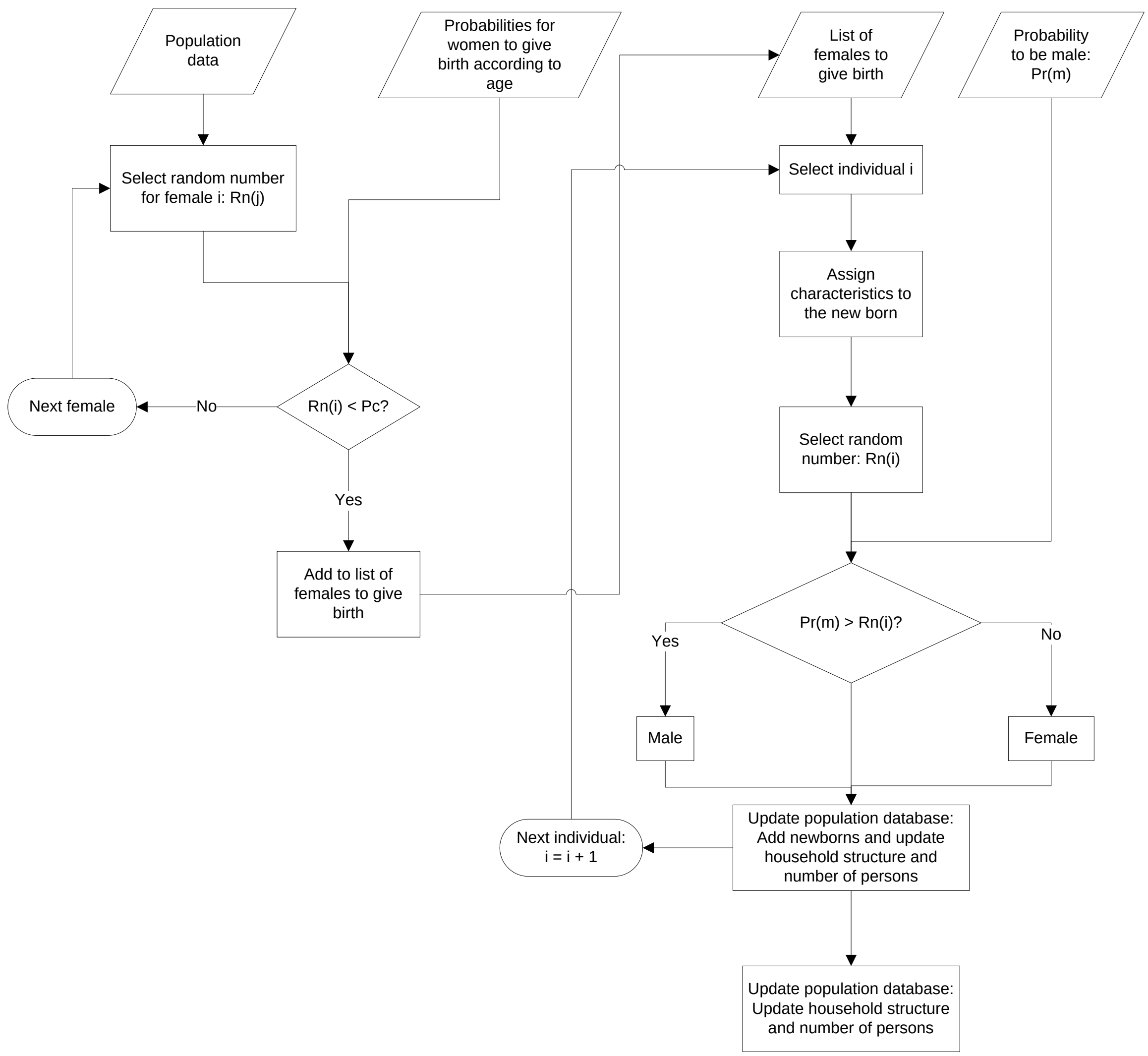


**Figure 5.8: Births**

When the males leaving their current household have been identified, the population database is updated. For the men leaving the household, the ‘household reference number’ (hid), the ‘relationship with the other members of the household’ (rlsp), the ‘number of persons in the household’ (hresnon), the ‘household structure’ (hhstruct) and the ‘household income’ (hincomei), as presented in Table 4.6, are updated. The single man temporarily forms a single household and if he does not find an appropriate match in the next processes he will have to look for a new home as a single household.

For the rest of the members staying in the current household, the variables ‘household structure’ (hhstruct), ‘household income’ (hincomei), ‘number of persons’ (hresnon) and ‘relationship with the other members’ (rlsp, only for the ex-partner) are updated.

Household income for both members separating is downgraded by two units (it is a categorical variable), which is equivalent to dividing income into two approximately equal parts.

#### 5.3.3.5 Household formation

In this process the focus is on the formation of new households, no matter whether they contain married or non-married couples. It starts by identifying individuals that will potentially look for a partner. For this purpose, people from single households (hhstruct = 1 or 2), single-parent households (hhstruct = 3) and all other households (hhstruct = 7) that do not have a partner or spouse (rlsp different than 1) are considered. Using marriage probabilities multiplied by a factor to capture the cohabiting couples, and Monte Carlo simulation, the individuals searching for a spouse or partner in order to look for a dwelling together, are identified.

Individuals looking to form a couple are imported into a new table and matched in couples according to age difference. Only different gender couples are currently formed. A new temporary household ID is assigned to each member of the newly formed couples. Then the population database is updated according to the demographic changes that have occurred (i.e. household formation). The individuals that did not form a couple remain in their old household. The individuals that have formed a couple are deleted from the "old" household in which they used to belong. Variables of the "old" household that are updated accordingly include 'number of people in household' (hresnon), 'household structure' (hhstruct) and 'relationship with the rest of the members of the household' (rlsp). In the case of households with dependent children, the children follow the parent that formed a new couple. The procedure is presented in Figure 5.9.

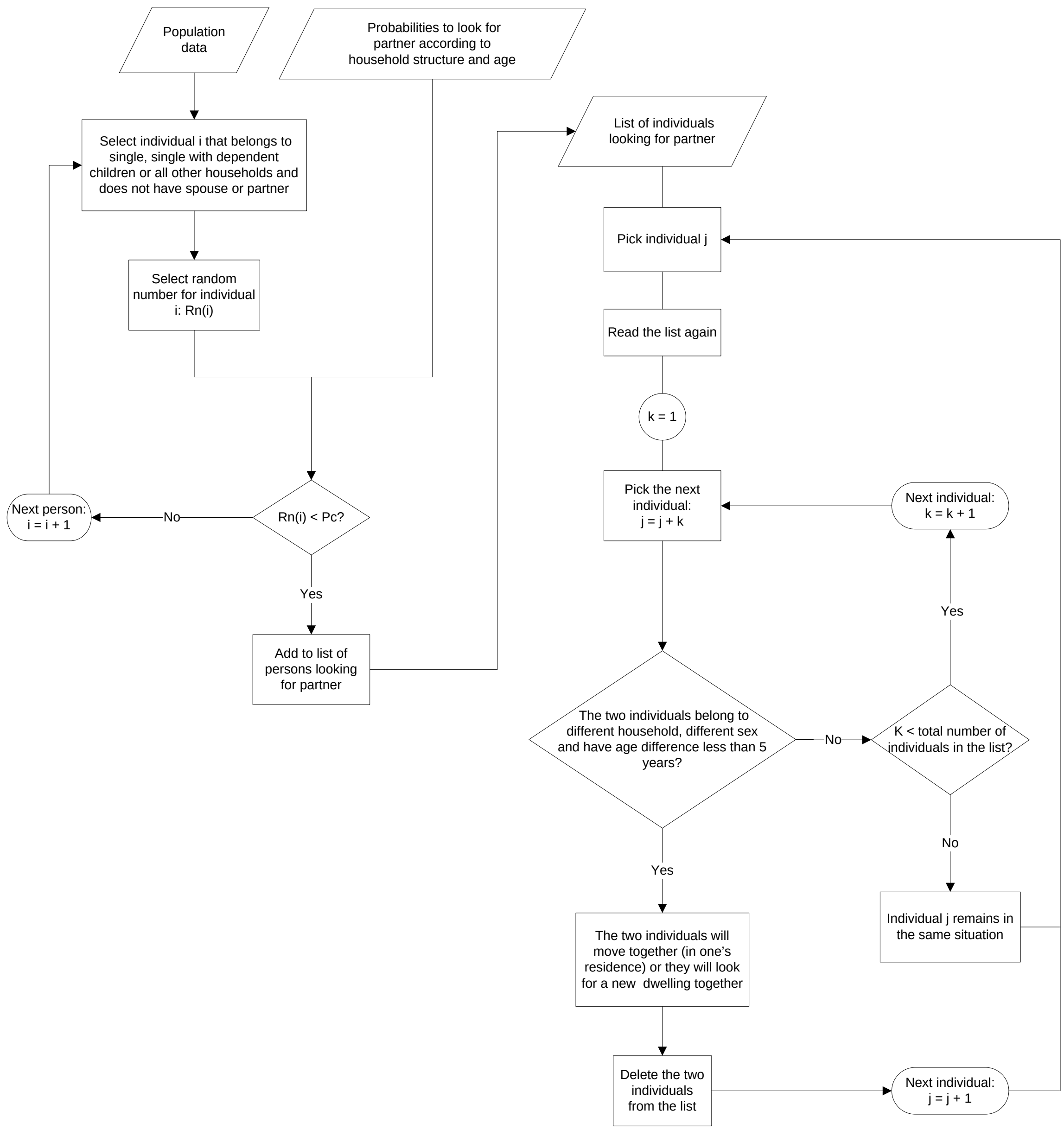


**Figure 5.9: Household formation**

For all the members of the new households, the variables household structure (hhstruct), number of persons in the household (hresnon), household ID (hid) and household income (hincomei) are updated. For the individuals who are not parents (rlsp ≠ 3) and have formed a couple, the relationship with the other members of the household variable is set equal to 1 (rlsp = 1). The incomes of the members of the new couple are summed.

If one of the two members of the new household used to live in a single household (hhstruct = 1 or 2) or was a single parent (hhstruct = 3), then the new couple will move there. If one is a single parent and the other single, then they will move to the dwelling of the single parent. If both were singles or single parents, then they will move to one of the two available dwellings and the other will be added to the stock of vacant dwellings; the choice is made randomly.

The employed individuals that move from one zone to another when they form a couple, are subtracted from the stock of labour of the former zone and added to the stock of labour of the latter zone. The moves of the people are recorded in order to keep track of the changes of population.

The newly formed couples that do not have a dwelling available to move into will look for one as described in Section 5.3.5.2.

### 5.3.4 Employment

#### 5.3.4.1 Employment status and employment location change

The employment location decisions of people that have been living in London in the previous simulation period (i.e. *T*-1) are simulated here. First the individuals looking for a job are identified using Monte Carlo simulation and then their employment location decisions are simulated.

The key variable in the first part, in which the aim is to identify the individuals that are looking for a job, is the current working status. The categories of employment status are shown in Table 4.6.

Different probabilities for changing working status for the various working status categories are defined using judgment due to lack of relevant data. The first category to be considered is pwkstat = 6 and the individual will certainly look for a job as he or she is waiting to take up one. The second category is pwkstat = 7, i.e. unemployed according to the LATS data. A high probability is assumed that he or she will look for a new job. Then the categories pwkstat = 1 and 2, i.e. paid employees are considered. Self-employed are not taken into account currently; it is assumed that they will not look for new employment.

For currently employed persons, the probability $P_a$ for person of age $a$ to consider changing job is an inverse exponential function of age:

$$P_a = Ce^{-da} \qquad (5.25)$$

where $C$ and $d$ are positive constants.

Then students are considered. There are two categories: one with pwkstat = -1 (i.e. unregistered employment status) and one with pwkstat = 5. For the first case, if the individual is less that 16 years old then he or she will not look for a job and his or her working status will remain the same; but if the individual is between 16 and 18 years old, there are two choices: either to become student, i.e. pwkstat = 5, or to look for a job, which means that he or she is registered as unemployed pwkstat = 7 and he or she will look for a job in the next simulation period.

The second case, pwkstat = 5, refers only to students who have to decide whether to continue their education or to enter the job market. A distinction according to ages is being made. If the student is less than 18 years old, then he or she will not look for a job. If older than 18 years old, then his or her potential to stay in education or to look for a job are considered. In this case, different probabilities are used for two age-bands (e.g. 18 to 22 and 23 to 27).

At the end a table with all the people to look for a job is formed. The procedure is presented in Figure 5.10.

#### 5.3.4.2 Employment location decisions

The search for a job by the individuals identified in the previous section is simulated here. Priority is given to the unemployed and individuals waiting to take up a job (pwkstat = 6 and 7); then students follow (pwkstat = 5), and the last category to search for a job are those that are already employed (pwkstat = 1 and 2).

Employment location choice will be based on residential location. Knowing the residential location of each individual looking for employment location, a set of alternative locations is formed based on proximity similarly to that discussed earlier in the business sub-model. So for each zone all other zones are ordered according to distance and an individual looking for a job will look first in the zone of residence and then in all other zones following an order of proximity to the zone of residence until he or she finds a job vacancy.

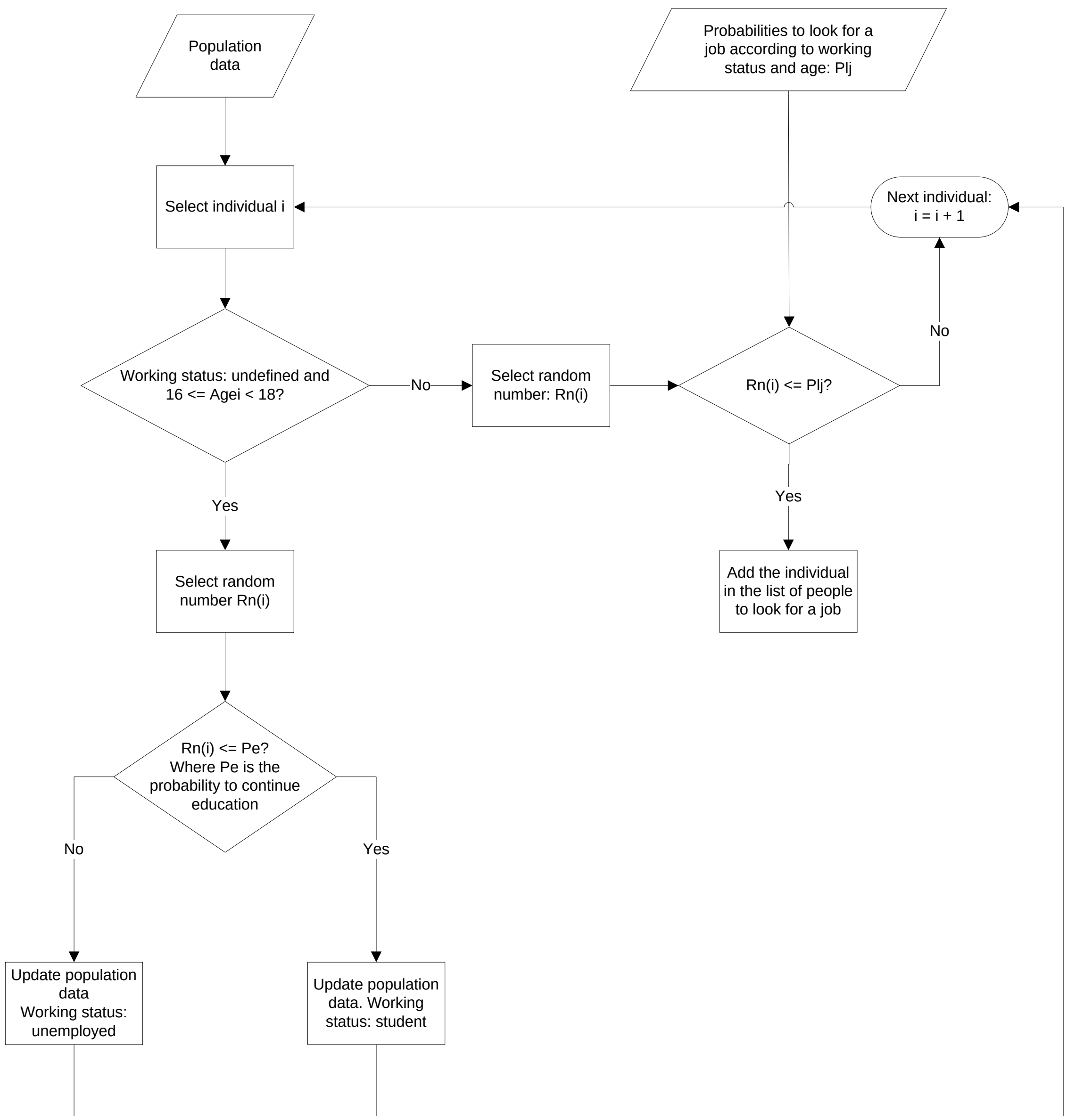


**Figure 5.10: Employment status changes**

In the case of already employed individuals interested in changing job, an additional rule is added: attractiveness of current job is compared with attractiveness of potential job. At the moment this attractiveness depends solely on the travel time to the zone of residence.

If a student looking for a job does not find one, he or she becomes unemployed, and is considered in the next simulation period again. When a student finds a job, Monte Carlo simulation is used to assign a category of employment status between 1 and 4 (Table 4.6), i.e. employed. The probability of each category is estimated using the employment status distribution of the initial population. Every time one individual changes job location, the stock of vacant jobs gets updated. The procedure is presented in Figure 5.11.

### 5.3.5 Residential location

#### 5.3.5.1 Location choice by separated people who did not find a match

Separated men who did not form a couple are the first to look for a new dwelling as singles, but first a new household ID is assigned to them. The key factor in the dwelling search process is the address of employment. The individual looks first in his employment zone (pwsaboro); if a dwelling is available he moves there and the stock of vacant dwellings is updated. If not, then he looks in the next zone of the set of alternatives. The set of alternatives is formed, as has already been discussed, according to proximity of the other zones to the zone where his job is. He will continue looking in all zones until an available dwelling is found. If at the end, he does not find anything, he is deleted from the database, assuming that he is moving out of London. At the end the stock of labour is updated by adding and subtracting the new people who have moved to and from each zone respectively. The moves of the people are recorded in order to keep track of the changes of population. The procedure follows the steps presented in Figure 5.13.

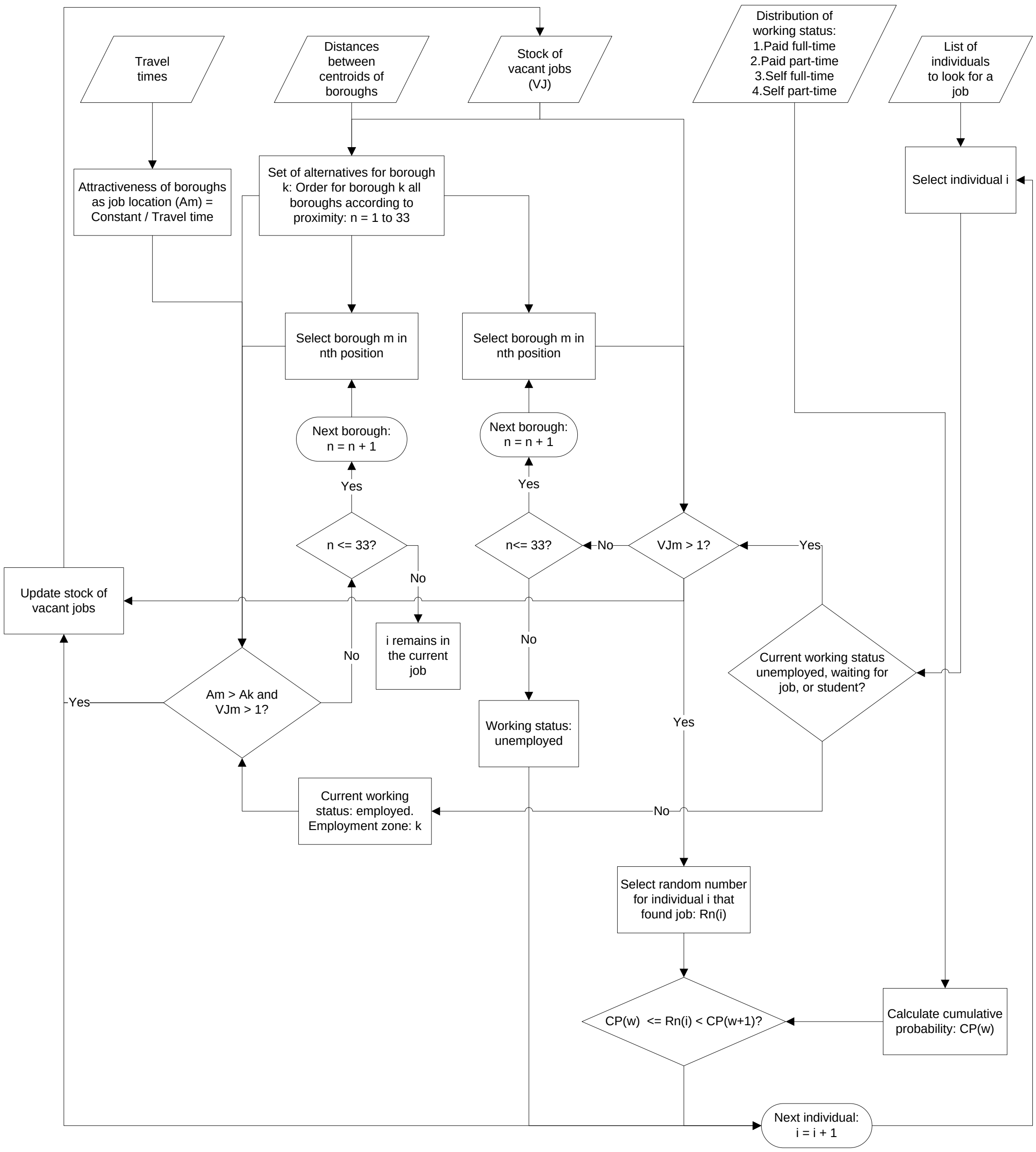


**Figure 5.11: Employment location decisions**

### 5.3.5.2 Search for dwelling by newly formed couples

The new households that have been formed will look for a dwelling considering the job zone of one of the members, who is chosen randomly. The set of alternative locations is formed in a similar way as in the case of separated men or businesses, by ordering all London zones according to the proximity to the job location of the member that has been chosen.

The couple looks first in the zone where the job of the chosen member is (pwsaboro): if a dwelling is available, they move there and the stock of vacant dwellings is updated; if not, then they continue looking in the next zone of the set of alternatives, and so forth.

The moves of the people are recorded in order to keep track of the changes of the population. The population in the zones the couples moved from and to is updated. Also the stock of labour is updated by subtracting the members of the couple from the zones they move from and by adding them to the zones they move to. The procedure follows the steps as presented in Figure 5.13.

After the formation and allocation of new households, the attractiveness of zones as residential locations is recalculated in order to take account of the change in the number of vacant dwellings. The variable 'Accessible businesses' does not change.

#### 5.3.5.3 Residential location decisions

The last part of the population sub-model considers relocation decisions by the current residents of London. Two methodologies are proposed for this purpose. In the first one, which is currently used, the probability of considering moving out is defined exogenously and is a fixed number. The probability is defined in order to allow a predetermined – according to judgment – proportion of the population to look for a new home. Judgment had to be used because it was not possible to gather information on the number of people moving annually. In the alternative methodology, which is not used because it needs further investigation, a utility is calculated considering household characteristics and changes. Then, using a binomial logit model, the probability of considering changing residential location is estimated.

Knowing the probability of considering moving out, Monte Carlo simulation is applied to identify the households that will look for new residential location in the next step. The procedure is presented in Figure 5.12.

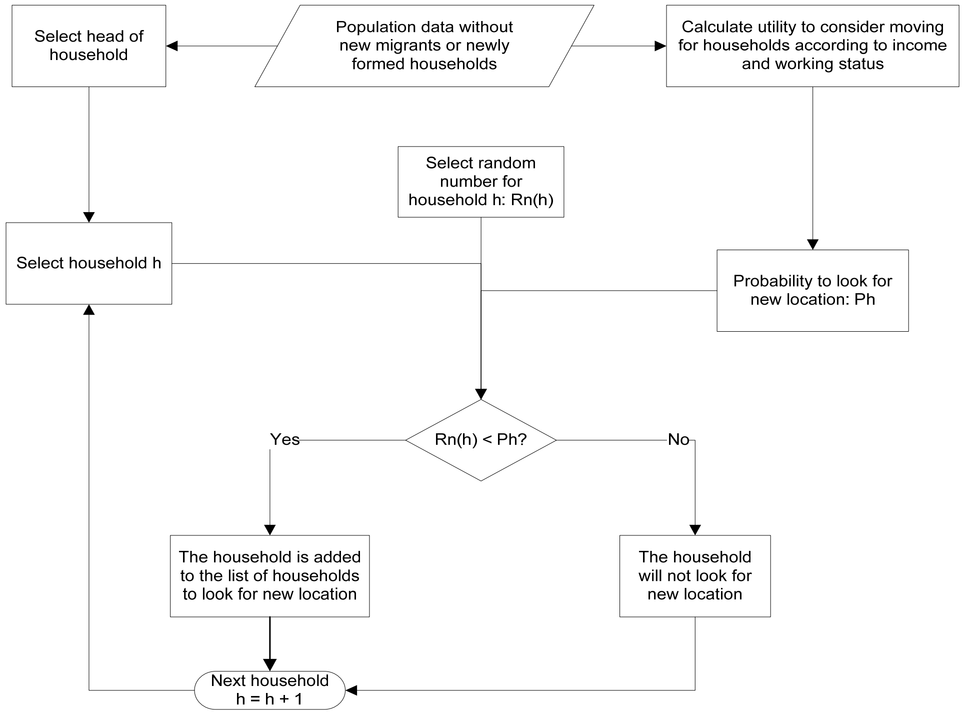


**Figure 5.12: Households considering relocation**

Finally, the households identified as potential movers look for a new residential location. The procedure is similar to the one followed in the business sub-model. The set of alternative locations is formed by ordering all London zones according to proximity to the current zone of the household (hhaboro, Table 4.7).

Starting from the zone closest to the current zone of residence of the household, the attractiveness of the current zone is compared to that of the zones in the set of alternative locations. The household moves to the zone with the highest attractiveness if there is a vacant dwelling. If not, it continues searching until it reaches the last zone in the set of alternative locations. If no zone with higher attractiveness than the current one is found, or if there is no vacant dwelling, the household remains in its current zone. Movements of similar households in both directions between any two boroughs cannot occur in the same simulation period because the attractiveness of one borough will be higher.

The moves of the households are recorded in order to keep track of the changes by the population. The population in the zones the households moved from and to is updated. Also the stock of labour is updated by subtracting the economic active members of the household from the zones they move from and by adding them to the zones they move to. Finally the stock of vacant dwellings is updated.At the end, the population database is updated for the next simulation period. The different sub-tables that were created during various procedures (new households, moved households, households willing to move but did not, etc.) are added to form the new database. The procedure is presented in Figure 5.13.

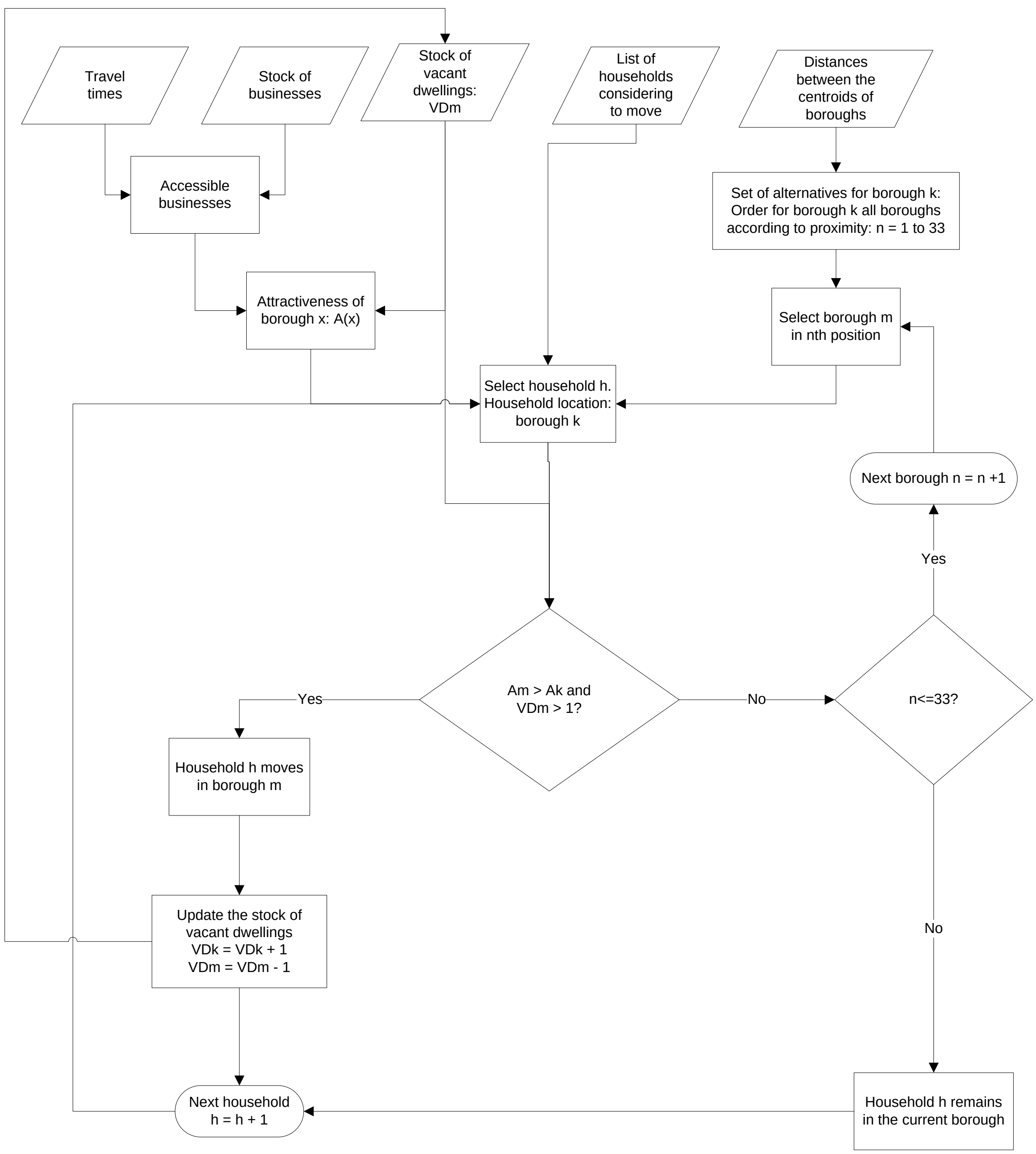


**Figure 5.13: Residential location decisions**

# 6 Estimation, Calibration and Validation of the STUDI model

## 6.1 Calibration

In the previous chapter (Chapter 5) the STUDI model was described and a number of equations and indicators representing processes were presented. In this chapter (Chapter 6) these equations are estimated, the choice of values of key indicators is justified, major assumptions made are discussed and finally the results of the STUDI model are validated against real data.

While estimating the equations used in the STUDI model, regression analysis is used to test the significance of various variables assumed to affect development, business and residential location decisions, and to evaluate the impacts of these variables on the attractiveness of locations. As a result, the significance and the level of interaction between the main agents of urban development are also tested.

A cross-sectional analysis is performed at borough level. Each borough is one unit and for each variable there are 33 observations (the number of boroughs). Although this spatial analysis level is not very detailed, it was chosen mainly because some of the datasets were disaggregated only down to borough level (Section 4.2) but also to achieve better computational time.

Travel time is imported in two ways: either as travel time from each zone to the city centre, or as travel time between pairs of zones. As explained in Section 4.1, the CAPITAL data provide travel time estimates from various zones to the JLE stations, with and without the JLE. Travel times to London Bridge or Westminster stations are used as estimates of the travel time to the city centre. The two stations are chosen as the most central – London Bridge is close to the City, and Westminster is close to many tourist, commercial and office (public and private) locations – among the ones for which CAPITAL estimates are currently available. At the current spatial level (i.e. local authorities) of the analysis, it can quite safely be assumed that the travel times to these stations sufficiently approximate the travel time to the city centre.

Travel-time estimates to the city centre are used in the development sub-model because a more general accessibility index is needed for its purposes. Travel time between pairs of zones is used in order to estimate the accessible workforce for businesses (Section 5.2.5.2) and the accessible businesses for population (Section 5.3.1).

### 6.1.1 Development sub-model

By using cross-sectional regression analysis to estimate the equation that provides the number of new premises to be added to the relevant stock in every simulation period, it is assumed that the coefficients estimated from a cross-sectional model are good approximates of the coefficients of a model that is running over time. In Sections 6.1.1.1 and 6.1.1.2, the results of the estimation of the residential and commercial development regression models used in the STUDI model, as described in Section 5.1, are presented.

In order to measure development, in the STUDI model, the number of applications granted by local authorities is used. Perhaps it would seem more logical to measure demand for development by considering the number of applications received by local authorities, but the dataset ‘planning applications received by local authorities’ (Section 4.2) does not distinguish between residential and commercial development. Additionally, the ratio of the applications granted over the applications submitted in every zone does not change significantly over time, which means that using the number of planning applications granted can be seen as a good alternative to using the number of planning applications received by local authorities and it will not create large bias in the results.

#### 6.1.1.1 Commercial premises

In order to evaluate the interactions between development and businesses, the development regression model uses information on number of businesses and vice versa. The number of planning applications for commercial development is regressed against the number of businesses or the net change in the number of businesses and the number of businesses is regressed against the number of commercial premises (Section 6.2.2).

In Table 6.1 and Table 6.2, the results from the analysis on commercial development are presented. For the estimation of the results in Table 6.1, travel time to the station of Westminster is used. The results presented in Table 6.2 are estimated using travel time to the station of London Bridge.

| **Ref** | **DC1** | | **DC2** | | **DC3** | | **DC4** | |
|---|---|---|---|---|---|---|---|---|
| **Dependent** | **Granted applications for commercial development at time T** | | **Granted applications for commercial development at time T** | | **Granted applications for commercial development at time T** | | **Granted applications for commercial development at time T** | |
| **Independent** | **Coef** | **Sig#** | **Coef** | **Sig#** | **Coef** | **Sig#** | **Coef** | **Sig#** |
| **Intercept** | -227.1 | . | 261.9743 | * | 260.5483 | * | | |
| **Number of businesses at time T-1** | 0.009 | | | | | | | |
| **Change in number of businesses from time T-2 to T-1** | | | 0.1478 | - | 0.15684 | - | | |
| **Travel time to Westminster with JLE** | 1.347 | | -4.39553 | ** | -4.28812 | * | -1.662 | *** |
| **Change in travel time to Westminster due to JLE** | | | | | -5.32447 | | | |
| **Number of commercial premises at time T-1** | 0.022 | | 0.06713 | *** | 0.06872 | *** | 0.043 | *** |
| **Vacant commercial premises at time T-1** | -0.03 | | -7.23796 | . | -7.16765 | . | -0.108 | ** |
| **Commercial values per sqm at time T-1** | 0.095 | * | | | | | | |
| **Change in commercial values per sqm from time T-2 to T-1** | | | 8.92849 | | 7.64264 | | | |
| **Land available for development at time T-1** | 0.102 | | 0.07615 | | 0.0528 | | | |
| | **Multiple R-sqrd** | 0.87 | **Multiple R-sqrd** | 0.762 | **Multiple R-sqrd** | 0.765 | **Multiple R-sqrd** | 0.892 |

**Table 6.1: Explanatory regression analysis of the commercial development location process using travel time to Westminster**

#Confidence interval at which the variable is significant: 99.95% '***'; 99.5% '**'; 99% '*'; 95% '.'; 90% '-'; lower than 90% ' '.

| **Ref** | **DC5** | |
|---|---|---|
| **Dependent** | **Granted applications for commercial development at time T** | |
| **Independent** | **Coef** | **Sig#** |
| **Intercept** | 234.1197 | * |
| **Change in number of businesses from time T-2 to T-1** | 0.12913 | - |
| **Travel time to London Bridge with JLE** | -4.64688 | * |
| **Change in travel time to London Bridge due to JLE** | 23.40172 | * |
| **Number of commercial premises at time T-1** | 0.06091 | *** |
| **Vacant commercial premises at time T-1** | -6.90832 | . |
| **Change in commercial values per sqm from time T-2 to T-1** | 6.28884 | |
| **Land available for development at time T-1** | 0.2076 | |
| | **Multiple R-squared** | 0.769 |

**Table 6.2: Explanatory regression analysis of the commercial development location process using travel time to London Bridge**

#Confidence interval at which the variable is significant: 99.95% ‘***’; 99.5% ‘**’; 99% ‘*’; 95% ‘.’; 90% ‘-’; lower than 90% ‘ ’.

The coefficients in the linear model are interpreted as change (if the coefficient is negative it is a decrease, and if positive an increase) in units in the output (i.e. the dependent variable) due to an increase by one unit in the input (i.e. the independent variable).

In model DC1 all the variables – but not changes from *T*-2 to *T*-1 – are included. The model does not perform very well in terms of statistical significance, as there is not enough evidence against the null hypothesis for all variables except commercial values per square meter (null hypothesis: the t-values are used to test the significance of the variable by testing against the hypothesis that the coefficient of the variable equals to zero).

In model DC2 the variable ‘change in the number of businesses’ from period *T*-2 to period *T*-1 has a positive impact on the number of applications in period *T* as expected. This means that by increasing the number of businesses, the number of commercial planning applications is increased. The variable is significant at 90% confidence level. This variable represents the interaction of the development sub-model with the business sub-model. Travel time to Westminster has negative impact, as expected, meaning that the greater the travel time to Westminster station, the smaller the number of commercial applications. It is significant at 99.5% confidence interval. The number of commercial properties has a small but positive impact and the number of vacant commercial properties has negative impact on the number of commercial applications, as expected. For both variables there is strong evidence against the null hypothesis. The sign of the coefficients of these variables reflects the fact that developers are attracted by commercial locations to build commercial development and avoid locations with high vacancy rates. The change in land values and the change in the amount of land available for development lack statistical significance. One of the reasons for this might be the relatively aggregate spatial level that is used.

Model DC5 is the equivalent of DC3 but travel time to London Bridge is used instead of travel time to Westminster. In models DC3 and DC5 the variables 'change in travel time to Westminster due to JLE' and 'change in travel time to London Bridge due to the JLE' are also included. They measure the difference of travel time from each zone (as estimated by CAPITAL) to Westminster and London Bridge stations respectively before and after the opening of JLE. All variables but 'change in travel time to London Bridge due to the JLE' in DC5 have similar impact to the number of granted applications as in DC3 where travel time to Westminster is used. The variable 'change in travel time to London Bridge due to the JLE' in DC5 is significant at a 99% confidence interval and has positive impact on the number of development applications as expected, meaning that an improvement in travel time to London Bridge station will increase the number of development applications. In DC3, where Westminster is the reference station, the variable 'change in travel time to Westminster due to JLE' is not significant at confidence interval higher than 90%.

For the estimation of the equation that is used in the STUDI model to calculate the number of new commercial premises to be added to the stock of the commercial premises at each simulation period, regression DC4 is used. The number of approved planning applications for commercial premises in period $T$ is regressed over travel time and development-related variables. Travel time captures the impact of new transport infrastructure. Vacant and total commercial premises capture the impacts of demand on developers' location decisions. They are updated in every simulation period in the model. As the model is running over time, it is important to be able to update the variables included in the development functions accordingly; for this reason, land values are not included, as a price model to update property prices has not been developed at this stage. The variables 'number of businesses' and 'land available for development' are not included because they appear to be statistically insignificant at any confidence interval higher than 90%, as can be seen in Table 6.1. Travel time to the city centre is the travel-time estimate to the station of Westminster. It was chosen instead of travel time to London Bridge because the borough of Westminster includes the most businesses of all boroughs in London. However, it can be seen in all regressions presented in this chapter that travel time estimates to anyone of the two stations have similar impact.

DC4 is the Equation 5.2 as presented in Section 5.1, according to which the number of new commercial premises $p_{iT}^{new}$ to be added in zone *i* in period *T* is given by:

$$p_{iT}^{new} = b_1 t_{iT} + b_2 p_{iT-1}^{total} + b_3 p_{iT-1}^{vacant} ,$$

where $t_{iT}$ is travel time from zone *i* to the city centre in simulation period *T*,

$p_{iT-1}^{total}$ is the total number of commercial premises in zone *i* in period *T*-1,

$p_{iT-1}^{vacant}$ is the number of vacant commercial premises in zone *i* in period *T*-1 and

$b_1$, $b_2$, $b_3$ and $b_4$ are the estimated coefficients.

The variables are discussed in more detail in Section 5.1.

As can be seen, in DC4 all the variables are significant at 99.5% or higher confidence interval. Travel time to the city centre has negative impact, reflecting the fact that less accessible areas attract less development. The total number of commercial premises has a positive impact, but the number of vacant commercial premises has a negative impact and it can be interpreted as a lack of demand.

#### 6.1.1.2 Residential premises

For the case of residential premises the number of 'approved planning applications for dwellings' (section 4.2.) is the dependent variable. Similarly as for commercial premises, demand is represented by the number of vacant dwellings. In Table 6.3 and Table 6.4 the results of the estimation of the regression of approved planning applications over various variables are presented.

The DR1 model contains travel time to Westminster station and all the development-related variables. The variables 'vacant dwellings' and 'mean house prices' are not significant at any confidence interval above 90%. Travel time to Westminster has a negative and total number of dwellings a positive impact, as expected. The DR2 model includes only the statistically significant variables. These are the variables that will be used in the function to be used in the STUDI model. In model DR3 the difference on travel time due to JLE is also included, in order to evaluate its impacts on residential development. It appears to be insignificant at any confidence interval above 90%. In models DR7 and DR8 the travel time to London Bridge is used as an indicator of travel time to the city centre instead of the travel time to Westminster. As in the case of commercial development, travel time to London Bridge has similar impact as travel time to Westminster.

For the estimation of the regression coefficients used in the STUDI model to approximate the number of new dwellings, the number of approved planning applications for dwellings in period *T* is regressed against travel time and development-related variables in *T*-1. A Cobb-Douglas (Cobb and Douglas, 1928) functional form is used, as it performs better statistically as can be seen by comparing the results of DR2 and DR6.

| Ref | DR1 | | DR2 | | DR3 | | DR4 | | DR5 | | DR6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Dependent** | **Granted applications for residential development at time T** | | **Granted applications for residential development at time T** | | **Granted applications for residential development at time T** | | **log(Granted applications for residential development at time T)** | | **log(Granted applications for residential development at time T)** | | **log(Granted applications for residential development at time T)** | |
| **Independent** | **Coef** | **Sig#** | **Coef** | **Sig#** | **Coef** | **Sig#** | **Coef** | **Sig#** | **Coef** | **Sig#** | **Coef** | **Sig#** |
| **Intercept** | 69.07 | | 87.689 | | 91.399 | - | -7.966 | *** | -8.766 | *** | -7.96 | *** |
| **Travel time to Westminster with JLE** | -3.941 | * | -3.495 | ** | -3.573 | ** | | | | | | |
| **log(Travel time to Westminster with JLE)** | | | | | | | -0.674 | * | -1.035 | ** | -0.673 | * |
| **Change in travel time to Westminster due to JLE** | | | | | 8.906 | | | | | | | |
| **Number of residential premises at time T-1** | 0.004 | *** | 0.003 | ** | 0.004 | *** | | | | | | |
| **log(Number of residential premises at time T-1)** | | | | | | | 1.452 | *** | 1.656 | *** | 1.451 | *** |
| **Vacant residential premises at time T-1** | -0.01 | | | | | | | | | | | |
| **log(Vacant residential premises at time T-1)** | | | | | | | -0.001 | | -0.124 | | | |
| **Mean house prices at time T-1** | 0.0002 | | | | | | | | | | | |
| **Land available for development at time T-1** | -0.292 | - | -0.408 | * | -0.383 | * | | | | | | |
| **log(Land available for development at time T-1)** | | | | | | | -0.201 | * | | | -0.201 | * |
| **Area with commercial premises at time T-1** | -0.007 | | | | | | | | | | | |
| | **Multiple R-squared** | 0.717 | **Multiple R-squared** | 0.698 | **Multiple R-squared** | 0.712 | **Multiple R-squared** | 0.79 | **Multiple R-squared** | 0.75 | **Multiple R-squared** | 0.79 |

**Table 6.3: Explanatory regression analysis of the residential development location process using travel time to Westminster**

#Confidence interval at which the variable is significant: 99.95% ‘***’; 99.5% ‘**’; 99% ‘*’; 95% ‘.’; 90% ‘-’; lower than 90% ‘ ’.

| Ref | DR7 | | DR8 | |
|---|---|---|---|---|
| Dependent | Granted applications for residential development at time T | | Granted applications for residential development at time T | |
| Independent | Coef | Sig# | Coef | Sig# |
| Intercept | 55.827 | | 50.28 | |
| Travel time to London Bridge with JLE | -2.453 | * | -3.193 | * |
| Change in travel time to London Bridge due to JLE | | | -10.89 | - |
| Number of residential premises at time T-1 | 0.003 | *** | 0.004 | *** |
| Land available for development at time T-1 | -0.498 | * | -0.46 | * |
| | Multiple R-squared | 0.648 | Multiple R-squared | 0.677 |

**Table 6.4: Explanatory regression analysis of the residential development location process using travel time to London Bridge**

#Confidence interval at which the variable is significant: 99.95% '***'; 99.5% '**'; 99% '*'; 95% '.'; 90% '-'; lower than 90% ' '.

The function used to estimate the number of new dwellings $d_{iT}^{new}$ as presented in Section 5.1 (Equation 5.1) is given by:

$$d_{iT}^{new} = At_{iT}^{b_1} d_{iT-1}^{total\ b_2} l_{iT-1}^{b_3} d_{iT-1}^{vacant\ b_4},$$

where $t_{iT}$ is travel time from zone *i* to the city centre in simulation period *T*,

$d_{iT-1}^{total}$ is the total number of dwellings in zone *i* in simulation period *T*-1,

$l_{iT-1}$ is the land available for development in zone *i* in period *T*-1,

$d_{iT-1}^{vacant}$ is the number of vacant dwellings in zone *i* in period *T*-1,

*A* is a constant (the intercept) and $b_1$, $b_2$, $b_3$ and $b_4$ are the estimated coefficients.

The variables are discussed in more detail in Section 5.1.

The variable 'vacant dwellings' is not included in the regression used in the STUDI model because it lacks statistical significance, as can be seen in models DR4 and DR5.

For the estimation of the function the following logarithmic linear regression was used:

$$\log(d_{iT}^{new}) = a + b_1 \log(t_{iT}) + b_2 \log(d_{iT-1}^{total}) + b_3 \log(l_{iT-1})$$

The results are presented in DR6. Using a Cobb-Douglas model, the coefficients are interpreted as elasticities. Hence one percent increase in the independent variable will create percentage change (if the coefficient is negative, a decrease; and if positive, an increase) equal to the coefficient of the dependent variable. As can be seen in DR6, all the variables are significant at a 99% confidence interval or higher. Land available for development is included, although currently not updated in every simulation period as it should be. It is not updated because there is not sufficient information to update the variable according to new development, i.e. to derive built space from each new development application. It has negative impact, meaning that less available land for development will increase the number of applications, which is the opposite of what was expected, but it reflects the attractiveness of already developed areas. Travel time to city centre has negative impact as expected, and total number of dwellings in the previous year, positive. The fact that the latter is larger than 1 indicates that an increase in the total number of dwellings in a borough will be followed by a large increase of granted development applications; this can be true only for a period of large growth and it is difficult to be the case for boroughs with limited development potentials.

### 6.1.2 Business sub-model

#### 6.1.2.1 Businesses-GDP relation

As discussed in Section 5.2.2, business closures and start-ups are forecast in relation to GDP change from period to period. The total number of businesses in the study area (i.e. London) is regressed over GDP according to Equation 5.4:

$$B_T^{total} = a + bGDP_T ,$$

where $B_T^{total}$ is the total number of businesses in London in period *T* and

$GDP_T$ is the value of GDP in period *T*.

The equation was estimated using 12 observations from 1995 to 2006. The results are presented in Table 6.5.

| **Dependent** / **Independent** | $B_T^{total}$ | | |
|---|---|---|---|
| | **Coefficient** | **Significance#** | **Multiple R-squared** |
| **Intercept** | 250747.1 | *** | 0.710 |
| **$GDP_T$** | 1182.5 | *** | |

**Table 6.5: Forecast of number of businesses according to GDP**

#Confidence interval at which the variable is significant: 99.95% ‘***’; 99.5% ‘**’; 99% ‘*’; 95% ‘.’; 90% ‘-’; lower than 90% ‘ ’.

For GDP the YBEU index is used, which is the Gross Domestic Product at current market prices. Index value for 2003 is 100.

#### 6.1.2.2 Business relocation

Businesses considering relocation are chosen using Monte Carlo simulation and a constant probability, which allows a predetermined percentage of the total number of businesses to do so (Section 5.2.5).

Regarding the final location decisions, the simulation of business location decisions is based on the assumption that the number of businesses in each zone is an indicator of the attractiveness of the zone. The impacts of location characteristics (such as accessibility, commercial property vacancy rates, property values, commercial floorspace etc.) and of population attributes (such as employment, unemployment etc.) on the number of businesses are estimated.

Only businesses of industrial sectors 3 to 7 (Table 4.2) are used for estimation of the location attractiveness for businesses. Industrial sectors 1, 2 and 8 were excluded. Sector 1 includes agriculture and fishing businesses; they represent a very small percentage of the total number of businesses and because of their nature they require locations with special characteristics. Sector 2 includes energy and water businesses; they also represent a small percentage of the total business population and they need mainly big plants in locations with specific characteristics. Sector 8 refers to public administration, education, health and other services; businesses of this sector are expected to follow a different logic from businesses of the industrial sectors 3 to 7, when making location decisions. At this point it should be mentioned that it is recognized that different industrial sectors have different priorities when choosing location and a future aim is to estimate one model for each industrial sector. At this stage one single attractiveness function is estimated and the aim is to keep it simple and to use only key variables such as employment, travel time and vacant commercial premises. However, it is recognized that even these variables can have differential impact on different industrial sectors.

In Table 6.6 the results of the cross-sectional regression of the number of businesses over various variables are presented. In models B1, B2 and B3 travel time to Westminster is used as an estimate of travel time to the city centre. In models B4 and B5 travel time is included in the variable accessible workforce allowing travel time between pairs of zones instead of travel time to the city centre to affect location decisions. This way the impact of accessibility is modelled more realistically. In models B6, B7 and B8 travel time to London Bridge is used as estimate of travel time to the city centre.

In regression B1, travel time to the station of Westminster has negative impact on the number of businesses, as expected, and there is strong evidence against the null hypothesis. As in the development model DC2, the change of property values does not appear to be statistically significant. The number of people in the zone employed in industrial sectors 3 to 7, has positive impact on the number of businesses and the number of unemployed people that used to work in these sectors is negative. Both variables are significant at a high confidence level and they represent the interaction between the business and the population sub-models. The number of commercial properties is significant at a high confidence level and has a positive impact on the number of businesses, as expected; as the variable is related to the development sub-model, it is one point of connection between the two sub-models. The other is the number of vacant dwellings. The variable ‘change in the percentage of vacant properties’ has a positive impact, meaning that businesses are attracted by an increase in vacant properties; the variable appears to be significant at 90% confidence level.

| **Ref** | **B1** | | **B2** | | **B3** | | **B4** | | **B5** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Dependent** | **Businesses of sectors 3-7 at time T** | | **Businesses of sectors 3-7 at time T** | | **Businesses of sectors 3-7 at time T** | | **Businesses of sectors 3-7 at time T** | | **Businesses of sectors 3-7 at time T** | |
| **Independent** | **Coef** | **Sig#** | **Coef** | **Sig#** | **Coef** | **Sig#** | **Coef** | **Sig#** | **Coef** | **Sig#** |
| **Intercept** | 12440 | ** | 18.3471 | | 12500 | ** | | | | |
| **Travel time to Westminster with JLE** | -243.6 | *** | | | -245 | *** | | | | |
| **Change in travel time to Westminster due to JLE** | | | | | 47.37 | | | | | |
| **Number of commercial premises at time T-1** | 2.552 | *** | 2.7812 | *** | 2.534 | *** | 1.484 | ** | | |
| **Vacant commercial premises at time T** | | | | | | | 3.474 | ** | 4.579 | ** |
| **Change in % of vacant commercial premises from time T-2 to T-1** | 611.1 | - | 288.1534 | | 598.2 | - | | | | |
| **Values per squared meter at time T-1** | | | | | | | 139.396 | *** | | |
| **Change in values per squared meter from time T-2 to T-1** | 172.5 | | -79.7909 | | 183.1 | | | | | |
| **Employed population in sectors 3-7 at time T-1** | 0.1168 | ** | | | 0.117 | ** | | | | |
| **Unemployed population in sectors 3-7 at time T-1** | -1.356 | ** | -1.3756 | *** | -1.366 | ** | | | | |
| **Employed population in sector D-K at time T-1 / Travel time to Westminster** | | | 5.6902 | *** | | | | | | |
| **Accessible Workforce** | | | | | | | -0.104 | *** | 0.092 | *** |
| | **Multiple R-squared** | 0.813 | **Multiple R-squared** | 0.842 | **Multiple R-squared** | 0.813 | **Multiple R-squared** | 0.87 | **Multiple R-squared** | 0.815 |

**Table 6.6: Explanatory regression analysis of the business location process using travel time to Westminster and accessible workforce**

#Confidence interval at which the variable is significant: 99.95% '***'; 99.5% '**'; 99% '*'; 95% '.'; 90% '-'; lower than 90% ' '.

| Ref | B6 | | B7 | | B8 | |
|---|---|---|---|---|---|---|
| Dependent | Businesses of sectors 3-7 at time T | | Businesses of sectors 3-7 at time T | | Businesses of sectors 3-7 at time T | |
| Independent | Coef | Sig# | Coef | Sig# | Coef | Sig# |
| Intercept | 818.8582 | | 11430 | * | 17642.55 | * |
| Travel time to London Bridge with JLE | | | -249.5 | ** | -211.217 | . |
| Change in travel time to London Bridge due to JLE | | | 443.3 | - | | |
| Number of commercial premises at time T-1 | 3.0909 | *** | 2.553 | *** | 3.2743 | *** |
| Change in % of vacant commercial premises from time T-2 to T-1 | 526.0193 | - | 654 | - | 884.2244 | . |
| Change in values per squared meter from time T-2 to T-1 | -142.746 | | 143.5 | | 180.0618 | |
| Employed population in sectors 3-7 at time T-1 | | | 0.123 | * | | |
| Unemployed population in sectors 3-7 at time T-1 | -1.6365 | ** | -1.44 | ** | -0.8693 | . |
| Employed population in sector D-K at time T-1 / Travel time to London Bridge | 5.3383 | ** | | | | |
| Employed population in sector D-K at time T-1 / Distance from the City of London | | | | | -360.734 | - |
| | Multiple R-squared | 0.782 | Multiple R-squared | 0.782 | Multiple R-squared | 0.726 |

**Table 6.7: Explanatory regression analysis of the business location process using travel time to London Bridge**

#Confidence interval at which the variable is significant: 99.95% ‘***’; 99.5% ‘**’; 99% ‘*’; 95% ‘.’; 90% ‘-’; lower than 90% ‘ ’.

In regressions B3 and B7 the variables ‘change in travel time to London Bridge due to JLE’ and ‘change in travel time to Westminster due to JLE’ are included in the independent variables together with travel time to London Bridge or Westminster stations respectively. The variable ‘change in travel time to London Bridge due to JLE’ is significant at 90% confidence interval, but the variable ‘change in travel time to Westminster due to JLE’ is not significant at a higher than 90% confidence interval.

In equations B2 and B6, employed population is substituted by accessible employees. This variable is calculated using travel time to the city centre and not travel time between pairs of zones, and is not, therefore, the same as the variable ‘accessible workforce’ that is imported in the attractiveness function used in the STUDI model (as presented in

Section 5.2.5.2). Accessible employees is the ratio of employees over the travel time to the city centre (i.e. 'Employed population in sectors 3-7 at time T-1 / Travel time to London Bridge with JLE' and 'Employed population in sectors D-K at time T-1 / Travel time to Westminster with JLE'). It represents accessibility of employees to the city centre and aims to capture the impact of the new line due to the impact it will have on the travel time to the city centre. In the business sub-model of STUDI the variable accessible employees/workforce of each borough separately is used instead of accessible employees to the city centre (Equation 5.17). In both models, B2 and B6, accessible population has a positive impact on the number of businesses, meaning that more businesses are attracted as the accessible population (to the city centre) increases. In regression B8, accessible population is represented by the ratio of employment over distance to the City (i.e. 'Employed population in sectors 3-7 at time T-1 / Distance from the City of London. The sign of the coefficient is the opposite of what would be expected.

Regarding the business relocation process in the STUDI model, the final location decision of businesses that have been found to be considering relocation (Section 5.2.5.1) depends on the attractiveness of the zones. The attractiveness function of each zone is based on the regression of the number of businesses over accessible workforce and number of vacant commercial premises. The attractiveness function is given by Equation 5.17 as presented in Section 5.2.5.2:

$$A_{iT} = b_1 P_{iT}^{vacant} + b_2 W_{iT}^{accessible}$$

where $P_{iT}^{vacant}$ is the number of vacant commercial premises in zone *i*, in period *T* and

$W_{iT}^{accessible}$ is the size of accessible workforce in zone *i*, in period *T*.

The results of the estimation are presented in B5, Table 6.6. Both variables have positive impact on attractiveness and are significant at 99.5% confidence interval. The positive impact of an accessible workforce can be interpreted as the positive impact of increasing the pool of potential employees on the attractiveness of a location as business location. In B4 land value and number of commercial premises are also included. Both appear to be statistical significant at high confidence levels. However, values per square meter are not included in the regression to be used in the STUDI model because a model to update prices has not been constructed at this stage. ‘Number of commercial premises’ is not included because the variable, as the variable ‘vacant commercial premises’, is updated by the development sub-model; including both variables could increase the impact of development on location decisions disproportionally.

### 6.1.3 Population

#### 6.1.3.1 Migration

As discussed in Section 5.3.2, the number of households migrating from and to London is estimated in relation to the number of the new businesses as approximated by the business sub-model. The relationship between the number of new businesses and number of migrants is discussed in Sections 5.3.2.1 and 5.3.2.2.

Regarding in-migration, as shown in Section 5.3.2.2 the number of new households $M_T$ is given by Equations 5.23 and 5.24:

$$M_T^{[1]} = \frac{B_T^{new}}{C^{[1]}}$$ and

$$M_T^{[2]} = \frac{B_T^{new}}{C^{[2]}}$$

where $B_T^{new}$ is the number of new businesses,

$C^{[1]}$ and $C^{[2]}$ are constants. They were determined ($C^{[1]}$=12 and $C^{[2]}$=24) using judgment and test runs of the STUDI model in order the forecast population of 2001 to be in the range of the population given by the 2001 Census of Population.

Two categories are created in order to reflect the assumption that the largest number of the in-migrants in London are of relatively younger age. Hence for the first category, which is larger as $C^{[1]} < C^{[2]}$, the maximum possible age of the chief economic supporter of the household moving to London is smaller than for the second category.

Regarding out-migration, as shown in Section 5.3.2.1, the probability for a household of household structure *s* to leave London in period *T* is given by Equation 5.22:

$$P_{sT} = C_s \frac{1}{B_T^{new}},$$

where $B_T^{new}$ is the number of new businesses added in London in period *T* as estimated by the business sub-model and

$C_s$ is a constant different for every household structure *s*, representing the fact that for some household categories it is more possible to move out of London than for others.

As in the case of in-migration, the constants $C_s$ were determined in order to obtain a forecast population in 2001 of size in the range of the population given by the 2001 Census. Seven $C_s$ values were determined, one for each of the seven household categories (as presented in Section 4.4).

#### 6.1.3.2 Employment location

In Section 5.3.4.1 the possibility of change of working status for students and of change of employment location for currently employed people is considered.

For the case of students, if the person is between 16 and 18 years old, the probability to continue in education is set equal to 0.7; if between 19 and 22, the probability to continue in education is set equal to 0.6; and if between 23 and 27, the probability to continue studying is set equal to 0.3.

For the case of currently employed people, the probability $P_a$ for person of age *a* to consider changing job was determined using judgement to be given by Equation 5.25:

$$P_a = Ce^{-da},$$

where $C$ and $d$ are positive constants determined using judgment (C = 0.4, d = 0.05)

This relationship between the probability and the age was chosen to reflect the flexibility in changing jobs according to age, but it is not calibrated against real data as such data could not be obtained. The possibility of rturning to education is not considered.

#### 6.1.3.3 Residential location

Households considering relocation are chosen using Monte Carlo simulation and a probability, which allows to a predetermined percentage of the population to look for a new dwelling (Section 5.3.5.3).

To simulate residential location decisions, it is assumed that the number of people migrating to one zone is an indicator of the attractiveness of that zone. To understand the impacts of different variables on residential location decisions and to explain the relationship of population with businesses and developers, migration is regressed over travel time, number of businesses and land-use variables. In Table 6.8 and Table 6.9 the results of the regression of migration over various variables are presented.

In models P1-P5 travel time estimates to Westminster are used. In P6 and P7 the variable ‘accessible businesses’ as presented in Section 5.3.5.3, is used instead of travel time to the city centre. In P8 travel time to London Bridge is used as an estimate of travel time to the city centre.

In models P1-P5 travel time to the station of Westminster has negative impact on the attractiveness of residential location, as expected, and is significant at higher than 99% confidence interval. The number of residential premises has a positive impact and is significant at 99.95% confidence interval in all models. Regression P1 includes travel time to Westminster and all the land-use- and business-related variables. In regressions P2, P3 and P4, some variables are taken out in order to achieve statistical significance.

| Reference code | P1 | | P2 | | P3 | | P4 | | P5 | | P6 | | P7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dependent | Migration at time T | | Migration at time T | | Migration at time T | | Migration at time T | | Migration at time T | | Migration at time T | | Migration at time T | |
| Independent | Coef | Sig# | Coef | Sig# | Coef | Sig# | Coef | Sig# | Coef | Sig# | Coef | Sig# | Coef | Sig# |
| Intercept | 5240 | | 4953 | | 2504 | | 6559.163 | * | 6553.6 | * | -8947 | ** | | |
| Travel time to Westminster with JLE | -201.2 | * | -203.3 | * | -208.1 | *** | -157.692 | *** | -157.5 | *** | | | | |
| Change in travel time to Westminster due to JLE | | | | | | | | | 19.087 | | | | | |
| Number of residential premises at time T-1 | 0.186 | *** | 0.192 | *** | 0.24 | *** | 0.232 | *** | 0.232 | *** | 0.208 | ** | | |
| Vacant residential premises at time T | 0.115 | | | | -0.315 | | | | | | 0.505 | . | 2.79 | *** |
| Vacant over total residential premises at time T-1 | -61010 | | -51800 | . | | | | | | | | | | |
| Total number of businesses of sectors 3-7 at time T-1 | 0.032 | | | | -0.261 | * | -0.197 | * | -0.196 | * | | | | |
| Accessible businesses | | | | | | | | | | | 1.106 | ** | 1.093 | *** |
| Mean house prices at time T-1 | -0.008 | | -0.008 | - | 0.006 | | | | | | -0.018 | * | | |
| Average rent to local authority at time T-1 | 131.6 | . | 131.7 | * | 137.8 | * | | | | | 26.91 | | | |
| Area covered with non domestic buildings at time T | 3.092 | . | 2.959 | * | | | | | | | | | | |
| Area covered with domestic gardens at time T | -0.125 | | -0.121 | - | | | | | | | | | | |
| Area covered with commercial premises at time T-1 | -2.253 | * | -2.104 | ** | | | | | | | | | | |
| | Mult. R-sqrd | 0.917 | Mult. R-sqrd | 0.917 | Mult. R-sqrd | 0.889 | Mult. R-sqrd | 0.864 | Mult. R-sqrd | 0.864 | Mult. R-sqrd | 0.837 | Mult. R-sqrd | 0.91 |

**Table 6.8: Explanatory regression analysis of the residential location process using travel time to Westminster and accessible workforce**

#Confidence interval at which the variable is significant: 99.95% '***'; 99.5% '**'; 99% '*'; 95% '.'; 90% '-'; lower than 90% ' '.

| Reference code | P8 | |
|---|---|---|
| **Dependent** | **Migration at time T** | |
| **Independent** | **Coef** | **Sig#** |
| **Intercept** | 2890.157 | |
| **Travel time to London Bridge with JLE** | -78.402 | . |
| **Number of residential premises at time T-1** | 0.22 | *** |
| **Total number of businesses of sectors 3-7 at time T-1** | -0.076 | |
| | **Multiple R-squared** | 0.815 |

**Table 6.9: Explanatory regression analysis of the residential location process using travel time to London Bridge**

#Confidence interval at which the variable is significant: 99.95% '***'; 99.5% '**'; 99% '*'; 95% '.'; 90% '-'; lower than 90% ' '.

In both P1 and P2 models there is very little evidence against the null hypothesis for the variables 'house prices', 'vacant residential premises' and 'area covered with domestic gardens'. In P2, the proportion of vacant over total dwellings is significant at 95% confidence interval and has negative impact on the attractiveness of one location, showing that areas with high proportion of vacant dwellings are unattractive. The area covered with commercial premises is significant at high confidence interval with a negative coefficient, indicating a preference of people moving towards residential areas. This is also reflected in the positive impact of the size of area covered with domestic buildings and on the negative impact of the number of businesses on the attractiveness of an area. The rent to local authorities also has a positive impact, reflecting, perhaps, the preference of people for "good" and hence more expensive areas.

P4 is a more abstract model. In model P5 the change in travel time due to JLE is added and it has positive impact, reflecting the positive effect of travel-time improvements to the attractiveness of one area as residential location.

Model P8 is similar to P4 but travel time to London Bridge instead of travel time to Westminster is used as an estimate of travel time to the city centre. Travel time to London Bridge station in P8 has a negative coefficient but almost half the impact of travel time to the station of Westminster in P4.

Regarding the residential relocation process in the STUDI model, by analogy to the business sub-model, the final location decision of households that have been found to be considering relocation (Section 5.3.5.3) depends on the attractiveness of the zones. The attractiveness function of each zone is based on the cross-sectional regression of the number of people migrating to one zone, i.e. local authority, against the number of accessible businesses and number of vacant dwellings. The attractiveness $A_{iT}$ of zone *i* in period *T* as described in Section 5.3.1 is given by Equation 5.20:

$$A_{iT} = aD_{iT}^{vacant} + bB_{iT}^{accessible}$$

where $D_{iT}^{vacant}$ is the number of vacant dwellings in zone *i*, in period *T* and

$B_{iT}^{accessible}$ is the amount of accessible businesses in zone *i*, in period *T*.

The results of the estimation process are presented in P7. Both variables have a positive impact on attractiveness and are significant at 99.95% confidence interval. The positive sign of accessible businesses shows the importance of accessible jobs to residential location attractiveness, and that by improving travel time and job supply, the attractiveness of a location as a residential location can be improved. The model includes only the two main variables that allow it to communicate with the business and development sub-models. This happens in order to keep the model simple at this stage and to avoid variables that need to, but currently cannot, be updated. For example, although the variable ‘mean house prices’ appears to be significant at 99% confidence interval in P6, it is not included because a model to update prices has not been developed at this stage.

### 6.1.4 Connection between sub -models

The issue of compatibility of the results from the population sub-model, which is applied to a sample population, with the results from the business and development sub-models, which refer to total numbers of businesses and premises, has already been addressed in Section 4.5. To feed back the results of the population sub-model to the business sub-model the interim expansion factor is used. For the opposite procedure such a factor does not exist.

To overcome this issue a weighting factor is used. The number of new jobs created in the business sub-model, is divided by this factor before being added to the stock of available jobs of each zone. As the sample of the LATS data is approximately 0.87% of the total population different values within range between 50 and 150 were and the weighting factor was set equal to 60 so that the simulated results for 2001 to match the Census 2001 data.

Similarly a weighting factor is calibrated for the connection between the population and the development sub-models. This time the weighting factor is set equal to 100.

## 6.2 Validation

In this section the results of the validation of the STUDI model are presented. The results presented and validated are the product of one single run of the STUDI model. It is recognized that due to the stochastic factor included in microsimulation models, they can produce different results for different runs. For this purpose the stochastic variation of the model is assessed in Section 6.2.4.

The STUDI model is validated by comparing the simulated and the actual spatial distributions of the agents of urban development. These are the spatial distributions of the quantities of the measured element, i.e. number of residential or commercial premises, number of businesses or number of people. The actual distributions are given by the datasets presented in Chapter 4. Four measures are used to validate the results:

- Deviation
- ‘Proportional distribution’ of a quantity in London
- Change of a quantity (i.e. number of residential or commercial premises, number of businesses and population) between two defined points in time
- ‘Proportional distribution of change’ of a quantity in London

The deviation (as a percentage) $D_i$ is given by:

$$D_i = \frac{F_i - A_i}{A_i} 100 ,$$

where $F_i$ is the forecast quantity in zone *i* in a specific year and

$A_i$ is the actual quantity in zone *i* for the specific year.

The ‘proportional distribution’ of a quantity in London is the distribution of the fractions of the quantity in each zone over the total quantity in London.

The change of a quantity between two points in time is estimated for the results of the forecast and for the actual data. The two changes are compared.

The 'proportional distribution of change' of a quantity is the distribution of the fractions of the change of the quantity in each zone over the total change of the quantity in London. It is used to represent the zonal distribution of changes eliminating any overestimation or underestimation of the total number of businesses. It is given by:

$$J_T^i = \frac{Q_T^i - Q_{T-t}^i}{Q_T^L - Q_{T-t}^L}100$$

where $J_T^i$ is the weighted percentage change of quantity *Q*,

$Q_T^i$ is the quantity in zone *i* in period *T*

$Q_{T-t}^i$ is the quantity in zone *i* in period *T-t*

$Q_T^L$ is the total quantity in London in period *T*

$Q_{T-t}^L$ is the total quantity in London in period *T-t*

### 6.2.1 Development sub-model

For both residential and commercial development the results are validated against the actual data for 2001 and 2006 as presented Section 4.2. The forecasts start from 1996.

#### 6.2.1.1 Residential development

In Table 6.10 the forecast distribution for 2001 is validated against the actual data as described in Section 4.2. The deviation between actual and forecast number of residential premises remains below 10% for most boroughs except City of London and Redbridge. The highest deviation occurs in the City of London and this can be explained by the low number of population and dwellings. In general the City of London is a zone with extreme characteristics: very small area, high density of businesses and low density of population. In the last column the differences between the proportional distributions of residential premises in London according to the actual data and as forecast by the STUDI model are shown. It can be seen that the differences are very small indicating that the model manages to forecast the spatial distribution of residential premises correctly.

In Table 6.11 the results for 2006 are validated. The deviation for City of London, Tower Hamlets and Islington increases. However, for some boroughs the deviation remains in the same scale as in 2001 meaning that the model manages to control the allocation of residential dwellings. The proportional distribution of residential premises in London as estimated by the STUDI model is very close to the one based on actual data.

In Table 6.12 the total changes and the proportional distributions of changes over time, according to the actual data and the forecasts made by the STUDI model are compared. In the column showing the absolute changes from 1995 to 2006 it can be seen that the STUDI model underestimates new residential development. The columns with the proportional distributions of changes show that the forecast spatial distribution of new residential development is close to the actual one. The differences between forecast and actual proportional distribution of changes lie in the range of -2.5% to 4% for all boroughs but Tower Hamlets for which the difference is -6.25%. These differences are spatially illustrated in Figure 6.1.

| Boroughs | Dwellings (actual) | | Dwellings (forecast) | | Comparison | |
|---|---|---|---|---|---|---|
| | Year 2001 | % of total | Year 2001 | % of total | % Deviation | Change in % of total |
| **Barking and Dagenham** | 67,156 | 2.15 | 65,893 | 2.17 | -1.88 | 0.020 |
| **Barnet** | 135,365 | 4.33 | 126,820 | 4.17 | -6.31 | -0.158 |
| **Bexley** | 92,454 | 2.96 | 91,686 | 3.02 | -0.83 | 0.059 |
| **Brent** | 104,052 | 3.33 | 101,983 | 3.35 | -1.99 | 0.027 |
| **Bromley** | 130,624 | 4.18 | 124,496 | 4.10 | -4.69 | -0.083 |
| **Camden** | 91,768 | 2.94 | 90,660 | 2.98 | -1.21 | 0.047 |
| **City of London** | 4,859 | 0.16 | 3,924 | 0.13 | -19.24 | -0.026 |
| **Croydon** | 136,857 | 4.38 | 136,104 | 4.48 | -0.55 | 0.100 |
| **Ealing** | 119,407 | 3.82 | 118,581 | 3.90 | -0.69 | 0.082 |
| **Enfield** | 114,101 | 3.65 | 110,335 | 3.63 | -3.30 | -0.020 |
| **Greenwich** | 92,819 | 2.97 | 90,921 | 2.99 | -2.04 | 0.022 |
| **Hackney** | 85,992 | 2.75 | 83,377 | 2.74 | -3.04 | -0.008 |
| **Hammersmith and Fulham** | 77,001 | 2.46 | 75,104 | 2.47 | -2.46 | 0.008 |
| **Haringey** | 94,138 | 3.01 | 94,841 | 3.12 | 0.75 | 0.109 |
| **Harrow** | 81,384 | 2.60 | 81,509 | 2.68 | 0.15 | 0.078 |
| **Havering** | 94,674 | 3.03 | 94,173 | 3.10 | -0.53 | 0.070 |
| **Hillingdon** | 99,622 | 3.19 | 97,268 | 3.20 | -2.36 | 0.013 |
| **Hounslow** | 86,850 | 2.78 | 84,233 | 2.77 | -3.01 | -0.007 |
| **Islington** | 84,866 | 2.71 | 78,270 | 2.57 | -7.77 | -0.140 |
| **Kensington and Chelsea** | 87,557 | 2.80 | 80,465 | 2.65 | -8.10 | -0.154 |
| **Kingston Upon Thames** | 61,238 | 1.96 | 58,757 | 1.93 | -4.05 | -0.026 |
| **Lambeth** | 120,547 | 3.86 | 117,928 | 3.88 | -2.17 | 0.024 |
| **Lewisham** | 114,705 | 3.67 | 108,427 | 3.57 | -5.47 | -0.102 |
| **Merton** | 76,623 | 2.45 | 76,402 | 2.51 | -0.29 | 0.062 |
| **Newham** | 92,821 | 2.97 | 88,108 | 2.90 | -5.08 | -0.071 |
| **Redbridge** | 104,659 | 3.35 | 91,948 | 3.02 | -12.15 | -0.323 |
| **Richmond Upon Thames** | 77,432 | 2.48 | 76,477 | 2.52 | -1.23 | 0.039 |
| **Southwark** | 113,964 | 3.65 | 112,095 | 3.69 | -1.64 | 0.042 |
| **Sutton** | 76,050 | 2.43 | 74,416 | 2.45 | -2.15 | 0.015 |
| **Tower Hamlets** | 82,851 | 2.65 | 74,690 | 2.46 | -9.85 | -0.193 |
| **Waltham Forest** | 93,130 | 2.98 | 98,226 | 3.23 | 5.47 | 0.252 |
| **Wandsworth** | 122,551 | 3.92 | 120,582 | 3.97 | -1.61 | 0.047 |
| **Westminster** | 108,241 | 3.46 | 111,158 | 3.66 | 2.69 | 0.194 |
| **Column Total** | **3,126,358** | **100.00** | **3,039,857** | **100.00** | **-2.77** | **0.000** |

**Table 6.10: Validation of the simulation results for 2001 against the actual data**

| Boroughs | Dwellings (actual data) | | Dwellings (forecast) | | Comparison | |
|---|---|---|---|---|---|---|
| | Year 2006 | % of total | Year 2006 | % of total | % Deviation | Change in % of total |
| **Barking and Dagenham** | 69,179 | 2.15 | 66,401 | 2.15 | -4.02 | 0.003 |
| **Barnet** | 134,142 | 4.17 | 128,430 | 4.16 | -4.26 | -0.004 |
| **Bexley** | 93,788 | 2.91 | 92,831 | 3.01 | -1.02 | 0.096 |
| **Brent** | 105,453 | 3.28 | 103,493 | 3.35 | -1.86 | 0.079 |
| **Bromley** | 131,834 | 4.10 | 126,760 | 4.11 | -3.85 | 0.014 |
| **Camden** | 96,872 | 3.01 | 92,204 | 2.99 | -4.82 | -0.020 |
| **City of London** | 5,720 | 0.18 | 3,954 | 0.13 | -30.87 | -0.050 |
| **Croydon** | 139,385 | 4.33 | 138,035 | 4.47 | -0.97 | 0.144 |
| **Ealing** | 122,588 | 3.81 | 120,198 | 3.90 | -1.95 | 0.088 |
| **Enfield** | 117,620 | 3.65 | 111,458 | 3.61 | -5.24 | -0.041 |
| **Greenwich** | 99,248 | 3.08 | 91,787 | 2.98 | -7.52 | -0.108 |
| **Hackney** | 94,090 | 2.92 | 84,759 | 2.75 | -9.92 | -0.175 |
| **Hammersmith and Fulham** | 78,607 | 2.44 | 76,339 | 2.47 | -2.89 | 0.033 |
| **Haringey** | 99,133 | 3.08 | 96,264 | 3.12 | -2.89 | 0.041 |
| **Harrow** | 83,582 | 2.60 | 82,441 | 2.67 | -1.37 | 0.076 |
| **Havering** | 97,016 | 3.01 | 94,991 | 3.08 | -2.09 | 0.065 |
| **Hillingdon** | 101,798 | 3.16 | 98,128 | 3.18 | -3.61 | 0.019 |
| **Hounslow** | 90,465 | 2.81 | 85,017 | 2.76 | -6.02 | -0.054 |
| **Islington** | 88,931 | 2.76 | 79,480 | 2.58 | -10.63 | -0.186 |
| **Kensington and Chelsea** | 85,655 | 2.66 | 82,669 | 2.68 | -3.49 | 0.019 |
| **Kingston Upon Thames** | 62,982 | 1.96 | 59,416 | 1.93 | -5.66 | -0.031 |
| **Lambeth** | 122,518 | 3.81 | 121,113 | 3.93 | -1.15 | 0.120 |
| **Lewisham** | 113,138 | 3.51 | 110,052 | 3.57 | -2.73 | 0.053 |
| **Merton** | 80,567 | 2.50 | 77,282 | 2.51 | -4.08 | 0.002 |
| **Newham** | 98,127 | 3.05 | 88,997 | 2.88 | -9.30 | -0.163 |
| **Redbridge** | 96,895 | 3.01 | 92,822 | 3.01 | -4.20 | -0.001 |
| **Richmond Upon Thames** | 80,026 | 2.49 | 77,328 | 2.51 | -3.37 | 0.021 |
| **Southwark** | 119,274 | 3.71 | 114,608 | 3.72 | -3.91 | 0.010 |
| **Sutton** | 77,743 | 2.42 | 75,266 | 2.44 | -3.19 | 0.025 |
| **Tower Hamlets** | 93,776 | 2.91 | 75,855 | 2.46 | -19.11 | -0.454 |
| **Waltham Forest** | 95,026 | 2.95 | 99,698 | 3.23 | 4.92 | 0.280 |
| **Wandsworth** | 126,428 | 3.93 | 122,835 | 3.98 | -2.84 | 0.054 |
| **Westminster** | 117,442 | 3.65 | 114,022 | 3.70 | -2.91 | 0.048 |
| **Column Total** | **3,219,048** | **100.00** | **3,084,933** | **100.00** | **-4.17** | **0.000** |

**Table 6.11: Validation of the simulation results for 2006 against the actual data**

| Borough | Change in the number of dwellings from 1995 to 2006 | | | | |
|---|---|---|---|---|---|
| | Absolute change | | Proportional distribution of change (%) | | |
| | Actual | Forecast | Actual | Forecast | Difference |
| **Barking and Dagenham** | 3,888 | 1,110 | 1.68 | 1.14 | -0.54 |
| **Barnet** | 9,200 | 3,488 | 3.98 | 3.60 | -0.38 |
| **Bexley** | 3,424 | 2,467 | 1.48 | 2.54 | 1.06 |
| **Brent** | 5,155 | 3,195 | 2.23 | 3.30 | 1.06 |
| **Bromley** | 9,958 | 4,884 | 4.31 | 5.04 | 0.73 |
| **Camden** | 7,947 | 3,279 | 3.44 | 3.38 | -0.06 |
| **City of London** | 1,832 | 66 | 0.79 | 0.07 | -0.72 |
| **Croydon** | 5,539 | 4,189 | 2.40 | 4.32 | 1.92 |
| **Ealing** | 5,879 | 3,489 | 2.54 | 3.60 | 1.05 |
| **Enfield** | 8,601 | 2,439 | 3.72 | 2.52 | -1.21 |
| **Greenwich** | 9,316 | 1,855 | 4.03 | 1.91 | -2.12 |
| **Hackney** | 12,323 | 2,992 | 5.33 | 3.09 | -2.25 |
| **Hammersmith and Fulham** | 4,927 | 2,659 | 2.13 | 2.74 | 0.61 |
| **Haringey** | 5,944 | 3,075 | 2.57 | 3.17 | 0.60 |
| **Harrow** | 3,121 | 1,980 | 1.35 | 2.04 | 0.69 |
| **Havering** | 3,811 | 1,786 | 1.65 | 1.84 | 0.19 |
| **Hillingdon** | 5,517 | 1,847 | 2.39 | 1.90 | -0.48 |
| **Hounslow** | 7,158 | 1,710 | 3.10 | 1.76 | -1.33 |
| **Islington** | 12,068 | 2,617 | 5.22 | 2.70 | -2.52 |
| **Kensington and Chelsea** | 7,695 | 4,709 | 3.33 | 4.86 | 1.53 |
| **Kingston Upon Thames** | 5,002 | 1,436 | 2.16 | 1.48 | -0.68 |
| **Lambeth** | 8,253 | 6,848 | 3.57 | 7.06 | 3.49 |
| **Lewisham** | 6,553 | 3,467 | 2.84 | 3.58 | 0.74 |
| **Merton** | 5,202 | 1,917 | 2.25 | 1.98 | -0.27 |
| **Newham** | 11,051 | 1,921 | 4.78 | 1.98 | -2.80 |
| **Redbridge** | 5,979 | 1,906 | 2.59 | 1.97 | -0.62 |
| **Richmond Upon Thames** | 4,551 | 1,853 | 1.97 | 1.91 | -0.06 |
| **Southwark** | 10,008 | 5,342 | 4.33 | 5.51 | 1.18 |
| **Sutton** | 4,327 | 1,850 | 1.87 | 1.91 | 0.04 |
| **Tower Hamlets** | 20,431 | 2,510 | 8.84 | 2.59 | -6.25 |
| **Waltham Forest** | -1,484 | 3,188 | -0.64 | 3.29 | 3.93 |
| **Wandsworth** | 8,472 | 4,879 | 3.67 | 5.03 | 1.37 |
| **Westminster** | 9,429 | 6,009 | 4.08 | 6.20 | 2.12 |
| **Column Total** | **231,077** | **96,962** | **100** | **100** | **0** |

**Table 6.12: Changes over time in the number of residential premises**

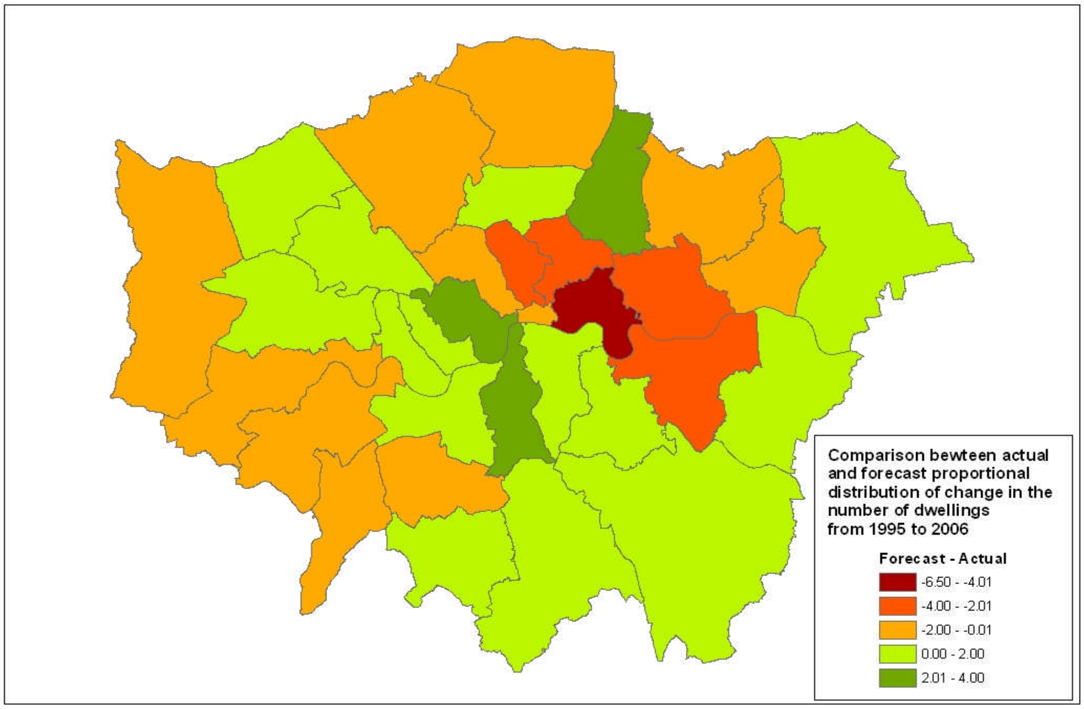


**Figure 6.1: Forecast - Actual proportional distributions of change of dwellings**

### 6.2.1.2 Commercial development

The commercial development model is a linear regression model. In Table 6.13 the forecast distribution of commercial premises for 2001 is validated against the actual data. Compared to the results for residential premises, there are more zones here with high deviations, which may indicate that the Cobb-Douglas model simulates development better. Such a model was not used in the case of commercial development because when estimated the linear model performed better. Regarding the JLE boroughs, the deviation is in the range of 10% for Southwark, Lambeth and Westminster and for Greenwich, Newham and Tower Hamlets the deviation is smaller than 5%. The differences between the actual and forecast proportional distributions of commercial development are very low.

In Table 6.14 the forecasts of commercial development for 2006 are validated. The deviation increases comparing to 2001, but the differences between actual and forecast proportional spatial distribution in London remain low.

In Table 6.15 the absolute changes and the proportional distributions of changes in commercial development over time, according to the actual data and the forecasts by the STUDI model are compared. In contrast to the residential development sub-model the commercial development sub-model overestimates the number of new commercial premises. The proportional distributions of changes show that the forecast spatial distribution of new commercial development is close to the actual one. The differences between forecast and actual proportional distribution of changes lie in the range of -2.7% to 4.6% for all the boroughs of London. These differences are spatially illustrated in Figure 6.2.

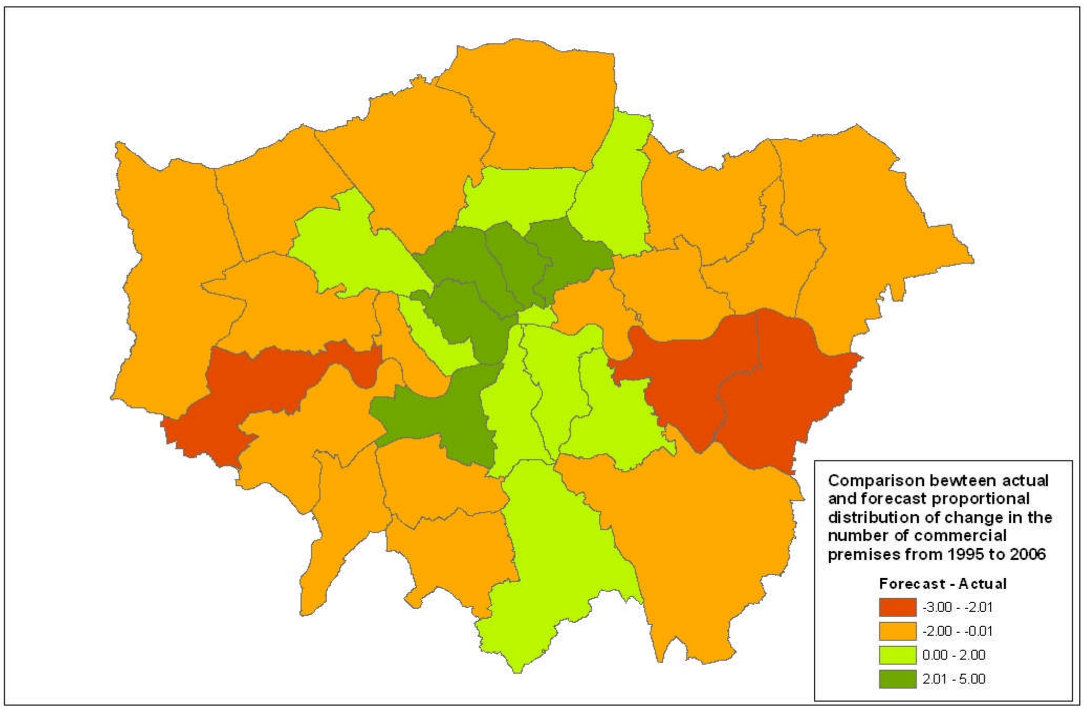


**Figure 6.2: Forecast - Actual proportional distributions of change for commercial premises**

| Boroughs | Commercial premises (actual) | | Commercial premises (forecast) | | Comparison | |
|---|---|---|---|---|---|---|
| | Year 2001 | % of total | Year 2001 | % of total | % Deviation | Change in % of total |
| **Barking and Dagenham** | 3,238 | 1.42 | 3,055 | 1.28 | -5.65 | -0.141 |
| **Barnet** | 6,830 | 3.00 | 7,033 | 2.95 | 2.97 | -0.050 |
| **Bexley** | 4,025 | 1.77 | 3,569 | 1.50 | -11.32 | -0.271 |
| **Brent** | 6,972 | 3.06 | 7,467 | 3.13 | 7.10 | 0.070 |
| **Bromley** | 5,569 | 2.45 | 5,422 | 2.28 | -2.64 | -0.172 |
| **Camden** | 12,409 | 5.45 | 14,227 | 5.97 | 14.65 | 0.518 |
| **City of London** | 11,328 | 4.98 | 12,786 | 5.37 | 12.87 | 0.388 |
| **Croydon** | 7,397 | 3.25 | 7,815 | 3.28 | 5.64 | 0.029 |
| **Ealing** | 7,407 | 3.26 | 7,804 | 3.28 | 5.36 | 0.020 |
| **Enfield** | 5,789 | 2.54 | 5,530 | 2.32 | -4.47 | -0.223 |
| **Greenwich** | 3,978 | 1.75 | 3,668 | 1.54 | -7.80 | -0.209 |
| **Hackney** | 8,158 | 3.59 | 8,899 | 3.74 | 9.09 | 0.150 |
| **Hammersmith and Fulham** | 6,175 | 2.71 | 6,540 | 2.75 | 5.90 | 0.031 |
| **Haringey** | 6,376 | 2.80 | 6,704 | 2.81 | 5.14 | 0.012 |
| **Harrow** | 4,161 | 1.83 | 3,911 | 1.64 | -6.02 | -0.187 |
| **Havering** | 4,421 | 1.94 | 4,111 | 1.73 | -7.02 | -0.218 |
| **Hillingdon** | 6,225 | 2.74 | 5,950 | 2.50 | -4.42 | -0.238 |
| **Hounslow** | 5,192 | 2.28 | 4,791 | 2.01 | -7.72 | -0.271 |
| **Islington** | 8,980 | 3.95 | 10,408 | 4.37 | 15.90 | 0.422 |
| **Kensington and Chelsea** | 6,431 | 2.83 | 7,172 | 3.01 | 11.52 | 0.184 |
| **Kingston Upon Thames** | 3,926 | 1.73 | 3,564 | 1.50 | -9.22 | -0.229 |
| **Lambeth** | 6,875 | 3.02 | 7,616 | 3.20 | 10.77 | 0.175 |
| **Lewisham** | 5,336 | 2.35 | 5,320 | 2.23 | -0.30 | -0.112 |
| **Merton** | 4,213 | 1.85 | 4,164 | 1.75 | -1.17 | -0.104 |
| **Newham** | 5,598 | 2.46 | 5,725 | 2.40 | 2.26 | -0.057 |
| **Redbridge** | 4,584 | 2.01 | 4,393 | 1.84 | -4.17 | -0.171 |
| **Richmond Upon Thames** | 4,496 | 1.98 | 4,417 | 1.85 | -1.76 | -0.122 |
| **Southwark** | 8,444 | 3.71 | 9,241 | 3.88 | 9.44 | 0.168 |
| **Sutton** | 3,467 | 1.52 | 3,158 | 1.33 | -8.91 | -0.198 |
| **Tower Hamlets** | 9,597 | 4.22 | 10,048 | 4.22 | 4.70 | 0.000 |
| **Waltham Forest** | 5,679 | 2.50 | 5,758 | 2.42 | 1.39 | -0.079 |
| **Wandsworth** | 7,959 | 3.50 | 8,971 | 3.77 | 12.71 | 0.268 |
| **Westminster** | 26,299 | 11.56 | 28,999 | 12.17 | 10.27 | 0.614 |
| **Column Total** | **227,534** | **100.00** | **238,232** | **100.00** | **4.70** | **0.000** |

**Table 6.13: Validation of the simulation results for 2001 against the actual data**

| Boroughs | Commercial premises (actual) | | Commercial premises (forecast) | | Comparison | |
|---|---|---|---|---|---|---|
| | Year 2006 | % of total | Year 2006 | % of total | % Deviation | Change in % of total |
| **Barking and Dagenham** | 3,292 | 1.40 | 3,118 | 1.15 | -5.28 | -0.252 |
| **Barnet** | 6,917 | 2.95 | 7,705 | 2.85 | 11.39 | -0.103 |
| **Bexley** | 4,182 | 1.78 | 3,468 | 1.28 | -17.07 | -0.501 |
| **Brent** | 6,953 | 2.96 | 8,633 | 3.19 | 24.16 | 0.225 |
| **Bromley** | 5,747 | 2.45 | 5,569 | 2.06 | -3.10 | -0.393 |
| **Camden** | 12,916 | 5.50 | 17,054 | 6.30 | 32.04 | 0.793 |
| **City of London** | 12,356 | 5.27 | 15,582 | 5.75 | 26.11 | 0.488 |
| **Croydon** | 7,292 | 3.11 | 8,572 | 3.17 | 17.55 | 0.058 |
| **Ealing** | 7,739 | 3.30 | 8,968 | 3.31 | 15.88 | 0.013 |
| **Enfield** | 5,727 | 2.44 | 5,713 | 2.11 | -0.24 | -0.331 |
| **Greenwich** | 4,382 | 1.87 | 3,761 | 1.39 | -14.18 | -0.479 |
| **Hackney** | 8,246 | 3.51 | 10,379 | 3.83 | 25.87 | 0.319 |
| **Hammersmith and Fulham** | 6,655 | 2.84 | 7,708 | 2.85 | 15.82 | 0.010 |
| **Haringey** | 6,268 | 2.67 | 7,558 | 2.79 | 20.58 | 0.120 |
| **Harrow** | 4,269 | 1.82 | 3,937 | 1.45 | -7.79 | -0.366 |
| **Havering** | 4,429 | 1.89 | 3,968 | 1.47 | -10.42 | -0.422 |
| **Hillingdon** | 6,295 | 2.68 | 6,194 | 2.29 | -1.61 | -0.396 |
| **Hounslow** | 5,443 | 2.32 | 5,153 | 1.90 | -5.33 | -0.417 |
| **Islington** | 8,933 | 3.81 | 12,394 | 4.58 | 38.74 | 0.770 |
| **Kensington and Chelsea** | 6,741 | 2.87 | 8,458 | 3.12 | 25.47 | 0.250 |
| **Kingston Upon Thames** | 3,947 | 1.68 | 3,654 | 1.35 | -7.42 | -0.333 |
| **Lambeth** | 6,932 | 2.95 | 8,911 | 3.29 | 28.54 | 0.336 |
| **Lewisham** | 5,224 | 2.23 | 5,803 | 2.14 | 11.09 | -0.083 |
| **Merton** | 4,425 | 1.89 | 4,511 | 1.67 | 1.94 | -0.220 |
| **Newham** | 5,898 | 2.51 | 6,487 | 2.40 | 9.98 | -0.118 |
| **Redbridge** | 4,640 | 1.98 | 4,523 | 1.67 | -2.53 | -0.307 |
| **Richmond Upon Thames** | 4,887 | 2.08 | 4,822 | 1.78 | -1.33 | -0.302 |
| **Southwark** | 8,895 | 3.79 | 10,850 | 4.01 | 21.98 | 0.216 |
| **Sutton** | 3,506 | 1.49 | 3,085 | 1.14 | -12.01 | -0.355 |
| **Tower Hamlets** | 10,630 | 4.53 | 11,941 | 4.41 | 12.33 | -0.121 |
| **Waltham Forest** | 5,582 | 2.38 | 6,401 | 2.36 | 14.67 | -0.015 |
| **Wandsworth** | 7,857 | 3.35 | 10,601 | 3.91 | 34.92 | 0.566 |
| **Westminster** | 27,447 | 11.70 | 35,330 | 13.05 | 28.72 | 1.349 |
| **Column Total** | **234,652** | **100.00** | **270,807** | **100.00** | **15.41** | **0.000** |

**Table 6.14: Validation of the simulation results for 2006 against the actual data**

| Borough | Change in the number of commercial premises from 1995 to 2006 | | | | |
|---|---|---|---|---|---|
| | Absolute change | | Proportional distribution of change (%) | | |
| | Actual | Forecast | Actual | Forecast | Difference |
| **Barking and Dagenham** | 404 | 230 | 1.42 | 0.36 | -1.07 |
| **Barnet** | 779 | 1,567 | 2.75 | 2.43 | -0.32 |
| **Bexley** | 648 | -66 | 2.28 | -0.10 | -2.39 |
| **Brent** | 661 | 2,341 | 2.33 | 3.63 | 1.30 |
| **Bromley** | 761 | 583 | 2.68 | 0.90 | -1.78 |
| **Camden** | 1,192 | 5,330 | 4.20 | 8.26 | 4.06 |
| **City of London** | 1,933 | 5,159 | 6.82 | 8.00 | 1.18 |
| **Croydon** | 493 | 1,772 | 1.74 | 2.75 | 1.01 |
| **Ealing** | 1,031 | 2,260 | 3.64 | 3.50 | -0.13 |
| **Enfield** | 583 | 569 | 2.05 | 0.88 | -1.17 |
| **Greenwich** | 850 | 229 | 3.00 | 0.35 | -2.64 |
| **Hackney** | 617 | 2,750 | 2.17 | 4.26 | 2.09 |
| **Hammersmith and Fulham** | 1,188 | 2,240 | 4.19 | 3.47 | -0.72 |
| **Haringey** | 451 | 1,741 | 1.59 | 2.70 | 1.11 |
| **Harrow** | 530 | 198 | 1.87 | 0.31 | -1.56 |
| **Havering** | 366 | -95 | 1.29 | -0.15 | -1.44 |
| **Hillingdon** | 829 | 728 | 2.92 | 1.13 | -1.80 |
| **Hounslow** | 1,042 | 752 | 3.67 | 1.17 | -2.51 |
| **Islington** | 407 | 3,868 | 1.44 | 6.00 | 4.56 |
| **Kensington and Chelsea** | 862 | 2,579 | 3.04 | 4.00 | 0.96 |
| **Kingston Upon Thames** | 527 | 234 | 1.86 | 0.36 | -1.50 |
| **Lambeth** | 566 | 2,545 | 2.00 | 3.94 | 1.95 |
| **Lewisham** | 338 | 917 | 1.19 | 1.42 | 0.23 |
| **Merton** | 671 | 757 | 2.37 | 1.17 | -1.19 |
| **Newham** | 863 | 1,452 | 3.04 | 2.25 | -0.79 |
| **Redbridge** | 551 | 434 | 1.94 | 0.67 | -1.27 |
| **Richmond Upon Thames** | 863 | 798 | 3.04 | 1.24 | -1.81 |
| **Southwark** | 1,132 | 3,087 | 3.99 | 4.78 | 0.79 |
| **Sutton** | 347 | -74 | 1.22 | -0.11 | -1.34 |
| **Tower Hamlets** | 2,032 | 3,343 | 7.17 | 5.18 | -1.98 |
| **Waltham Forest** | 359 | 1,178 | 1.27 | 1.83 | 0.56 |
| **Wandsworth** | 446 | 3,190 | 1.57 | 4.94 | 3.37 |
| **Westminster** | 4,037 | 11,920 | 14.23 | 18.48 | 4.24 |
| **Column Total** | **28,361** | **64,516** | **100** | **100** | **0** |

**Table 6.15: Changes over time in the number of commercial premises**

### 6.2.2 Business sub-model

The next step is to validate the results of the business sub-model which is a microsimulation model. In Table 6.16 the forecast distribution of businesses for 2001 is validated against the Annual Business Inquiry (ABI) data. For the majority of the boroughs the deviation is below 10%. For 11 boroughs the deviation is between 10% and 15 % and for one it is approximately 16%. For all the JLE boroughs except Greenwich the deviation is below 5%. The differences between the actual and forecast proportional spatial distributions of businesses are very low and only for Westminster the difference is larger than 1%.

In Table 6.17 the forecast distribution of businesses for 2006 is validated against the 2006 ABI data. The deviation increases and for five boroughs it exceeds 20%. The differences between the actual and forecast proportional spatial distributions of businesses remain low except for Westminster for which it rises above 2.5%.

In Table 6.18 the absolute changes and the proportional distributions of changes in the number of businesses over time, according to the ABI data and the forecasts made by the STUDI model are compared. In general the changes in the number of businesses are underestimated by the STUDI model. The differences between forecast and actual proportional distribution of changes lie in the range -3.2% to 2.6% for all boroughs but Westminster, Camden and City of London. These differences are illustrated better in Figure 6.3. There it can be noticed that positive deviations from the actual data occur in the boroughs of inner London and Croydon and negative in the boroughs of outer London. A similar pattern can be observed in Figure 6.2 where the differences between forecast and actual distributions of changes for commercial premises are presented. The results of the business sub-model are affected by the ones of the development sub-model, which deals with the supply and the demand of commercial premises. This pattern can be explained by the fact that the commercial development model is a linear model depending on travel time to the city centre.

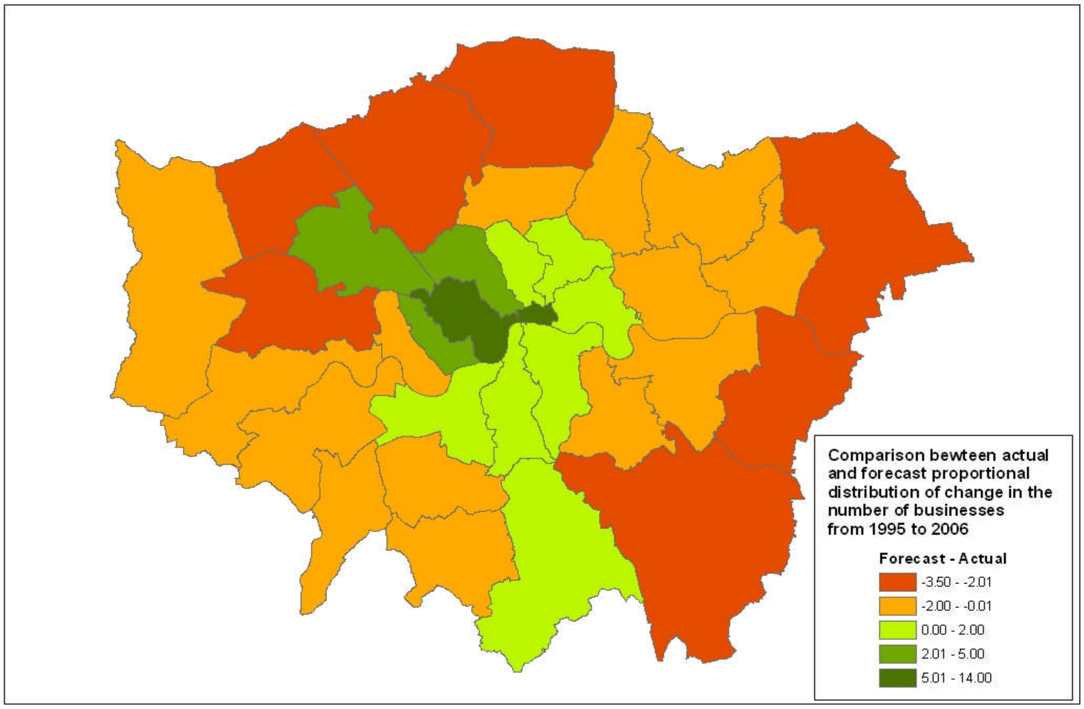


**Figure 6.3: Forecast - Actual proportional distributions of change in the number of businesses**

In Table 6.18 it can be seen that the difference between forecast and actual proportional distributions of change is very high (14%) only for the borough of Westminster and this can be attributed to the differences between the VAT and ABI data. The VAT data are used to consider business start ups and closures. In total, more new businesses open in London according to VAT registrations-deregistrations than according to the ABI data as shown in Table 6.19. The difference between the two datasets is particularly large for the borough of Westminster: the number of businesses from 1995 to 2006 in the borough of Westminster increases by 10,535 businesses according to the VAT data and by 5,257 businesses according to the ABI data (Table 6.19).

| Boroughs | ABI data | | Simulation results | | Comparison | |
|---|---|---|---|---|---|---|
| | ABI 2001 | % of total | Simulated 2001 | % of total | Deviation % | Change in % of total |
| **Barking and Dagenham** | 3,521 | 0.96 | 3,329 | 0.95 | -5.45 | -0.012 |
| **Barnet** | 16,312 | 4.46 | 13,913 | 3.97 | -14.71 | -0.488 |
| **Bexley** | 6,671 | 1.82 | 5,597 | 1.60 | -16.10 | -0.226 |
| **Brent** | 11,374 | 3.11 | 11,337 | 3.23 | -0.33 | 0.127 |
| **Bromley** | 11,132 | 3.04 | 10,243 | 2.92 | -7.99 | -0.119 |
| **Camden** | 23,605 | 6.45 | 24,172 | 6.90 | 2.40 | 0.447 |
| **City of London** | 15,262 | 4.17 | 17,174 | 4.90 | 12.53 | 0.730 |
| **Croydon** | 12,075 | 3.30 | 12,164 | 3.47 | 0.74 | 0.171 |
| **Ealing** | 12,535 | 3.43 | 10,417 | 2.97 | -16.90 | -0.453 |
| **Enfield** | 8,910 | 2.43 | 7,617 | 2.17 | -14.51 | -0.261 |
| **Greenwich** | 5,903 | 1.61 | 5,151 | 1.47 | -12.74 | -0.143 |
| **Hackney** | 8,972 | 2.45 | 9,249 | 2.64 | 3.09 | 0.187 |
| **Hammersmith and Fulham** | 10,954 | 2.99 | 9,660 | 2.76 | -11.81 | -0.237 |
| **Haringey** | 8,310 | 2.27 | 7,507 | 2.14 | -9.66 | -0.129 |
| **Harrow** | 8,830 | 2.41 | 7,579 | 2.16 | -14.17 | -0.250 |
| **Havering** | 7,254 | 1.98 | 6,404 | 1.83 | -11.72 | -0.155 |
| **Hillingdon** | 9,821 | 2.68 | 9,274 | 2.65 | -5.57 | -0.038 |
| **Hounslow** | 9,462 | 2.59 | 8,173 | 2.33 | -13.62 | -0.254 |
| **Islington** | 13,039 | 3.56 | 11,376 | 3.25 | -12.75 | -0.317 |
| **Kensington and Chelsea** | 13,829 | 3.78 | 13,175 | 3.76 | -4.73 | -0.020 |
| **Kingston Upon Thames** | 7,102 | 1.94 | 6,232 | 1.78 | -12.25 | -0.162 |
| **Lambeth** | 9,199 | 2.51 | 9,673 | 2.76 | 5.15 | 0.246 |
| **Lewisham** | 6,431 | 1.76 | 6,182 | 1.76 | -3.87 | 0.007 |
| **Merton** | 7,609 | 2.08 | 7,091 | 2.02 | -6.81 | -0.056 |
| **Newham** | 5,674 | 1.55 | 5,634 | 1.61 | -0.70 | 0.057 |
| **Redbridge** | 7,817 | 2.14 | 7,074 | 2.02 | -9.50 | -0.118 |
| **Richmond Upon Thames** | 10,530 | 2.88 | 9,614 | 2.74 | -8.70 | -0.134 |
| **Southwark** | 10,859 | 2.97 | 10,988 | 3.14 | 1.19 | 0.168 |
| **Sutton** | 6,507 | 1.78 | 6,190 | 1.77 | -4.87 | -0.012 |
| **Tower Hamlets** | 10,359 | 2.83 | 10,113 | 2.89 | -2.37 | 0.055 |
| **Waltham Forest** | 6,400 | 1.75 | 6,586 | 1.88 | 2.91 | 0.130 |
| **Wandsworth** | 12,752 | 3.48 | 12,560 | 3.58 | -1.51 | 0.099 |
| **Westminster** | 46,962 | 12.83 | 49,040 | 13.99 | 4.42 | 1.160 |
| **Column Total** | **365,972** | **100.00** | **350,488** | **100.00** | **-4.23** | **0.000** |

**Table 6.16: Validation of the business simulation results for 2001 against the actual data**

| Borough | ABI data | | Simulation results | | Comparison | |
|---|---|---|---|---|---|---|
| | ABI 2006 | % of total | Simulated 2006 | % of total | Deviation % | Change in % of total |
| **Barking and Dagenham** | 3,829 | 1.00 | 3,313 | 0.88 | -13.48 | -0.123 |
| **Barnet** | 17,011 | 4.46 | 14,638 | 3.89 | -13.95 | -0.568 |
| **Bexley** | 6,979 | 1.83 | 5,307 | 1.41 | -23.96 | -0.419 |
| **Brent** | 11,276 | 2.95 | 12,679 | 3.37 | 12.44 | 0.414 |
| **Bromley** | 12,169 | 3.19 | 10,136 | 2.69 | -16.71 | -0.495 |
| **Camden** | 23,332 | 6.11 | 26,482 | 7.04 | 13.50 | 0.923 |
| **City of London** | 15,672 | 4.11 | 19,775 | 5.25 | 26.18 | 1.148 |
| **Croydon** | 12,096 | 3.17 | 12,238 | 3.25 | 1.17 | 0.082 |
| **Ealing** | 13,365 | 3.50 | 11,211 | 2.98 | -16.12 | -0.523 |
| **Enfield** | 9,646 | 2.53 | 7,431 | 1.97 | -22.96 | -0.553 |
| **Greenwich** | 6,512 | 1.71 | 5,254 | 1.40 | -19.32 | -0.310 |
| **Hackney** | 9,748 | 2.55 | 10,547 | 2.80 | 8.20 | 0.248 |
| **Hammersmith and Fulham** | 11,119 | 2.91 | 10,383 | 2.76 | -6.62 | -0.155 |
| **Haringey** | 8,478 | 2.22 | 7,663 | 2.04 | -9.61 | -0.185 |
| **Harrow** | 9,575 | 2.51 | 7,419 | 1.97 | -22.52 | -0.538 |
| **Havering** | 7,883 | 2.07 | 6,156 | 1.64 | -21.91 | -0.430 |
| **Hillingdon** | 10,499 | 2.75 | 9,413 | 2.50 | -10.34 | -0.250 |
| **Hounslow** | 9,716 | 2.55 | 8,505 | 2.26 | -12.46 | -0.286 |
| **Islington** | 13,076 | 3.43 | 13,555 | 3.60 | 3.66 | 0.175 |
| **Kensington and Chelsea** | 13,118 | 3.44 | 14,786 | 3.93 | 12.72 | 0.491 |
| **Kingston Upon Thames** | 7,339 | 1.92 | 6,003 | 1.59 | -18.20 | -0.328 |
| **Lambeth** | 10,329 | 2.71 | 10,705 | 2.84 | 3.64 | 0.138 |
| **Lewisham** | 7,013 | 1.84 | 6,422 | 1.71 | -8.43 | -0.131 |
| **Merton** | 8,162 | 2.14 | 7,247 | 1.93 | -11.21 | -0.213 |
| **Newham** | 6,969 | 1.83 | 6,206 | 1.65 | -10.95 | -0.177 |
| **Redbridge** | 8,102 | 2.12 | 7,031 | 1.87 | -13.22 | -0.255 |
| **Richmond Upon Thames** | 11,151 | 2.92 | 9,934 | 2.64 | -10.91 | -0.282 |
| **Southwark** | 12,263 | 3.21 | 12,484 | 3.32 | 1.80 | 0.104 |
| **Sutton** | 6,784 | 1.78 | 5,459 | 1.45 | -19.53 | -0.327 |
| **Tower Hamlets** | 10,886 | 2.85 | 11,675 | 3.10 | 7.25 | 0.250 |
| **Waltham Forest** | 7,082 | 1.86 | 6,884 | 1.83 | -2.80 | -0.027 |
| **Wandsworth** | 14,160 | 3.71 | 14,115 | 3.75 | -0.32 | 0.040 |
| **Westminster** | 46,368 | 12.15 | 55,371 | 14.71 | 19.42 | 2.562 |
| **Column Total** | **381,707** | **100.00** | **376,427** | **100.00** | **-1.38** | **0.000** |

**Table 6.17: Validation of the business simulation results for 2006 against the actual data**

| Borough | Change in the number of businesses from 1995 to 2006 | | | | |
|---|---|---|---|---|---|
| | Absolute change | | Proportional distribution of change (%) | | |
| | Actual | Forecast | Actual | Forecast | Difference |
| **Barking and Dagenham** | 673 | 157 | 0.93 | 0.23 | -0.70 |
| **Barnet** | 3,419 | 1,046 | 4.74 | 1.56 | -3.17 |
| **Bexley** | 1,054 | -618 | 1.46 | -0.92 | -2.38 |
| **Brent** | 1,338 | 2,741 | 1.85 | 4.10 | 2.24 |
| **Bromley** | 1,695 | -338 | 2.35 | -0.51 | -2.85 |
| **Camden** | 2,576 | 5,726 | 3.57 | 8.56 | 4.99 |
| **City of London** | 1,694 | 5,797 | 2.35 | 8.66 | 6.32 |
| **Croydon** | 894 | 1,036 | 1.24 | 1.55 | 0.31 |
| **Ealing** | 4,607 | 2,453 | 6.38 | 3.67 | -2.72 |
| **Enfield** | 2,015 | -200 | 2.79 | -0.30 | -3.09 |
| **Greenwich** | 1,308 | 50 | 1.81 | 0.07 | -1.74 |
| **Hackney** | 3,831 | 4,630 | 5.31 | 6.92 | 1.61 |
| **Hammersmith and Fulham** | 2,913 | 2,177 | 4.03 | 3.25 | -0.78 |
| **Haringey** | 2,419 | 1,604 | 3.35 | 2.40 | -0.95 |
| **Harrow** | 1,733 | -423 | 2.40 | -0.63 | -3.03 |
| **Havering** | 1,019 | -708 | 1.41 | -1.06 | -2.47 |
| **Hillingdon** | 1,178 | 92 | 1.63 | 0.14 | -1.49 |
| **Hounslow** | 2,204 | 993 | 3.05 | 1.48 | -1.57 |
| **Islington** | 4,411 | 4,890 | 6.11 | 7.31 | 1.20 |
| **Kensington and Chelsea** | 1,016 | 2,684 | 1.41 | 4.01 | 2.60 |
| **Kingston Upon Thames** | 1,237 | -99 | 1.71 | -0.15 | -1.86 |
| **Lambeth** | 2,198 | 2,574 | 3.04 | 3.85 | 0.80 |
| **Lewisham** | 1,199 | 608 | 1.66 | 0.91 | -0.75 |
| **Merton** | 1,530 | 615 | 2.12 | 0.92 | -1.20 |
| **Newham** | 2,703 | 1,940 | 3.74 | 2.90 | -0.84 |
| **Redbridge** | 1,083 | 12 | 1.50 | 0.02 | -1.48 |
| **Richmond Upon Thames** | 1,902 | 685 | 2.63 | 1.02 | -1.61 |
| **Southwark** | 3,278 | 3,499 | 4.54 | 5.23 | 0.69 |
| **Sutton** | 651 | -674 | 0.90 | -1.01 | -1.91 |
| **Tower Hamlets** | 4,021 | 4,810 | 5.57 | 7.19 | 1.62 |
| **Waltham Forest** | 1,754 | 1,556 | 2.43 | 2.33 | -0.10 |
| **Wandsworth** | 3,390 | 3,345 | 4.70 | 5.00 | 0.30 |
| **Westminster** | 5,257 | 14,260 | 7.28 | 21.31 | 14.03 |
| **Column Total** | **72,200** | **66,920** | **100** | **100** | **0** |

**Table 6.18: Changes over time in the number of businesses**

| Borough | Total number of new businesses in London from 1995 to 2006 according to: | |
|---|---|---|
| | **VAT data** | **ABI data** |
| **Barking and Dagenham** | 670 | 673 |
| **Barnet** | 725 | 3,419 |
| **Bexley** | 1,055 | 1,054 |
| **Brent** | 2,105 | 1,338 |
| **Bromley** | 1,635 | 1,695 |
| **Camden** | 3,645 | 2,576 |
| **City of London** | 2,570 | 1,694 |
| **Croydon** | 1,315 | 894 |
| **Ealing** | 3,130 | 4,607 |
| **Enfield** | 1,615 | 2,015 |
| **Greenwich** | 1,380 | 1,308 |
| **Hackney** | 3,080 | 3,831 |
| **Hammersmith and Fulham** | 3,045 | 2,913 |
| **Haringey** | 1,625 | 2,419 |
| **Harrow** | 1,140 | 1,733 |
| **Havering** | 935 | 1,019 |
| **Hillingdon** | 1,380 | 1,178 |
| **Hounslow** | 2,005 | 2,204 |
| **Islington** | 2,970 | 4,411 |
| **Kensington and Chelsea** | 2,795 | 1,016 |
| **Kingston Upon Thames** | 1,365 | 1,237 |
| **Lambeth** | 2,725 | 2,198 |
| **Lewisham** | 1,485 | 1,199 |
| **Merton** | 1,605 | 1,530 |
| **Newham** | 1,300 | 2,703 |
| **Redbridge** | 1,175 | 1,083 |
| **Richmond Upon Thames** | 2,560 | 1,902 |
| **Southwark** | 3,420 | 3,278 |
| **Sutton** | 650 | 651 |
| **Tower Hamlets** | 3,210 | 4,021 |
| **Waltham Forest** | 945 | 1,754 |
| **Wandsworth** | 3,885 | 3,390 |
| **Westminster** | 10,535 | 5,257 |
| **Column Total** | **73,680** | **72,200** |

**Table 6.19: New businesses in London from 1995 to 2006**

### 6.2.3 Population sub-model

Finally the results of the population sub-model, are validated against the Census and the ONS mid-year population estimates. In Table 6.20 the estimated distribution of population for 2001 is validated against the 2001 Census data. The deviation is below 9% for twenty one boroughs, in the range of 9 to 14 % for nine boroughs, and between 15% and 20% for three boroughs. The differences between the actual and forecast proportional spatial distributions of population are very low.

In Table 6.21 the simulation results for 2006 are validated against the ONS mid-year estimates for 2006. The deviation is higher than 20% for four boroughs. The differences between the actual and forecast proportional spatial distributions of businesses are very low. However, these are estimates by ONS and not actual data.

For population, absolute changes and proportional distributions of changes over time are not compared because actual data on population are available only for 2001 from the 2001 Census of Population. For the rest years of the whole simulation period – 1995 to 2006 – only population estimates are available.

To evaluate the ONS estimates and to obtain a better picture for the validation of the results presented in Table 6.21, the ONS estimates for 2001 are validated against the 2001 Census data. The results are presented in Table 6.22. The deviation in general is in the range of 3%, but for Westminster it exceeds 12%. The differences between the actual and forecast proportional spatial distributions of population are lower than the ones of the STUDI model but in many cases of the same scale

| Boroughs | Census data | | Simulation results | | Comparison | |
|---|---|---|---|---|---|---|
| | Census 2001 | % of total | Simulated 2001 | % of total | Deviation % | Change in % of total |
| **Barking and Dagenham** | 163,936 | 2.29 | 169,495 | 2.28 | 3.39 | -0.004 |
| **Barnet** | 314,566 | 4.39 | 327,889 | 4.41 | 4.24 | 0.029 |
| **Bexley** | 218,317 | 3.04 | 197,155 | 2.65 | -9.69 | -0.389 |
| **Brent** | 263,464 | 3.67 | 267,680 | 3.60 | 1.60 | -0.069 |
| **Bromley** | 295,530 | 4.12 | 258,547 | 3.48 | -12.51 | -0.639 |
| **Camden** | 198,015 | 2.76 | 187,301 | 2.52 | -5.41 | -0.239 |
| **City of London** | 7,175 | 0.10 | 6,953 | 0.09 | -3.10 | -0.006 |
| **Croydon** | 330,581 | 4.61 | 339,033 | 4.57 | 2.56 | -0.044 |
| **Ealing** | 300,950 | 4.20 | 305,612 | 4.12 | 1.55 | -0.081 |
| **Enfield** | 273,567 | 3.81 | 271,059 | 3.65 | -0.92 | -0.165 |
| **Greenwich** | 214,408 | 2.99 | 215,315 | 2.90 | 0.42 | -0.090 |
| **Hackney** | 202,826 | 2.83 | 224,940 | 3.03 | 10.90 | 0.201 |
| **Hammersmith and Fulham** | 165,248 | 2.30 | 176,582 | 2.38 | 6.86 | 0.074 |
| **Haringey** | 216,505 | 3.02 | 241,247 | 3.25 | 11.43 | 0.230 |
| **Harrow** | 206,811 | 2.88 | 201,364 | 2.71 | -2.63 | -0.172 |
| **Havering** | 224,241 | 3.13 | 193,914 | 2.61 | -13.52 | -0.516 |
| **Hillingdon** | 243,000 | 3.39 | 227,905 | 3.07 | -6.21 | -0.319 |
| **Hounslow** | 212,344 | 2.96 | 224,453 | 3.02 | 5.70 | 0.062 |
| **Islington** | 175,804 | 2.45 | 187,280 | 2.52 | 6.53 | 0.070 |
| **Kensington and Chelsea** | 158,929 | 2.22 | 190,336 | 2.56 | 19.76 | 0.347 |
| **Kingston Upon Thames** | 147,274 | 2.05 | 160,395 | 2.16 | 8.91 | 0.106 |
| **Lambeth** | 266,167 | 3.71 | 308,982 | 4.16 | 16.09 | 0.449 |
| **Lewisham** | 248,918 | 3.47 | 261,545 | 3.52 | 5.07 | 0.051 |
| **Merton** | 187,918 | 2.62 | 195,749 | 2.64 | 4.17 | 0.016 |
| **Newham** | 243,884 | 3.40 | 246,653 | 3.32 | 1.14 | -0.079 |
| **Redbridge** | 238,638 | 3.33 | 223,853 | 3.01 | -6.20 | -0.313 |
| **Richmond Upon Thames** | 172,341 | 2.40 | 192,552 | 2.59 | 11.73 | 0.190 |
| **Southwark** | 244,868 | 3.41 | 291,681 | 3.93 | 19.12 | 0.513 |
| **Sutton** | 179,765 | 2.51 | 186,165 | 2.51 | 3.56 | 0.000 |
| **Tower Hamlets** | 196,099 | 2.73 | 216,873 | 2.92 | 10.59 | 0.186 |
| **Waltham Forest** | 218,346 | 3.04 | 242,616 | 3.27 | 11.12 | 0.222 |
| **Wandsworth** | 260,382 | 3.63 | 288,614 | 3.89 | 10.84 | 0.256 |
| **Westminster** | 181,290 | 2.53 | 196,991 | 2.65 | 8.66 | 0.125 |
| **Column Total** | **7,172,107** | **100.00** | **7,426,729** | **100.00** | **3.55** | **0.000** |

**Table 6.20: Validation of the population simulation results for 2001 against the actual data**

| Boroughs | ONS estimates | | Simulation results | | Comparison | |
|---|---|---|---|---|---|---|
| | ONS 2006 | % of total | Simulated 2006 | % of total | Deviation % | Change in % of total |
| **Barking and Dagenham** | 165,700 | 2.21 | 163,261 | 2.20 | -1.47 | -0.001 |
| **Barnet** | 328,600 | 4.37 | 330,132 | 4.46 | 0.47 | 0.084 |
| **Bexley** | 221,600 | 2.95 | 169,473 | 2.29 | -23.52 | -0.661 |
| **Brent** | 271,400 | 3.61 | 260,480 | 3.52 | -4.02 | -0.095 |
| **Bromley** | 299,100 | 3.98 | 227,600 | 3.07 | -23.91 | -0.908 |
| **Camden** | 227,500 | 3.03 | 200,942 | 2.71 | -11.67 | -0.315 |
| **City of London** | 7,800 | 0.10 | 6,598 | 0.09 | -15.41 | -0.015 |
| **Croydon** | 337,000 | 4.49 | 306,496 | 4.14 | -9.05 | -0.347 |
| **Ealing** | 306,400 | 4.08 | 309,414 | 4.18 | 0.98 | 0.100 |
| **Enfield** | 285,300 | 3.80 | 254,204 | 3.43 | -10.90 | -0.365 |
| **Greenwich** | 222,600 | 2.96 | 235,895 | 3.19 | 5.97 | 0.222 |
| **Hackney** | 208,400 | 2.77 | 235,867 | 3.18 | 13.18 | 0.411 |
| **Hammersmith and Fulham** | 171,400 | 2.28 | 192,678 | 2.60 | 12.41 | 0.320 |
| **Haringey** | 225,700 | 3.00 | 261,811 | 3.54 | 16.00 | 0.531 |
| **Harrow** | 214,600 | 2.86 | 175,185 | 2.37 | -18.37 | -0.491 |
| **Havering** | 227,300 | 3.03 | 160,038 | 2.16 | -29.59 | -0.865 |
| **Hillingdon** | 250,000 | 3.33 | 215,794 | 2.91 | -13.68 | -0.414 |
| **Hounslow** | 218,600 | 2.91 | 227,768 | 3.08 | 4.19 | 0.166 |
| **Islington** | 185,500 | 2.47 | 188,521 | 2.55 | 1.63 | 0.076 |
| **Kensington and Chelsea** | 178,000 | 2.37 | 198,099 | 2.67 | 11.29 | 0.306 |
| **Kingston Upon Thames** | 155,900 | 2.08 | 180,649 | 2.44 | 15.87 | 0.364 |
| **Lambeth** | 272,000 | 3.62 | 330,557 | 4.46 | 21.53 | 0.843 |
| **Lewisham** | 255,700 | 3.40 | 272,548 | 3.68 | 6.59 | 0.277 |
| **Merton** | 197,700 | 2.63 | 201,593 | 2.72 | 1.97 | 0.091 |
| **Newham** | 248,400 | 3.31 | 251,887 | 3.40 | 1.40 | 0.095 |
| **Redbridge** | 251,900 | 3.35 | 212,520 | 2.87 | -15.63 | -0.483 |
| **Richmond Upon Thames** | 179,500 | 2.39 | 197,256 | 2.66 | 9.89 | 0.274 |
| **Southwark** | 269,200 | 3.58 | 305,179 | 4.12 | 13.37 | 0.538 |
| **Sutton** | 184,400 | 2.45 | 175,524 | 2.37 | -4.81 | -0.084 |
| **Tower Hamlets** | 212,800 | 2.83 | 219,702 | 2.97 | 3.24 | 0.134 |
| **Waltham Forest** | 221,700 | 2.95 | 246,437 | 3.33 | 11.16 | 0.377 |
| **Wandsworth** | 279,000 | 3.71 | 294,286 | 3.97 | 5.48 | 0.260 |
| **Westminster** | 231,900 | 3.09 | 197,289 | 2.66 | -14.93 | -0.423 |
| **Column Total** | **7,512,600** | **100.00** | **7,405,683** | **100.00** | **-1.42** | **0.000** |

**Table 6.21: Validation of the population simulation results for 2006 against the ONS mid-year population estimates**

| Boroughs | Census data | | ONS mid-year estimates | | Comparison | |
|---|---|---|---|---|---|---|
| | Census 2001 | % of total | ONS2001 | % of total | Deviation % | Change in % of total |
| **Barking and Dagenham** | 163,936 | 2.29 | 165,700 | 2.26 | 1.08 | -0.023 |
| **Barnet** | 314,566 | 4.39 | 319,500 | 4.36 | 1.57 | -0.023 |
| **Bexley** | 218,317 | 3.04 | 218,800 | 2.99 | 0.22 | -0.056 |
| **Brent** | 263,464 | 3.67 | 269,600 | 3.68 | 2.33 | 0.008 |
| **Bromley** | 295,530 | 4.12 | 296,200 | 4.05 | 0.23 | -0.075 |
| **Camden** | 198,015 | 2.76 | 202,600 | 2.77 | 2.32 | 0.006 |
| **City of London** | 7,175 | 0.10 | 7,400 | 0.10 | 3.14 | 0.001 |
| **Croydon** | 330,581 | 4.61 | 335,100 | 4.58 | 1.37 | -0.033 |
| **Ealing** | 300,950 | 4.20 | 307,300 | 4.20 | 2.11 | 0.001 |
| **Enfield** | 273,567 | 3.81 | 277,300 | 3.79 | 1.36 | -0.027 |
| **Greenwich** | 214,408 | 2.99 | 217,500 | 2.97 | 1.44 | -0.019 |
| **Hackney** | 202,826 | 2.83 | 207,200 | 2.83 | 2.16 | 0.002 |
| **Hammersmith and Fulham** | 165,248 | 2.30 | 169,400 | 2.31 | 2.51 | 0.009 |
| **Haringey** | 216,505 | 3.02 | 221,300 | 3.02 | 2.21 | 0.003 |
| **Harrow** | 206,811 | 2.88 | 210,000 | 2.87 | 1.54 | -0.016 |
| **Havering** | 224,241 | 3.13 | 224,700 | 3.07 | 0.20 | -0.058 |
| **Hillingdon** | 243,000 | 3.39 | 245,600 | 3.35 | 1.07 | -0.034 |
| **Hounslow** | 212,344 | 2.96 | 216,000 | 2.95 | 1.72 | -0.011 |
| **Islington** | 175,804 | 2.45 | 179,400 | 2.45 | 2.05 | -0.001 |
| **Kensington and Chelsea** | 158,929 | 2.22 | 162,200 | 2.22 | 2.06 | -0.001 |
| **Kingston Upon Thames** | 147,274 | 2.05 | 149,000 | 2.03 | 1.17 | -0.019 |
| **Lambeth** | 266,167 | 3.71 | 273,400 | 3.73 | 2.72 | 0.023 |
| **Lewisham** | 248,918 | 3.47 | 254,300 | 3.47 | 2.16 | 0.002 |
| **Merton** | 187,918 | 2.62 | 191,100 | 2.61 | 1.69 | -0.010 |
| **Newham** | 243,884 | 3.40 | 249,400 | 3.41 | 2.26 | 0.005 |
| **Redbridge** | 238,638 | 3.33 | 241,900 | 3.30 | 1.37 | -0.024 |
| **Richmond Upon Thames** | 172,341 | 2.40 | 174,300 | 2.38 | 1.14 | -0.023 |
| **Southwark** | 244,868 | 3.41 | 256,700 | 3.51 | 4.83 | 0.091 |
| **Sutton** | 179,765 | 2.51 | 181,500 | 2.48 | 0.97 | -0.028 |
| **Tower Hamlets** | 196,099 | 2.73 | 201,100 | 2.75 | 2.55 | 0.012 |
| **Waltham Forest** | 218,346 | 3.04 | 222,000 | 3.03 | 1.67 | -0.013 |
| **Wandsworth** | 260,382 | 3.63 | 271,700 | 3.71 | 4.35 | 0.080 |
| **Westminster** | 181,290 | 2.53 | 203,300 | 2.78 | 12.14 | 0.249 |
| **Column Total** | **7,172,107** | **100.00** | **7,322,500** | **100.00** | **2.10** | **0.000** |

**Table 6.22: Comparison of the ONS mid-year estimates and Census data for 2001**

### 6.2.4 Stochastic variation

The stochastic element exists in various processes of the STUDI model and hence its impact on the forecasts made needs to be investigated. In the present section, the stochastic variability of the results produced by the model will be analysed and discussed. For this purpose, the forecasts of ten runs of STUDI, using different random number sequences, will be presented. These are runs from 1995 to 2006 including the JLE. The residential development sub-model uses a log-linear model, which is not affected by the number of vacant dwellings in previous years (Equation 5.1), therefore it not affected by stochastic variation. On the other hand, the commercial development sub-model uses a linear model but, as the number of vacant commercial premises is one of its variables (Equation 5.2), stochastic variation occurs indirectly as a result of the stochastic variation in the business sub-model. The business and population sub-models are using Monte Carlo simulation in various processes (Sections 5.2 and 5.3 respectively), hence stochastic variation in the results they produce is expected. The results of the ten runs will be presented in scatter plots to illustrate the differences. The x axis represents the boroughs of London. A key to the reference codes (1-33) is provided in Table 6.23.

#### 6.2.4.1 Commercial development

Figure 6.4 illustrates the total number of commercial premises in 2006 in each borough as forecast in each of the ten runs of the STUDI model and Figure 6.5 illustrates the change in the number of commercial premises from 1995 to 2006. There is a small stochastic variation in the forecasts of the commercial development sub-model, reflecting the stochastic variation in the number of vacant commercial premises as updated by the businesses sub-model.

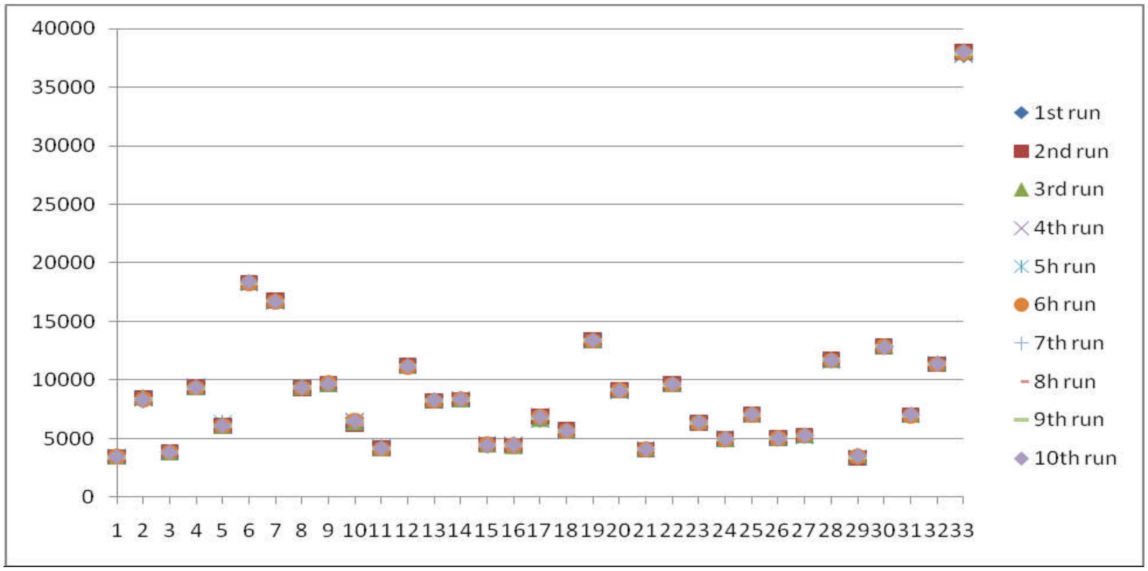


**Figure 6.4: Total number of commercial premises in each borough (forecast)**

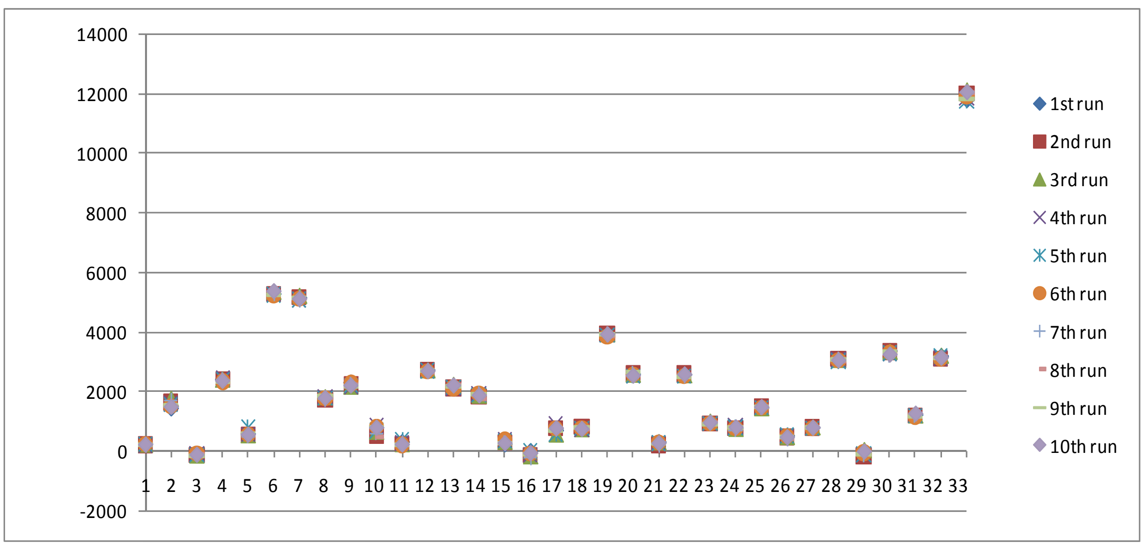


**Figure 6.5: Change in the number of commercial premises in each borough (forecast)**

### 6.2.4.2 Businesses

The business sub-model is a microsimulation model. Monte Carlo simulation is used to identify the businesses that will search for new location (Section 5.2.5.1). Figure 6.6 illustrates the total number of businesses in 2006 in each borough as forecast in each of the ten runs of the STUDI model and Figure 6.7 illustrates the change in the number of businesses during the whole simulation period, i.e. from 1995 to 2006. Although there is a variation among the results of the ten runs, it seems to be relatively small. However, this variation should be evaluated in relevance to the impact that is attributed to the JLE.

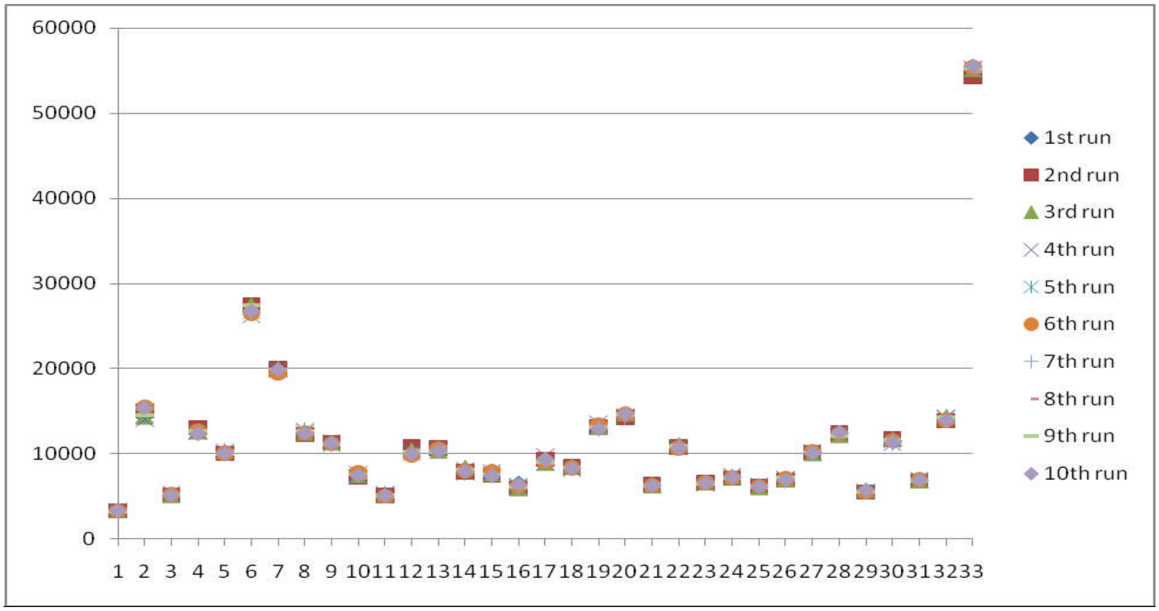


**Figure 6.6: Total number of businesses in each borough (forecast)**

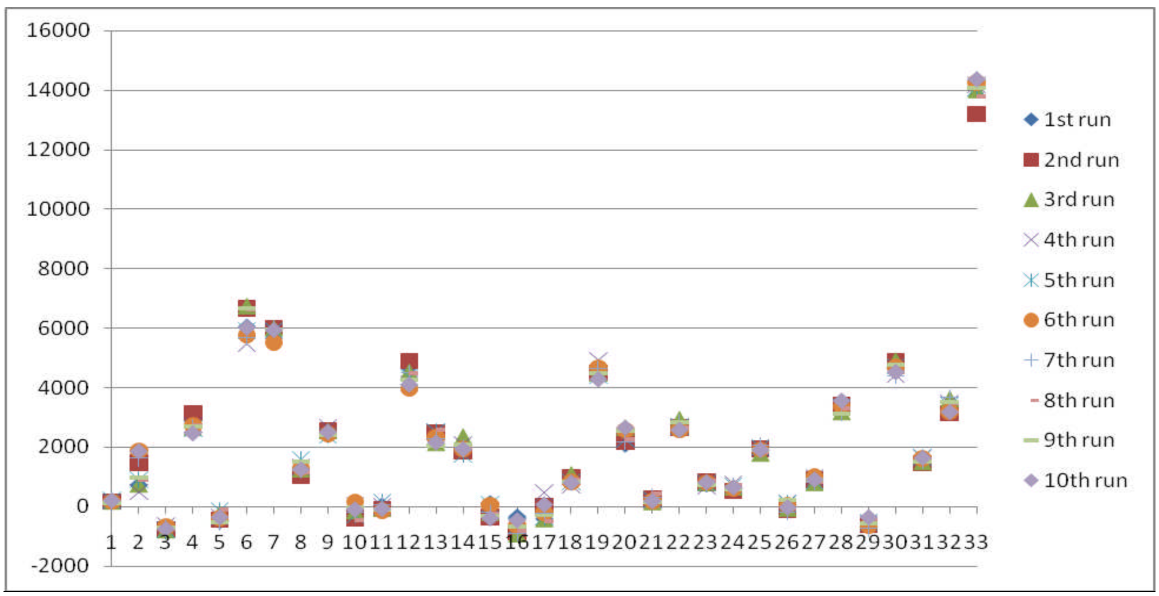


**Figure 6.7: Changes in the number of businesses in each borough**

### 6.2.4.3 Population

In the population sub-model there are many processes using Monte Carlo simulation. Moreover, stochastic variation increases because sample population is used in the simulation and the results are aggregated using the interim expansion factor. The interim expansion factor multiplies any bias created by stochastic variation on the distribution of population. Figure 6.8 illustrates the total size of population in 2006 in each borough as forecast in each of the ten runs of STUDI. It can be seen that the forecast results follow a pattern. However, there is variation between the results of the different runs. This variation is more obvious in Figure 6.9 where the changes in the population during the simulation period are presented. As noted earlier, the significance of this variation should be evaluated in relevance to the size of the forecast impact of the JLE.

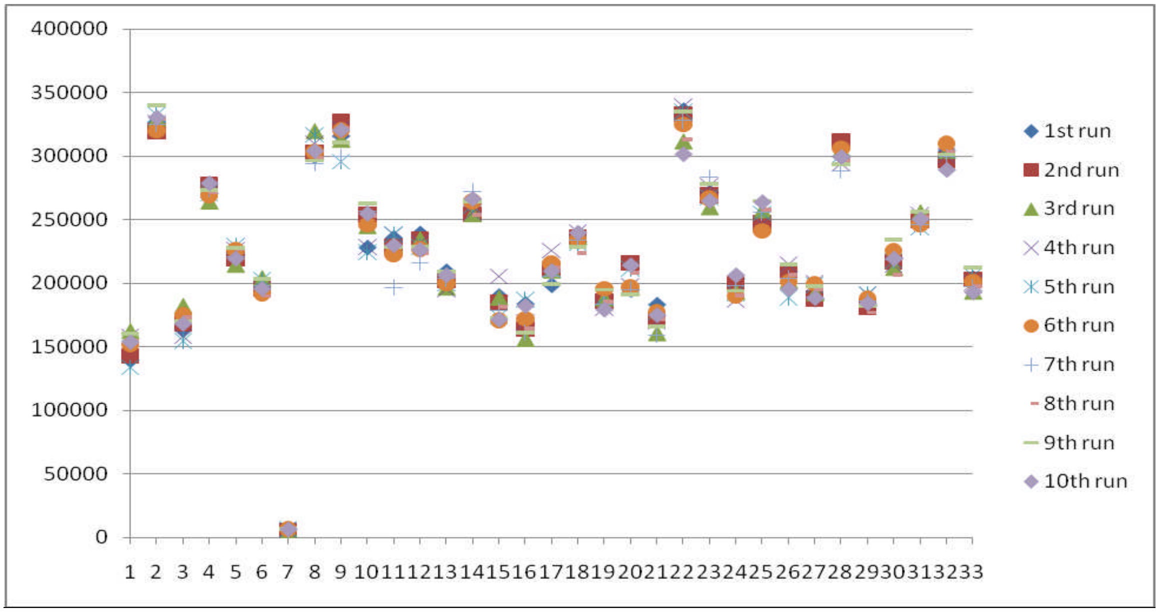


**Figure 6.8: Total population in each borough (forecast)**

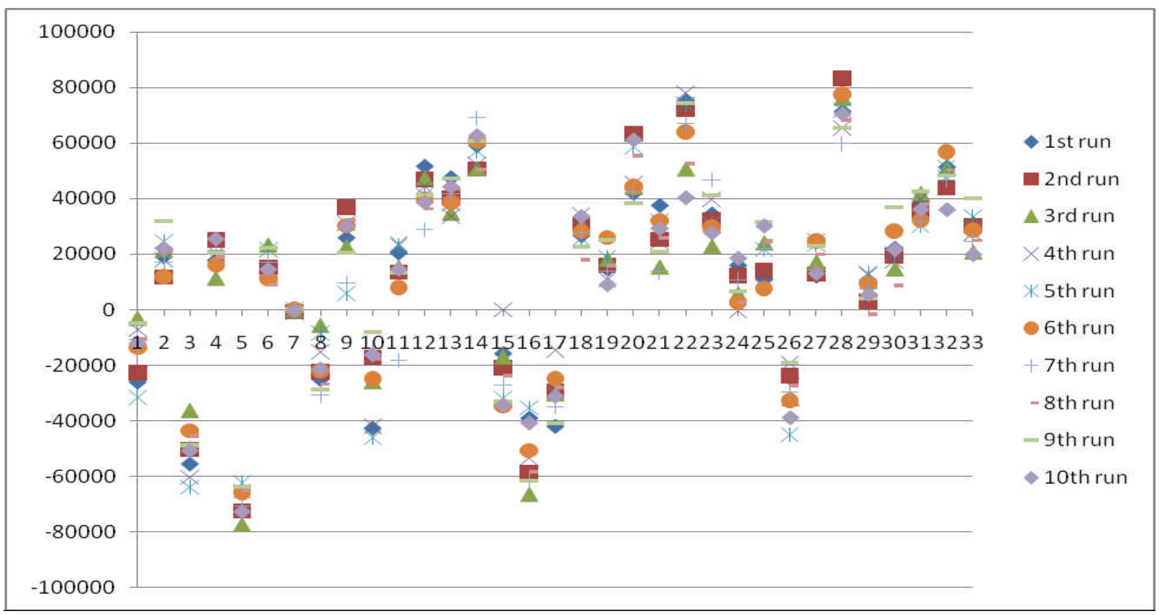


**Figure 6.9: Population changes in each borough**

| Reference | Borough |
|---|---|
| 1 | Barking & Dagenham |
| 2 | Barnet |
| 3 | Bexley |
| 4 | Brent |
| 5 | Bromley |
| 6 | Camden |
| 7 | City of London |
| 8 | Croydon |
| 9 | Ealing |
| 10 | Enfield |
| 11 | Greenwich |
| 12 | Hackney |
| 13 | Hammersmith & Fulham |
| 14 | Haringey |
| 15 | Harrow |
| 16 | Havering |
| 17 | Hillingdon |
| 18 | Hounslow |
| 19 | Islington |
| 20 | Kensington & Chelsea |
| 21 | Kingston upon Thames |
| 22 | Lambeth |
| 23 | Lewisham |
| 24 | Merton |
| 25 | Newham |
| 26 | Redbridge |
| 27 | Richmond upon Thames |
| 28 | Southwark |
| 29 | Sutton |
| 30 | Tower Hamlets |
| 31 | Waltham Forest |
| 32 | Wandsworth |
| 33 | Westminster |

**Table 6.23: Reference codes of London Boroughs**

## 6.3 Summary

In this chapter the results of the estimation, calibration and validation of the STUDI model were presented. The significance of various variables that are expected to affect development, business and residential location decisions has been assessed and the equations used in the STUDI model as discussed in Chapter 5 have been estimated. The variables in these equations have been chosen according to their theoretical and statistical significance and considering practical issues such as the ability to be updated over time. In some cases judgment had to be used to determine factors related to processes for which data could not be obtained.

The calibration of a microsimulation model is a complex and time consuming procedure. For this reason the processing time of the model is very important. For the STUDI model it takes about 30 minutes to complete one whole simulation period, i.e. year, when run in a Pentium 3.4 GHz with 1GB RAM.

The results produced by running the model with the JLE are validated against real data presented in Chapter 4. A general conclusion is that the STUDI model manages to produce forecasts of proportional spatial distributions of residential and commercial premises, businesses and population very close to the actual ones. The deviation of the forecast from the actual data for 2006 for residential development is lower than the one for commercial development. This can be attributed partly to the functional form and partly to the variables used. The use of ‘land available for development’, although not updated as it should be, may improve the performance of the model. The ‘vacant premises’ variable, which is only used in the commercial development sub-model, is important in representing the interactions with the other two sub-models but its temporal relation with the development location decisions and hence with new development has to be reassessed. The results of the business sub-model have been validated against the ABI data. Part of the deviation that occurs should be attributed to the differences between the VAT and the ABI data. Population results for 2001 have been validated against the 2001 Census data and for 2006 against the ONS mid-year estimates.

Finally the stochastic variation of the STUDI model has been illustrated. The results of ten runs of the model using different random number sequences have been presented. In the case of commercial premises and businesses, stochastic variation appears to be small. However, it is comparable to the impacts attributed to the JLE, which are presented in the next chapter (Chapter 7). In the case of population, stochastic variation is larger. In order to investigate this further, to evaluate the impacts of the new metro line and to explain in more detail the processes of STUDI, in the next chapter the results of various runs using pseudo-random number sequences will be presented. The evaluation of the new line will be based on the average of many runs with and without the JLE.

# 7 The Jubilee Line Extension (JLE) application

The STUDI model has been applied in London in order to evaluate the impacts of the Jubilee Line Extension (JLE) on urban development. To do so, it has been run with and without the JLE from 1995 to 2006. When running the model with the JLE, the JLE is added in the London Underground network at the beginning of 2000 (it actually opened at the end of 1999). The differences between the runs represent the impact of the JLE on urban development.

In the previous chapter it has been shown that the forecasts of the STUDI model are affected by stochastic variation. In order to further investigate this and reduce the effects of the stochastic element as much as possible, the model was run 30 times using 15 different pseudo-random number sequences: i.e., it was run 15 times with and 15 without the JLE. The same pseudo-random sequence is used to run the model once with and once without the JLE. As a result, until 2000 the two runs produce exactly the same results and after 2000 – when the JLE is added – the differences between the two runs represent the modelled impacts of the addition of the JLE to the London underground network.

In Section 7.1, the results of the different runs are compared in order to show the impact of stochastic variation. Comparative statistics are presented for the 15 runs without and the 15 runs with the JLE.

The results presented in the following sections are the ones derived from the differences between the average of the results of the 15 runs with the JLE and the average of the results of the 15 runs without the JLE. Section 7.2 contains the results of the development sub-model, Section 7.3 those of the business sub-model and Section 7.4 those of the population sub-model. The results of the STUDI model that refer to the distribution of development, businesses and population are presented in maps of London (Figure 7.1) in which the boroughs with stations of the Jubilee line (the old part and the extension) appear in different colours. Furthermore, diagrams, tables and time series are presented to explain the modelled impacts of the JLE.

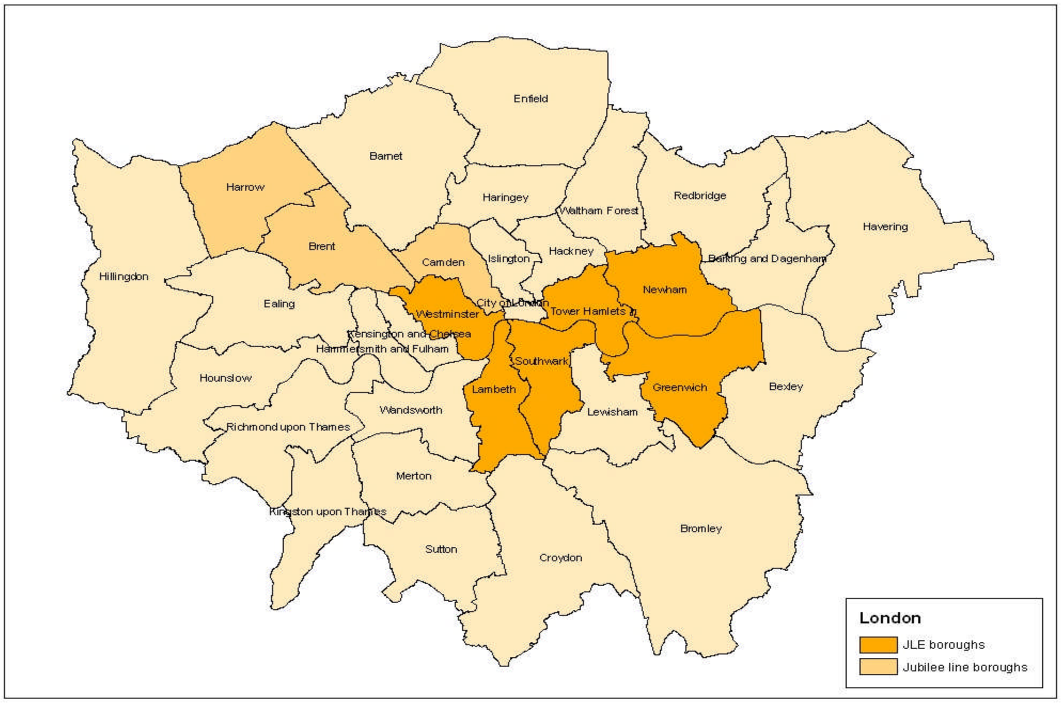


**Figure 7.1: Boroughs of London**

## 7.1 Comparative statistics of the different runs of STUDI

The results for commercial development, businesses and population for each set of 15 runs (with and without the JLE) will be compared in this section. As has already been discussed in Chapter 6, the residential development model is not affected by stochastic variation.

In each case, the average of the forecast value for 2006, the average of the forecast changes from 1995 to 2006, and the standard deviations and relative standard deviations (RSD) are presented. Relative standard deviation is a percentage given by the ratio of standard deviation over average, multiplied by 100.

The number of commercial premises in each borough as forecast from running the STUDI model without the JLE is presented in Table 7.1. Regarding the relative standard deviations for the forecast changes in the number of commercial premises from 1995 to 2006 (last column), RSD is very large for two boroughs: Sutton and Havering. RSD is around 20% for Enfield, Greenwich and Kingston upon Thames, and above 10% for Bexley and Bromley. For the rest of the boroughs, RSD remains at relatively low levels.

The number of businesses in each borough as forecast from running the STUDI model without the JLE is presented in Table 7.2. Standard deviation is large for several boroughs. Regarding the relative standard deviations for the forecast changes in the number of businesses from 1995 to 2006 (last column), RSD is below 5% for 9 boroughs, between 5% and 10% for 8 boroughs, between 10% and 15% for 6 boroughs, between 15% and 20% for 2 boroughs and above 20% for 8 boroughs. Regarding the JLE boroughs, RSD is below 5% for Westminster, Tower Hamlets, Southwark and Newham, 6.25% for Lambeth and 12.48% for Greenwich.

Population of each borough as forecast when running the STUDI model without the JLE is presented in Table 7.3. In this case standard deviation is larger. The population sub-model uses Monte Carlo simulation in various cases and stochastic variation increases due to the use of sample population which is aggregated at the end of every simulation period using the interim expansion factor. Regarding the relative standard deviations for the forecast changes in the number of population from 1995 to 2006 (last column), RSD is below 10% for 4 boroughs, between 10% and 15% for 8 boroughs including Southwark, between 15% and 20% for 3 boroughs including Lambeth and above 20% for 18 boroughs including Westminster, Tower Hamlets, Newham and Greenwich.

The number of commercial premises in each borough as forecast when running the STUDI model with the JLE is presented in Table 7.4. The distribution of RSDs follows a similar pattern as in the case without the JLE.

The number of businesses in each borough as forecast when running the model with the JLE is presented in Table 7.5. Regarding the RSD for the forecast changes in the number of businesses from 1995 to 2006 (last column), a similar pattern as in the case without JLE can be observed. In the case of Greenwich, a very large standard deviation can be observed. In both cases, with and without the JLE, a reduction in the number of businesses in Greenwich is forecast. Looking at the results of each run with the JLE separately it can be noted that in some runs an increase in the number of businesses is forecast. The issue will be discussed further in Section 7.3.

Population in each borough as forecast by running the model with the JLE is presented in Table 7.6. Standard deviations are similar as in the case without JLE. Regarding the relative standard deviations for the forecast changes in population from 1995 to 2006 (last column), RSD is below 10% for 6 boroughs, between 10% and 15% for 7 boroughs including Southwark, between 15% and 20% for 5 boroughs including Lambeth and Westminster, and above 20% for 15 boroughs including Tower Hamlets, Newham and Greenwich.

| no JLE | Commercial premises in 2006 | | | Changes from 1995 to 2006 | | |
|---|---|---|---|---|---|---|
| **Borough** | **Average** | **St. Dev.** | **Rel.St.Dev.** | **Average** | **St. Dev.** | **Rel.St.Dev.** |
| Barking & Dagenham | 3,113.37 | 14.61 | 0.47 | 225.27 | 14.61 | 6.49 |
| Barnet | 7,696.00 | 82.34 | 1.07 | 1,558.00 | 82.34 | 5.28 |
| Bexley | 3,397.10 | 18.10 | 0.53 | -137.20 | 18.10 | 13.20 |
| Brent | 8,606.37 | 28.49 | 0.33 | 2,314.47 | 28.49 | 1.23 |
| Bromley | 5,598.00 | 74.71 | 1.33 | 612.00 | 74.71 | 12.21 |
| Camden | 16,948.57 | 39.35 | 0.23 | 5,224.27 | 39.35 | 0.75 |
| City of London | 15,515.63 | 58.65 | 0.38 | 5,092.73 | 58.65 | 1.15 |
| Croydon | 8,619.10 | 53.71 | 0.62 | 1,819.60 | 53.71 | 2.95 |
| Ealing | 8,950.97 | 38.75 | 0.43 | 2,243.27 | 38.75 | 1.73 |
| Enfield | 5,736.47 | 125.32 | 2.18 | 592.07 | 125.32 | 21.17 |
| Greenwich | 3,622.67 | 16.19 | 0.45 | 91.07 | 16.19 | 17.78 |
| Hackney | 10,322.43 | 34.99 | 0.34 | 2,693.13 | 34.99 | 1.30 |
| Hammersmith & Fulham | 7,645.63 | 26.00 | 0.34 | 2,178.13 | 26.00 | 1.19 |
| Haringey | 7,617.17 | 68.17 | 0.89 | 1,800.47 | 68.17 | 3.79 |
| Harrow | 3,971.33 | 35.15 | 0.89 | 232.73 | 35.15 | 15.10 |
| Havering | 4,007.67 | 51.45 | 1.28 | -54.93 | 51.45 | 93.66 |
| Hillingdon | 6,174.50 | 73.63 | 1.19 | 708.80 | 73.63 | 10.39 |
| Hounslow | 5,173.00 | 36.76 | 0.71 | 772.00 | 36.76 | 4.76 |
| Islington | 12,418.90 | 31.05 | 0.25 | 3,893.20 | 31.05 | 0.80 |
| Kensington & Chelsea | 8,472.20 | 22.71 | 0.27 | 2,593.40 | 22.71 | 0.88 |
| Kingston upon Thames | 3,681.80 | 48.85 | 1.33 | 261.80 | 48.85 | 18.66 |
| Lambeth | 8,925.77 | 15.80 | 0.18 | 2,560.07 | 15.80 | 0.62 |
| Lewisham | 5,864.43 | 35.39 | 0.60 | 978.33 | 35.39 | 3.62 |
| Merton | 4,559.90 | 57.77 | 1.27 | 806.00 | 57.77 | 7.17 |
| Newham | 6,463.93 | 30.17 | 0.47 | 1,429.33 | 30.17 | 2.11 |
| Redbridge | 4,590.83 | 38.91 | 0.85 | 502.13 | 38.91 | 7.75 |
| Richmond upon Thames | 4,804.43 | 26.71 | 0.56 | 780.53 | 26.71 | 3.42 |
| Southwark | 10,702.80 | 49.54 | 0.46 | 2,939.40 | 49.54 | 1.69 |
| Sutton | 3,106.47 | 64.59 | 2.08 | -52.53 | 64.59 | 122.95 |
| Tower Hamlets | 11,833.37 | 29.50 | 0.25 | 3,235.67 | 29.50 | 0.91 |
| Waltham Forest | 6,403.77 | 23.71 | 0.37 | 1,181.07 | 23.71 | 2.01 |
| Wandsworth | 10,591.27 | 42.39 | 0.40 | 3,180.67 | 42.39 | 1.33 |
| Westminster | 35,302.83 | 97.70 | 0.28 | 11,892.93 | 97.70 | 0.82 |

**Table 7.1: Comparative statistics for commercial premises (no JLE)**

| no JLE | Total businesses in 2006 | | | Changes from 1995 to 2006 | | |
|---|---|---|---|---|---|---|
| **Borough** | **Average** | **St. Dev.** | **Rel.St.Dev.** | **Average** | **St. Dev.** | **Rel.St.Dev.** |
| Barking & Dagenham | 3,318.67 | 30.75 | 0.93 | 162.67 | 30.75 | 18.90 |
| Barnet | 14,822.13 | 569.49 | 3.84 | 1,230.13 | 569.49 | 46.29 |
| Bexley | 5,166.20 | 32.07 | 0.62 | -758.80 | 32.07 | 4.23 |
| Brent | 12,559.27 | 165.81 | 1.32 | 2,621.27 | 165.81 | 6.33 |
| Bromley | 10,239.53 | 155.31 | 1.52 | -234.47 | 155.31 | 66.24 |
| Camden | 27,000.13 | 466.72 | 1.73 | 6,244.13 | 466.72 | 7.47 |
| City of London | 19,766.60 | 214.76 | 1.09 | 5,788.60 | 214.76 | 3.71 |
| Croydon | 12,597.13 | 165.19 | 1.31 | 1,395.13 | 165.19 | 11.84 |
| Ealing | 11,233.27 | 147.91 | 1.32 | 2,475.27 | 147.91 | 5.98 |
| Enfield | 7,324.47 | 195.15 | 2.66 | -306.53 | 195.15 | 63.66 |
| Greenwich | 4,938.33 | 33.16 | 0.67 | -265.67 | 33.16 | 12.48 |
| Hackney | 10,321.67 | 226.86 | 2.20 | 4,404.67 | 226.86 | 5.15 |
| Hammersmith & Fulham | 10,597.60 | 185.67 | 1.75 | 2,391.60 | 185.67 | 7.76 |
| Haringey | 7,833.13 | 230.65 | 2.94 | 1,774.13 | 230.65 | 13.00 |
| Harrow | 7,645.20 | 187.00 | 2.45 | -196.80 | 187.00 | 95.02 |
| Havering | 6,236.07 | 94.41 | 1.51 | -627.93 | 94.41 | 15.03 |
| Hillingdon | 9,162.00 | 138.13 | 1.51 | -159.00 | 138.13 | 86.87 |
| Hounslow | 8,436.93 | 67.09 | 0.80 | 924.93 | 67.09 | 7.25 |
| Islington | 13,275.93 | 222.75 | 1.68 | 4,610.93 | 222.75 | 4.83 |
| Kensington & Chelsea | 14,475.13 | 225.64 | 1.56 | 2,373.13 | 225.64 | 9.51 |
| Kingston upon Thames | 6,333.07 | 139.49 | 2.20 | 231.07 | 139.49 | 60.37 |
| Lambeth | 10,929.73 | 174.97 | 1.60 | 2,798.73 | 174.97 | 6.25 |
| Lewisham | 6,687.47 | 127.88 | 1.91 | 873.47 | 127.88 | 14.64 |
| Merton | 7,324.53 | 130.81 | 1.79 | 692.53 | 130.81 | 18.89 |
| Newham | 6,111.27 | 50.62 | 0.83 | 1,845.27 | 50.62 | 2.74 |
| Redbridge | 7,136.60 | 107.38 | 1.50 | 117.60 | 107.38 | 91.31 |
| Richmond upon Thames | 10,064.60 | 108.84 | 1.08 | 815.60 | 108.84 | 13.35 |
| Southwark | 12,091.27 | 134.52 | 1.11 | 3,106.27 | 134.52 | 4.33 |
| Sutton | 5,696.13 | 161.97 | 2.84 | -436.87 | 161.97 | 37.07 |
| Tower Hamlets | 11,355.47 | 104.45 | 0.92 | 4,490.47 | 104.45 | 2.33 |
| Waltham Forest | 6,943.13 | 128.77 | 1.85 | 1,615.13 | 128.77 | 7.97 |
| Wandsworth | 14,174.20 | 96.87 | 0.68 | 3,404.20 | 96.87 | 2.85 |
| Westminster | 54,975.20 | 495.76 | 0.90 | 13,864.20 | 495.76 | 3.58 |

**Table 7.2: Comparative statistics for businesses (no JLE)**

| no JLE | Total Population in 2006 | | | Changes from 1995 to 2006 | | |
|---|---|---|---|---|---|---|
| **Borough** | **Average** | **St. Dev.** | **Rel.St.Dev.** | **Average** | **St. Dev.** | **Rel.St.Dev.** |
| Barking & Dagenham | 121,662.62 | 3,024.37 | 2.49 | -43,897.07 | 3,024.37 | 6.89 |
| Barnet | 333,511.94 | 10,186.66 | 3.05 | 25,476.40 | 10,186.66 | 39.98 |
| Bexley | 161,695.84 | 5,160.58 | 3.19 | -56,956.53 | 5,160.58 | 9.06 |
| Brent | 263,847.74 | 6,934.74 | 2.63 | 10,927.73 | 6,934.74 | 63.46 |
| Bromley | 220,055.13 | 5,346.48 | 2.43 | -71,879.53 | 5,346.48 | 7.44 |
| Camden | 201,132.19 | 6,650.55 | 3.31 | 20,211.20 | 6,650.55 | 32.91 |
| City of London | 6,396.76 | 517.24 | 8.09 | -79.13 | 517.24 | 653.63 |
| Croydon | 271,167.90 | 5,985.29 | 2.21 | -54,026.87 | 5,985.29 | 11.08 |
| Ealing | 308,967.68 | 7,254.76 | 2.35 | 18,929.53 | 7,254.76 | 38.33 |
| Enfield | 192,076.83 | 5,311.99 | 2.77 | -78,695.73 | 5,311.99 | 6.75 |
| Greenwich | 223,831.50 | 10,525.46 | 4.70 | 8,662.47 | 10,525.46 | 121.51 |
| Hackney | 225,631.12 | 7,145.30 | 3.17 | 38,217.67 | 7,145.30 | 18.70 |
| Hammersmith & Fulham | 202,772.02 | 9,164.14 | 4.52 | 40,940.27 | 9,164.14 | 22.38 |
| Haringey | 267,798.90 | 6,835.80 | 2.55 | 64,310.87 | 6,835.80 | 10.63 |
| Harrow | 153,145.69 | 6,747.01 | 4.41 | -52,455.73 | 6,747.01 | 12.86 |
| Havering | 163,536.70 | 7,052.47 | 4.31 | -59,264.40 | 7,052.47 | 11.90 |
| Hillingdon | 176,321.30 | 8,292.07 | 4.70 | -64,185.60 | 8,292.07 | 12.92 |
| Hounslow | 226,305.47 | 6,225.75 | 2.75 | 20,387.20 | 6,225.75 | 30.54 |
| Islington | 183,199.26 | 5,047.92 | 2.76 | 13,267.20 | 5,047.92 | 38.05 |
| Kensington & Chelsea | 201,961.26 | 7,338.55 | 3.63 | 49,217.93 | 7,338.55 | 14.91 |
| Kingston upon Thames | 154,014.06 | 9,213.46 | 5.98 | 8,455.00 | 9,213.46 | 108.97 |
| Lambeth | 321,204.82 | 9,929.23 | 3.09 | 60,267.40 | 9,929.23 | 16.48 |
| Lewisham | 270,682.61 | 6,600.17 | 2.44 | 33,767.53 | 6,600.17 | 19.55 |
| Merton | 198,302.93 | 5,041.63 | 2.54 | 10,807.80 | 5,041.63 | 46.65 |
| Newham | 253,025.41 | 6,915.08 | 2.73 | 19,614.47 | 6,915.08 | 35.26 |
| Redbridge | 172,683.44 | 8,331.92 | 4.82 | -61,318.80 | 8,331.92 | 13.59 |
| Richmond upon Thames | 193,086.41 | 6,114.50 | 3.17 | 18,002.53 | 6,114.50 | 33.96 |
| Southwark | 305,516.14 | 8,245.45 | 2.70 | 76,898.53 | 8,245.45 | 10.72 |
| Sutton | 142,443.49 | 9,034.12 | 6.34 | -36,104.33 | 9,034.12 | 25.02 |
| Tower Hamlets | 220,704.39 | 6,219.83 | 2.82 | 23,206.73 | 6,219.83 | 26.80 |
| Waltham Forest | 243,955.36 | 11,114.56 | 4.56 | 29,959.27 | 11,114.56 | 37.10 |
| Wandsworth | 301,713.31 | 11,134.62 | 3.69 | 48,811.87 | 11,134.62 | 22.81 |
| Westminster | 201,149.26 | 8,928.76 | 4.44 | 28,378.47 | 8,928.76 | 31.46 |

**Table 7.3: Comparative statistics for population (no JLE)**

| JLE | Commercial premises in 2006 | | | Changes from 1995 to 2006 | | |
|---|---|---|---|---|---|---|
| **Borough** | **Average** | **St. Dev.** | **Rel.St.Dev.** | **Average** | **St. Dev.** | **Rel.St.Dev.** |
| Barking & Dagenham | 3,112.17 | 12.22 | 0.39 | 224.07 | 12.22 | 5.45 |
| Barnet | 7,682.27 | 81.23 | 1.06 | 1,544.27 | 81.23 | 5.26 |
| Bexley | 3,439.70 | 25.44 | 0.74 | -94.60 | 25.44 | 26.90 |
| Brent | 8,685.17 | 31.63 | 0.36 | 2,393.27 | 31.63 | 1.32 |
| Bromley | 5,546.47 | 95.28 | 1.72 | 560.47 | 95.28 | 17.00 |
| Camden | 16,975.50 | 48.37 | 0.28 | 5,251.20 | 48.37 | 0.92 |
| City of London | 15,536.03 | 35.58 | 0.23 | 5,113.13 | 35.58 | 0.70 |
| Croydon | 8,592.83 | 74.34 | 0.87 | 1,793.33 | 74.34 | 4.15 |
| Ealing | 8,975.03 | 41.79 | 0.47 | 2,267.33 | 41.79 | 1.84 |
| Enfield | 5,792.93 | 129.50 | 2.24 | 648.53 | 129.50 | 19.97 |
| Greenwich | 3,790.40 | 33.00 | 0.87 | 258.80 | 33.00 | 12.75 |
| Hackney | 10,306.23 | 36.99 | 0.36 | 2,676.93 | 36.99 | 1.38 |
| Hammersmith & Fulham | 7,644.03 | 27.11 | 0.35 | 2,176.53 | 27.11 | 1.25 |
| Haringey | 7,599.97 | 66.84 | 0.88 | 1,783.27 | 66.84 | 3.75 |
| Harrow | 4,051.53 | 40.90 | 1.01 | 312.93 | 40.90 | 13.07 |
| Havering | 3,993.47 | 54.02 | 1.35 | -69.13 | 54.02 | 78.15 |
| Hillingdon | 6,205.77 | 94.23 | 1.52 | 740.07 | 94.23 | 12.73 |
| Hounslow | 5,169.07 | 31.44 | 0.61 | 768.07 | 31.44 | 4.09 |
| Islington | 12,422.50 | 24.99 | 0.20 | 3,896.80 | 24.99 | 0.64 |
| Kensington & Chelsea | 8,442.20 | 23.70 | 0.28 | 2,563.40 | 23.70 | 0.92 |
| Kingston upon Thames | 3,691.47 | 41.68 | 1.13 | 271.47 | 41.68 | 15.35 |
| Lambeth | 8,899.97 | 26.05 | 0.29 | 2,534.27 | 26.05 | 1.03 |
| Lewisham | 5,859.57 | 46.81 | 0.80 | 973.47 | 46.81 | 4.81 |
| Merton | 4,531.90 | 43.90 | 0.97 | 778.00 | 43.90 | 5.64 |
| Newham | 6,495.47 | 38.34 | 0.59 | 1,460.87 | 38.34 | 2.62 |
| Redbridge | 4,579.63 | 29.32 | 0.64 | 490.93 | 29.32 | 5.97 |
| Richmond upon Thames | 4,801.97 | 27.20 | 0.57 | 778.07 | 27.20 | 3.50 |
| Southwark | 10,819.27 | 46.54 | 0.43 | 3,055.87 | 46.54 | 1.52 |
| Sutton | 3,089.80 | 67.82 | 2.19 | -69.20 | 67.82 | 98.01 |
| Tower Hamlets | 11,903.97 | 50.10 | 0.42 | 3,306.27 | 50.10 | 1.52 |
| Waltham Forest | 6,399.57 | 29.66 | 0.46 | 1,176.87 | 29.66 | 2.52 |
| Wandsworth | 10,555.93 | 37.40 | 0.35 | 3,145.33 | 37.40 | 1.19 |
| Westminster | 35,335.90 | 127.44 | 0.36 | 11,926.00 | 127.44 | 1.07 |

**Table 7.4: Comparative statistics for commercial premises (JLE)**

| JLE | Total businesses in 2006 | | | Changes from 1995 to 2006 | | |
|---|---|---|---|---|---|---|
| **Borough** | **Average** | **St. Dev.** | **Rel.St.Dev.** | **Average** | **St. Dev.** | **Rel.St.Dev.** |
| Barking & Dagenham | 3,315.80 | 27.71 | 0.84 | 159.80 | 27.71 | 17.34 |
| Barnet | 14,776.73 | 538.38 | 3.64 | 1,184.73 | 538.38 | 45.44 |
| Bexley | 5,214.53 | 70.02 | 1.34 | -710.47 | 70.02 | 9.86 |
| Brent | 12,684.73 | 222.16 | 1.75 | 2,746.73 | 222.16 | 8.09 |
| Bromley | 10,120.27 | 192.40 | 1.90 | -353.73 | 192.40 | 54.39 |
| Camden | 26,761.13 | 491.68 | 1.84 | 6,005.13 | 491.68 | 8.19 |
| City of London | 19,765.80 | 207.51 | 1.05 | 5,787.80 | 207.51 | 3.59 |
| Croydon | 12,441.80 | 191.64 | 1.54 | 1,239.80 | 191.64 | 15.46 |
| Ealing | 11,293.80 | 152.01 | 1.35 | 2,535.80 | 152.01 | 5.99 |
| Enfield | 7,381.20 | 213.22 | 2.89 | -249.80 | 213.22 | 85.36 |
| Greenwich | 5,201.80 | 100.58 | 1.93 | -2.20 | 100.58 | 4,571.97 |
| Hackney | 10,215.40 | 157.31 | 1.54 | 4,298.40 | 157.31 | 3.66 |
| Hammersmith & Fulham | 10,432.80 | 170.26 | 1.63 | 2,226.80 | 170.26 | 7.65 |
| Haringey | 7,899.53 | 243.29 | 3.08 | 1,840.53 | 243.29 | 13.22 |
| Harrow | 7,739.40 | 202.57 | 2.62 | -102.60 | 202.57 | 197.43 |
| Havering | 6,215.47 | 106.58 | 1.71 | -648.53 | 106.58 | 16.43 |
| Hillingdon | 9,129.07 | 205.80 | 2.25 | -191.93 | 205.80 | 107.22 |
| Hounslow | 8,416.27 | 83.10 | 0.99 | 904.27 | 83.10 | 9.19 |
| Islington | 13,233.33 | 236.14 | 1.78 | 4,568.33 | 236.14 | 5.17 |
| Kensington & Chelsea | 14,497.13 | 218.50 | 1.51 | 2,395.13 | 218.50 | 9.12 |
| Kingston upon Thames | 6,285.73 | 148.66 | 2.36 | 183.73 | 148.66 | 80.91 |
| Lambeth | 10,974.40 | 219.71 | 2.00 | 2,843.40 | 219.71 | 7.73 |
| Lewisham | 6,706.07 | 145.70 | 2.17 | 892.07 | 145.70 | 16.33 |
| Merton | 7,254.27 | 114.82 | 1.58 | 622.27 | 114.82 | 18.45 |
| Newham | 6,175.80 | 81.26 | 1.32 | 1,909.80 | 81.26 | 4.25 |
| Redbridge | 7,110.47 | 83.45 | 1.17 | 91.47 | 83.45 | 91.24 |
| Richmond upon Thames | 10,076.80 | 109.92 | 1.09 | 827.80 | 109.92 | 13.28 |
| Southwark | 12,262.33 | 146.59 | 1.20 | 3,277.33 | 146.59 | 4.47 |
| Sutton | 5,625.93 | 135.12 | 2.40 | -507.07 | 135.12 | 26.65 |
| Tower Hamlets | 11,508.87 | 141.25 | 1.23 | 4,643.87 | 141.25 | 3.04 |
| Waltham Forest | 6,935.33 | 152.30 | 2.20 | 1,607.33 | 152.30 | 9.48 |
| Wandsworth | 14,210.13 | 180.70 | 1.27 | 3,440.13 | 180.70 | 5.25 |
| Westminster | 55,215.53 | 288.70 | 0.52 | 14,104.53 | 288.70 | 2.05 |

**Table 7.5: Comparative statistics for businesses (JLE)**

| JLE | Total Population in 2006 | | | Changes from 1995 to 2006 | | |
|---|---|---|---|---|---|---|
| **Borough** | **Average** | **St. Dev.** | **Rel.St.Dev.** | **Average** | **St. Dev.** | **Rel.St.Dev.** |
| Barking & Dagenham | 120,993.62 | 3,353.16 | 2.77 | -44,566.07 | 3,353.16 | 7.52 |
| Barnet | 331,288.48 | 9,135.83 | 2.76 | 23,252.93 | 9,135.83 | 39.29 |
| Bexley | 162,337.91 | 6,280.35 | 3.87 | -56,314.47 | 6,280.35 | 11.15 |
| Brent | 264,505.07 | 7,287.61 | 2.76 | 11,585.07 | 7,287.61 | 62.91 |
| Bromley | 221,494.33 | 4,508.82 | 2.04 | -70,440.33 | 4,508.82 | 6.40 |
| Camden | 201,763.92 | 6,648.41 | 3.30 | 20,842.93 | 6,648.41 | 31.90 |
| City of London | 6,269.90 | 710.61 | 11.33 | -206.00 | 710.61 | 344.96 |
| Croydon | 273,744.43 | 7,463.66 | 2.73 | -51,450.33 | 7,463.66 | 14.51 |
| Ealing | 307,877.15 | 6,636.61 | 2.16 | 17,839.00 | 6,636.61 | 37.20 |
| Enfield | 194,237.16 | 7,180.99 | 3.70 | -76,535.40 | 7,180.99 | 9.38 |
| Greenwich | 225,128.43 | 12,622.91 | 5.61 | 9,959.40 | 12,622.91 | 126.74 |
| Hackney | 226,488.06 | 7,220.44 | 3.19 | 39,074.60 | 7,220.44 | 18.48 |
| Hammersmith & Fulham | 204,396.29 | 5,223.89 | 2.56 | 42,564.53 | 5,223.89 | 12.27 |
| Haringey | 266,184.44 | 6,028.99 | 2.26 | 62,696.40 | 6,028.99 | 9.62 |
| Harrow | 155,892.36 | 5,486.17 | 3.52 | -49,709.07 | 5,486.17 | 11.04 |
| Havering | 162,676.43 | 6,101.83 | 3.75 | -60,124.67 | 6,101.83 | 10.15 |
| Hillingdon | 178,808.90 | 7,086.23 | 3.96 | -61,698.00 | 7,086.23 | 11.49 |
| Hounslow | 223,253.67 | 8,341.96 | 3.74 | 17,335.40 | 8,341.96 | 48.12 |
| Islington | 185,105.99 | 6,714.70 | 3.63 | 15,173.93 | 6,714.70 | 44.25 |
| Kensington & Chelsea | 201,675.66 | 6,956.87 | 3.45 | 48,932.33 | 6,956.87 | 14.22 |
| Kingston upon Thames | 157,689.79 | 6,256.65 | 3.97 | 12,130.73 | 6,256.65 | 51.58 |
| Lambeth | 325,198.15 | 9,397.57 | 2.89 | 64,260.73 | 9,397.57 | 14.62 |
| Lewisham | 272,957.68 | 6,913.67 | 2.53 | 36,042.60 | 6,913.67 | 19.18 |
| Merton | 197,833.99 | 6,857.50 | 3.47 | 10,338.87 | 6,857.50 | 66.33 |
| Newham | 252,952.14 | 9,574.91 | 3.79 | 19,541.20 | 9,574.91 | 49.00 |
| Redbridge | 175,771.57 | 9,136.95 | 5.20 | -58,230.67 | 9,136.95 | 15.69 |
| Richmond upon Thames | 195,593.28 | 5,984.84 | 3.06 | 20,509.40 | 5,984.84 | 29.18 |
| Southwark | 302,977.01 | 6,107.34 | 2.02 | 74,359.40 | 6,107.34 | 8.21 |
| Sutton | 144,075.55 | 8,296.91 | 5.76 | -34,472.27 | 8,296.91 | 24.07 |
| Tower Hamlets | 220,366.59 | 6,196.50 | 2.81 | 22,868.93 | 6,196.50 | 27.10 |
| Waltham Forest | 243,901.23 | 7,622.23 | 3.13 | 29,905.13 | 7,622.23 | 25.49 |
| Wandsworth | 299,570.91 | 8,574.55 | 2.86 | 46,669.47 | 8,574.55 | 18.37 |
| Westminster | 203,787.26 | 5,324.05 | 2.61 | 31,016.47 | 5,324.05 | 17.17 |

**Table 7.6: Comparative statistics for population (JLE)**

## 7.2 Development sub-model

The development sub-model (Section 5.1) estimates the number of new commercial and residential premises to be added in the relevant stock of each borough annually. The residential development sub-model is not affected at all by stochastic variability but the commercial development sub-model is, as a result of the inclusion of the variable ‘vacant commercial premises’ which varies according to the annual update by the business sub-model. The results presented refer to the difference between averages of the two sets of runs: with and without the JLE.

### 7.2.1 Residential development

Figure 7.2 illustrates the absolute changes (change with JLE minus change without JLE) in the stock of residential premises from 1995 to 2006 due to the JLE. It can be seen that the impact of the JLE is positive for almost all boroughs of London – and for the ones that it is not positive, it is negligible. This happens due to the inversely proportional relationship of the number of new dwellings to travel time (Equation 5.1). A table with the annual differences between the number of new dwellings as forecast with and without the JLE is presented later (Table 7.17) to help the interpretation of the results of the population sub-model.

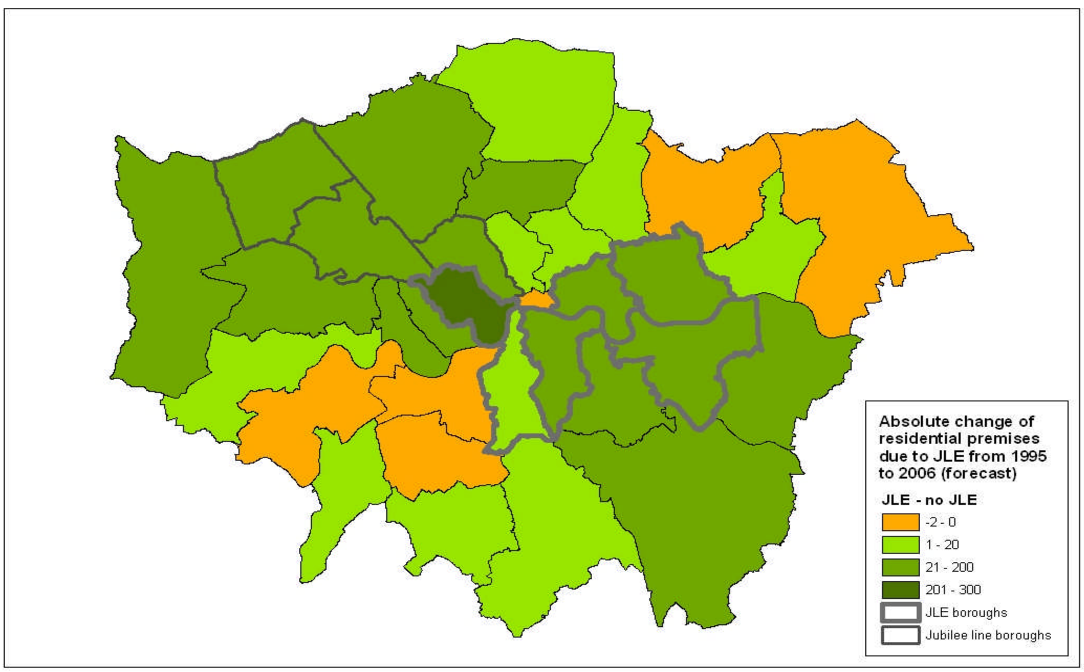


**Figure 7.2: Difference of number of new dwellings forecast with and without the JLE**

Then, the results are aggregated in three zones (Table 7.7). The first one includes the boroughs with JLE stations, i.e. Westminster, Lambeth, Southwark, Greenwich, Tower Hamlets and Newham, the second one the boroughs with stations of the initial part of the Jubilee Line, i.e. Brent, Harrow and Camden, and the last one includes the rest of the

London boroughs. The opening of the JLE has positive impact for all areas but proportionally higher for the JLE and Jubilee line boroughs.

| | **Total number of residential premises in 2006** | | | |
|---|---|---|---|---|
| **Areas** | **Without JLE** | **With JLE** | **Dif. JLE - no JLE** | **% Diff. JLE - no JLE** |
| JLE boroughs | 605,798 | 606,382 | 584 | 0.10 |
| Jubilee Line boroughs | 277,763 | 278,138 | 375 | 0.14 |
| Rest of London | 2,199,874 | 2,200,413 | 539 | 0.02 |

**Table 7.7: Residential development in 2006 in aggregate areas (forecast)**

### 7.2.2 Commercial development

Commercial development is forecast using a linear regression model as described in Section 5.1 (Equation 5.2). In Figure 7.3 the absolute changes due to the JLE (changes with the JLE minus changes without the JLE) in the stock of commercial premises from 1995 to 2006 are presented. It can be seen that the inclusion of the JLE has a positive impact on the commercial development of all the JLE boroughs but Lambeth. In contrast to the residential development results, there are boroughs in which the JLE appears to have had a negative impact. This is due to the fact that in the commercial development model the number of vacant commercial premises is included as a variable and it has negative impact on the number of new commercial premises. Hence, as the opening of the JLE increases the attractiveness of some areas and, consequently, the number of businesses in these areas, it also increases the number of vacant commercial premises in less attractive areas from which the businesses move out.

In Table 7.8, results for aggregate areas are presented. Here it can be seen that the opening of the JLE has a clearly positive impact on the JLE and Jubilee line boroughs and negative on the rest of the London boroughs.

| | Total number of commercial premises in 2006 | | | |
|---|---|---|---|---|
| **Areas** | **Without JLE** | **With JLE** | **Dif. JLE - no JLE** | **% Diff. JLE - no JLE** |
| JLE boroughs | 76,851 | 77,245 | 394 | 0.51 |
| Jubilee Line boroughs | 29,526 | 29,712 | 186 | 0.63 |
| Rest of London | 164,061 | 163,971 | -91 | -0.06 |

**Table 7.8: Commercial development in 2006 in aggregate areas (forecast)**

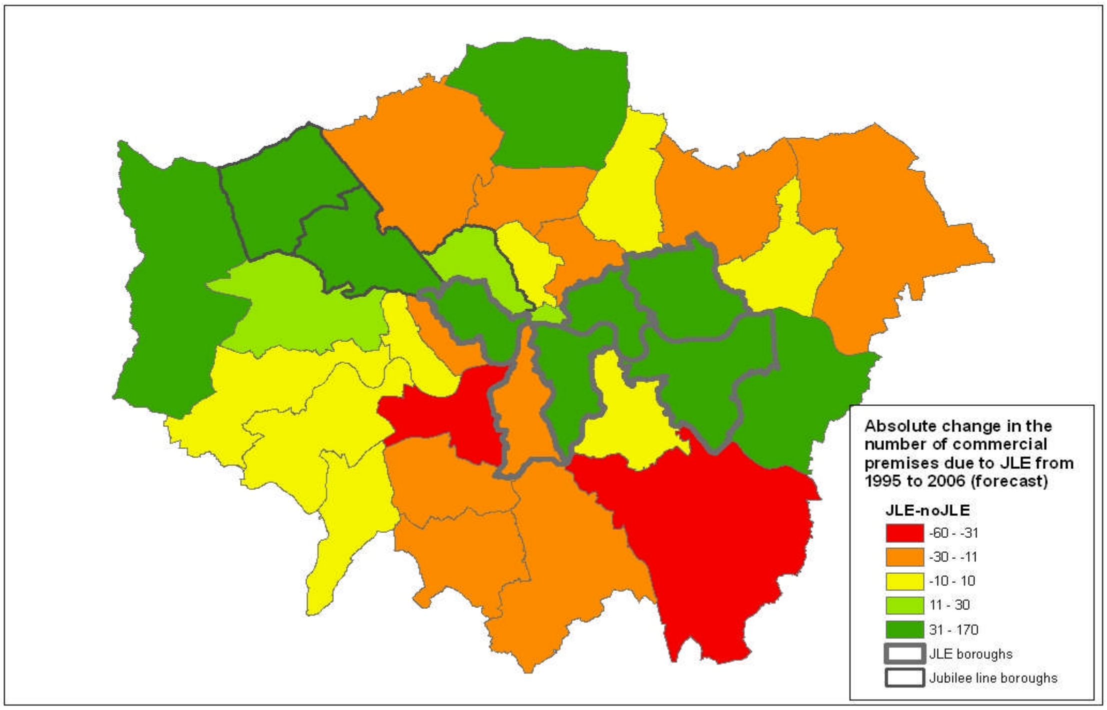


**Figure 7.3: Difference of the number of new commercial premises forecast with and without the JLE**

In Figure 7.4 the annual change in the number of commercial premises in Tower Hamlets is shown. The JLE has a small but positive impact on the development of commercial premises in Tower Hamlets.

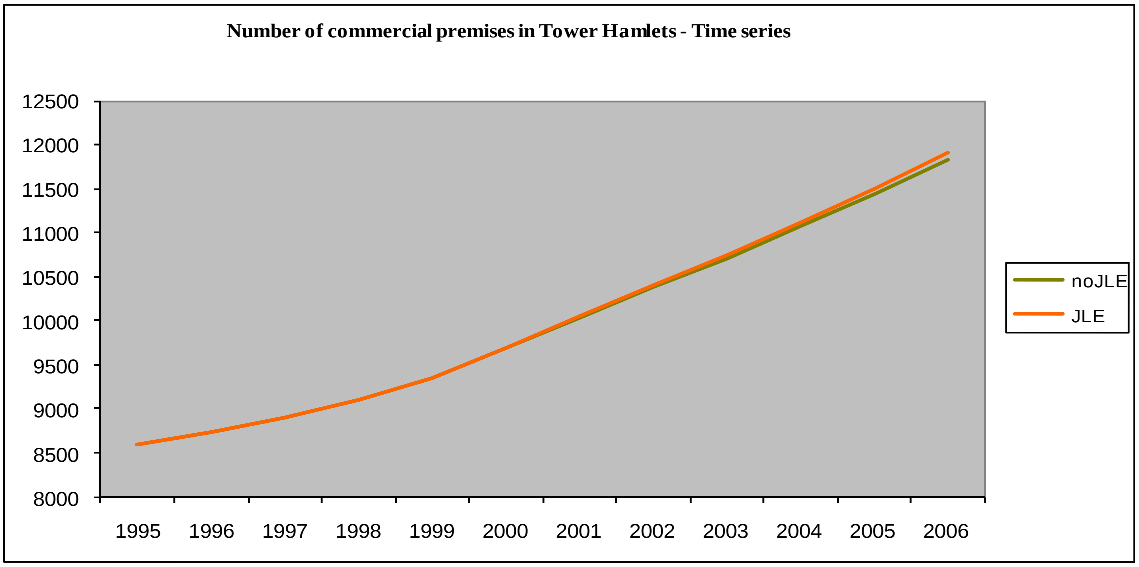


**Figure 7.4: Annual change of the number of commercial premises in Tower Hamlets**

The number of commercial premises is a function of the travel time to the city centre, total number of commercial premises and vacant commercial premises. The relationship between vacant and new commercial premises is presented in Figure 7.5 where the annual variation of the two variables is presented for the borough of Lambeth. In 2004 the simulation with the JLE predicts a lower number of new commercial premises than the simulation without the JLE. This is the result of a large number of vacant commercial premises.

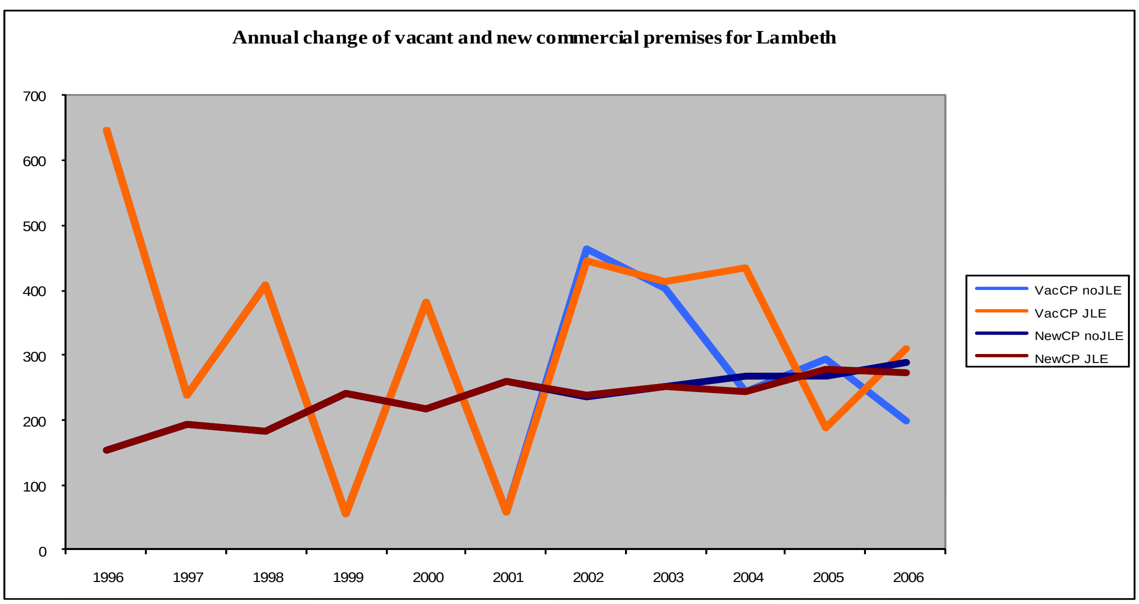


**Figure 7.5: Annual variation of vacant and commercial premises in Lambeth**

## 7.3 Business sub-model

The business sub-model is a microsimulation model. At the end of each simulation period the updated dataset, including individual business records, is aggregated. The main outcome is number of businesses in each borough of London for each year of the whole simulation period.

As the industrial sector of each business is known, it is possible to observe the annual forecast spatial distribution of businesses categorised by industrial sector. In Figure 7.6 the distribution of industrial sectors in London for the base year, i.e. 1995, and for 2006 as forecast with and without the JLE is presented. From 1995 to 2006 the industrial Sector 7, which includes banking, finance, insurance and real estate, grows more than any other sector. On the other hand, manufacturing (Sector 3) is the industrial sector that shrinks the most. A key to the industrial sectors' labelling is presented in Section 4.3. For 2006 the results of the simulation with and without the JLE are as expected, because the number of businesses added and deleted in London is not affected by any endogenous factors, but only by the number of businesses to be added according to VAT registration/deregistration data (Section 4.3). When the number of business start-ups and closures is forecast as described in Section 5.2, the total number of new businesses in London is affected by the economic growth rate.

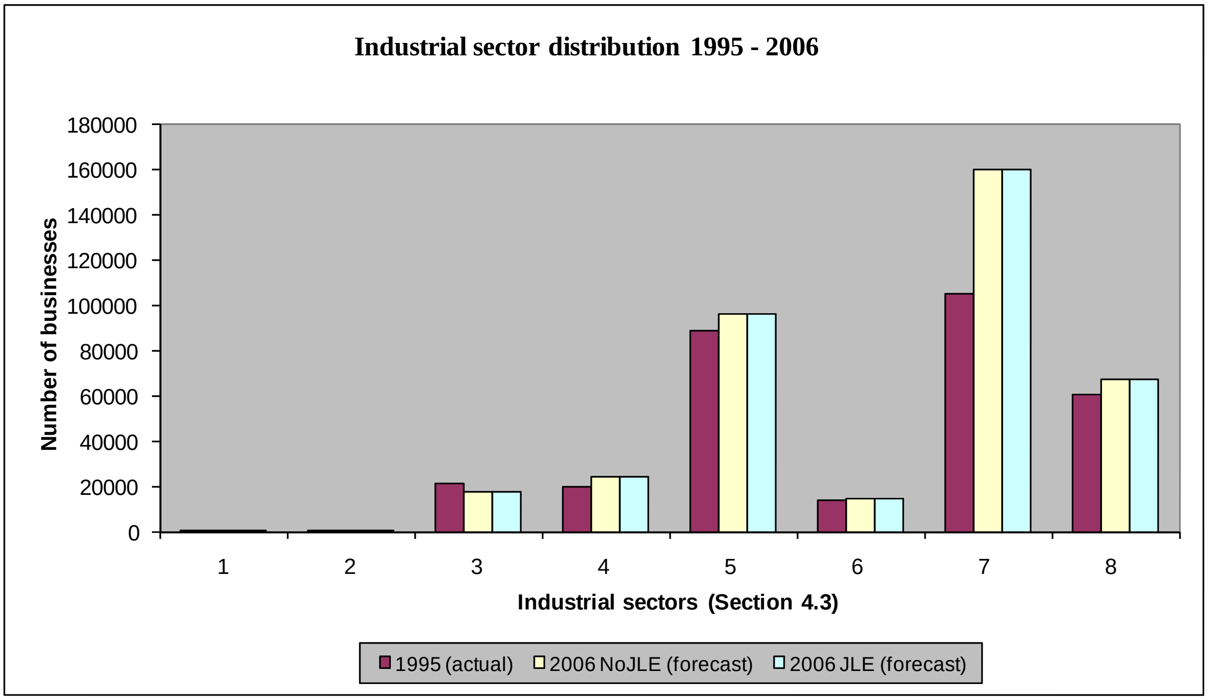


**Figure 7.6: Industrial sector distribution of businesses in London in years 1995 (actual) and 2006 (forecast)**

Regarding the spatial distribution of businesses, Figure 7.7 illustrates the absolute changes in the number of businesses from 1995 to 2006 due to the JLE, i.e. the difference between the change in the total number of businesses from 1995 to 2006 as forecast with the JLE and the change in the total number of businesses from 1995 to 2006 as forecast without the JLE. It can be seen that the JLE has positive impact in all JLE boroughs. In fact, it has the largest positive impact on the JLE boroughs than other areas. Regarding the Jubilee line boroughs, the JLE appears to have positive impact on Brent and Harrow and negative on Camden. This will be further analysed, later in the present section.

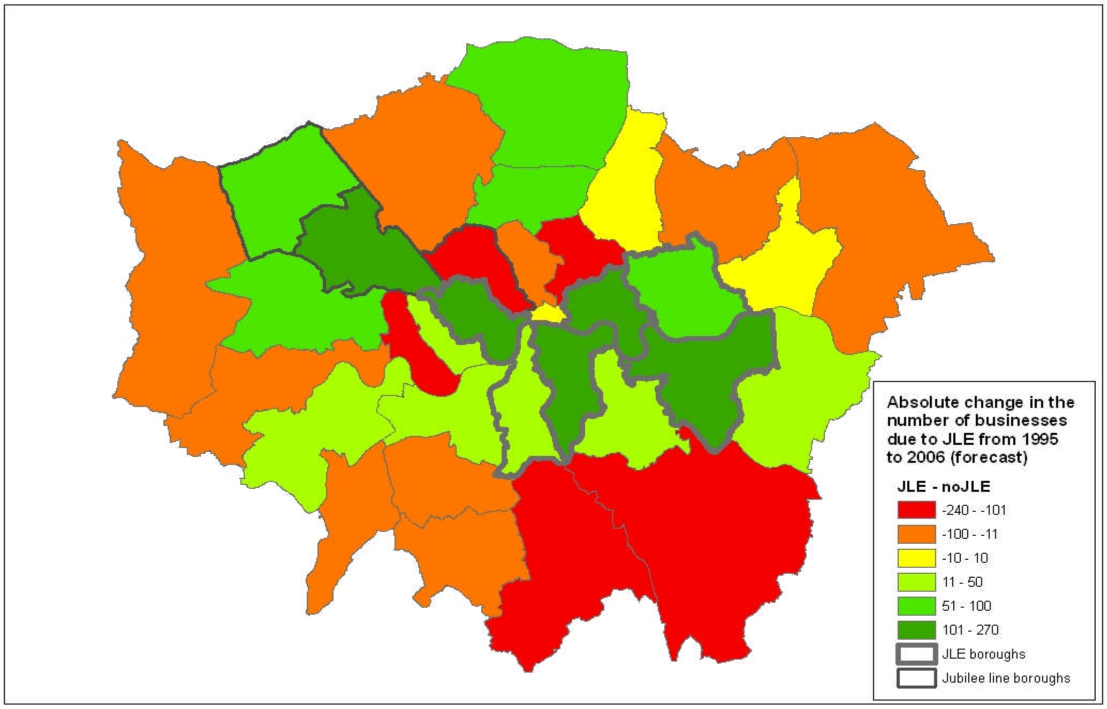


**Figure 7.7: Difference of the number of new businesses added from 1995 to 2006 as forecast with and without the JLE**

The London boroughs are aggregated in three main zones according to their relationship to the JLE, and the impact of the JLE on these zones is presented in Table 7.9. According to this, only the JLE boroughs are positively affected by the JLE.

| | Total number of businesses in 2006 | | | |
|---|---|---|---|---|
| **Areas** | **Without JLE** | **With JLE** | **Dif. JLE - no JLE** | **% Diff. JLE - no JLE** |
| JLE boroughs | 100,401 | 101,339 | 937 | 0.93 |
| Jubilee Line boroughs | 47,205 | 47,185 | -19 | -0.04 |
| Rest of London | 229,166 | 228,554 | -613 | -0.27 |

**Table 7.9: Total number of businesses in aggregate areas (forecast)**

In the case of Southwark and Tower Hamlets, the JLE has a positive impact over time, as illustrated in the time series graphs in Figures 7.8 and 7.9 respectively.

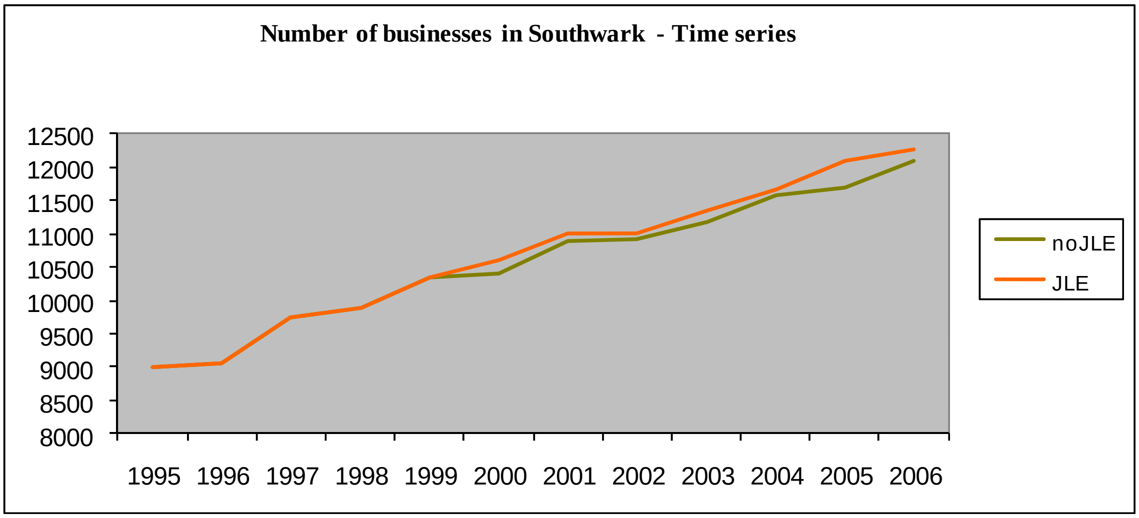


**Figure 7.8: Annual change of the number of businesses in Southwark**

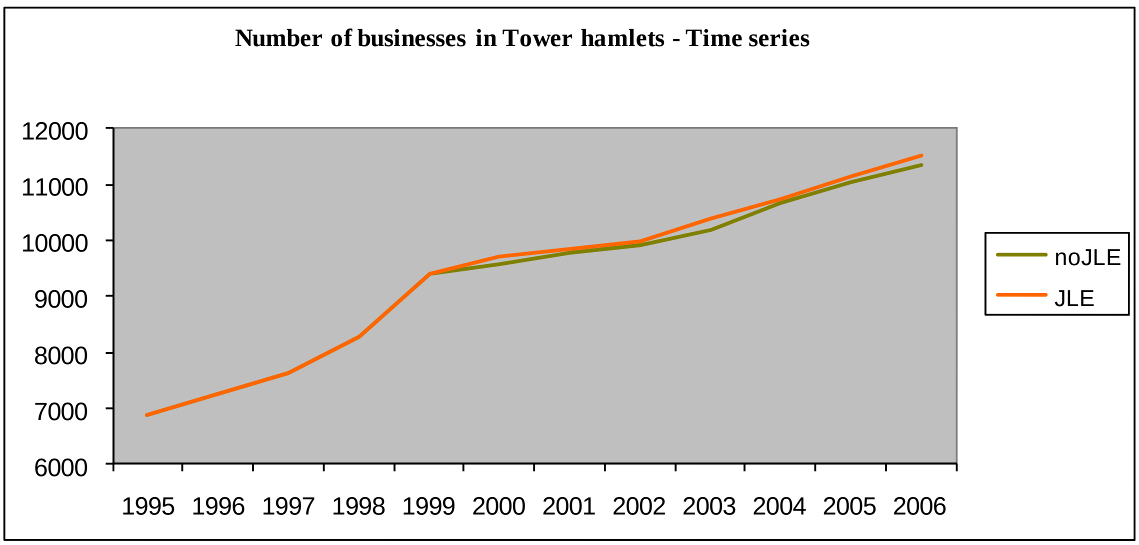


**Figure 7.9: Annual change of the number of businesses in Tower Hamlets**

Figure 7.7 is based on Table 7.10. There it can be seen that the JLE boroughs are the ones with the highest increase in the number of businesses due to JLE. However, for some boroughs such as Greenwich the results should be interpreted keeping in mind the large variation between the results of the different runs that was shown in Section 7.1.

| Reference | Borough | Absolute changes in the number of businesses due to JLE |
|---|---|---|
| 1 | Barking & Dagenham | -3 |
| 2 | Barnet | -45 |
| 3 | Bexley | 48 |
| 4 | Brent | 125 |
| 5 | Bromley | -119 |
| 6 | Camden | -239 |
| 7 | City of London | -1 |
| 8 | Croydon | -155 |
| 9 | Ealing | 61 |
| 10 | Enfield | 57 |
| 11 | Greenwich | 263 |
| 12 | Hackney | -106 |
| 13 | Hammersmith & Fulham | -165 |
| 14 | Haringey | 66 |
| 15 | Harrow | 94 |
| 16 | Havering | -21 |
| 17 | Hillingdon | -33 |
| 18 | Hounslow | -21 |
| 19 | Islington | -43 |
| 20 | Kensington & Chelsea | 22 |
| 21 | Kingston upon Thames | -47 |
| 22 | Lambeth | 45 |
| 23 | Lewisham | 19 |
| 24 | Merton | -70 |
| 25 | Newham | 65 |
| 26 | Redbridge | -26 |
| 27 | Richmond upon Thames | 12 |
| 28 | Southwark | 171 |
| 29 | Sutton | -70 |
| 30 | Tower Hamlets | 153 |
| 31 | Waltham Forest | -8 |
| 32 | Wandsworth | 36 |
| 33 | Westminster | 240 |

**Table 7.10: Difference of the number of new businesses added from 1995 to 2006 as forecast with and without the JLE**

In the STUDI model the main factors affecting the number of businesses are accessible employees – as given by Equation 5.18 – and vacant commercial premises. Location attractiveness is a function of these two variables as shown in Equation 5.17. In general, ‘attractiveness’ is a measure that controls changes in the model and should not be interpreted as a general index of attractiveness of the borough. The ranking of boroughs according to attractiveness, hence the relevant position of the attractiveness of one borough to the attractiveness of the alternative boroughs, determines whether a business will move or not. Table 7.11 and Table 7.12 illustrate the ranking of the boroughs according to attractiveness over time. A key of the reference numbers is included in Table 7.10. This ranking varies according to changes in accessible employees – e.g. in 2000, when the JLE is added – and changes in vacant commercial premises, the number of which varies annually.

| JLE | Ranking of London Boroughs according to attractiveness for businesses | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| order | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| 1 | 12 | 33 | 7 | 33 | 6 | 33 | 33 | 2 | 33 | 33 | 33 |
| 2 | 33 | 7 | 6 | 30 | 19 | 7 | 6 | 7 | 6 | 6 | 2 |
| 3 | 30 | 30 | 30 | 7 | 7 | 2 | 2 | 6 | 7 | 2 | 6 |
| 4 | 7 | 6 | 31 | 31 | 17 | 6 | 7 | 19 | 8 | 8 | 8 |
| 5 | 19 | 31 | 33 | 20 | 8 | 19 | 19 | 33 | 2 | 5 | 10 |
| 6 | 6 | 20 | 19 | 19 | 22 | 20 | 20 | 8 | 17 | 17 | 17 |
| 7 | 31 | 28 | 22 | 2 | 2 | 13 | 32 | 17 | 5 | 10 | 7 |
| 8 | 4 | 14 | 23 | 32 | 10 | 14 | 8 | 30 | 12 | 19 | 5 |
| 9 | 25 | 8 | 32 | 12 | 32 | 32 | 30 | 5 | 30 | 14 | 14 |
| 10 | 14 | 25 | 13 | 10 | 33 | 30 | 5 | 20 | 10 | 7 | 31 |
| 11 | 32 | 23 | 20 | 5 | 5 | 16 | 16 | 14 | 20 | 20 | 12 |
| 12 | 22 | 32 | 12 | 17 | 4 | 4 | 12 | 12 | 14 | 12 | 19 |
| 13 | 9 | 19 | 25 | 6 | 20 | 5 | 4 | 13 | 16 | 26 | 30 |
| 14 | 28 | 17 | 8 | 15 | 16 | 28 | 17 | 16 | 19 | 31 | 16 |
| 15 | 8 | 12 | 10 | 23 | 23 | 17 | 14 | 10 | 31 | 16 | 20 |
| 16 | 13 | 22 | 14 | 8 | 15 | 12 | 22 | 32 | 26 | 15 | 15 |
| 17 | 23 | 10 | 16 | 13 | 29 | 31 | 15 | 31 | 15 | 32 | 4 |
| 18 | 18 | 13 | 4 | 28 | 14 | 8 | 10 | 15 | 22 | 29 | 32 |
| 19 | 20 | 9 | 17 | 16 | 13 | 25 | 26 | 28 | 13 | 13 | 29 |
| 20 | 24 | 18 | 2 | 29 | 30 | 24 | 13 | 22 | 4 | 30 | 13 |
| 21 | 10 | 4 | 27 | 4 | 11 | 9 | 31 | 4 | 28 | 4 | 23 |
| 22 | 17 | 16 | 15 | 9 | 9 | 15 | 9 | 26 | 32 | 28 | 26 |
| 23 | 1 | 26 | 29 | 25 | 28 | 21 | 23 | 21 | 24 | 23 | 3 |
| 24 | 16 | 15 | 28 | 14 | 18 | 26 | 18 | 23 | 29 | 3 | 28 |
| 25 | 21 | 27 | 24 | 27 | 12 | 27 | 24 | 29 | 9 | 25 | 22 |
| 26 | 15 | 21 | 5 | 22 | 31 | 10 | 3 | 3 | 25 | 24 | 25 |
| 27 | 27 | 29 | 1 | 24 | 21 | 29 | 21 | 24 | 3 | 27 | 21 |
| 28 | 26 | 5 | 9 | 26 | 3 | 3 | 27 | 9 | 21 | 21 | 9 |
| 29 | 2 | 24 | 21 | 18 | 27 | 23 | 28 | 11 | 11 | 22 | 24 |
| 30 | 29 | 2 | 3 | 3 | 24 | 22 | 25 | 18 | 23 | 11 | 11 |
| 31 | 5 | 1 | 26 | 21 | 26 | 11 | 11 | 25 | 18 | 9 | 27 |
| 32 | 3 | 3 | 18 | 1 | 25 | 1 | 29 | 27 | 27 | 1 | 1 |
| 33 | 11 | 11 | 11 | 11 | 1 | 18 | 1 | 1 | 1 | 18 | 18 |

**Table 7.11: Annual ranking of London boroughs according to attractiveness as resulted from the simulation with the JLE**

| noJLE | Ranking of London Boroughs according to attractiveness for businesses | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| order | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| 1 | 12 | 33 | 7 | 33 | 6 | 33 | 33 | 7 | 33 | 33 | 33 |
| 2 | 33 | 7 | 6 | 30 | 19 | 7 | 6 | 2 | 6 | 6 | 6 |
| 3 | 30 | 30 | 30 | 7 | 7 | 6 | 2 | 6 | 2 | 2 | 2 |
| 4 | 7 | 6 | 31 | 31 | 17 | 2 | 7 | 19 | 7 | 8 | 10 |
| 5 | 19 | 31 | 33 | 20 | 8 | 19 | 19 | 33 | 8 | 10 | 7 |
| 6 | 6 | 20 | 19 | 19 | 22 | 13 | 20 | 8 | 30 | 5 | 8 |
| 7 | 31 | 28 | 22 | 2 | 2 | 20 | 8 | 17 | 10 | 19 | 17 |
| 8 | 4 | 14 | 23 | 32 | 10 | 30 | 32 | 20 | 17 | 17 | 14 |
| 9 | 25 | 8 | 32 | 12 | 32 | 32 | 12 | 30 | 14 | 12 | 5 |
| 10 | 14 | 25 | 13 | 10 | 5 | 4 | 30 | 12 | 12 | 14 | 31 |
| 11 | 32 | 23 | 20 | 5 | 4 | 16 | 16 | 5 | 5 | 7 | 19 |
| 12 | 22 | 32 | 12 | 17 | 20 | 28 | 17 | 14 | 19 | 20 | 12 |
| 13 | 9 | 19 | 25 | 6 | 16 | 14 | 5 | 10 | 16 | 26 | 16 |
| 14 | 28 | 17 | 8 | 15 | 33 | 5 | 10 | 13 | 20 | 4 | 15 |
| 15 | 8 | 12 | 10 | 23 | 23 | 17 | 22 | 16 | 31 | 31 | 20 |
| 16 | 13 | 22 | 14 | 8 | 14 | 10 | 4 | 31 | 26 | 16 | 28 |
| 17 | 23 | 10 | 16 | 13 | 29 | 31 | 15 | 4 | 15 | 32 | 30 |
| 18 | 18 | 13 | 4 | 28 | 15 | 8 | 14 | 22 | 9 | 15 | 13 |
| 19 | 20 | 9 | 17 | 16 | 13 | 15 | 26 | 32 | 13 | 29 | 4 |
| 20 | 24 | 18 | 2 | 29 | 9 | 24 | 31 | 15 | 24 | 13 | 23 |
| 21 | 10 | 4 | 27 | 4 | 18 | 21 | 13 | 26 | 28 | 3 | 3 |
| 22 | 17 | 16 | 15 | 9 | 12 | 27 | 9 | 21 | 32 | 23 | 32 |
| 23 | 1 | 26 | 29 | 25 | 31 | 26 | 18 | 28 | 4 | 30 | 29 |
| 24 | 16 | 15 | 28 | 14 | 30 | 9 | 21 | 29 | 29 | 22 | 26 |
| 25 | 21 | 27 | 24 | 27 | 21 | 12 | 3 | 3 | 3 | 28 | 9 |
| 26 | 15 | 21 | 5 | 22 | 3 | 29 | 24 | 23 | 21 | 27 | 21 |
| 27 | 27 | 29 | 1 | 24 | 27 | 3 | 27 | 24 | 22 | 21 | 22 |
| 28 | 26 | 5 | 9 | 26 | 24 | 22 | 29 | 9 | 18 | 25 | 25 |
| 29 | 2 | 24 | 21 | 18 | 28 | 25 | 23 | 18 | 27 | 24 | 24 |
| 30 | 29 | 2 | 3 | 3 | 26 | 1 | 28 | 27 | 23 | 1 | 27 |
| 31 | 5 | 1 | 26 | 21 | 1 | 18 | 25 | 1 | 25 | 9 | 1 |
| 32 | 3 | 3 | 18 | 1 | 25 | 11 | 1 | 11 | 1 | 18 | 18 |
| 33 | 11 | 11 | 11 | 11 | 11 | 23 | 11 | 25 | 11 | 11 | 11 |

**Table 7.12: Annual ranking of London boroughs according to attractiveness as resulted from the simulation with the JLE**

Vacant commercial premises are a critical factor for businesses to move to a location with higher attractiveness, given as, if there are not any premises available, a business cannot move there. Figure 7.10 illustrates the change of accessible employees over time and shows that the JLE is affecting mainly the JLE boroughs, shifting up their accessible employees after 2000 when the JLE is added.

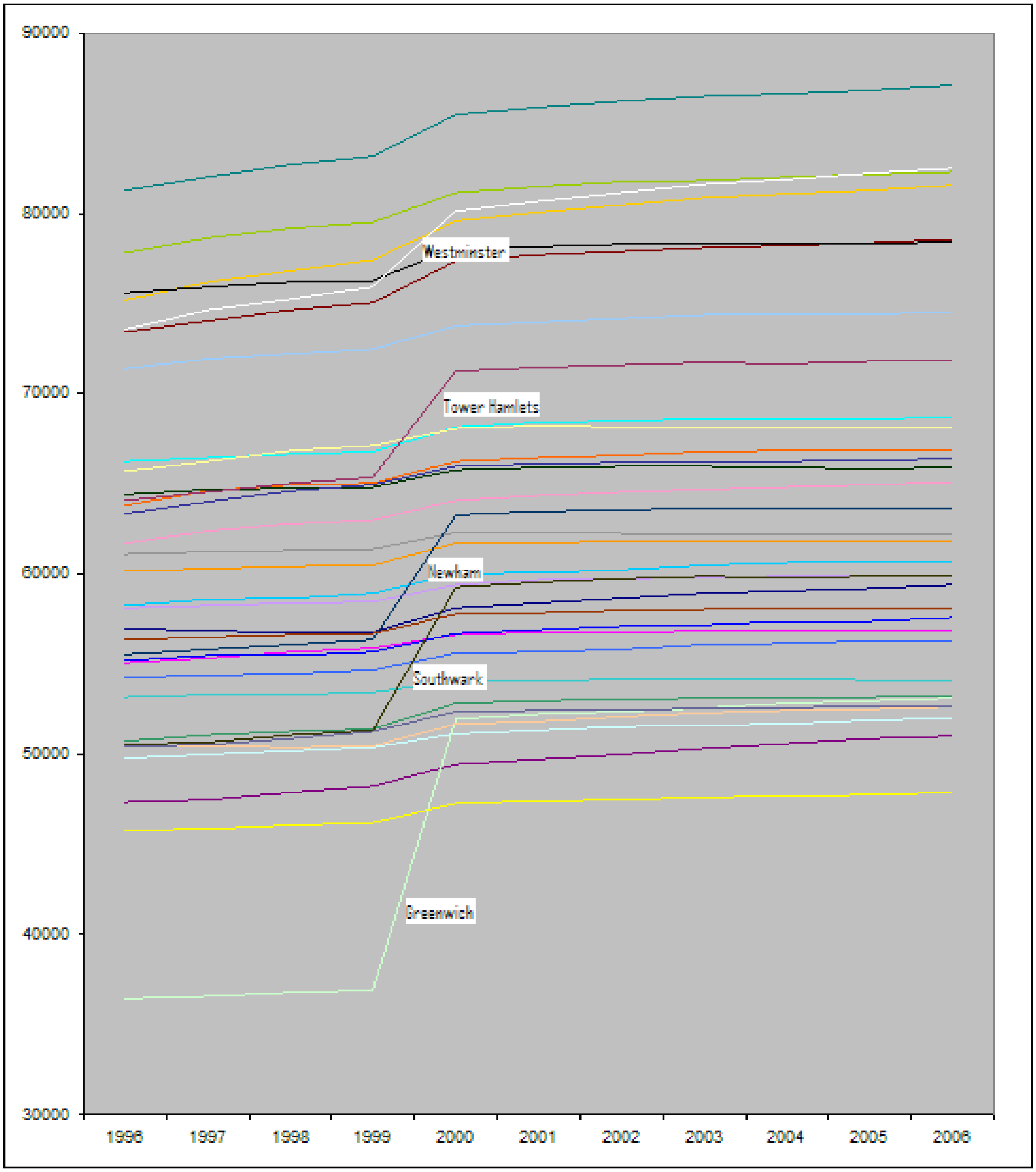


**Figure 7.10: Annual change of accessible employees**

There are various boroughs where the JLE appears to have negative impact. Businesses leave these zones for the zones benefited by the JLE. Such a borough is Camden. In general, businesses willing to relocate will move to the closest borough with higher attractiveness than the current one and with available space. In the case of Camden, the closest borough is Islington and the next one is Westminster. As can be seen in Table 7.11, from 2000 when the JLE is added, the attractiveness of Westminster (reference number: 33) is higher than the one of Camden (6) for five years. The opposite happens only for two years (2000 and 2003). However, the same happens in absence of the JLE. The difference between the runs with and without the JLE occurs due to the positive impact of the JLE on the number of new commercial premises. If the same number of businesses in Camden is willing to relocate, the difference is that in presence of the JLE more businesses willing to move out of Camden will find vacant premises in Westminster and will, as a result, move there. The impact appears to be so large for Camden because it is one of the boroughs with the larger number of businesses, therefore many businesses will be willing to relocate every year.

The forecast impact of the JLE on Greenwich (11) is largely affected by stochastic variation as explained earlier. However, the positive impact of the JLE can be explained by looking at Table 7.11 and Table 7.12 and Figure 7.10. At first, in Figure 7.10 it can be seen that after the addition of the JLE in 2000 the number of accessible employees increases significantly, so that it exceeds those of Bexley, Bromley, Enfield and Havering. In Table 7.11 (results of the simulation with the JLE) it can be seen that, in contrast to the results of the simulation without the JLE (Table 7.12), after 2000 Greenwich (11) is not the most unattractive borough anymore and businesses from other boroughs will move to this one. The fact that Greenwich has a low attractiveness index can also explain the large stochastic variation. When running the simulation without JLE, a decline in the number of businesses in Greenwich is forecast. When running the simulation with JLE, in several runs the number of businesses increases or the decline is much smaller. In these cases, more businesses from boroughs with smaller attractiveness than Greenwich's (Table 7.11) are looking to relocate. For example, when running the simulation with the JLE in 2004 Greenwich (11) has a larger attractiveness than Lewisham (23) (Table 7.11) but when running the simulation without the JLE (Table 7.12) it does not.

Figure 7.11 illustrates the over time change of attractiveness and Figure 7.12 the over time change of the number of businesses in Greenwich. In both figures the impact of JLE is obvious; especially in 2000, the year when the JLE is introduced.

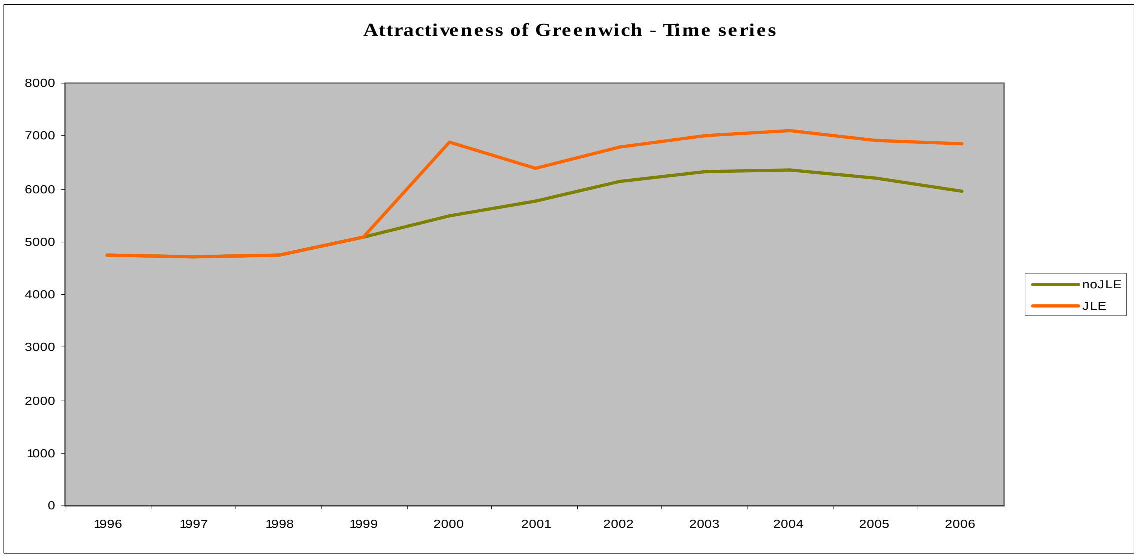


**Figure 7.11: Annual change of attractiveness of Greenwich**

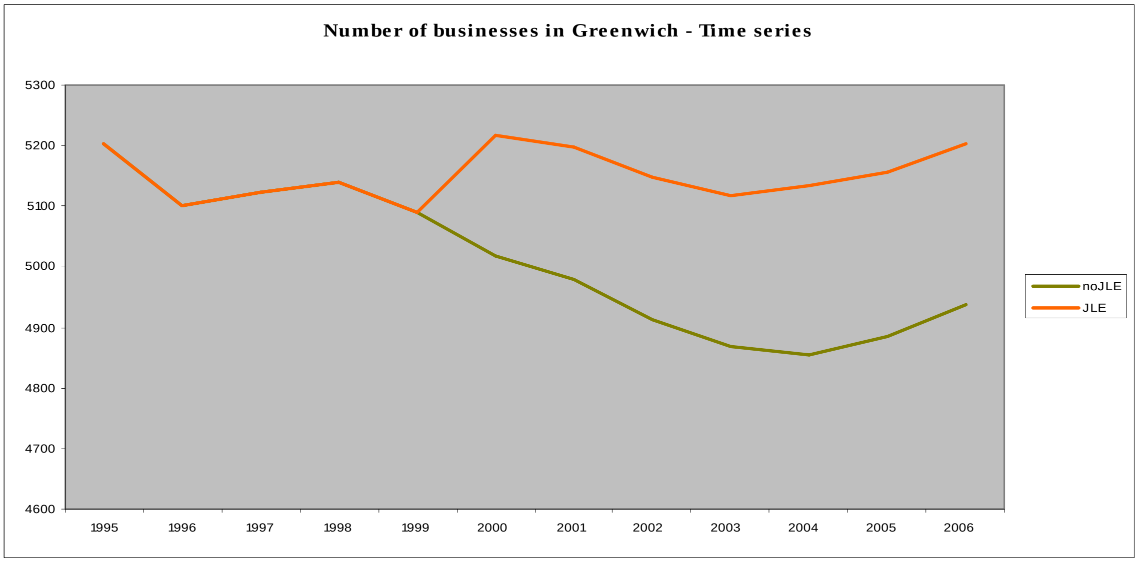


**Figure 7.12: Annual change of number of businesses in Greenwich**

## 7.4 Population sub-model

The population sub-model is a microsimulation model; hence population is simulated at individual or household level. A sample population is used and the interim expansion factor (Section 4.4) is applied to aggregate the results to the total population. The results of the population sub-model are largely affected by stochastic variation as shown in Section 7.1. One important reason for this is the use of the interim expansion factor. When aggregating the results derived using the sample population, each household or person is multiplied by the interim expansion factor. Therefore, if the interim expansion factor is 100, a household leaving a borough, chosen randomly to look for new location according to the pseudo-random number, is multiplied by 100 to aggregate to the total population. If a total population had been used, less bias between different random number sequences would occur, but the computational time would be significantly larger. The main results of the population sub-model refer to population distribution in London, population changes over time and employment distribution. As population is updated, changes in the demographics can also be observed.

### 7.4.1 Demographics

In Figure 7.13 the age distributions in 1995 (LATS data) and in 2006 (as forecast with and without the JLE) of the population living in London are presented. According to this, population ageing occurs in the range of the middle ages, but in the range of older ages the size of population remains in similar levels. This happens because the probability to move in London was set to be lower for older than for younger people (Section 5.3.2.2).

This is also shown in Figure 7.14, in which the household structure distributions in London in 1995 (LATS data) and in 2006 (as forecast with and without the JLE) are presented. There is a large decrease in the all pensioner households, and also a large increase in households with dependent children. It is recognized that demographics need to be modelled in more detail in the future.

In Figure 7.15 the working status distributions of the London population in 1995 (LATS data) and in 2006 (as forecast with and without the JLE) are presented. A large increase in full-time employment and decrease in non-working population is forecast. The number of retired persons is decreasing because it is assumed that for all pensioner households it is more likely to out-migrate and less likely to in-migrate (Section 5.3.2). A more detailed simulation for employment decisions is needed, because the current method favours finding full-time jobs and is restrictive for employment categories represented in the middle of the diagram, such as the unemployed and students. Currently the unemployed population is increased only by adding ex-students looking for a job and students' location decisions are not modelled explicitly.

In Figure 7.16 the household income distributions in London in 1995 (LATS data) and in 2006 (as forecast with and without the JLE) are presented. On the *y* axis, the number of people that belong to each household-income category is represented. It should be noted, at this point, that the incomes change when new households are formed and existing incomes are combined, and no rules involving salary increases etc. have been set to update household incomes.

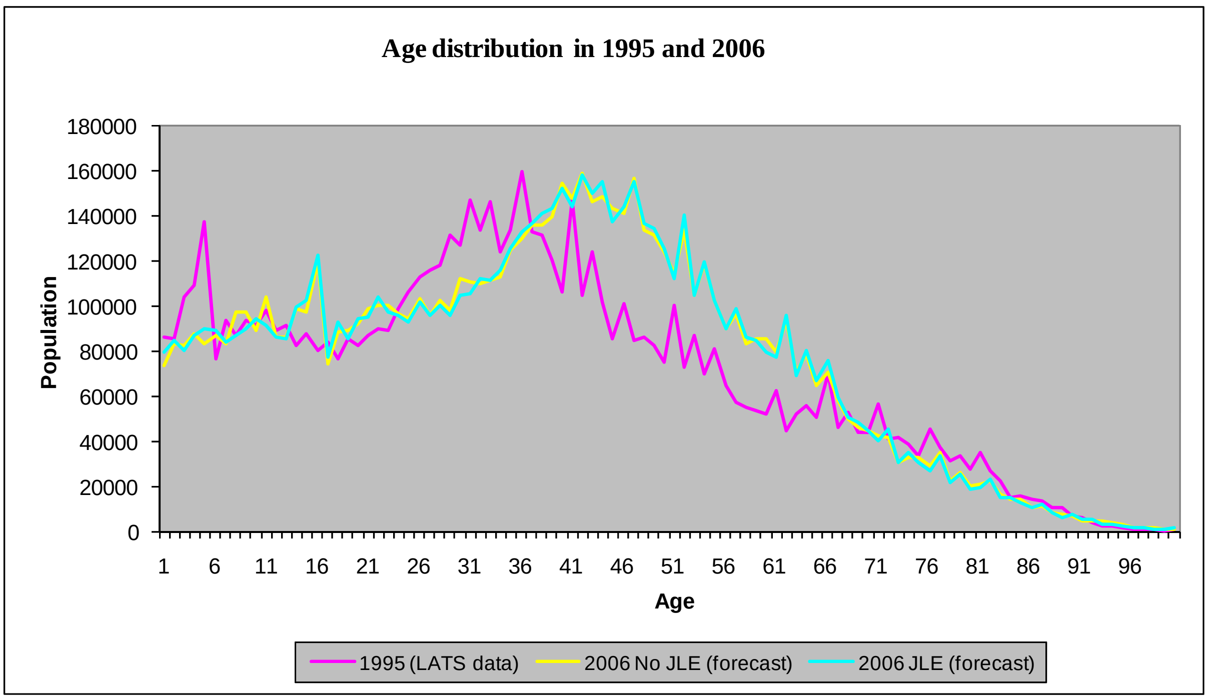


**Figure 7.13: Age distribution of population in London in 1995 (LATS data) and 2006 ( forecast)**

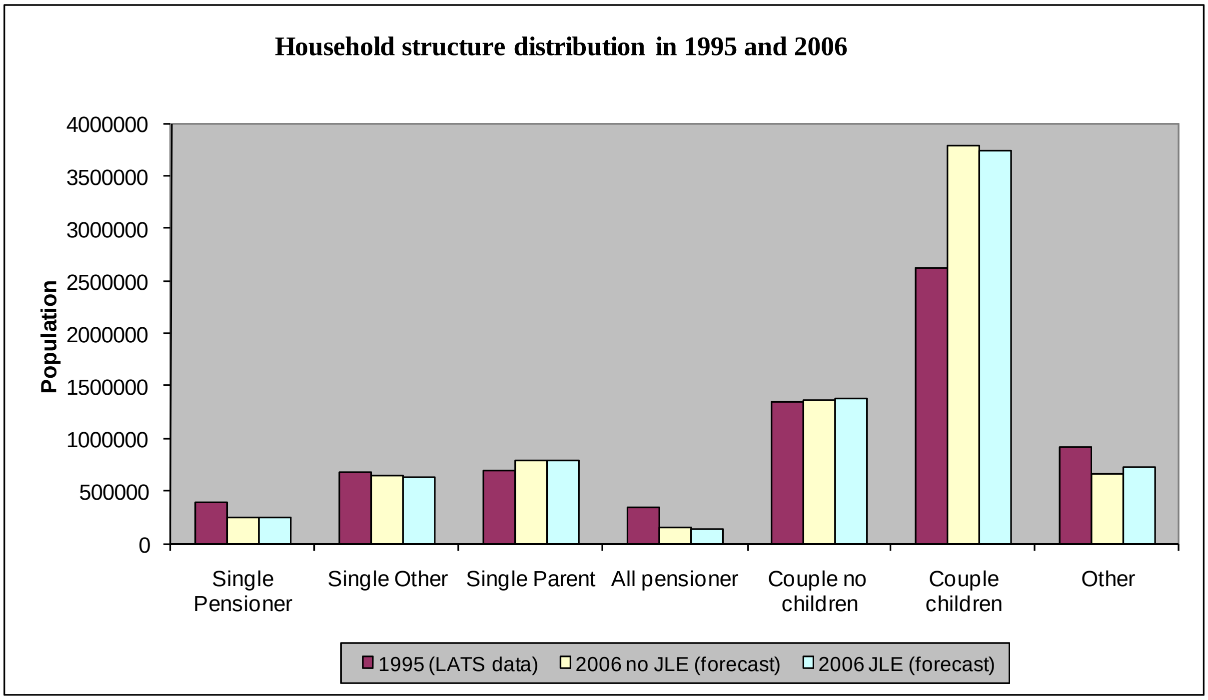


**Figure 7.14: Distribution of population in London according to their household structure in 1995 and in 2006**

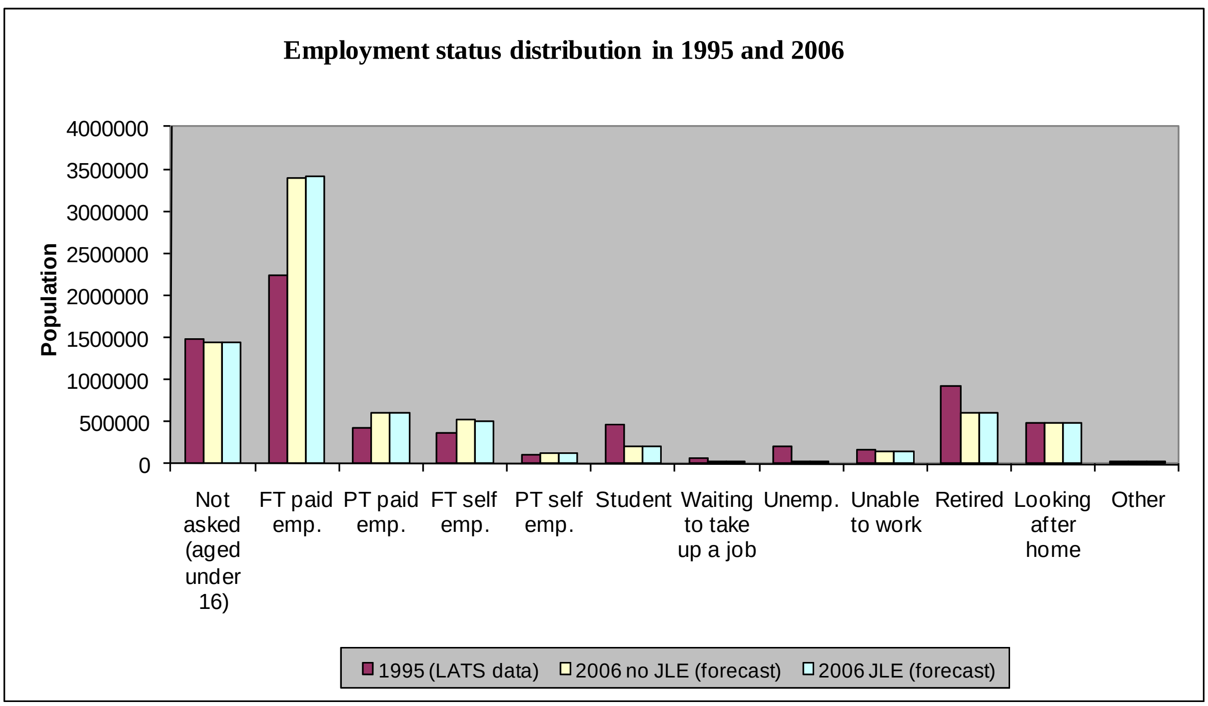


**Figure 7.15: Employment status distribution of London population in 1995 (LATS data) and 2006 (forecast)**

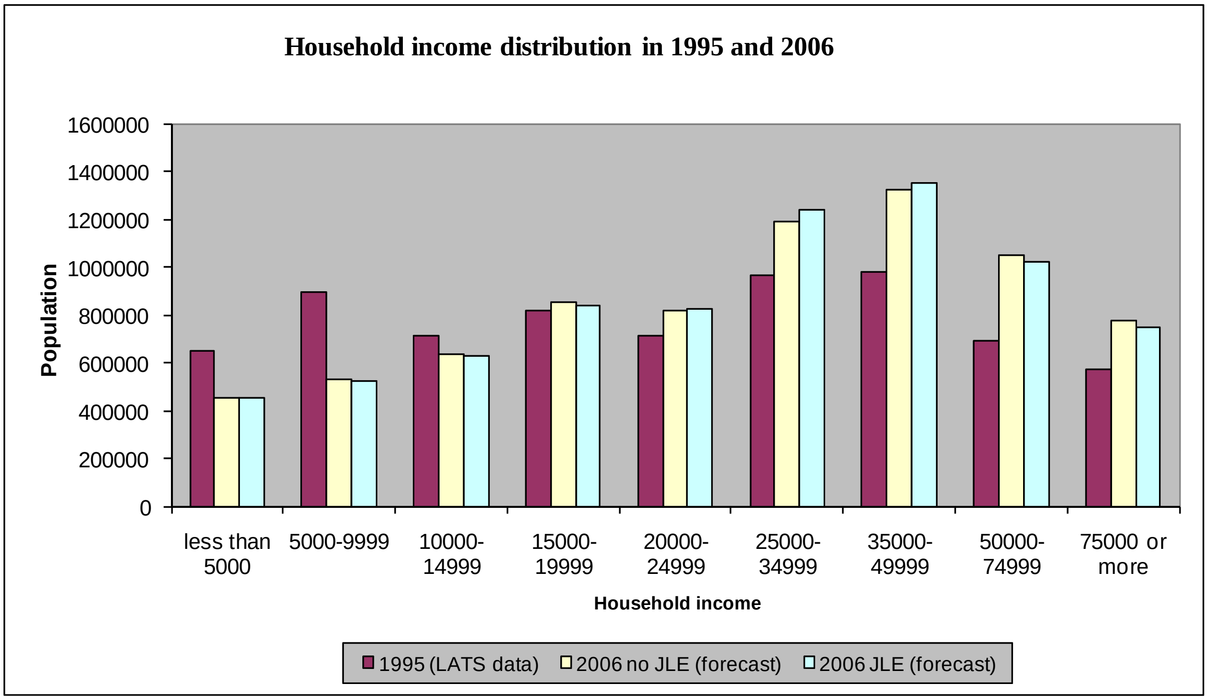


**Figure 7.16: Household income distribution of London population in 1995 (LATS data) and 2006 (forecast)**

### 7.4.2 Residential location

In this section, results related to the impacts of the JLE on residential location choices are presented. Figure 7.17 illustrates the absolute changes of population from 1995 to 2006 due to the JLE, i.e. the differences between the changes of population from 1995 to 2006 as forecast with and without the JLE. Although a JLE borough (Lambeth) is the one with the highest increase in population due to JLE, the results do not indicate that the JLE boroughs are the ones mostly benefited by the extension line. Table 7.14 contains the results used to produce the map in Figure 7.17.

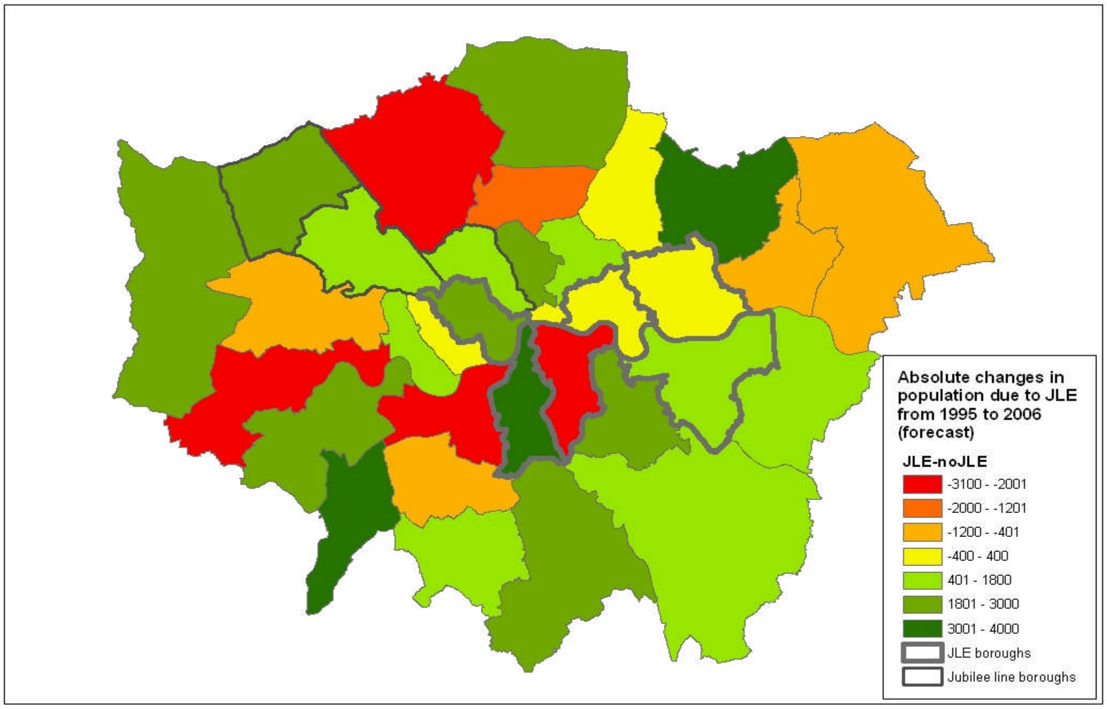


**Figure 7.17: Difference of population changes from 1995 to 2006, forecast with and without the JLE**

In Table 7.13 the results are aggregated in three main zones according to their relationship to the JLE and the impact of the JLE on these zones. It can be seen that the forecast impact is positive, if low.

| | Total population in 2006 | | | |
|---|---|---|---|---|
| **Areas** | **Without JLE** | **With JLE** | **Dif. JLE - no JLE** | **% Diff. JLE - no JLE** |
| JLE boroughs | 1,525,432 | 1,530,410 | 4,978 | 0.33 |
| Jubilee Line boroughs | 618,126 | 622,161 | 4,036 | 0.65 |
| Rest of London | 4,939,942 | 4,954,226 | 14,284 | 0.29 |

**Table 7.13: Total population in 2006 in aggregate areas (forecast)**

| Borough | Absolute changes in population due to JLE |
|---|---|
| Barking & Dagenham | -669 |
| Barnet | -2,223 |
| Bexley | 642 |
| Brent | 657 |
| Bromley | 1,439 |
| Camden | 632 |
| City of London | -127 |
| Croydon | 2,577 |
| Ealing | -1,091 |
| Enfield | 2,160 |
| Greenwich | 1,297 |
| Hackney | 857 |
| Hammersmith & Fulham | 1,624 |
| Haringey | -1,614 |
| Harrow | 2,747 |
| Havering | -860 |
| Hillingdon | 2,488 |
| Hounslow | -3,052 |
| Islington | 1,907 |
| Kensington & Chelsea | -286 |
| Kingston upon Thames | 3,676 |
| Lambeth | 3,993 |
| Lewisham | 2,275 |
| Merton | -469 |
| Newham | -73 |
| Redbridge | 3,088 |
| Richmond upon Thames | 2,507 |
| Southwark | -2,539 |
| Sutton | 1,632 |
| Tower Hamlets | -338 |
| Waltham Forest | -54 |
| Wandsworth | -2,142 |
| Westminster | 2,638 |

**Table 7.14: Difference of population changes from 1995 to 2006, forecast with and without the JLE**

In analogy to businesses, attractiveness and vacant dwellings are the key factors affecting population relocation. Attractiveness is a function of accessible businesses and vacant dwellings (Equation 5.20). Table 7.15 and Table 7.16 illustrate the ranking of the boroughs according to attractiveness as residential locations from 1996 to 2006 as resulted from the simulation with and without the JLE respectively. A key of the reference codes is provided in Table 7.10. Because of the annual variation of the number of vacant dwellings, attractiveness of some boroughs shows large variation from year to year.

| JLE | Ranking of London Boroughs according to attractiveness as residential locations | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| order | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| 1 | 20 | 5 | 5 | 5 | 5 | 5 | 5 | 8 | 5 | 8 | 5 |
| 2 | 22 | 23 | 8 | 10 | 8 | 8 | 8 | 5 | 8 | 5 | 8 |
| 3 | 8 | 28 | 23 | 8 | 10 | 16 | 16 | 16 | 16 | 16 | 16 |
| 4 | 32 | 22 | 10 | 23 | 16 | 10 | 10 | 10 | 10 | 10 | 10 |
| 5 | 14 | 8 | 31 | 16 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| 6 | 33 | 31 | 9 | 17 | 11 | 3 | 3 | 3 | 3 | 3 | 3 |
| 7 | 12 | 10 | 16 | 11 | 15 | 15 | 15 | 1 | 2 | 2 | 15 |
| 8 | 19 | 12 | 28 | 15 | 3 | 1 | 1 | 15 | 1 | 1 | 1 |
| 9 | 2 | 30 | 30 | 26 | 26 | 26 | 26 | 26 | 26 | 15 | 26 |
| 10 | 5 | 9 | 17 | 3 | 1 | 11 | 11 | 11 | 15 | 26 | 29 |
| 11 | 9 | 2 | 25 | 2 | 29 | 29 | 29 | 2 | 11 | 11 | 21 |
| 12 | 6 | 4 | 11 | 1 | 21 | 21 | 2 | 29 | 29 | 29 | 11 |
| 13 | 23 | 25 | 4 | 31 | 33 | 33 | 21 | 23 | 21 | 21 | 2 |
| 14 | 31 | 11 | 2 | 25 | 27 | 18 | 23 | 21 | 31 | 31 | 31 |
| 15 | 30 | 17 | 12 | 21 | 31 | 32 | 9 | 31 | 23 | 27 | 33 |
| 16 | 13 | 16 | 15 | 29 | 18 | 22 | 31 | 9 | 24 | 18 | 20 |
| 17 | 28 | 32 | 26 | 18 | 23 | 2 | 33 | 4 | 9 | 33 | 6 |
| 18 | 4 | 33 | 3 | 32 | 28 | 20 | 14 | 14 | 18 | 32 | 22 |
| 19 | 10 | 26 | 1 | 33 | 2 | 14 | 22 | 24 | 27 | 9 | 13 |
| 20 | 25 | 3 | 21 | 22 | 20 | 9 | 20 | 32 | 33 | 23 | 14 |
| 21 | 26 | 15 | 20 | 9 | 6 | 6 | 18 | 18 | 4 | 20 | 32 |
| 22 | 11 | 21 | 29 | 19 | 4 | 19 | 24 | 25 | 20 | 6 | 28 |
| 23 | 18 | 6 | 33 | 6 | 22 | 28 | 6 | 22 | 14 | 13 | 4 |
| 24 | 27 | 19 | 24 | 27 | 30 | 30 | 32 | 28 | 6 | 19 | 19 |
| 25 | 17 | 1 | 18 | 13 | 32 | 31 | 28 | 27 | 28 | 22 | 18 |
| 26 | 16 | 13 | 14 | 14 | 19 | 13 | 4 | 33 | 19 | 28 | 30 |
| 27 | 29 | 24 | 19 | 20 | 13 | 23 | 25 | 19 | 32 | 30 | 25 |
| 28 | 21 | 29 | 6 | 30 | 14 | 12 | 30 | 6 | 22 | 4 | 23 |
| 29 | 3 | 20 | 32 | 4 | 12 | 4 | 19 | 20 | 30 | 14 | 9 |
| 30 | 24 | 18 | 27 | 12 | 9 | 25 | 13 | 13 | 13 | 12 | 12 |
| 31 | 1 | 27 | 13 | 28 | 24 | 27 | 27 | 12 | 12 | 25 | 24 |
| 32 | 15 | 14 | 22 | 24 | 25 | 24 | 12 | 30 | 25 | 24 | 27 |
| 33 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |

**Table 7.15: Annual ranking of London boroughs according to attractiveness as resulted from the simulation with the JLE**

| noJLE | Ranking of London Boroughs according to attractiveness as residential locations | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| order | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| 1 | 20 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 2 | 22 | 23 | 8 | 10 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| 3 | 8 | 28 | 23 | 8 | 10 | 16 | 16 | 16 | 16 | 16 | 16 |
| 4 | 32 | 22 | 10 | 23 | 16 | 10 | 10 | 10 | 10 | 10 | 10 |
| 5 | 14 | 8 | 31 | 16 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| 6 | 33 | 31 | 9 | 17 | 15 | 3 | 3 | 3 | 2 | 3 | 3 |
| 7 | 12 | 10 | 16 | 11 | 11 | 15 | 15 | 15 | 3 | 2 | 1 |
| 8 | 19 | 12 | 28 | 15 | 3 | 1 | 1 | 1 | 1 | 1 | 15 |
| 9 | 2 | 30 | 30 | 26 | 26 | 26 | 26 | 26 | 26 | 15 | 26 |
| 10 | 5 | 9 | 17 | 3 | 1 | 11 | 11 | 11 | 15 | 26 | 29 |
| 11 | 9 | 2 | 25 | 2 | 29 | 29 | 29 | 2 | 11 | 11 | 21 |
| 12 | 6 | 4 | 11 | 1 | 21 | 21 | 2 | 29 | 29 | 29 | 11 |
| 13 | 23 | 25 | 4 | 31 | 27 | 33 | 21 | 23 | 21 | 21 | 2 |
| 14 | 31 | 11 | 2 | 25 | 33 | 2 | 23 | 21 | 31 | 31 | 31 |
| 15 | 30 | 17 | 12 | 21 | 31 | 22 | 31 | 31 | 23 | 27 | 33 |
| 16 | 13 | 16 | 15 | 29 | 18 | 32 | 9 | 9 | 9 | 18 | 20 |
| 17 | 28 | 32 | 26 | 18 | 23 | 18 | 33 | 4 | 24 | 33 | 6 |
| 18 | 4 | 33 | 3 | 32 | 2 | 14 | 32 | 14 | 18 | 32 | 14 |
| 19 | 10 | 26 | 1 | 33 | 20 | 20 | 18 | 24 | 27 | 23 | 32 |
| 20 | 25 | 3 | 21 | 22 | 28 | 9 | 28 | 22 | 33 | 9 | 13 |
| 21 | 26 | 15 | 20 | 9 | 6 | 6 | 22 | 25 | 4 | 19 | 19 |
| 22 | 11 | 21 | 29 | 19 | 22 | 19 | 14 | 18 | 20 | 22 | 18 |
| 23 | 18 | 6 | 33 | 6 | 19 | 23 | 20 | 32 | 32 | 20 | 4 |
| 24 | 27 | 19 | 24 | 27 | 32 | 31 | 24 | 33 | 6 | 13 | 28 |
| 25 | 17 | 1 | 18 | 13 | 4 | 13 | 4 | 27 | 14 | 6 | 30 |
| 26 | 16 | 13 | 14 | 14 | 30 | 28 | 19 | 28 | 28 | 4 | 22 |
| 27 | 29 | 24 | 19 | 20 | 14 | 30 | 6 | 19 | 19 | 14 | 23 |
| 28 | 21 | 29 | 6 | 30 | 13 | 12 | 25 | 6 | 30 | 12 | 9 |
| 29 | 3 | 20 | 32 | 4 | 12 | 27 | 13 | 20 | 13 | 28 | 12 |
| 30 | 24 | 18 | 27 | 12 | 9 | 25 | 30 | 13 | 22 | 30 | 25 |
| 31 | 1 | 27 | 13 | 28 | 24 | 4 | 27 | 12 | 12 | 25 | 24 |
| 32 | 15 | 14 | 22 | 24 | 25 | 24 | 12 | 30 | 25 | 24 | 27 |
| 33 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |

**Table 7.16: Annual ranking of London boroughs according to attractiveness as resulted from the simulation without the JLE**

The number of accessible businesses for each borough is significantly affected by the addition of the JLE. As can be seen in Figure 7.18, JLE has larger impact on the number of accessible businesses of the JLE boroughs than of the other boroughs.

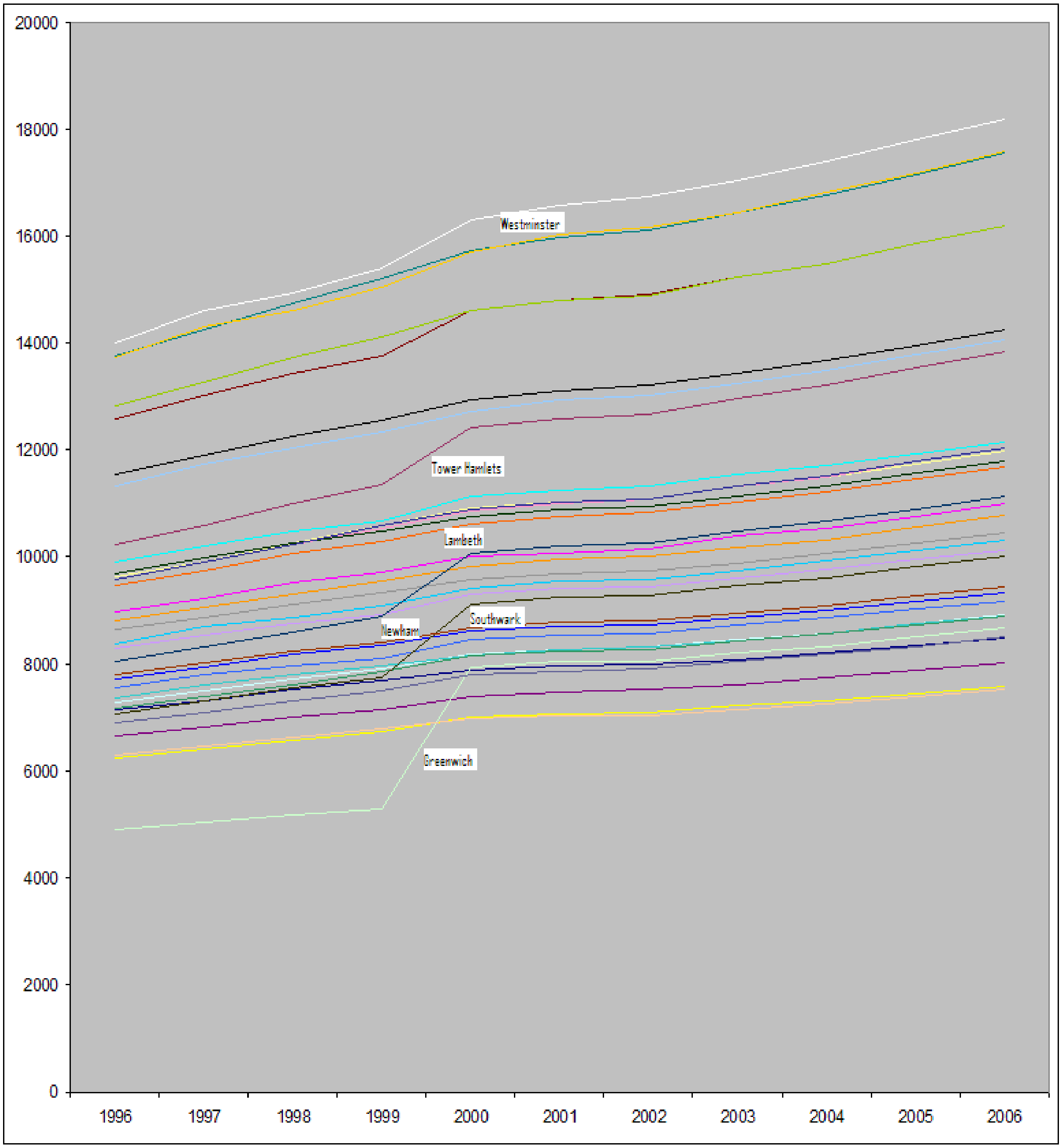


**Figure 7.18: Annual change of accessible businesses**

A key assumption made in the location-choice process is that households looking to relocate will move to the closest borough with higher attractiveness than their current one. The changes of population in Southwark and Lambeth illustrate the implications of this. It can be seen that the overall impact of the JLE appears to be positive for Lambeth and negative for Southwark. In fact, the two boroughs exchange population over time depending on which has the highest attractiveness. This happens because Lambeth is the first borough in the set of alternative locations for households from Southwark and vice versa.

Considering the results of the simulation without the JLE, from 2000 onwards Lambeth (reference number: 22, Table 7.14) has higher attractiveness than Southwark (28, Table 7.14) in 2001, 2003 and 2005. In years 2000, 2002, 2004 and 2006 Southwark has higher attractiveness. Considering the results of the simulation with the JLE (Table 7.15), from 2000 onwards, Lambeth (22) has higher attractiveness than Southwark (28) in more years, i.e. in 2001, 2002, 2003, 2005 and 2006. Southwark has largest attractiveness than Lambeth in 2000 and 2004. Year 2000 is the year when JLE is added and before that the results of the two simulations are exactly the same as pseudo-random number sequences are used. The variation of attractiveness of the two boroughs is illustrated in Figure 7.19.

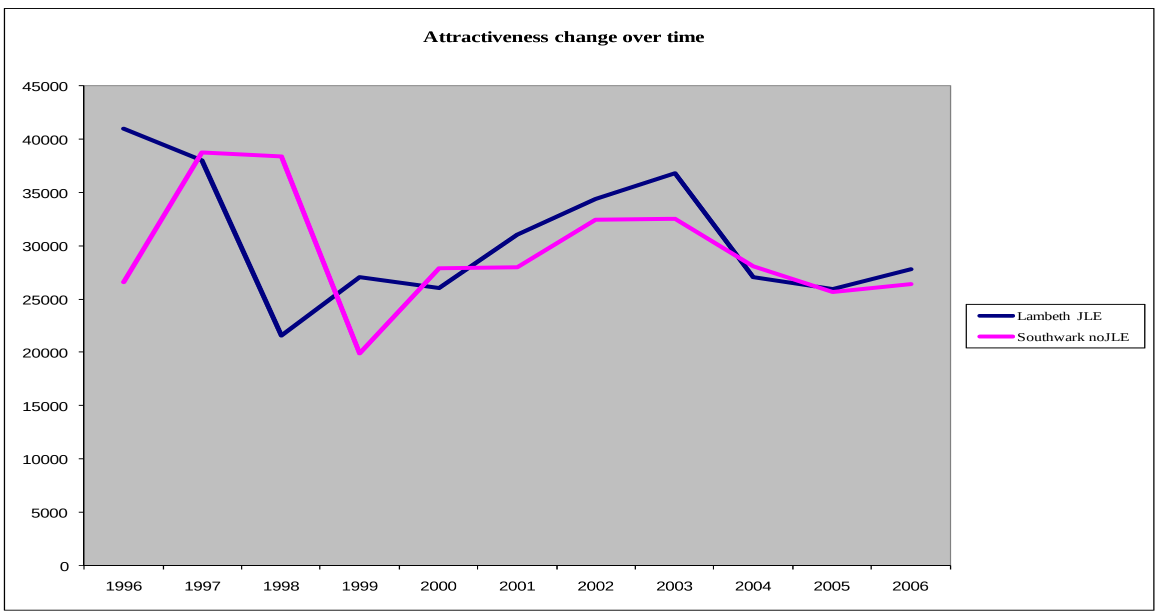


**Figure 7.19: Annual variation of attractiveness of Lambeth and Southwark**

As a result, until 2006 Lambeth receives overall more people from Southwark with than without the existence of JLE. Additionally, as more new dwellings are added in Lambeth with the JLE, it can accommodate more of the people looking to move there.

Tower Hamlets is one of the boroughs on which the JLE was expected to have positive impact. However, the simulation showed a very small negative impact. Figure 7.20 illustrates the annual change of population from 1995 to 2006 with and without the JLE.

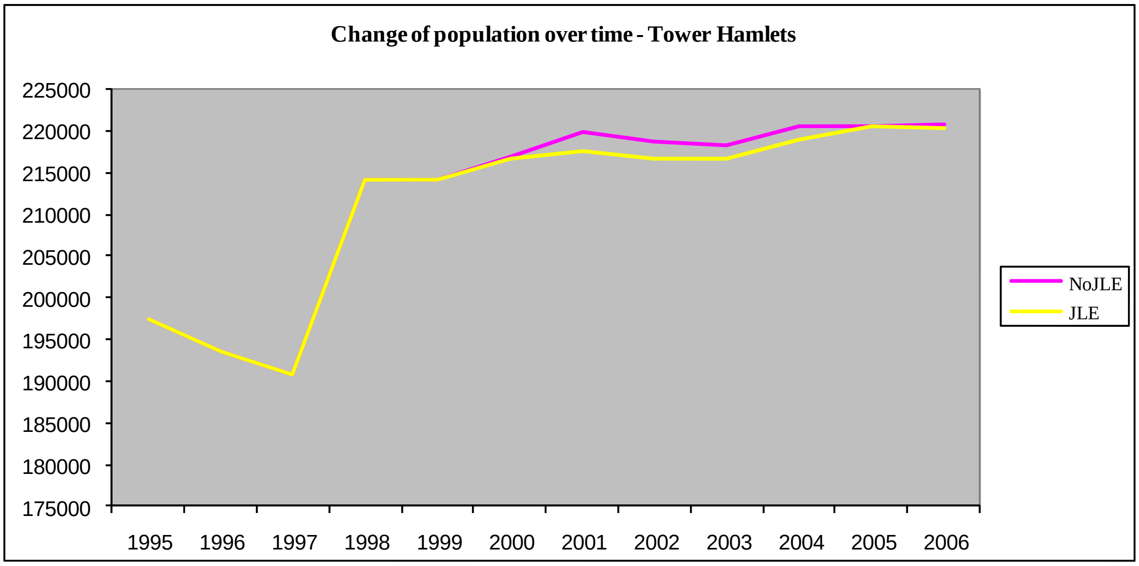


**Figure 7.20: Population in Tower Hamlets - time series**

The first ten boroughs in the set of alternative locations – which is determined according to proximity – of Tower Hamlets are (in the parentheses the reference numbers used in Tables 7.15 and 7.16 are included): City of London (7), Hackney (12), Newham (25), Southwark (28), Islington (19), Lewisham (23), Greenwich (11), Westminster (33), Waltham Forest (31) and Lambeth (22). City of London has the lowest attractiveness of all boroughs during all years, because of its very small number of vacant dwellings. From 2000 onwards, Hackney has higher attractiveness than Tower Hamlets only in 2003 and 2005 as resulted from both simulations with and without the JLE (Tables 7.15 and 7.16). Newham has higher attractiveness than Tower Hamlets in 2002 and 2003 as resulted from both simulations with and without the JLE. Southwark has higher attractiveness than Tower Hamlets in all years from 2000 onwards, when running the simulation with and without the JLE. However, as discussed earlier, JLE has an overall negative impact on the population in Southwark until 2006. Islington has higher attractiveness than Tower Hamlets for all the year from 2000 when running the model with the JLE and for 2001, 2003, 2004, 2005 and 2006 when running the simulation without the JLE. Greenwich has always (after 2000, with and without the JLE) higher attractiveness than Tower Hamlets.

So does Lewisham, with the exception of 2006. In order to justify the decline in Tower Hamlets, the focus is on the boroughs in which the attractiveness became larger than that of Tower Hamlets after the addition of JLE, but also on the number of new dwellings. In Figure 7.18 it can be seen that the number of accessible businesses for Tower Hamlets increases with the addition of JLE in 2000, but it does not exceed that of any other borough, as is the case with Greenwich, Southwark and Newham. The key element in the case of Tower Hamlets is the number of new dwellings. In Figure 7.2 it has been shown that almost all boroughs are benefited by the opening of the JLE. Moreover, looking at the annual differences between the forecast numbers of new dwellings with and without the JLE the following boroughs are benefited mostly by the JLE: Westminster (33), Southwark (28), Lewisham (23), Harrow (15), Camden (6), Brent (4) and Greenwich (11) (Table 7.17). Hence even though the relationship of the attractiveness of Tower Hamlets and Lewisham, or Tower Hamlets and Greenwich, does not change by adding the JLE, now there are more available dwellings in Greenwich and Lewisham that have higher attractiveness than Tower Hamlets and more households from Tower Hamlets will move there.

| **Annual impact of JLE on the London Boroughs** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Borough** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** |
| **1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| **2** | 0 | 0 | 0 | 0 | 4 | 9 | 13 | 17 | 21 | 25 | 29 |
| **3** | 0 | 0 | 0 | 0 | 7 | 14 | 20 | 26 | 33 | 40 | 47 |
| **4** | 0 | 0 | 0 | 0 | 22 | 44 | 66 | 89 | 112 | 135 | 158 |
| **5** | 0 | 0 | 0 | 0 | 5 | 10 | 15 | 20 | 26 | 31 | 37 |
| **6** | 0 | 0 | 0 | 0 | 18 | 35 | 53 | 71 | 89 | 107 | 126 |
| **7** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **8** | 0 | 0 | 0 | 0 | 2 | 5 | 7 | 10 | 12 | 14 | 16 |
| **9** | 0 | 0 | 0 | 0 | 7 | 15 | 22 | 29 | 36 | 44 | 52 |
| **10** | 0 | 0 | 0 | 0 | 3 | 6 | 8 | 11 | 14 | 16 | 19 |
| **11** | 0 | 0 | 0 | 0 | 9 | 18 | 27 | 36 | 45 | 54 | 63 |
| **12** | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 6 | 7 | 9 | 11 |
| **13** | 0 | 0 | 0 | 0 | 4 | 9 | 14 | 19 | 24 | 29 | 34 |
| **14** | 0 | 0 | 0 | 0 | 4 | 8 | 12 | 16 | 21 | 25 | 29 |
| **15** | 0 | 0 | 0 | 0 | 13 | 25 | 38 | 51 | 64 | 77 | 91 |
| **16** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **17** | 0 | 0 | 0 | 0 | 7 | 15 | 23 | 31 | 39 | 46 | 54 |
| **18** | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 2 |
| **19** | 0 | 0 | 0 | 0 | 3 | 6 | 9 | 12 | 15 | 18 | 20 |
| **20** | 0 | 0 | 0 | 0 | 7 | 14 | 22 | 29 | 37 | 45 | 53 |
| **21** | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| **22** | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 2 | 3 | 4 | 5 |
| **23** | 0 | 0 | 0 | 0 | 16 | 32 | 48 | 65 | 82 | 98 | 115 |
| **24** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **25** | 0 | 0 | 0 | 0 | 5 | 9 | 14 | 18 | 23 | 27 | 32 |
| **26** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **27** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **28** | 0 | 0 | 0 | 0 | 21 | 43 | 65 | 87 | 110 | 133 | 156 |
| **29** | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 3 | 3 |
| **30** | 0 | 0 | 0 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 |
| **31** | 0 | 0 | 0 | 0 | 2 | 5 | 8 | 10 | 12 | 15 | 18 |
| **32** | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -2 |
| **33** | 0 | 0 | 0 | 0 | 40 | 81 | 122 | 164 | 207 | 250 | 293 |

**Table 7.17: Annual change of dwellings due to JLE**

To obtain a clearer picture of all the changes that occur in population, Table 7.18 presents the annual changes in every borough due to JLE. There it can be seen that in 2000, when the JLE is added in the London underground network, the impact is larger for Greenwich and Lewisham. Once again, this is the result of the combination between attractiveness and vacant dwellings.

| Annual impact of JLE on the London Boroughs | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Borough** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** |
| **1** | 0 | 0 | 0 | 0 | -115 | 124 | -425 | -976 | -466 | 423 | -669 |
| **2** | 0 | 0 | 0 | 0 | -111 | -309 | -293 | -261 | -2,269 | -667 | -2,223 |
| **3** | 0 | 0 | 0 | 0 | -422 | -164 | 92 | 763 | 643 | 247 | 642 |
| **4** | 0 | 0 | 0 | 0 | -442 | -87 | -492 | -783 | 630 | 870 | 657 |
| **5** | 0 | 0 | 0 | 0 | 44 | 15 | 433 | 371 | 2,019 | 1,289 | 1,439 |
| **6** | 0 | 0 | 0 | 0 | -149 | -351 | 927 | 604 | -1,175 | 773 | 632 |
| **7** | 0 | 0 | 0 | 0 | 50 | 125 | 43 | 24 | -81 | -110 | -127 |
| **8** | 0 | 0 | 0 | 0 | -191 | 1,365 | 1,766 | 2,726 | 1,708 | 2,107 | 2,577 |
| **9** | 0 | 0 | 0 | 0 | -432 | 277 | -5 | -863 | -950 | -1,323 | -1,091 |
| **10** | 0 | 0 | 0 | 0 | -323 | -96 | -1,486 | -510 | 719 | 1,801 | 2,160 |
| **11** | 0 | 0 | 0 | 0 | 3,638 | 2,061 | 3,154 | 2,586 | 4,383 | 4,502 | 1,297 |
| **12** | 0 | 0 | 0 | 0 | -305 | -165 | -281 | 1,521 | 2,213 | 381 | 857 |
| **13** | 0 | 0 | 0 | 0 | -148 | -264 | 352 | -78 | 481 | 783 | 1,624 |
| **14** | 0 | 0 | 0 | 0 | -3 | -1,001 | 469 | -1,031 | -1,670 | -647 | -1,614 |
| **15** | 0 | 0 | 0 | 0 | 148 | 144 | 1,351 | 1,175 | 2,286 | 1,475 | 2,747 |
| **16** | 0 | 0 | 0 | 0 | 152 | -386 | -494 | -133 | -730 | -1,383 | -860 |
| **17** | 0 | 0 | 0 | 0 | 214 | 1,099 | 2,324 | 2,412 | 2,302 | 2,644 | 2,488 |
| **18** | 0 | 0 | 0 | 0 | -2,033 | -1,009 | -1,108 | -1,792 | -3,412 | -498 | -3,052 |
| **19** | 0 | 0 | 0 | 0 | -258 | -118 | 338 | -748 | 2,236 | 63 | 1,907 |
| **20** | 0 | 0 | 0 | 0 | 686 | -17 | 188 | -338 | -601 | 453 | -286 |
| **21** | 0 | 0 | 0 | 0 | -131 | -1,024 | -445 | -308 | -1,078 | 1,122 | 3,676 |
| **22** | 0 | 0 | 0 | 0 | -255 | -1,409 | -1,824 | -3,231 | 1,461 | -1,509 | 3,993 |
| **23** | 0 | 0 | 0 | 0 | 1,773 | 25 | 426 | 2,794 | 2,955 | 3,138 | 2,275 |
| **24** | 0 | 0 | 0 | 0 | -107 | -3,192 | -3,142 | -4,023 | -1,553 | 297 | -469 |
| **25** | 0 | 0 | 0 | 0 | 975 | 768 | 1,161 | 751 | 685 | 252 | -73 |
| **26** | 0 | 0 | 0 | 0 | -203 | 216 | -395 | -1,265 | -1,067 | -1,148 | 3,088 |
| **27** | 0 | 0 | 0 | 0 | -529 | -455 | -1,316 | -764 | 1,840 | 1,334 | 2,507 |
| **28** | 0 | 0 | 0 | 0 | -576 | 1,398 | 1,186 | 1,056 | -1,271 | 1,173 | -2,539 |
| **29** | 0 | 0 | 0 | 0 | 50 | 317 | 1,416 | 1,108 | 1,290 | 859 | 1,632 |
| **30** | 0 | 0 | 0 | 0 | -178 | -2,234 | -2,181 | -1,676 | -1,575 | -102 | -338 |
| **31** | 0 | 0 | 0 | 0 | 173 | -235 | 782 | -230 | -1,586 | -449 | -54 |
| **32** | 0 | 0 | 0 | 0 | -131 | -1,580 | -4,194 | 456 | -1,305 | -317 | -2,142 |
| **33** | 0 | 0 | 0 | 0 | -683 | 771 | 1,433 | 891 | 2,909 | 2,442 | 2,638 |

**Table 7.18: Annual change of population due to JLE**

Despite the fact that JLE seems to have negative impact on some JLE boroughs, it appears to have positive impact on other boroughs. Particularly, JLE appears to have an overall large impact until 2006 on the borough of Kingston upon Thames (21). Before explaining this, it is noted that Kingston is one of the boroughs with very large variation between the results of the different runs of the STUDI model, as shown in Table 7.3 and Table 7.6. In Table 7.18 it can be seen that until 2004 the JLE has negative impact on the size of population of Kingston. This is the reason that a large number of vacant dwellings has been accumulated. The comparison of the two runs shows that the difference between vacant dwellings in 2005 as simulated with and without the JLE is the largest for Kingston upon Thames. As a result, the impact of JLE on the attractiveness of this borough in 2005 is the largest one and a lot of households move to Kingston in 2005 and 2006; this happens not necessarily because Kingston becomes the most attractive borough, but because it is the most attractive with vacant dwellings.

For similar reasons a total increase due to JLE occurs in the population of Redbridge (26) until 2006. Many vacancies that have been created allow people from boroughs with lower attractiveness, such as Newham (25) and Haringey (14), to move there. In 2006 there are two boroughs in which the JLE seems to have the largest impact on the number of vacant dwellings (this is the result of the decline of population in previous years): Lambeth and Redbridge. In both boroughs JLE had negative impact on population in 2005 and positive in 2006 (Table 7.18).

There are boroughs that seem to be constantly benefited by the JLE, such as Westminster, and boroughs where the impact fluctuates according to the number of vacant dwellings (Table 7.18). Hillingdon (17) is one of the boroughs on which the positive impact of the extension line is constant. It is high in the ranking according to attractiveness and its position is not significantly affected by the addition of JLE. However, as the number of new dwellings in Hillingdon increases due to JLE, the size of population also increases. On the other hand, people are leaving Hounslow (18) for Hillingdon and population in Hounslow declines.

### 7.4.3 Employment

In this section, employment is estimated aggregating the number of persons working in each zone. As discussed in Section 5.3.4, the only criterion for people looking for a job is the proximity to residential location. Types of jobs are not considered. Furthermore, the results are affected by stochastic variation and by the use of the interim expansion factor (Section 4.4). Here, only a map of the simulated impacts of the JLE on employment distribution in London is presented, recognising that modelling of employment needs further development. It should be perceived as an indicator of the potentials of the model, rather than as reliable estimations.

The impact of JLE on employment is illustrated in Figure 7.21, in which the absolute change in the number of persons working in each zone from 1995 to 2006 due to the JLE is presented, i.e. the difference between the change of employed population from 1995 to 2006 as forecast with and without the JLE. In most cases increase of employment occurs in boroughs where the number of businesses increases (Figure 7.7). There are some boroughs where employment decreases although the number of businesses increases, such as Westminster. This has to do partly with the size of businesses and partly with the use of interim expansion factor. The size of businesses is not included in the location-decision process. Thus, in one borough the number of businesses might increase as new businesses move in but the number of jobs might decrease as large firms move out and small move in. Moreover, for businesses belonging to the largest size category the number of employees is restricted to 250.

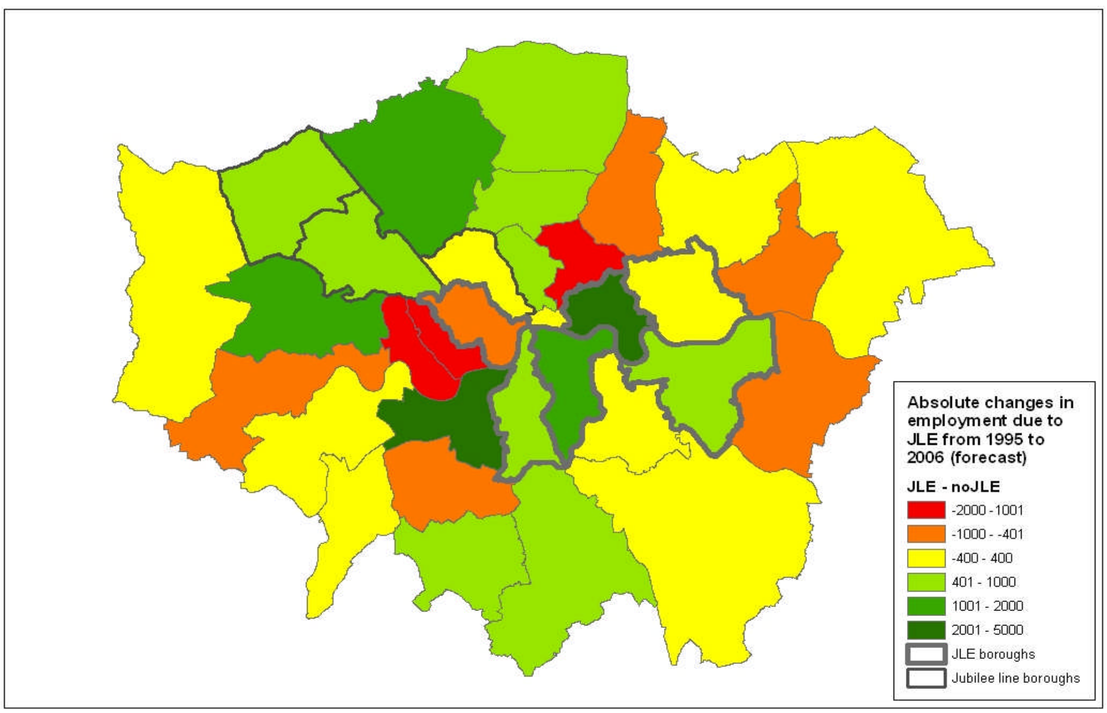


**Figure 7.21: Difference of employment changes from 1995 to 2006 forecast with and without the JLE**

Results on employment for areas aggregated according to their relationship with the JLE are presented in Table 7.19.

| | Number of persons working in each area in 2006 | | | |
|---|---|---|---|---|
| **Areas** | **Without JLE** | **With JLE** | **Dif. JLE - no JLE** | **% Diff. JLE - no JLE** |
| JLE boroughs | 1,139,732 | 1,143,802 | 4,071 | 0.36 |
| Jubilee Line boroughs | 391,613 | 393,080 | 1,467 | 0.37 |
| Rest of London | 2,165,908 | 2,170,354 | 4,446 | 0.21 |

**Table 7.19: Total employment in 2006 in aggregate areas (forecast)**

## 7.5 Summary

In this chapter, results of the application of the STUDI model to evaluate the impacts of JLE on urban development were presented. The results are based on the differences between the averages of 15 runs with the JLE and 15 runs without the JLE, using pseudo-random number sequences. The purpose of this was to further investigate the impacts of stochastic variation and to reduce their impacts on forecasts. Variation between the results of the different runs occurs for the business and population sub-models and for the commercial development sub-model as a result of the updates it receives from the business sub-model.

Results regarding demographics and employment should be perceived as an indicator of the potentials of the STUDI model, rather than accurate estimations. The need for more detailed and sophisticated demographic and employment modelling is recognised.

Regarding the results on the distribution of industrial sectors in London, the number of businesses in the sectors of banking and finance, real estate and insurances is increasing. These results are based on the VAT data and for this reason there is no differentiation between the runs with and without JLE. On the other hand, regarding the demographic changes, there is variation between the results of the runs with and without the JLE, as they are produced by the microsimulation model and the changes in the dynamics together with a stochastic impact are reflected.

The main outputs of the STUDI model are forecasts of the spatial distributions of development, businesses and population. The aggregate tables show a positive impact of the JLE on the JLE boroughs for businesses and development. For population the impact is positive but it does not exceed the impact on the other areas of London.

Regarding the impacts of JLE at a borough level, residential development in all JLE boroughs benefits from the opening of the JLE. So does commercial development in all JLE boroughs but Lambeth. The number of businesses also benefits from the opening of the new line in all JLE boroughs. However, the results on population do not indicate a clearly positive effect of the JLE on the JLE boroughs.

# 8 The East London Line Extension (ELLX) application

In the previous chapter the STUDI model was applied to London in order to estimate the impacts of the JLE on urban development. The results presented in Chapter 7 were extracted from running the model from 1995 to 2006. In this chapter STUDI is used to forecast the impacts of the opening of a new line, or more correctly, of the extension of an existing line to open in the future: the East London Line Extension (ELLX). In this case the model was run 30 times from 1995 to 2016 using 15 different pseudo-random number sequences: i.e., it was run 15 times with and 15 without the JLE. A common pseudo-random sequence was used to run the model once with and once without the JLE. Stochastic variation is not discussed here because its size and effects have already been analysed in the previous two chapters (Chapters 6 and 7). The numbers of new businesses and population to be added in the future (after 2006) are forecast as described in Sections 5.2.2 and 5.3.2 respectively. As explained in Section 5.2.2, the number of new businesses to be added in the future depends on economic (GDP) growth. In this application of the STUDI model, an annual GDP growth of 5% is assumed. The number of population migrating depends on the number of new businesses (Section 5.3.2).

The reopening of the East London Line (Phase 1), extended so that it will run from Dalston Junction in the north to New Cross, Crystal Palace and West Croydon in the south, is expected in June 2010 according to TfL (TfL, 2009). The ELLX is illustrated in Figure 8.1: orange colour is used to mark the part of the line that will be completed at the end of the first phase (Phase 1) and that is studied in this chapter. This runs through the following boroughs: Hackney, Tower Hamlets, Southwark, Lewisham, Bromley, and Croydon. The travel time reduction estimates were obtained from TfL (2007).

When running STUDI with the ELLX – i.e., when travel times between boroughs are estimated taking into account the line – the ELLX is added at the beginning of 2011.

The results presented in this chapter include residential and commercial development, the number of businesses and population as well as changes that occur in them from 2006 to 2016 as forecast by the model with and without the ELLX.

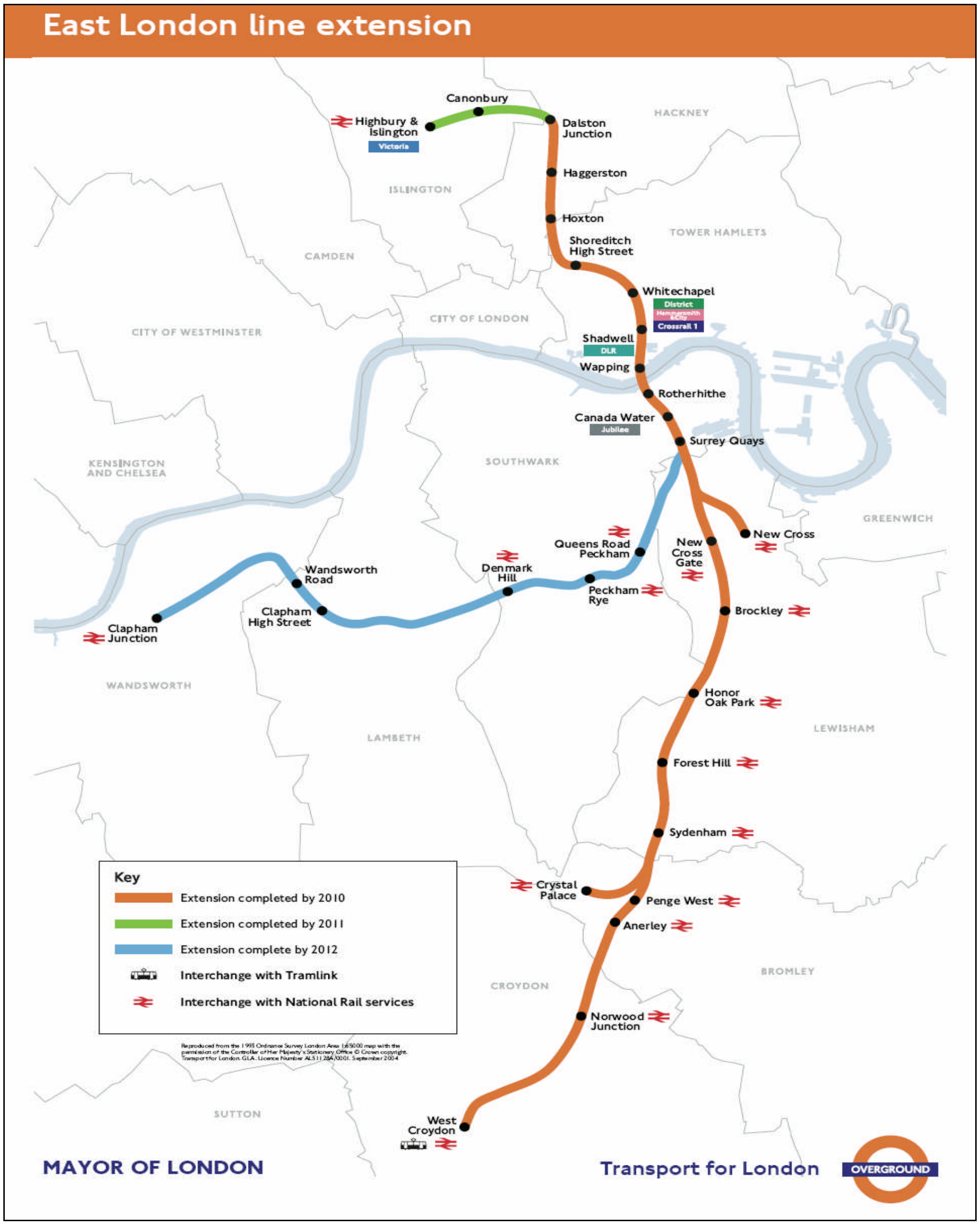


**Figure 8.1: East London Line Extension (TfL 2009)**

In Section 8.1, results relevant to the impacts of ELLX on accessibility are presented. Section 8.2 contains the results of the development sub-model, Section 8.3 the results of the business sub-model, and Section 8.4 the results of the population sub-model.

## 8.1 Travel-time changes due to East London Line Extension

The travel-time estimates without the East London Line Extension are given by the Railplan data (Section 4.1.2). TfL (2007) provides estimates (in minutes) of the impact of ELLX on accessibility to Canary Wharf (LB [London Borough] of Tower Hamlets), Broadgate (LB of Hackney), London Bridge (LB of Southwark), Croydon (LB of Croydon), Dalston (LB of Hackney), Hoxton (LB of Hackney) and Sydenham (LB of Lewisham). These estimates are aggregated to a borough level and subtracted from the Railplan estimates in order to obtain travel-time estimates with the ELLX.

Although three of the ELLX stations are in Bromley, Bromley is not included in the ELLX boroughs as presented in Figure 8.2. Penge West, Anerley and Crystal Palace are minor stations covering a very small area in Bromley's north-western borders with Lewisham, Croydon and Lambeth. Moreover, none of the areas for which the accessibility impacts of ELLX are estimated in TfL (2007) is in the borough of Bromley and hence the impacts on travel time from an area within Bromley to all other boroughs cannot be estimated.

The impacts of ELLX on travel times are illustrated in Figure 8.3 to Figure 8.7 (the data used to produce these figures can be found in Table A.2, Appendix). The legends on the maps show the travel-time improvements, in minutes, due to ELLX.


**Figure 8.2: Boroughs of London and ELLX boroughs**

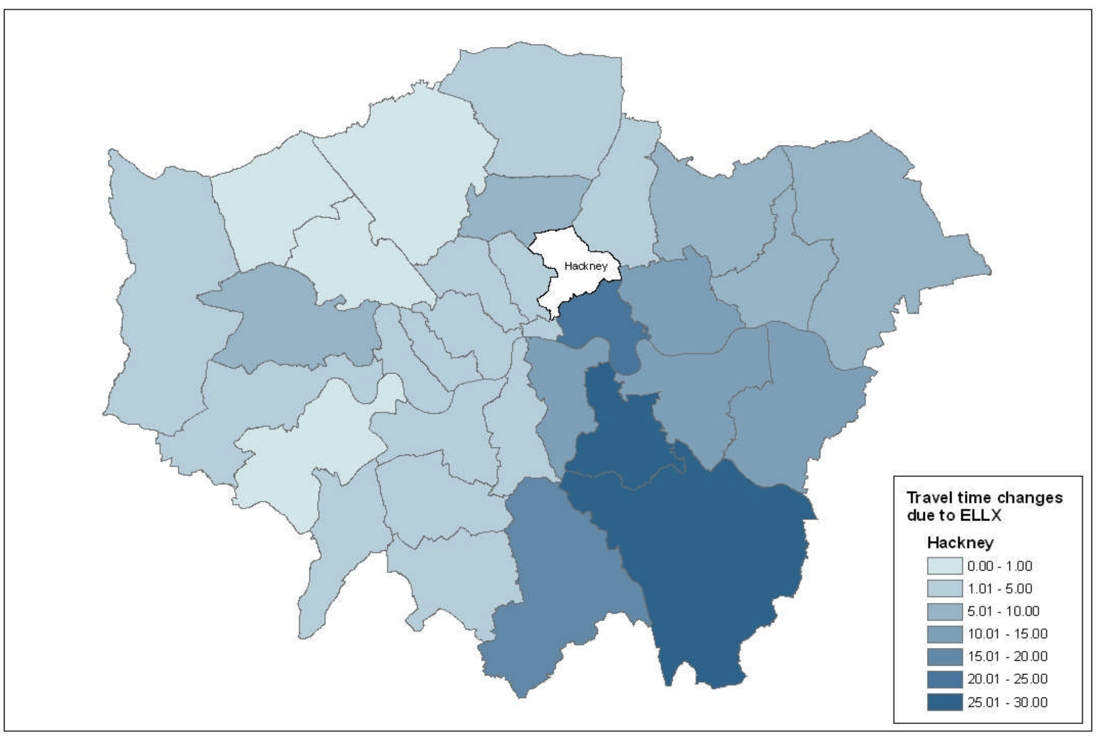


**Figure 8.3: Changes in travel times from Hackney due to ELLX**

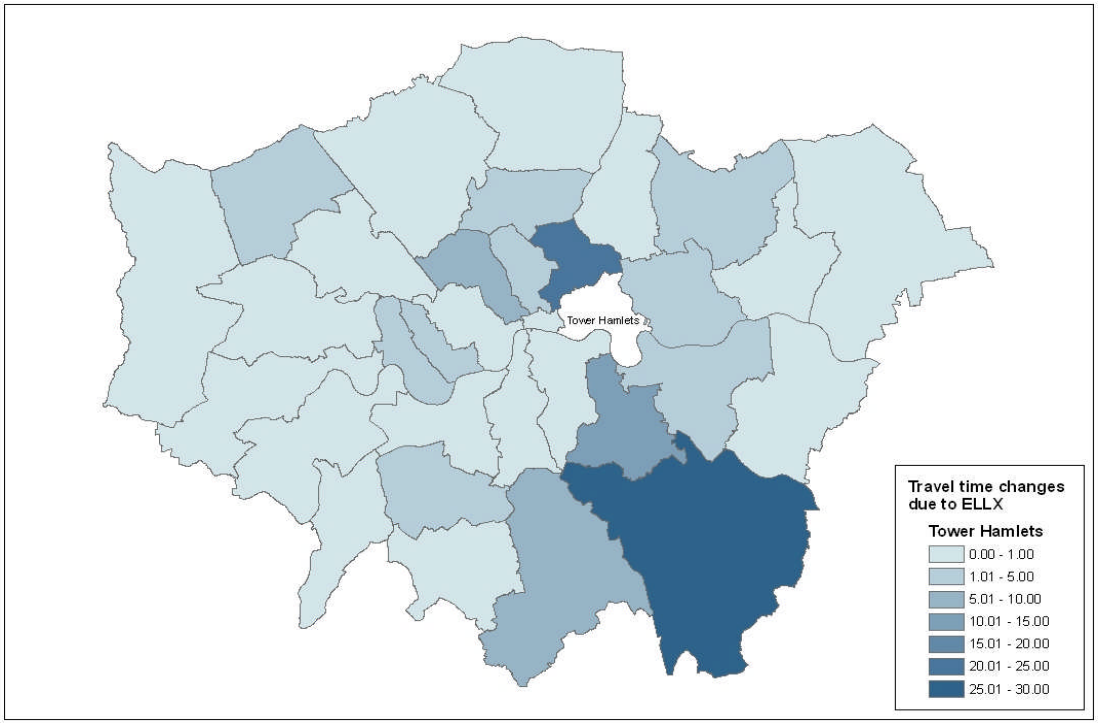


**Figure 8.4: Changes in travel times from Tower Hamlets due to ELLX**

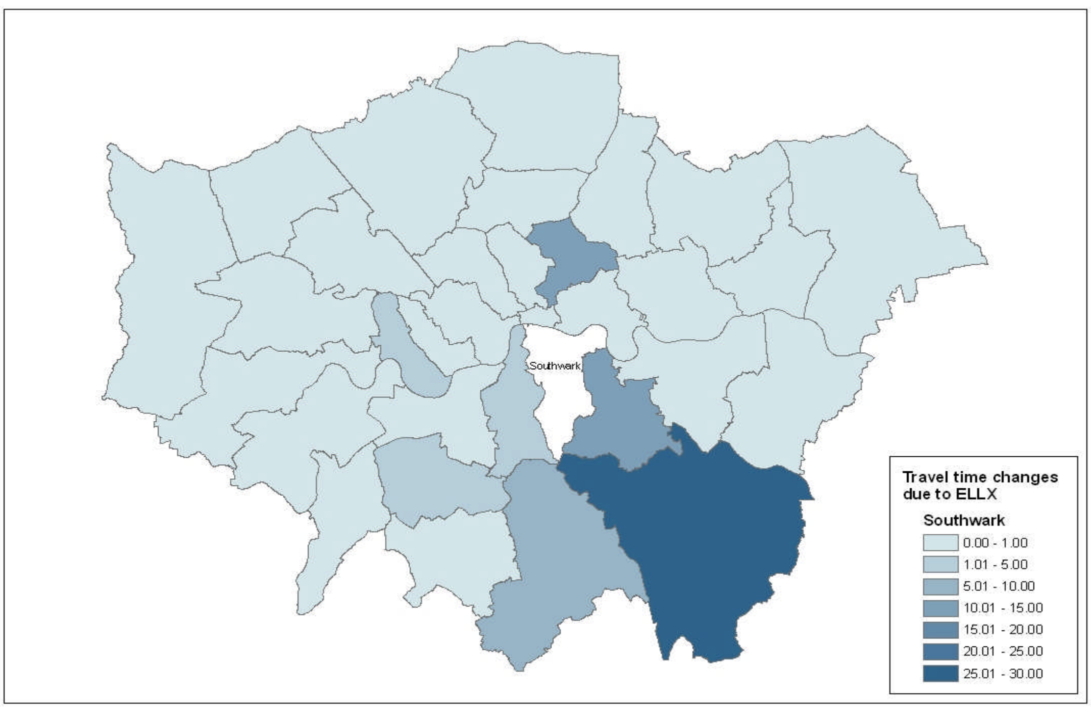


**Figure 8.5: Changes in travel times from Southwark due to ELLX**

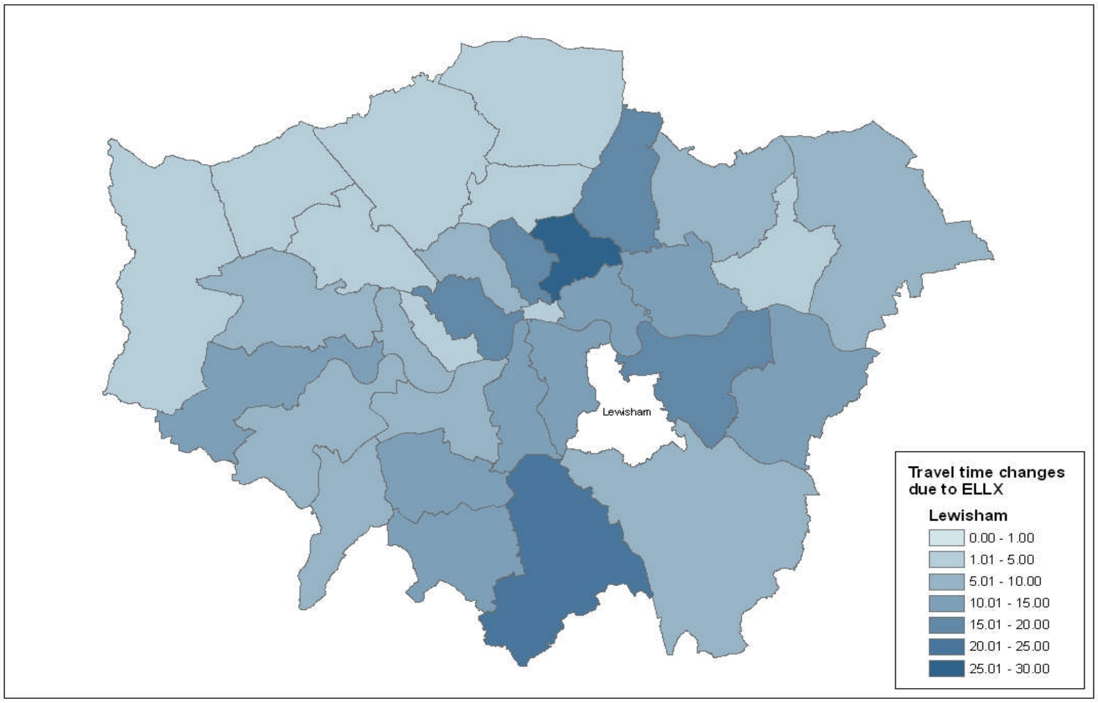


**Figure 8.6: Changes in travel times from Lewisham due to ELLX**

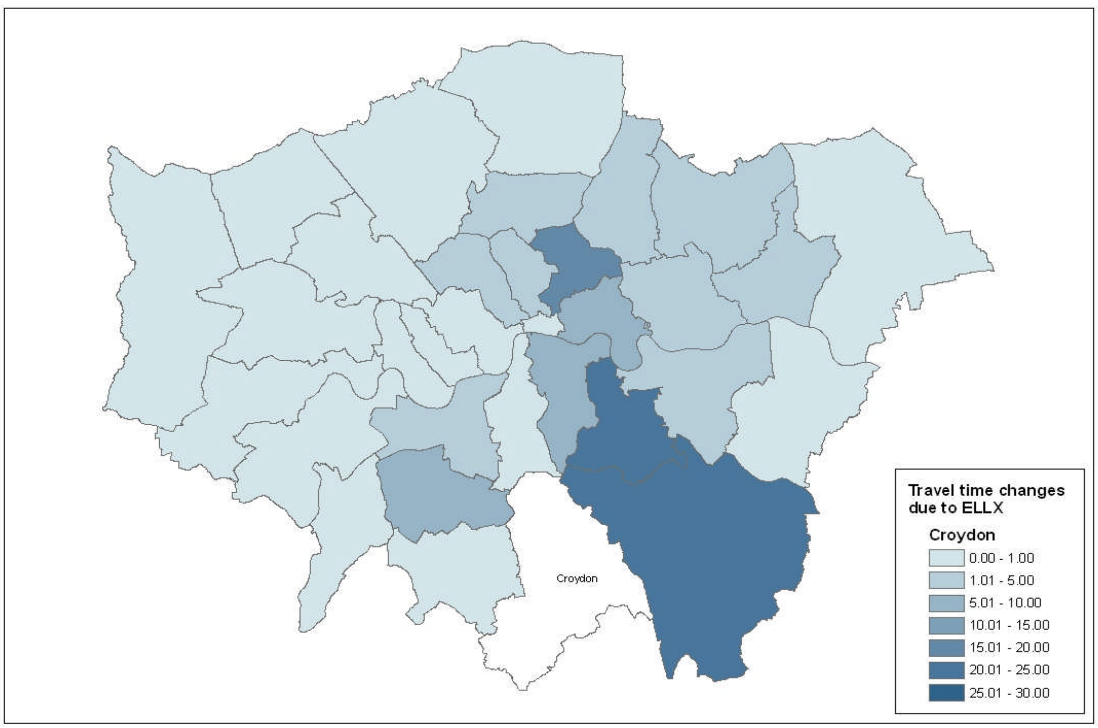


**Figure 8.7: Changes in travel times from Croydon due to ELLX**

## 8.2 Development sub-model

In the development sub-model as described in Section 5.1, the number of new commercial and residential premises to be added annually in the relevant stock of each borough is estimated.

### 8.2.1 Residential development

The residential development sub-model (Section 5.1) is not expected to show a large increase caused by the East London Line Extension. That is because the only variable affected by the addition of ELLX is travel time to the city centre, and changes in travel time to the city centre are relatively small to have a significant impact on the number of new dwellings.

The impact of the new line on residential development is illustrated in Figure 8.8, in which the absolute changes (change with ELLX minus change without ELLX) in the stock of residential premises from 2006 to 2016 due to the ELLX are presented. As can be seen, the impact of the ELLX is positive for all boroughs of London. This is due to the inversely proportional relationship of the number of new dwellings to travel time in the residential development model (Equation 5.1, Sections 5.1 and 6.1.1.2). Travel time is the only variable affected by the addition of the ELLX in the transport network. The largest increase occurs in the boroughs of Hackney, Southwark, Croydon, and Lewisham.

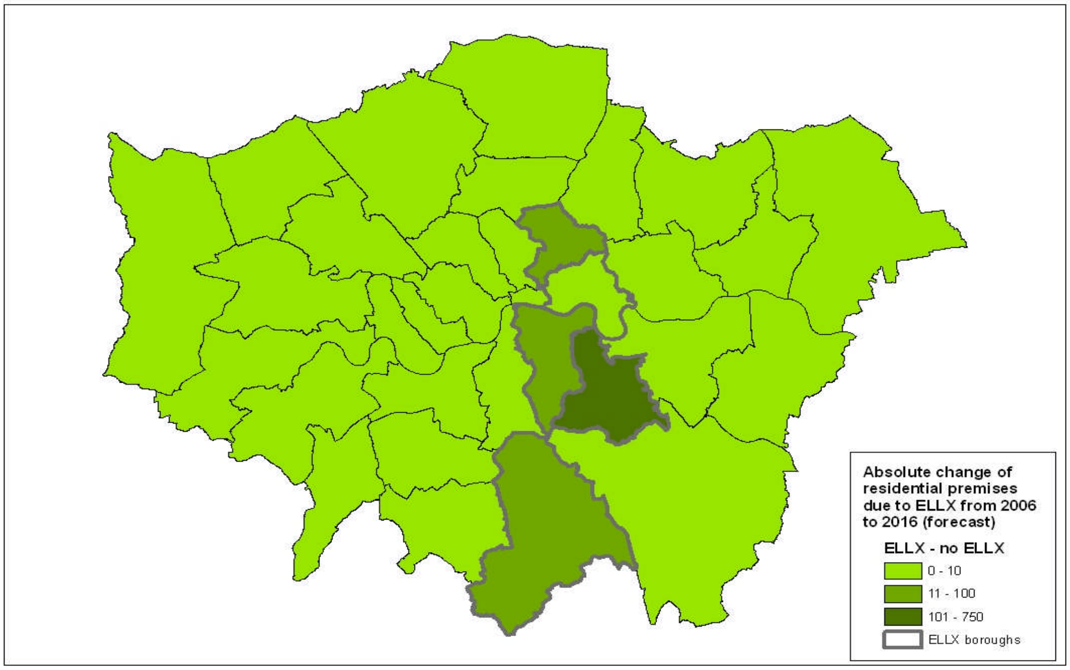


**Figure 8.8: Difference of number of new dwellings forecast with and without the ELLX**

To better illustrate the impacts of ELLX, London is divided into two areas: the first one consists of the ELLX boroughs; the second one, of the rest of London boroughs. Table 8.1 shows the positive impact of the new line on the ELLX boroughs.

| | Total number of residential premises in 2016 (forecast) | | | |
|---|---|---|---|---|
| **Zones** | **Without ELLX** | **With ELLX** | **Diff. ELLX - no ELLX** | **% Diff. ELLX - no ELLX** |
| ELLX boroughs | 541,205 | 542,059 | 854 | 0.16 |
| Rest of London | 2,637,217 | 2,637,239 | 22 | 0.00 |

**Table 8.1: Total number of residential premises in 2016 in aggregate areas**

### 8.2.2 Commercial development

The commercial development sub-model is a linear regression model. However, in contrast to the residential development sub-model, travel time is not the only variable affected by the addition of the new line. The number of vacant commercial premises is also affected (indirectly); it is updated by the business sub-model so that the inter-relationship of the two sub-models is represented more dynamically.

In Figure 8.9 the absolute changes due to the ELLX (changes with the ELLX minus changes without the ELLX) in the stock of commercial premises from 2006 to 2016 are presented. All the ELLX boroughs except Croydon (i.e. Hackney, Tower Hamlets, Southwark and Lewisham) are positively affected by the opening of the new line, and in fact they are the boroughs for which the ELLX seems to have the largest impact on commercial development. Bromley, which has not been included in the ELLX boroughs for reasons explained earlier, is also positively affected by the opening of ELLX.

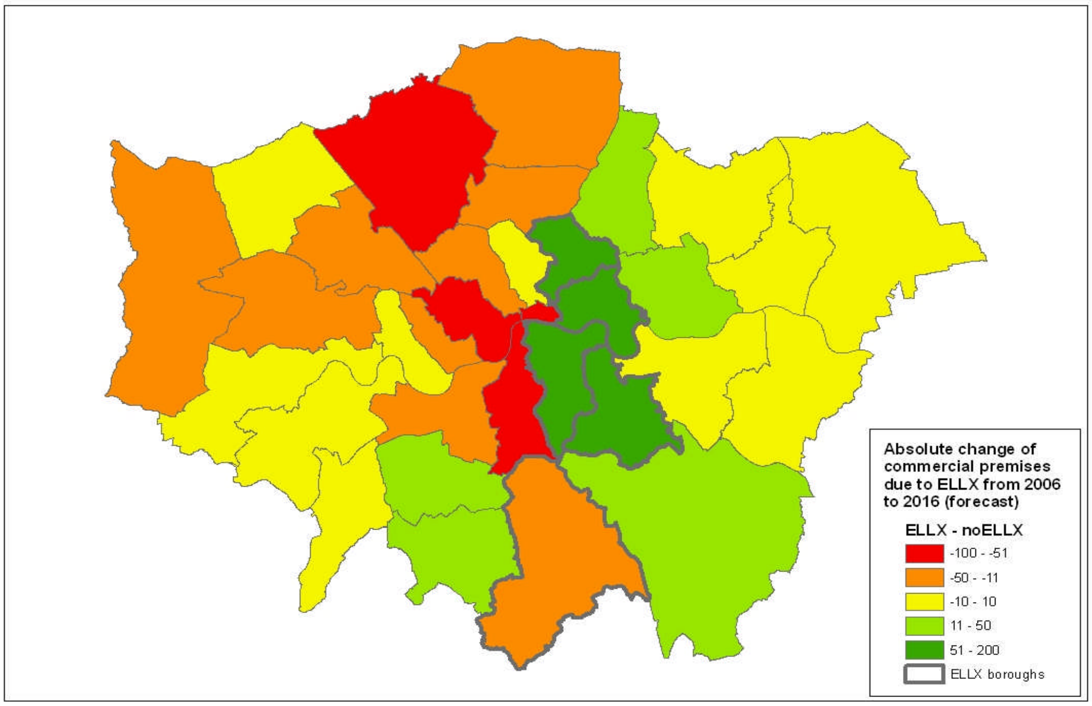


**Figure 8.9: Difference of the number of new commercial premises forecast with and without the ELLX**

The positive impact of ELLX on the ELLX boroughs is also illustrated in Table 8.2. There it is shown that the change in commercial development due to the new line is positive for the ELLX boroughs and negative for the rest of London.

| | Total number of commercial premises in 2016 (forecast) | | | |
|---|---|---|---|---|
| **Areas** | **Without ELLX** | **With ELLX** | **Diff. ELLX - no ELLX** | **% Diff. ELLX - no ELLX** |
| ELLX boroughs | 68,063 | 68,620 | 558 | 0.82 |
| Rest of London | 315,171 | 314,826 | -345 | -0.11 |

**Table 8.2: Total number of commercial premises in aggregate areas in 2016**

The positive impact of the ELLX on two ELLX boroughs is also illustrated in Figure 8.10 and Figure 8.11 where the annual change in the number of commercial premises in Lewisham and Hackney is shown.

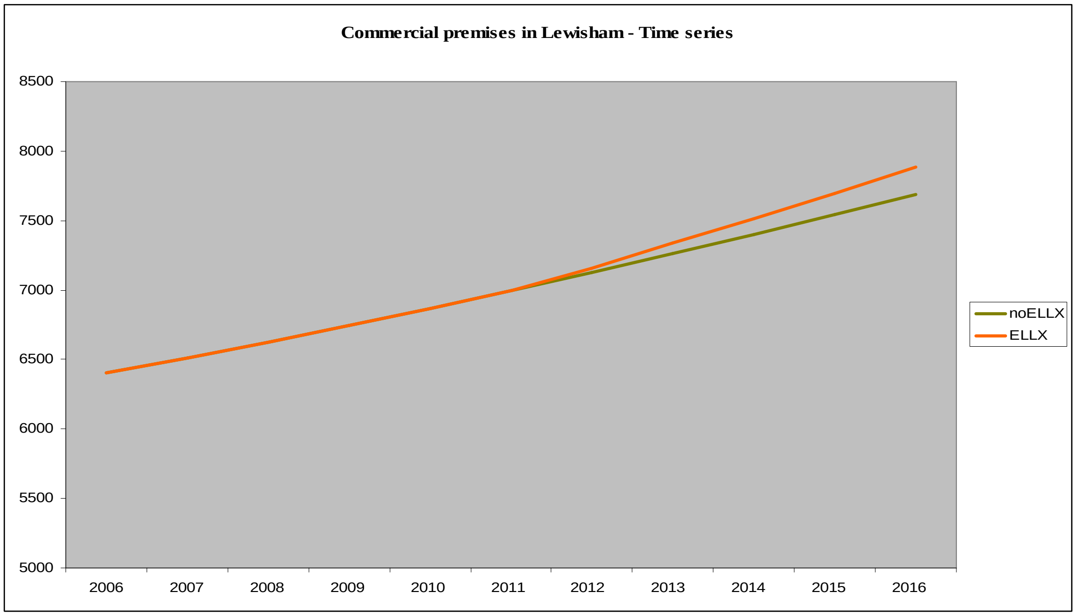


**Figure 8.10: Annual change of the number of commercial premises in Lewisham**

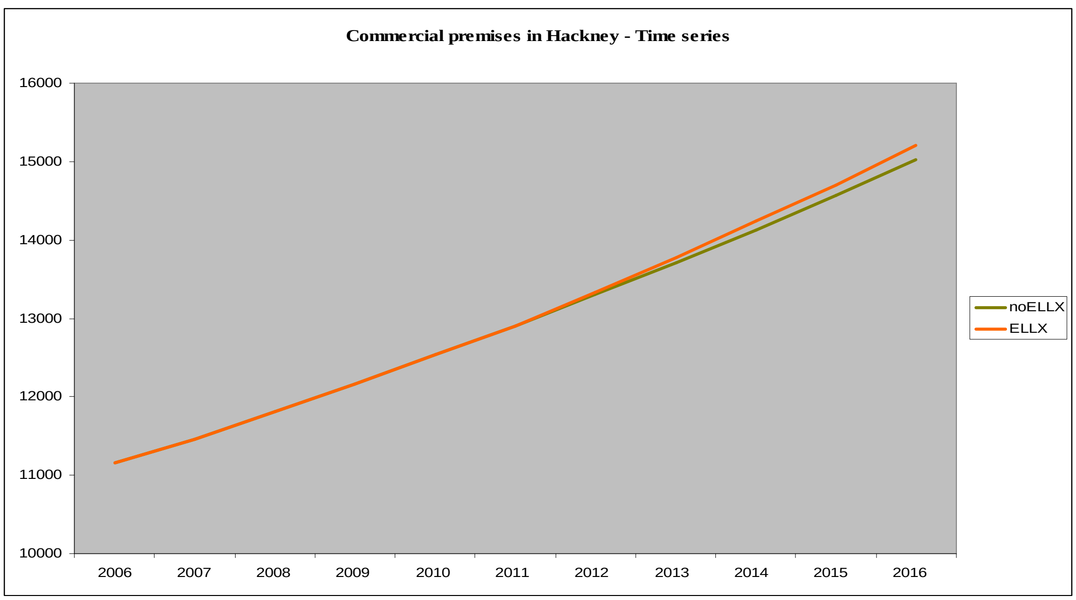


**Figure 8.11: Annual change of the number of commercial premises in Hackney**

## 8.3 Business sub-model

In Section 7.3, in which the business-related results of the application of the STUDI model for the case of the JLE were presented, besides spatial distribution of businesses in London, businesses' distribution according to industrial sector have also been presented. Here, only results on the distribution of businesses are presented. The distribution according to industrial sector depends on the data used; when the number of new businesses is forecast, only the total number is estimated and the spatial and sectoral distribution applied to the number of new businesses is the one of the last year for which real data exist (Section 5.2.2), i.e. 2006, so the information on the change of distribution according to industrial sector will be the projection of the results of 2006. Furthermore, business-relocation decisions as described in 5.2.5 do not depend on the industrial sector.

The impact of ELLX is illustrated in Figure 8.12, in which the absolute changes due to the line extension (changes with the ELLX minus changes without the ELLX) in the number of businesses from 2006 to 2016 are presented. It can be seen that four out of five ELLX boroughs are the ones for which the ELLX has the highest positive impact. ELLX appears to have a small positive impact on various South London boroughs. Of the eastern boroughs, Waltham Forest and Newham are also positively affected by the line. It is noted that the line has had negative impact on Croydon. This will be further discussed later.

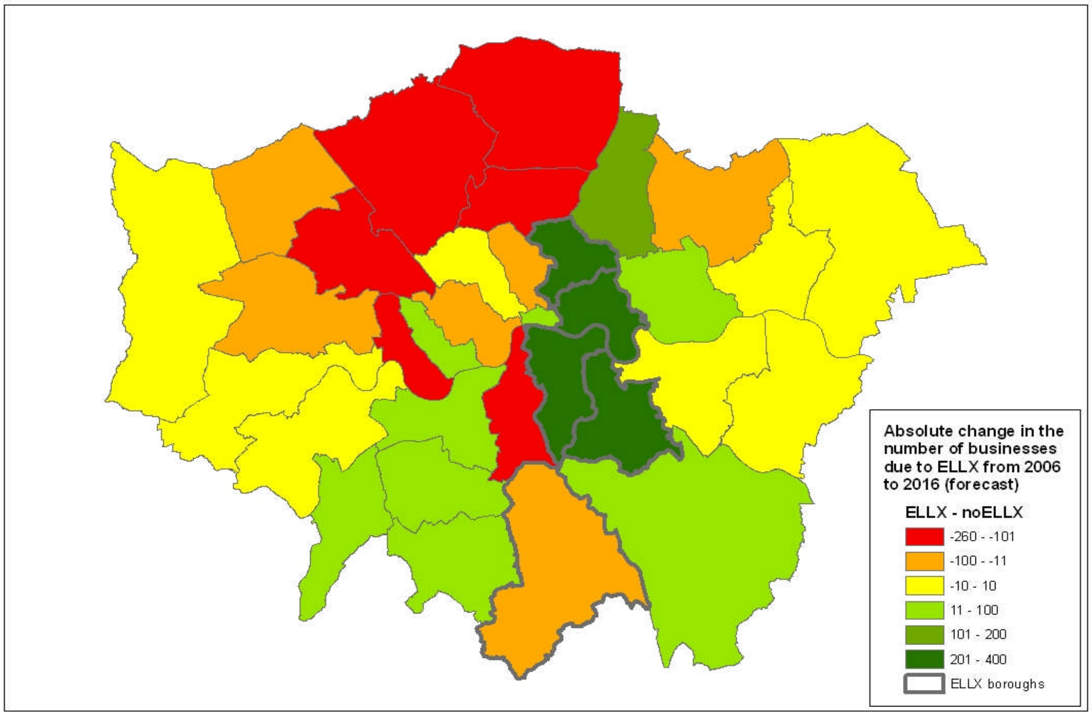


**Figure 8.12: Difference of the number of new businesses added from 2006 to 2016 forecast with and without the ELLX**

The positive impact of the ELLX on the ELLX boroughs is illustrated in Table 8.3: In the simulation with the ELLX, more businesses move to the ELLX boroughs and fewer to the rest of London, than in the simulation without the ELLX.

| | Total number of businesses in 2016 (forecast) | | | |
|---|---|---|---|---|
| **Areas** | **Without ELLX** | **With ELLX** | **Diff. ELLX - no ELLX** | **% Diff. ELLX - no ELLX** |
| ELLX boroughs | 69,554 | 70,577 | 1,023 | 1.47 |
| Rest of London | 396,701 | 395,861 | -840 | -0.21 |

**Table 8.3: Total number of businesses in aggregate areas (forecast)**

The annual change in the number of businesses for Hackney and Lewisham is illustrated in Figure 8.13 and Figure 8.14. There, the positive impact of the ELLX, which is added in 2011, is obvious.

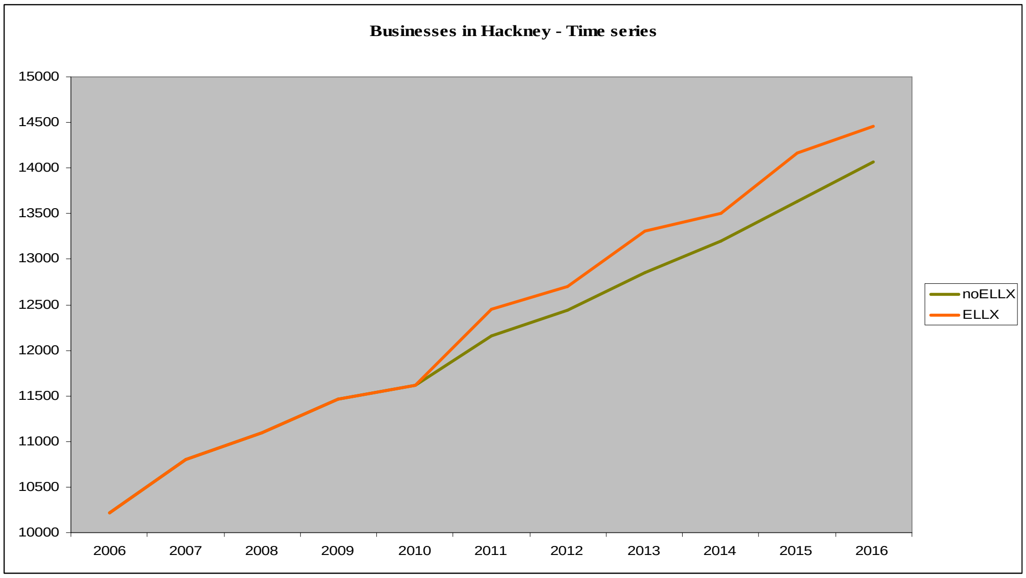


**Figure 8.13: Annual change of the number of businesses in Hackney**

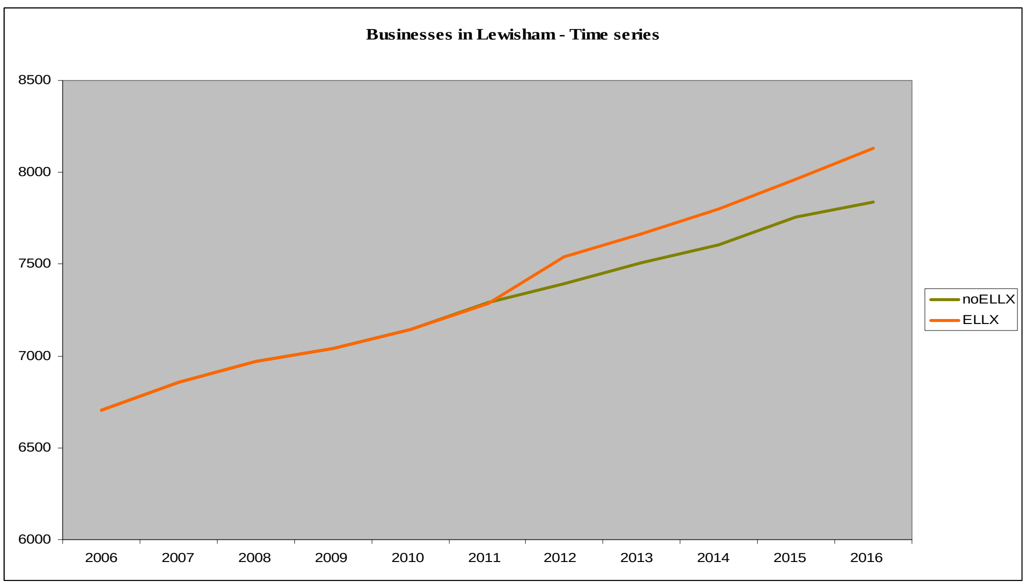


**Figure 8.14: Annual change of the number of businesses in Lewisham**

It is noted again that the main factors affecting the number of businesses are accessible employees – as given by Equation 5.18 – and vacant commercial premises. Location attractiveness is a function of these two variables as shown in Equation 5.17.

Figure 8.15 illustrates the change of accessible employees over time and shows how the ELLX is affecting ELLX boroughs and Bromley, shifting up the number of accessible employees after 2011 when the ELLX is added. In particular for Lewisham, the number of accessible employees exceeds those of Croydon and Bromley

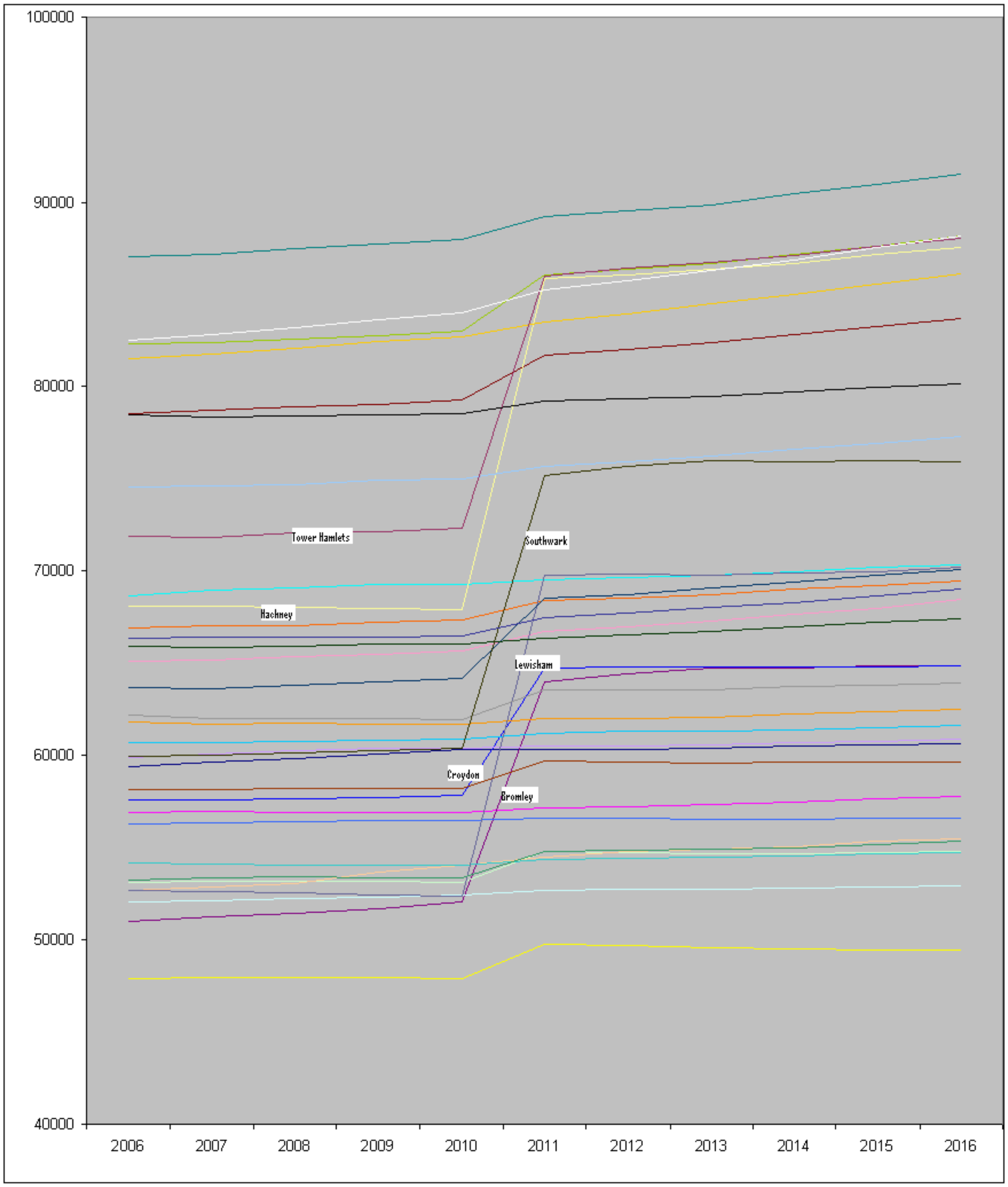


**Figure 8.15: Annual change of accessible employees**

The negative impact of the ELLX on Croydon is consistent to the negative impact on the number of new commercial premises. In general the attractiveness of Croydon is not improved as much as the attractiveness of the other ELLX boroughs. Neither the number of accessible employees increases as much as Lewisham's, nor the number of new and hence vacant commercial premises. This does not mean necessarily that businesses are leaving Croydon for other boroughs, but that fewer businesses are moving to it. As the number of commercial premises in Bromley, Lewisham and Southwark increases, these boroughs can accommodate more businesses from other boroughs that look first in them for vacant commercial premises; as a result fewer businesses go to Croydon – because they did not find a place in boroughs higher in their list of alternative locations (e.g. Bromley, Lewisham or Southwark) – when running STUDI with than without the ELLX. Furthermore, the attractiveness of Bromley, Lewisham and Southwark increases and exceeds that of boroughs looking first there, so businesses will move in these boroughs and will not look elsewhere, i.e. in Bromley that has anyway large attractiveness. For similar reasons the number of businesses of Haringey and Enfield decreases and that of Waltham Forest increases.

Figure 8.16 and Figure 8.17 illustrate the change over time of the attractiveness of the boroughs of Hackney and Lewisham respectively. The annual change of the number of businesses in the two boroughs has been shown in Figure 8.13 and Figure 8.14.

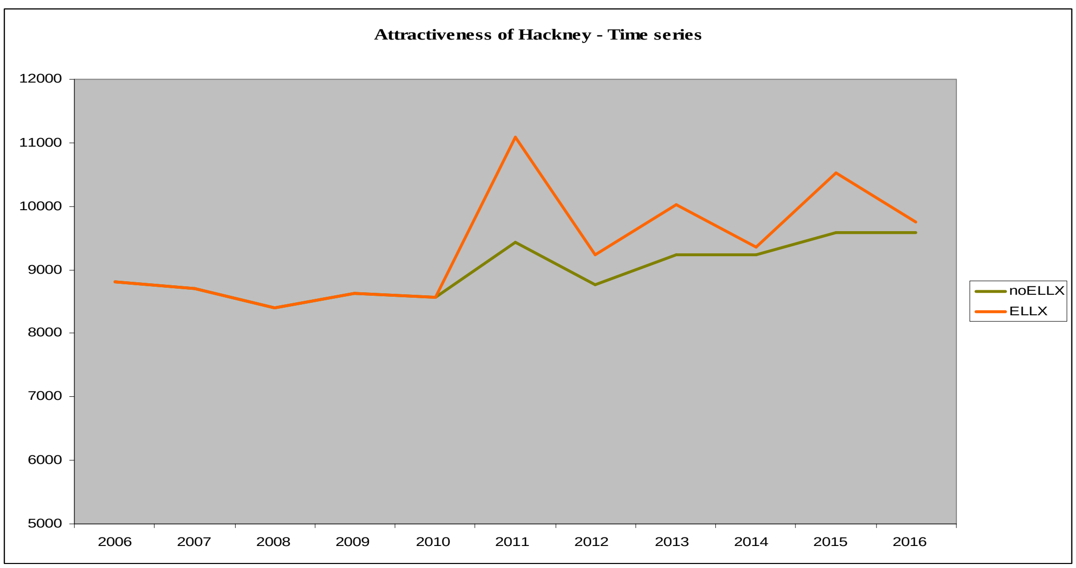


**Figure 8.16: Annual change of attractiveness of Hackney**

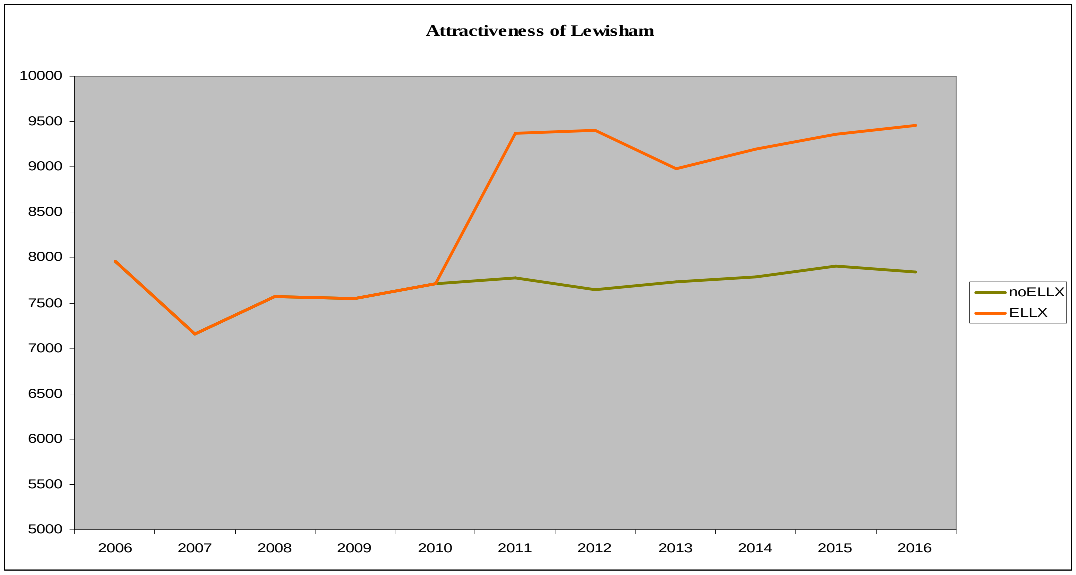


**Figure 8.17: Annual change of attractiveness of Lewisham**

## 8.4 Population sub-model

In Section 7.4, population-related results of the application of the STUDI model for the JLE were presented, including forecast changes in demographics, employment and residential locations. In the ELLX application of the model, only results related to residential locations are presented. The demographic changes that occur from 2006 to 2016 follow the pattern shown in Section 7.4.1. As the need for more detailed representation of demographics and employment has been recognised, results of demographic and employment changes expected to occur in the future are not presented.

In Figure 8.18 the absolute changes in population due to the ELLX (changes with the ELLX minus changes without the ELLX) from 2006 to 2016 are presented. The largest increase in population due to the line extension occurs in two of the ELLX boroughs: Lewisham and Tower Hamlets. Population increase is forecast also for Southwark and Bromley but the ELLX appears to have very large negative impact on Croydon and smaller but still negative impact on Hackney. Both cases will be discussed in more detail later. In general, most of the boroughs positively affected by the ELLX are in the eastern side of London.

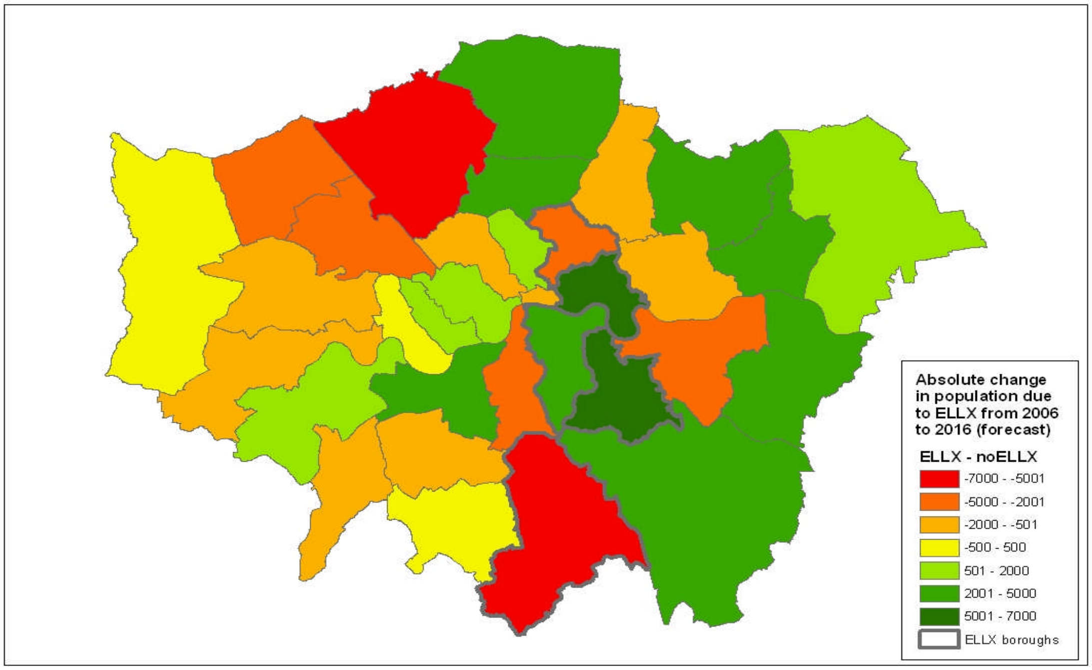


**Figure 8.18: Difference of population changes from 2006 to 2016, forecast with and without the ELLX**

Table 8.4 presents results aggregated in two main zones according to their relationship to the ELLX. The impact of the new line on the ELLX boroughs is positive and larger than its impact on the rest of London boroughs, but small.

| | Population in 2016 (forecast) | | | |
|---|---|---|---|---|
| **Areas** | **Without ELLX** | **With ELLX** | **Diff. ELLX - no ELLX** | **% Diff. ELLX - no ELLX** |
| ELLX boroughs | 1,544,030 | 1,549,356 | 5,326 | 0.34 |
| Rest of London | 6,935,345 | 6,938,256 | 2,911 | 0.04 |

**Table 8.4: Population in 2016 in aggregate areas**

The main factors affecting population's location decisions are accessible businesses and vacant commercial premises. Location attractiveness is a function of these two variables as shown in Equation 5.20. Population changes depend on the change of the attractiveness of the borough – more specifically, on the relative position of the borough in the ranking of all boroughs according to their attractiveness (Table 7.15 and Table 7.16) –, on the availability of vacant dwellings and on the selection of households willing to relocate. The latter creates stochastic variation, which increases with the use of the interim expansion factor.

The number of accessible businesses of the ELLX boroughs is affected by the addition of the line extension. As can be seen in Figure 8.19, ELLX has significantly larger impact on the number of accessible businesses of the ELLX boroughs and Bromley, than in that of the other London boroughs. The shift of the line is larger for Lewisham and smaller for Croydon.

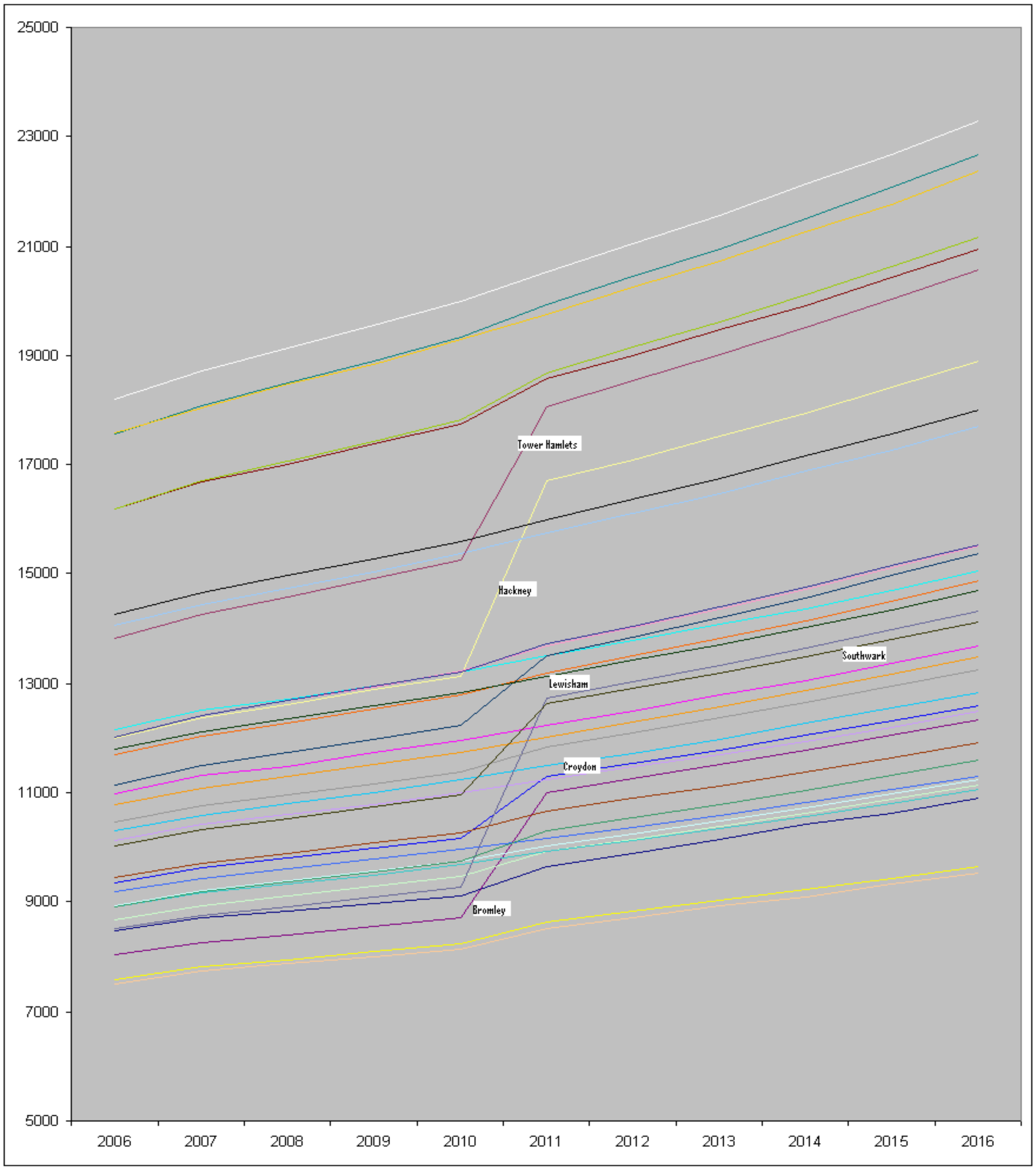


**Figure 8.19: Annual change of accessible businesses**

STUDI indicates that because of the ELLX population in Croydon decreases, a result which is opposite than the one expected. In fact, population of Croydon decreases as population in Lewisham increases. It is noted again that a key assumption in the location-choice simulation process of STUDI is that households looking to relocate will move to the closest borough with higher attractiveness than their current one.

Table 7.15 and Table 7.16 illustrate the ranking of the boroughs according to their attractiveness as residential locations from 2006 to 2016. A key for the reference codes is provided in Table 7.10. There it can be seen that when running the model without the ELLX, after 2011 Croydon (reference number: 8, Table 7.15) has higher attractiveness than Lewisham (23, Table 7.15) in years 2011, 2012, 2013, 2015 and 2016. When running the simulation with the ELLX the situation reverses: Lewisham has now largest attractiveness than Croydon in 2012, 2013, 2014 and 2015. On top of that, Lewisham receives many new dwellings annually (Figure 8.8) and can accommodate many more households willing to move there. The annual change of population in Lewisham is illustrated in Figure 8.20.

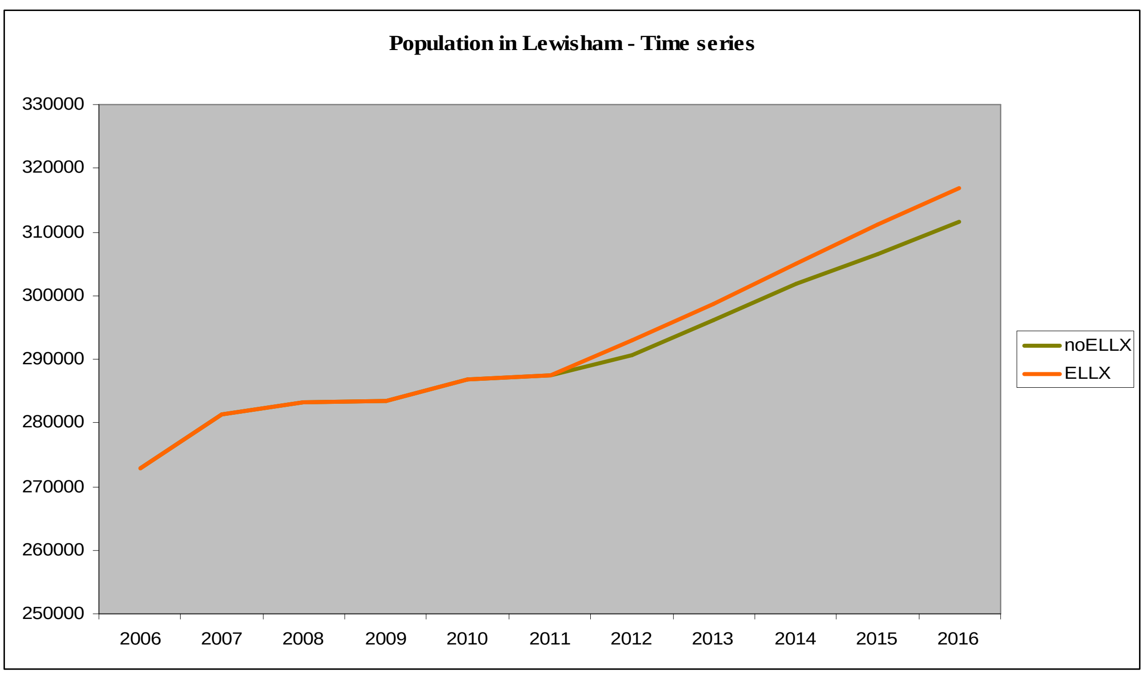


**Figure 8.20: Annual change of population in Lewisham**

| noELLX | Ranking of the London boroughs according to their attractiveness as residential locations | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Order** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** |
| **1** | 5 | 5 | 5 | 5 | 5 | 5 | 16 | 16 | 33 | 33 | 33 |
| **2** | 8 | 8 | 16 | 16 | 16 | 16 | 5 | 33 | 20 | 20 | 20 |
| **3** | 16 | 16 | 8 | 3 | 3 | 3 | 33 | 20 | 19 | 6 | 19 |
| **4** | 10 | 10 | 3 | 8 | 8 | 8 | 20 | 6 | 32 | 32 | 13 |
| **5** | 17 | 17 | 1 | 1 | 17 | 33 | 3 | 32 | 6 | 19 | 6 |
| **6** | 3 | 3 | 17 | 17 | 1 | 20 | 32 | 30 | 22 | 30 | 22 |
| **7** | 15 | 1 | 10 | 10 | 33 | 32 | 6 | 22 | 13 | 13 | 32 |
| **8** | 1 | 15 | 15 | 29 | 20 | 13 | 19 | 2 | 2 | 22 | 2 |
| **9** | 26 | 26 | 29 | 33 | 32 | 17 | 22 | 31 | 14 | 31 | 30 |
| **10** | 29 | 29 | 26 | 32 | 29 | 6 | 13 | 13 | 30 | 28 | 12 |
| **11** | 21 | 21 | 33 | 6 | 19 | 19 | 2 | 19 | 31 | 8 | 14 |
| **12** | 11 | 33 | 20 | 20 | 6 | 22 | 30 | 14 | 4 | 2 | 4 |
| **13** | 2 | 20 | 32 | 2 | 22 | 2 | 14 | 28 | 28 | 14 | 31 |
| **14** | 31 | 32 | 6 | 19 | 2 | 31 | 25 | 8 | 5 | 4 | 8 |
| **15** | 33 | 19 | 22 | 13 | 13 | 14 | 31 | 12 | 25 | 27 | 7 |
| **16** | 20 | 30 | 2 | 31 | 31 | 30 | 12 | 4 | 12 | 12 | 25 |
| **17** | 6 | 6 | 13 | 14 | 30 | 12 | 8 | 23 | 21 | 7 | 28 |
| **18** | 22 | 13 | 31 | 22 | 14 | 28 | 4 | 9 | 27 | 9 | 9 |
| **19** | 13 | 2 | 14 | 30 | 23 | 4 | 27 | 21 | 15 | 5 | 21 |
| **20** | 14 | 14 | 19 | 12 | 4 | 25 | 9 | 27 | 7 | 10 | 5 |
| **21** | 32 | 11 | 28 | 28 | 12 | 15 | 21 | 15 | 9 | 15 | 27 |
| **22** | 28 | 31 | 23 | 15 | 28 | 21 | 28 | 17 | 10 | 17 | 17 |
| **23** | 4 | 4 | 12 | 4 | 27 | 9 | 23 | 25 | 23 | 23 | 10 |
| **24** | 19 | 22 | 30 | 9 | 15 | 1 | 10 | 7 | 17 | 24 | 29 |
| **25** | 18 | 12 | 9 | 23 | 9 | 23 | 15 | 24 | 29 | 21 | 15 |
| **26** | 30 | 25 | 4 | 25 | 21 | 11 | 11 | 10 | 24 | 11 | 23 |
| **27** | 25 | 28 | 25 | 21 | 25 | 24 | 7 | 11 | 8 | 18 | 24 |
| **28** | 23 | 9 | 27 | 26 | 11 | 27 | 29 | 18 | 18 | 26 | 18 |
| **29** | 9 | 24 | 21 | 24 | 24 | 10 | 24 | 29 | 26 | 16 | 16 |
| **30** | 12 | 23 | 24 | 11 | 10 | 26 | 17 | 26 | 11 | 29 | 11 |
| **31** | 24 | 27 | 11 | 27 | 26 | 18 | 26 | 1 | 3 | 25 | 3 |
| **32** | 27 | 18 | 18 | 18 | 7 | 7 | 18 | 5 | 1 | 3 | 1 |
| **33** | 7 | 7 | 7 | 7 | 18 | 29 | 1 | 3 | 16 | 1 | 26 |

**Table 8.5: Annual ranking of London boroughs according to attractiveness as resulted from the simulation without the ELLX**

| ELLX | Ranking of the London boroughs according to their attractiveness as residential locations | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Order** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** |
| **1** | 5 | 5 | 5 | 5 | 5 | 5 | 16 | 33 | 33 | 33 | 33 |
| **2** | 8 | 8 | 16 | 16 | 16 | 16 | 5 | 16 | 20 | 20 | 20 |
| **3** | 16 | 16 | 8 | 3 | 3 | 3 | 33 | 6 | 32 | 19 | 6 |
| **4** | 10 | 10 | 3 | 8 | 8 | 8 | 20 | 30 | 6 | 30 | 32 |
| **5** | 17 | 17 | 1 | 1 | 17 | 33 | 32 | 20 | 19 | 6 | 12 |
| **6** | 3 | 3 | 17 | 17 | 1 | 20 | 6 | 32 | 30 | 22 | 30 |
| **7** | 15 | 1 | 10 | 10 | 33 | 32 | 30 | 19 | 12 | 13 | 19 |
| **8** | 1 | 15 | 15 | 29 | 20 | 12 | 19 | 22 | 13 | 32 | 28 |
| **9** | 26 | 26 | 29 | 33 | 32 | 30 | 23 | 12 | 2 | 12 | 13 |
| **10** | 29 | 29 | 26 | 32 | 29 | 13 | 22 | 13 | 23 | 23 | 22 |
| **11** | 21 | 21 | 33 | 6 | 19 | 6 | 3 | 28 | 28 | 2 | 2 |
| **12** | 11 | 33 | 20 | 20 | 6 | 17 | 2 | 23 | 5 | 28 | 14 |
| **13** | 2 | 20 | 32 | 2 | 22 | 19 | 14 | 2 | 31 | 14 | 31 |
| **14** | 31 | 32 | 6 | 19 | 2 | 31 | 12 | 8 | 14 | 8 | 5 |
| **15** | 33 | 19 | 22 | 13 | 13 | 22 | 13 | 31 | 25 | 31 | 8 |
| **16** | 20 | 30 | 2 | 31 | 31 | 28 | 28 | 14 | 22 | 5 | 23 |
| **17** | 6 | 6 | 13 | 14 | 30 | 2 | 31 | 4 | 4 | 4 | 25 |
| **18** | 22 | 13 | 31 | 22 | 14 | 23 | 8 | 25 | 8 | 7 | 7 |
| **19** | 13 | 2 | 14 | 30 | 23 | 14 | 25 | 27 | 7 | 27 | 4 |
| **20** | 14 | 14 | 19 | 12 | 4 | 25 | 4 | 21 | 21 | 21 | 21 |
| **21** | 32 | 11 | 28 | 28 | 12 | 4 | 27 | 17 | 17 | 9 | 27 |
| **22** | 28 | 31 | 23 | 15 | 28 | 15 | 21 | 9 | 15 | 25 | 24 |
| **23** | 4 | 4 | 12 | 4 | 27 | 21 | 9 | 15 | 27 | 24 | 9 |
| **24** | 19 | 22 | 30 | 9 | 15 | 9 | 15 | 7 | 9 | 10 | 29 |
| **25** | 18 | 12 | 9 | 23 | 9 | 1 | 11 | 5 | 10 | 17 | 17 |
| **26** | 30 | 25 | 4 | 25 | 21 | 11 | 29 | 24 | 29 | 15 | 10 |
| **27** | 25 | 28 | 25 | 21 | 25 | 24 | 10 | 11 | 24 | 11 | 15 |
| **28** | 23 | 9 | 27 | 26 | 11 | 26 | 7 | 10 | 18 | 18 | 11 |
| **29** | 9 | 24 | 21 | 24 | 24 | 27 | 24 | 18 | 11 | 29 | 18 |
| **30** | 12 | 23 | 24 | 11 | 10 | 10 | 17 | 26 | 26 | 26 | 16 |
| **31** | 24 | 27 | 11 | 27 | 26 | 18 | 26 | 29 | 3 | 3 | 26 |
| **32** | 27 | 18 | 18 | 18 | 7 | 7 | 18 | 3 | 16 | 16 | 3 |
| **33** | 7 | 7 | 7 | 7 | 18 | 29 | 1 | 1 | 1 | 1 | 1 |

**Table 8.6: Annual ranking of London boroughs according to attractiveness as resulted from the simulation with the ELLX**

STUDI also forecasts a decline in population in Hackney due to ELLX. Looking at the annual changes, the large difference is in the number of households moving to rather than from Hackney. This means a number of households from other boroughs, which went to Hackney in absence of the ELLX, will go to boroughs higher in the list of alternative locations (e.g. Tower Hamlets) that have now become more attractive, or that have available dwellings. This reliance on where the households are leaving from is a key factor of the stochastic variation of STUDI, which increases as the interim expansion factor is used to aggregate the results for population. In general, the decline of population in Hackney (12) happens in benefit of the population in Tower Hamlets (30) which has higher attractiveness as can be seen in Table 7.16. For example, in 2011 when Hackney (12) has larger attractiveness than Tower Hamlets (30) (Table 7.16) the ELLX has a small but positive impact on Hackney. After this, the attractiveness of Tower Hamlets is larger until 2015 and the population of Hackney increases less with the ELLX than without it.

The increase of population in Southwark is related to the decrease in Lambeth. The relation of the two boroughs has been discussed more analytically in Section 7.4.2. In this case (ELLX application of the STUDI model), when running the simulation without the ELLX, Lambeth (22) has a higher attractiveness than Southwark (28) in all years after 2011 when the ELLX is added (Table 7.15). When running STUDI with the ELLX, Southwark has a larger attractiveness than Lambeth in 2014 and 2016 (Table 7.16). Of course this does no mean that only households from Lambeth move to Southwark. The increase in attractiveness and in vacant dwellings indicates that it attracts households from other boroughs as well.

When examining the impacts on one borough, the focus is not only on the neighbouring boroughs. The fact that businesses willing to relocate start looking in the closest borough, does not mean that they can not move to a borough far away from their current location. It can be seen in Figure 8.18 that the positive impact of the ELLX occurs mainly in the eastern side of London. The western side seems to be overall negatively affected.

## 8.5 Summary

In this chapter the STUDI model has been applied in London in order to evaluate the impacts of the East London Line Extension on urban development. The line is expected to open during 2010, hence the forecasting ability of the model is tested. Population migration depends on the number of new businesses, and the number of new businesses depends on economic growth. Recognising the crudeness of the forecast of the number of new businesses (a linear regression model as estimated in Section 6.1.2.1 is used to forecast the total number of businesses to be added annually), results related to the distributions of development, businesses and population and to the changes occurred due to ELLX are presented, aiming to capture the impact of the new line on location decisions made by the agents of urban development.

Regarding development and businesses, the tables with results for two aggregate areas – the one containing only the ELLX boroughs and the other the rest of London boroughs – clearly indicate a positive impact of the ELLX on the ELLX area, which is always higher than the impact on the rest of London boroughs. Regarding population, although the increase for the ELLX boroughs is larger than the increase for the rest of London boroughs, the impact is relatively small.

From the results at borough level, the number of business in all the ELLX boroughs except Croydon is positively affected by the opening of ELLX. In fact, the change in the four ELLX boroughs is significantly larger than in the other boroughs. The same applies for the commercial premises. In terms of population, Lewisham, Tower Hamlets and Southwark are positively affected by the ELLX and so is Bromley. Croydon and Hackney are negatively affected by the ELLX. In general, the largest impacts of the ELLX occur in the ELLX boroughs, but the results do not indicate that population in the ELLX boroughs increases more due to the line extension and the changes that occur are small.

# 9 Discussion

During the design, development and application of the STUDI model various issues relevant to assumptions and decisions about modelling have been raised. In this chapter these issues will be further addressed in order to understand their implications and propose solutions that will help to improve the model in the future, so as to achieve a more realistic simulation of urban development.

## 9.1 Connection of the main sub-models

The three main sub-models of the STUDI model, i.e. the development, the business and the population sub-models, interact and exchange information over time. Issues relevant to the connection of these sub-models will be discussed in this section.

Businesses and population are simulated at a micro level. In the business sub-model the location decisions of each business are modelled separately in each simulation period and the model is applied to the total number of businesses. In the population sub-model, population is modelled either at individual or at household level, depending on the procedure (e.g., employment decisions are modelled at an individual level and residential location decisions are modelled at a household level), but the model is applied to a sample population which is approximately 1% of the total population.

The two sub-models are linked through the stocks of labour and businesses. The location attractiveness for businesses depends on the number of accessible workforce, which is updated by the population sub-model, and the residential location attractiveness for households depends on the number of accessible businesses, which is updated by the business sub-model. Additionally, the employment location decisions of people are affected by the number of vacant job positions and hence by the number of businesses. Finally, the number of new migrants each year depends on the total number of new businesses. This way, migration can be controlled endogenously under the assumption that it is related to economic growth and to the changes in the number of businesses.

In order to aggregate the results of the population sub-model so that they can be fed back to the business sub-model, the interim expansion factor (Section 4.4) is used. This increases stochastic variation, because if, for example, the interim expansion factor for one household moving in one borough is 80, then it is assumed that 80 households of the same household type will move into this borough.

The reverse procedure, i.e. the feedback of the results by the business sub-model into the population sub-model, is cruder: in order to make the number of businesses and hence the number of vacant job positions produced compatible to the sample population, vacant job positions are divided by a fixed number. This number was set equal to 60 (Section 6.1.4), which is a relatively small number (i.e., it can lead to overestimation of job vacancies) considering that the sample population is approximately 0.87% of the total population. It was chosen to be small in order to balance the fact that the number of new job vacancies is downgraded by the assumption that the largest businesses have 250 employees (Section 5.2.6).

To obtain complete integration between the business and the population sub-models, the business and population databases should be interconnected, in order that the exact working place (i.e. business) of each person and the exact spatial distribution of the employees of each business to be known. In this case, when a business closes down, the working status of its employees will automatically change into ‘unemployed’.

A similar compatibility issue occurs when the development and the population sub-models are connected. The development sub-model estimates the total number of new dwellings; in order to update annually the stock of vacant dwellings in the population sub-model, the number of new dwellings is divided by a fixed number, which is set equal to 100 (Section 6.1.4). For the reverse procedure, i.e. to feed back the updated – by the population sub-model – stock of vacant dwellings in the development sub-model, the stock of vacant dwellings is multiplied by 100.

The interactions between the sub-models occur either in the same simulation period or in the next one. The time factor of urban development should be addressed in more detail, taking into account that for the different sub-systems of the urban system the speed of change varies. Changes in development such as workplaces and housing happen with medium-speed and changes in employment and residential location happen faster (Wegener, 1994). The issue is also discussed in Section 9.2. Another time-related issue is the consideration of the dynamics of the impacts of new transport infrastructure: changes after the decision to build it and in advance of its opening are expected and the changes in urban development in the period after the opening indicate specific interest. These issues should be addressed in a spatially more disaggregate level.

## 9.2 Development sub-model

Development is currently simulated by using a log-linear and a linear model for residential and commercial development respectively. Cross-sectional data are used for the estimation of the equations, which are applied for over time forecasts. If a regression model continues to be used in the future to model development, time series data will be used to estimate it.

In Section 6.2.1.1 it has been pointed out that the development model has difficulties in modelling zones with extreme characteristics such as the City of London. A dummy variable could help to improve the forecasting ability of the STUDI model for such cases as well as for major development schemes such as the infrastructure for the 2012 Olympic Games in Stratford.

In the residential development model the variable ‘land available for development’ is included. The variable is measured in hectares and it is used because it improves the statistical significance of the model; but it is not updated, as it should be, after new development is added, because there is no information to calculate how much land is occupied by the new development or which of the newly developed sites are located in previously developed areas. The latter is a significant factor, as previously developed land in London is preferred for new development; in GLA (2007) it is stated that: “one of the overarching objectives of the Mayor's London Plan is to accommodate London's growth within its boundaries without encroaching on open spaces. Policies seek to achieve this objective through an urban renaissance of higher-density development that makes efficient use of land and protects open spaces. In 2000, when the GLA was created, 89 per cent of development was recorded as being on previously developed land. The Further Alterations to the London Plan sets a target that at least 96 per cent of new residential development should be on previously developed land, which is well above the national target of 60 per cent. The London Plan Annual Monitoring Report 3 (February, 2006) states that the 96% target was achieved in 2005/06. This puts London way ahead of other regions in the proportion of development on previously developed land."

In the future, land available for development will play a more active role in the model, because it can help to import construction limitations and to test relevant policies. Further development of the STUDI model will focus, among others, on testing development policies.

One important assumption that is made in the development sub-model is that one planning application leads to the development of one building that accommodates one occupier. This occupier can be one business for the case of commercial development or one household for the case of residential development. The new building is added in the same simulation period. Development will be modelled in more detail in the future: A distinction between different types of buildings, with each type being appropriate for different types of occupiers, will be made and the time and space factors of new development will be taken into account. New buildings will be added after some simulation periods according to their size in order for the dynamics to be represented better.

The type of the development is expected to affect the decisions of the potential occupier. Therefore, when a distinction between different types of developments is made, the type and size of the development will affect the attractiveness of the site for a potential occupier (i.e. household or business). In this context the age of the building shall also be taken into account and the relocations to new developments – as forecast by the model – should also be monitored.

The relationship between development and businesses, and development and population is very important. In the commercial development model the variable vacant commercial premises is included. This helps to address demand of commercial premises and as a result to create development in areas affected by changes, such as accessibility improvement due to a new line. The residential development model does not include vacant dwellings as a variable because it appeared to be insignificant in the estimation of the model (Section 6.1.1.2). Hence it is not directly updated by the population sub-model.

An alternative methodology to simulate development that is being considered for the future is the use of an optimisation model. Abraham and Hunt (2007) are using a mixed discrete-continuous logit model to forecast choice of development types based on construction cost and rent revenue and to provide expected values. Two-level optimisation is used to determine relative use of development types by zones and average consumption rates of land by different household categories.

## 9.3 Business sub-model

Businesses are modelled by using microsimulation and the business database is updated by using the VAT registrations-deregistrations until 2006. After 2006 business start-ups and closures are estimated according to GDP growth and their spatial distribution follows that for the last year for which VAT data were available. Hence the spatial distribution of new and closing-down businesses is always determined exogenously, which means that the impact of the JLE is captured by the location choices of existing businesses in London that decide to relocate. Using VAT data limits the forecasting ability of the model, as new businesses are imported exogenously, but gives robustness to the model and renders the results of the population sub-model more reliable.

Regarding the spatial distribution of business start-ups and closures, in Section 5.2.2 an alternative methodology using Monte Carlo simulation was presented. Its main weakness refers to the deletion of businesses that are closing down. Adding new businesses can be directly related to location characteristics but deleting existing businesses has to do with economy and business growth in the zone. This issue will be further investigated, together with business lifecycle modelling, in order to manage endogenously business start-ups and closures.

Integration of the STUDI model with a more sophisticated economic model with the aim of forecasting the number of new and closing-down businesses would improve much of the forecasting ability of the business sub-model, which already manages to capture the impact of new metro lines on business location-decisions.

Furthermore, on business start-ups and closures, there is an issue of compatibility between VAT registrations-deregistrations and the ABI data that has already been addressed in Section 6.3, as there are differences between the annual changes in the number of businesses provided by the two datasets.

In the case of reduction in the number of businesses, unemployment can be predicted as in the vector of new jobs, negative values will appear and there will be a decline in the stock of job vacancies.

Two important assumptions made in the business sub-model have to do with the determination of the exact size of businesses (in terms of number of employees) and the number of vacant job positions. The issue is discussed in various occasions including Sections 7.2.2 and 7.3.3 where results on the JLE impacts were presented. An assumption about the exact number of employees in each business is necessary as the ABI data categorise firms into four categories (Section 4.3) and the exact number of employees is needed to estimate the number of vacant job positions. The second assumption on job vacancies has to do with the number of vacant positions in each new or relocating business. It is assumed that for businesses relocating within London, 10% of the total employment positions will become available and for new business start-ups the full number of employment positions will be vacant. The number of employment positions as estimated according to the ranges given by the ABI data is shown in Section 5.2.6. Furthermore, regarding new businesses, the VAT data do not provide information on the size of businesses, so for the new businesses the distribution of sizes of the existing businesses is applied. More detailed modelling of businesses and further research on the number of vacancies is needed.

In Section 4.3 the creation and inclusion in the business database of a variable related to growth was discussed. It aims to provide a more realistic simulation of businesses' moving-choices if, for example, the alternative methodology for the identification of businesses considering relocation is used (Section 5.2.5.1). Additionally, it can help to simulate the size change of businesses and the creation of new employment positions – i.e. job vacancies – in growing businesses; currently, job vacancies are not considered for businesses that do not relocate. At this stage the variable representing business growth is simply included in the database and is not used, firstly because growth is not updated and a set of rules to update it has not been determined and, secondly, because further research is needed in order to identify businesses considering relocation using business characteristics.

Proceeding to location choices of businesses considering relocation as described in Section 5.2.5.2, the assumption that one firm will look to be relocated relatively near to its current location is not far from the truth for businesses that belong in specific industrial sectors such as distribution, hotels, restaurants and manufacturing. However, it may restrict the representation of the relocation of very large businesses or the choice of newly developed areas. This indicates the necessity to distinguish, during the search for new locations, between different industrial sectors and different business sizes or to deal in a different way with major developments such as the ones in Canary Wharf, Stratford or other business parks. In the development sub-model (Section 9.2) the use of a dummy variable is proposed for similar cases. The potential impact of such developments needs to be further investigated in order to be incorporated in the business sub-model properly.

In the STUDI model, there is no restriction for a business considering moving into a new zone from doing so in every simulation period. Furthermore, there is no rule for businesses considering relocation in one simulation period but which did not move, to consider relocation in the next simulation period.

## 9.4 Population sub-model

Population is modelled by using microsimulation. The results that are currently presented are in the form of spatial distributions. However, microsimulation has the advantage that the exact moves of individuals can be traced. In the future it should be possible to show location changes (from-to zones) explicitly, in order to better understand the dynamics between zones.

The issue of unemployment has already been addressed in Sections 9.1 and 9.3, but it is mentioned here, too, because the unemployed population is not properly updated: currently only students leaving education become unemployed for one simulation period; from the next simulation period they start looking for a job. Redundancies or people coming to London as unemployed are not considered. The in-migrants have to find a job first and then move in London (Section 5.3.2.2.2). The rest of the members of an in-migrating household remain in their current situation and they can look for a job in London in the next simulation period. However, some of them continue working outside London. In the initial dataset (LATS data) there is a percentage of people staying in London and working outside London.

In general, the development of the STUDI model is based on the assumption of economic growth to provide a full range of valid results. Under economic decline, it manages to show the decline in the number of businesses and hence in the number of employment positions and in the number of in-migrants, but it does not capture phenomena such as increase of unemployment due to redundancies or income decline.

Income is only updated after the formation of a new household, where the incomes of the two members are combined in one; it is not updated annually or after finding a new job. Although it is a necessary process, it is not vital for the current form of the STUDI model, because it is not involved in any of the decisions. In Section 5.3.5.3, where the modelling of residential location decisions is described, income is involved in the alternative method to identify households considering relocation.

Currently, employment location changes are not connected to residential location changes. This means that the fact that somebody changes job location will not affect his or her decision of whether to move home. The choice not to relate the two decisions was made on the grounds that there are other factors that affect location decisions according to household structure category (e.g. schools for families) and by excluding them and allowing only the employment location of one member of the household to lead the residential choices would not improve the representation of reality.

Residential location decisions of existing households relocating within London are based on their current residential location. Residential location decisions of new households are based on the employment location of the chief economic supporter. The chief economic supporter is chosen randomly each time among the economic active members of the household. A permanent chief economic supporter is not chosen, in order to allow more flexibility. Currently the employment locations of the other members of a household do not affect the residential location decision of the household. Before increasing the level of detail in modelling residential locations, distinction between household structure categories needs to be made and tenure needs to be modelled. For single households and in-migrants the employment location of the chief economic supporter plays the key role in residential location decisions. In the future, the aim is to consider more person- and job-specific details, such as job characteristics, salary etc., to model the employment location decisions. These details shall be included in the form of variables in a job attractiveness function.

Decisions related to the employment status of students are modelled, as well as location decisions of students that decide to look for a job. However, location decisions of students that continue their education, such as to which university to go etc., are not modelled. Regarding the employment location decisions, a distinction needs to be made between job categories as, for example, students aim for different jobs from professionals.

House-shares are included in household structure category 7 (all other households). However, they are not modelled explicitly. In the future they will be modelled in more detail by allowing individuals with specific characteristics to be added in an existing household fitting these characteristics. This should be done in combination with a more detailed development database as discussed in Section 9.2.

The attractiveness of a zone as a residential location is calculated by using the number of vacant premises as updated by the development sub-model and does not change as vacant premises are occupied during one simulation period. It is assumed that the attractiveness of one zone does not change within one year. Vacant premises are anyway involved in the location choice procedure; they are updated in real time as one agent is changing location. Continuously updating attractiveness could reflect the impact of demand and supply on attractiveness. However, this issue will be addressed better in the context of a price model, which is discussed in the next section (Section 9.5).

Although the key demographic changes are modelled, demographics should be modelled in more detail in the future. Regarding the simulation of births in order to avoid ending up with many too big families a restriction rule is imposed and only women in households with fewer than 7 people are considered as potential mothers. Furthermore, it is possible to have two births in one household by two adult women, e.g. mother and daughter. Finally, the potential of a mother giving birth to twins is not considered.

## 9.5 Other issues

The need for a price model has been recognised in different parts of this thesis. At this stage such a model has not been developed. The main reason for this is the detail and hence the time that would be needed to develop it. However, a price model is considered very important for the modelling of both the demand (businesses and population) and the supply (developers) sides of new development. In the future the STUDI model will be integrated with a model simulating land values and price changes.

Currently, location decisions in the STUDI model are driven by attractiveness. It is considered in the future to experiment with the use of random utility maximisation and multinomial logit model.

Other developments of the STUDI model aimed for the future include integration with ArcGIS, this was one of the reasons that Python was chosen as the programming language, spatial disaggregation and integration with a transport model to provide accessibility and travel-time measures and to receive land-use information. The latter together with some developments that have already been discussed will make the STUDI model capable for further applications such as testing of energy policies. Another aim for the future is to make the STUDI model applicable to other cities and transferable to other users by developing a more general framework and a user-friendly environment.

# 10 Conclusions

This thesis has explored the interactions between transport and urban development in the context of urban modelling. A new model, STUDI (Simulation of Transport and Urban Development Interactions), has been developed for this purpose. It is based on a comprehensive approach of urban systems focusing on the dynamic interactions between the agents of urban development – i.e. authorities, developers, businesses and population – and the impact of transport on their location decisions. The four agents of urban development and their relationship with transport were discussed in Chapter 2 in the context of a review of impact studies of new transport infrastructure.

Microsimulation is used to model businesses and population. It is the preferred methodology because by considering each agent individually it can better represent complex systems such as cities, and dynamic interactions occurring in urban development. It can also incorporate behavioural characteristics of choices. A review of land-use and transport models, evaluating the different modelling approaches according to their compliance with the desired characteristics, was presented in Chapter 3.

This research was triggered by the interest of Transport for London in the wider impacts of new metro lines. The STUDI model has been implemented in London to evaluate two transport schemes, and the data used for this purpose were described in Chapter 4. Then in Chapter 5 the model was presented in detail and in Chapter 6 it was estimated, calibrated and validated.

In the first application of the STUDI model, the impacts that the Jubilee Line Extension (JLE) – it opened at the end of 1999 – had on urban development until 2006 were assessed. The JLE application was discussed in Chapter 7. In the second application the impacts of the East London Line Extension (ELLX) – which is expected to open in 2010 – on urban development until 2016 were forecast. The ELLX application was discussed in Chapter 8. The STUDI model runs over time in one-year steps. The major results presented are in the form of spatial distributions of residential and commercial development, businesses and population; the impacts of the new transport infrastructure are reflected in the differences between the forecasts with and without the new transport line. In this context the main factors driving the changes are also discussed. In the case of the JLE, results on employment distributions and demographics were also presented.

Comprehensiveness has been one of the major targets from the beginning of the research, as it is necessary in order to provide a complete as well as valid picture of urban systems. Following this logic, various processes are modelled in the STUDI model. However, combining comprehensiveness with detail under time and data constraints has left some factors related to urban development in need of further investigation and more detailed modelling. Relevant issues were discussed in Chapter 9.

Whilst acknowledging the flaws in the STUDI model, it can be concluded that it manages to capture impacts of new transport infrastructure. A general conclusion drawn from the applications of the model is that in both cases investigated, the opening of the new line (or more correctly, of the extension of the line) has positive impacts on development and businesses in the boroughs crossed by it. In terms of population, the results of the simulation do not indicate a clearly positive impact for the boroughs crossed by the line.

The STUDI model, based on the principles of comprehensive microsimulation of urban systems, is the basis for further development towards an improved model of the interactions between transport and urban development.

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# Appendix

The Appendix contains tables with the travel time changes attributed to the JLE and the ELLX as illustrated in the maps in Chapter 4 and Chapter 8 respectively. Table A.1 contains the changes in travel times due to JLE and Table A.2 those due to ELLX.

| Travel time changes between boroughs due to JLE | | | | | | |
|---|---|---|---|---|---|---|
| | **Westminster** | **Lambeth** | **Saouthwark** | **Tower Hamlets** | **Greenwich** | **Newham** |
| **Barking and Dagenham** | -0.05 | -0.49 | -6.33 | -0.43 | -23.39 | -2.33 |
| **Barnet** | -0.98 | 0.09 | -6.78 | -0.21 | -29.29 | -1.48 |
| **Bexley** | -2.67 | -1.54 | -4.29 | -1.02 | -6.48 | -7.38 |
| **Brent** | -4.83 | -0.35 | -13.08 | -5.55 | -33.95 | -4.40 |
| **Bromley** | -0.98 | -0.88 | -4.67 | -4.68 | -15.79 | -5.71 |
| **Camden** | -2.68 | -0.27 | -9.11 | -2.23 | -30.73 | -2.77 |
| **City of London** | -0.11 | -0.14 | -4.04 | -0.14 | -25.11 | -1.23 |
| **Croydon** | -0.45 | -0.36 | -5.44 | -5.87 | -22.42 | -6.25 |
| **Ealing** | -1.64 | 0.16 | -10.89 | -2.34 | -31.07 | -3.08 |
| **Enfield** | -0.99 | 0.12 | -5.19 | -0.02 | -24.82 | -1.81 |
| **Greenwich** | -17.85 | -16.62 | -15.05 | -10.69 | 0.00 | -17.32 |
| **Hackney** | -0.35 | 0.05 | -3.81 | -0.03 | -23.11 | -2.54 |
| **Hammersmith and Fulham** | -0.97 | 0.15 | -10.32 | -2.77 | -31.40 | -3.21 |
| **Haringey** | -0.89 | 0.12 | -6.42 | -0.01 | -27.64 | -1.41 |
| **Harrow** | -5.79 | -0.79 | -12.57 | -5.47 | -33.07 | -4.24 |
| **Havering** | -0.02 | -0.15 | -5.99 | -1.34 | -26.36 | -4.70 |
| **Hillingdon** | -4.49 | -0.30 | -12.03 | -4.38 | -32.03 | -3.63 |
| **Hounslow** | -0.18 | -0.08 | -10.90 | -4.50 | -34.12 | -4.26 |
| **Islington** | -0.49 | 0.05 | -6.19 | -0.04 | -28.37 | -1.60 |
| **Kensington and Chelsea** | -0.62 | 0.17 | -10.11 | -2.96 | -31.29 | -3.27 |
| **Kingston-upon-Thames** | -0.10 | 0.00 | -10.82 | -3.37 | -35.41 | -4.20 |
| **Lambeth** | -0.07 | 0.00 | -3.73 | -1.48 | -16.62 | -2.76 |
| **Lewisham** | -3.47 | -2.85 | -3.61 | -2.93 | -9.61 | -5.88 |
| **Merton** | 0.01 | 0.10 | -8.06 | -2.12 | -32.89 | -3.59 |
| **Newham** | -2.68 | -2.76 | -7.28 | -1.96 | -17.32 | 0.00 |
| **Redbridge** | -0.05 | -0.10 | -5.28 | -2.17 | -27.38 | -5.81 |
| **Richmond-upon-Thames** | 0.02 | 0.02 | -10.47 | -3.50 | -34.73 | -4.04 |
| **Southwark** | -6.62 | -3.73 | 0.00 | -5.62 | -15.05 | -7.28 |
| **Sutton** | -0.22 | -0.04 | -5.78 | -4.09 | -25.26 | -4.91 |
| **Tower Hamlets** | -2.46 | -1.48 | -4.10 | 0.00 | -10.69 | -1.73 |
| **Waltham Forest** | -0.59 | 0.08 | -4.72 | -2.18 | -27.32 | -6.09 |
| **Wandsworth** | 0.04 | 0.09 | -8.87 | -2.52 | -33.44 | -3.59 |
| **Westminster** | 0.00 | -0.08 | -6.62 | -2.46 | -17.85 | -2.68 |

**Table A.1**

| Travel time changes between boroughs due to ELLX | | | | | |
|---|---|---|---|---|---|
| **Borough** | **Hackney** | **Tower Hamlets** | **Southwark** | **Lewisham** | **Croydon** |
| **Barking and Dagenham** | 8.50 | 0.50 | 0.05 | 4.00 | 2.00 |
| **Barnet** | 0.85 | 0.05 | 0.10 | 4.00 | 0.50 |
| **Bexley** | 10.68 | 0.05 | 0.20 | 12.00 | 1.00 |
| **Brent** | 0.55 | 0.50 | 0.20 | 5.00 | 0.80 |
| **Bromley** | 26.67 | 30.00 | 28.00 | 7.00 | 25.00 |
| **Camden** | 4.00 | 7.00 | 0.50 | 10.00 | 5.00 |
| **City of London** | 2.17 | 0.05 | 1.00 | 5.00 | 0.05 |
| **Croydon** | 19.50 | 9.75 | 8.50 | 21.00 | 0.00 |
| **Ealing** | 8.02 | 0.05 | 0.60 | 8.00 | 0.05 |
| **Enfield** | 2.00 | 0.05 | 0.90 | 4.00 | 0.60 |
| **Greenwich** | 13.00 | 1.50 | 1.00 | 20.00 | 1.20 |
| **Hackney** | 2.50 | 22.83 | 14.58 | 27.33 | 19.50 |
| **Hammersmith and Fulham** | 2.33 | 2.00 | 2.00 | 7.00 | 1.00 |
| **Haringey** | 7.67 | 1.50 | 1.00 | 4.00 | 2.00 |
| **Harrow** | 0.72 | 1.50 | 0.50 | 4.00 | 0.80 |
| **Havering** | 8.35 | 0.05 | 0.05 | 6.00 | 0.10 |
| **Hillingdon** | 2.02 | 0.05 | 0.10 | 4.00 | 0.10 |
| **Hounslow** | 3.33 | 1.00 | 0.40 | 14.00 | 0.30 |
| **Islington** | 1.50 | 5.00 | 1.00 | 16.00 | 5.00 |
| **Kensington and Chelsea** | 1.70 | 1.50 | 0.50 | 5.00 | 0.50 |
| **Kingston Upon Thames** | 1.95 | 0.50 | 0.10 | 7.00 | 0.05 |
| **Lambeth** | 3.33 | 0.05 | 3.00 | 12.00 | 0.90 |
| **Lewisham** | 27.33 | 15.00 | 11.00 | 0.00 | 21.00 |
| **Merton** | 4.50 | 5.00 | 5.00 | 12.00 | 6.00 |
| **Newham** | 11.05 | 2.00 | 0.05 | 13.00 | 1.50 |
| **Redbridge** | 6.73 | 2.00 | 0.10 | 9.00 | 1.60 |
| **Richmond Upon Thames** | 0.70 | 0.50 | 0.50 | 8.00 | 0.40 |
| **Southwark** | 14.58 | 0.78 | 0.00 | 11.00 | 8.50 |
| **Sutton** | 4.00 | 0.50 | 1.00 | 15.00 | 0.40 |
| **Tower Hamlets** | 22.83 | 0.00 | 0.78 | 15.00 | 9.75 |
| **Waltham Forest** | 4.17 | 1.00 | 1.00 | 17.00 | 2.00 |
| **Wandsworth** | 1.02 | 0.05 | 0.50 | 7.00 | 1.20 |
| **Westminster** | 2.83 | 0.05 | 0.50 | 18.00 | 0.50 |

**Table A.2**