Modelling the Economic Impacts of Inter-City Connectivity

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The candidate confirms that the work submitted is his own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

This thesis contains text from a journal paper which was published during the research which was jointly authored by the candidate and his PhD supervisors Simon Shepherd and Daniel Johnson. The candidate confirms that he was the lead author of the paper and his supervisors contributed only in an advisory and supervisory role. The journal paper is:

Pierce, D., Shepherd, S., & Johnson, D. (2019). Modelling the Impacts of Inter-City Connectivity on City Specialisation. *International Journal of System Dynamics Applications*, *8*(4), 47-70.

The text from this journal paper is included in this thesis in the following locations. Some of the text from the literature review is included in Chapters 2 and 5, some of the text and diagrams from the methodology are included in Chapter 4 and some of the text from the results, discussion and conclusion are included in Chapter 5.

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Abstract

Current economic appraisal guidelines focus on direct cost savings and over the last 10 to 15 years methods have also been developed to evaluate urbanisation effects within city regions but there has been much less focus on the effects of linking urban areas. These effects include the potential for fostering increased trade and specialisation leading to localisation benefits. The lack of focus on these impacts in economic appraisals is due to the complexity of the processes and the small evidence base which this thesis aims to contribute to.

To investigate the economic impacts of inter-city connectivity a dynamic model was developed based on the system dynamics approach. The model includes an innovative structure with a target-based/goal-seeking approach for determining equilibrium in the labour and capital markets. Changes in effective density impact on wages and capital rents and labour and capital can move sector and zone to maximise their returns. The results show that sectoral and zonal mobility costs limit the potential for increased specialisation through investment in inter-city transport and increases in specialisation are more likely to arise when the scheme effects differ between sectors and between cities.

The impact of including localisation benefits and changes in specialisation in the economic appraisal of inter-city connectivity schemes was investigated using an abstract static model. With the central case assumptions it was estimated that their inclusion would increase the total present value of benefits by 7.9% for a 150km distance between two cities. Using a similar method a case study was undertaken of the proposed Northern Powerhouse Rail scheme in the north of England. This showed that with detailed GJT and land-use changes the estimated additional benefits are comparable to those from the abstract model but they can be unevenly distributed and that there can be losers as well as winners.

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1 Introduction

1.1 Background to Research

There are major investment programmes currently in progress to develop and expand inter-city transport infrastructure around the world. In the UK these include the Road Investment Strategy (RIS) (DfT, 2015a) and the planned HS2 high-speed rail (HSR) network which will connect most of the country's largest cities. Other examples include the continuing development of the Trans-European Transport Network (TEN-T) in Europe (European Commission, 2017) and the rapid expansion of China's High-Speed Rail (HSR) network since the first line opened in 2008 (Wang et al., 2018).

One of the bases for these investments is that transport infrastructure enhances the economy through increased productivity, employment and output. There are well established methodologies for evaluating the direct benefits of transport schemes such as time savings and over recent years techniques have been developed to estimate Wider Economic Impacts (WEIs). These include urbanisation economies through which higher productivity can arise from increased economic density (see Wangsness et al., 2017 for a review). Urbanisation economies are a function of labour market pooling, supply chain linkages and knowledge spill overs (Combes and Overman, 2004) and they typically account for approximately 10 to 15% of total benefits in an economic appraisal of an inter-urban scheme (Eddington, 2006, DfT, 2017a). They were first outlined by Jacobs (1969) and are often referred to as 'Jacobs' externalities (Henderson et al., 1995) or diversity economies (Glaeser et al., 1992).

Rosewell and Venables (2013) suggest that there may be further potential productivity gains from inter-urban transport schemes if they can promote increased trade and specialisation. They argue that this could generate significant benefits arising from the increased density of sectors and these are currently missing from economic appraisal methods. The productivity impacts relating to the economic density of sectors are called localisation economies and they arise as greater proximity of firms can lead to the development of a specialised labour market pool, improved sharing of inputs and own-industry knowledge spill overs (Rosenthal and Strange, 2003). They are often referred to as 'Marshallian' economies after Marshall (1890) who first outlined the theory behind them (Duranton and Puga, 2000). The magnitude of these benefits may potentially be significant and their omission from current appraisal guidance is a gap and may be leading to sub-optimal decision-making.

The theoretical basis for changes in specialisation due to improvements in connectivity between regions is based on David Ricardo's Theory of Comparative Advantage (Ricardo, 1817). He demonstrated that reducing trade barriers can lead to welfare gains through incentivising places to specialise in the production of goods in which they are more productive. More recently the theory of new economic geography (Krugman, 1991b, Fujita et al., 1999) has been developed which shows how changes in inter-city transport costs can impact on dispersion and concentration forces. Over time this can lead to a process of cumulative causation in which sectors become concentrated in different locations.

The UK's Department for Transport (DfT) usually only invests in projects which represent a high or very high value for money[1] and some of the major proposed schemes do not have high Benefit Cost Ratios (BCRs) when WEIs are not included. For instance, the BCR of the proposed HS2 network in the UK was 2.3 with WEIs included but when they were excluded it was only 1.9 (DfT, 2017a) and the projected capital cost of the project has increased significantly since then[2]. This raises important policy questions as to whether there is an economic basis for investing significant sums of money in transport schemes which improve links between cities and regions.

The initial new economic geography models focussed on manufacturing industries but the structure of many advanced economies has changed significantly over recent decades[3]. The proportion of employment in manufacturing across Western members of the European Union (EU) declined from 31% in 1991 to 18% in 2018 (World Bank, 2019) and the comparative advantages of many advanced economies have switched

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[1] In the UK DfT WebTAG guidelines the value for money of a scheme is high if it is has a BCR of greater than 2 and very high if it has a BCR of greater than 4 (DfT, 2015b).

[2] The present values of costs in the DfT (2016) business case were £56.2bn (2015 Prices) but the latest estimates are that the cost will be £80.7bn to £87.7bn (2019 Prices) (Oakervee, 2019).

[3] These structural changes are explained by a combination of technological change and increased competition with low-cost firms in developing economies (Greenaway et al., 2009). The latter is likely to be influenced by lower international shipping costs including transfer costs which have fallen considerably due to the rapid growth of container ships since their introduction in the 1950s. World Bank (2009) state evidence from Levinson (2006) that the costs of loading fell from $5.83 per ton to $0.16 per ton following the introduction of containerisation in 1956. World Bank (2009) also state that air freight prices fell from $3.87 per ton km in 1955 to $0.30 per ton km in 2004 (2000 Prices).

from heavy manufacturing industries to service sectors. For example, the UK now has comparative advantages in pharmaceuticals, finance and insurance (BIS, 2010) and the US in finance, computing and information services (Langhammer, 2004).

These structural changes are relevant to the consideration of the impacts of transport improvements on trade and specialisation. There is also evidence that inter-city highways impact more on heavy manufacturing industries (Bougheas et al., 2000, Duranton et al., 2014) whereas rail schemes are more likely to generate changes in land-use in service sectors (Lin, 2017, Qin, 2017). The combination of the recent development of comparative advantages in service sectors and the evidence that rail schemes are more likely to affect land-use in such sectors suggests that there is a need for research to focus on investigating the economic impacts of inter-urban rail projects.

1.2 Research Gaps

The research background and review of the literature presented in Chapter 2 led to the identification of several research gaps which informed the objectives of the research. The key knowledge gaps which were identified are:

1. Determining how the scale of localisation benefits compare to urbanisation benefits and under what conditions the inclusion of localisation benefits will be more important;
2. Understanding the dynamic processes over time of changes in specialisation and trade resulting from a change in inter-city transport costs;
3. Understanding the effect of adjustment times on the transition to a new equilibrium; and,
4. Developing techniques for estimating the benefits from increased trade and specialisation resulting from improvements to inter-city connectivity and identifying the level of additionality.

1.3 Research Objectives

The objectives of this research have been defined to address the gaps identified in the literature. The research objectives are:

1. To expand the economic framework for improved inter-city connectivity to include trade and specialisation and localisation effects.

The framework will incorporate Ricardo’s Theory of Comparative Advantage and elements of new economic geography and endogenous growth theory (Romer, 1986, Lucas, 1988). The framework will be developed using the system dynamics approach which can take into account interdependency between variables and time lags which are expected to be important.

2. To understand the dynamic processes of how inter-city connectivity impacts on economic activity.

Dynamic models will be developed of inter-city transport and economic impacts including specialisation from first principles using a system dynamics approach. The models will include variables such as labour, capital, wages, capital rents and productivity. Effects in the labour market will be important in understanding transitional changes in the economy and the model will include mobility of workers between sectors and zones.

3. To understand how different transition elements within the system interact with one another.

The dynamic models will use the goal-seeking archetype[4] to determine equilibrium in the labour and capital markets. In this archetype the discrepancy between the target and current level of a variable is used to move the system towards equilibrium. The models will be used to understand how different elements interact with one another such as time lags and moving targets. The models will be simulated with capital either fixed or variable to understand any differences between the two situations.

4. To identify the level of additionality to transport user benefits in a cost benefit analysis that increased productivity through changes in specialisation will have.

An abstract model will be developed to estimate the localisation and urbanisation benefits resulting from inter-city journey time improvements. Scenarios will be undertaken with both land-use fixed (static clustering) and variable (dynamic clustering) and the distance between cities and input assumptions will be varied to determine under what conditions localisation benefits are more important. A case study will also be undertaken on the proposed Northern Powerhouse Rail (NPR) rail scheme in the north of England. The results from the case study will be compared to those from the abstract modelling to see if the real world case gives similar relative benefits to the abstract case and if they confirm the other findings.

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[4] An overview of the goal-seeking archetype is provided in Section 3.2 in Chapter 3.

5. To identify differences between the abstract and detailed real world cases.

The NPR case study will be used to identify if there are any differences between undertaking analysis at the detailed real world case and the abstract case.

1.4 Thesis Structure

The thesis roadmap is presented in Figure 1.1. The thesis is organised into nine chapters and the roadmap shows the key aspects of each chapter and how the chapters are connected.

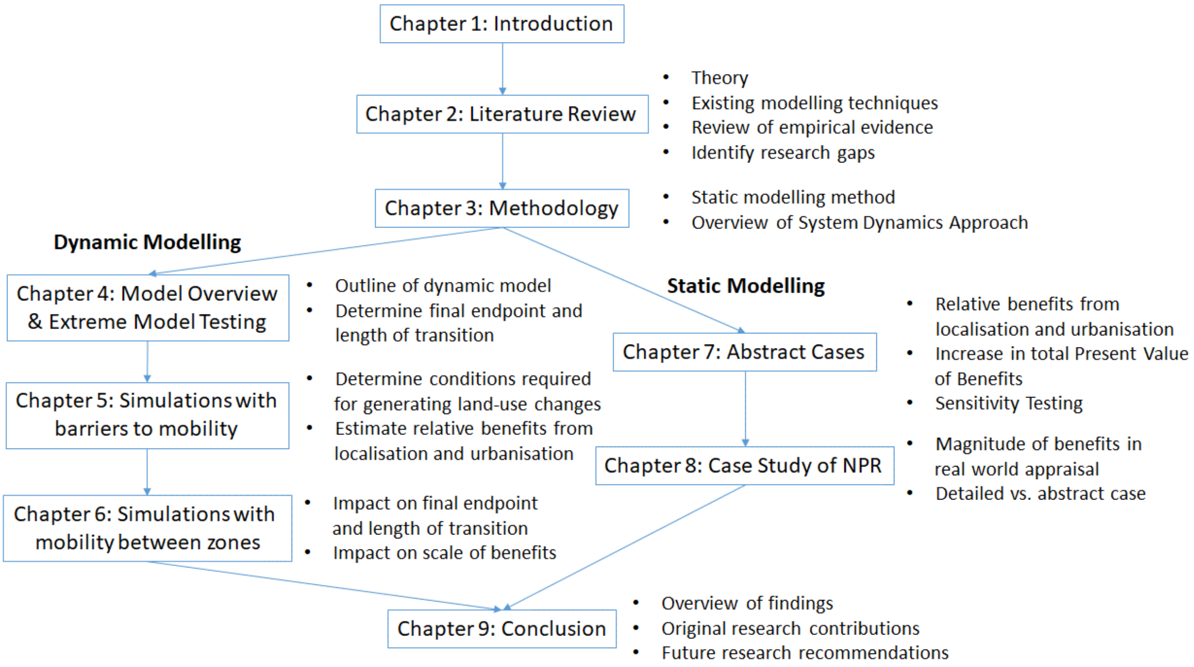

Figure 1.1 Thesis Roadmap

In Chapter 2 a review is undertaken of the literature which has been identified as being most relevant to the research. The review is divided into three sections. In the first section the theoretical basis for the economic impacts of inter-city connectivity is discussed. This includes an overview of the different mechanisms through which inter-city transport can impact on productivity and a discussion of which are likely to provide a source of additional benefits in economic appraisals. A review is then provided of the current modelling methods which are used to assess the economic effects of inter-city connectivity with a focus on the extent to which they take into account the potential for trade and specialisation and localisation benefits. In the following section the empirical evidence on parameters and the land-use changes in response to inter-city connectivity improvements is reviewed. The chapter concludes with a summary of the literature and identification of the key research gaps.

In Chapter 3 the methodology used in the analysis is outlined. This consists of an outline of the method used for estimating localisation and urbanisation benefits and includes an overview of the differences between assessing the impacts with fixed and variable land-use. This is followed by an overview of the system dynamics approach which has been selected for the dynamic modelling which is presented in Chapters 4, 5 and 6.

In Chapter 4 the dynamic model which has been developed for the purposes of this thesis is outlined including the Causal Loop Diagrams (CLDs) and stock and flow model. In the model there are two cities and an inter-city rail scheme is introduced to test the impact on land-use changes in two business service sectors. The model is used to determine the final endpoint and length of transition and the benefits from urbanisation and localisation effects are estimated to compare their magnitude.

In Chapter 5 the dynamic model is extended to take account of the findings from the modelling in Chapter 4 which includes introducing costs for labour and capital of moving sector to make it more realistic. The updated model is then used to determine the extent to which barriers to localisation impacts due to factor mobility costs can be unlocked through inter-city transport. Sensitivity tests are undertaken to determine the impact on the land-use changes and magnitude of the benefits of varying the scale of the mobility costs. In Chapter 6 the dynamic model is further extended to allow mobility of labour and capital between zones. The objectives of this chapter are to test the introduction of zonal mobility on the final endpoint, speed of transition to the new steady state and the conditions required for an inter-city transport scheme to generate changes in specialisation.

In Chapter 7 the evidence from the empirical literature is used to determine how relevant localisation economies are to the economic appraisal of inter-city transport schemes. The analysis is undertaken using an abstract model of two cities and across all sectors of the economy. The benefits are estimated first with fixed land-use which is the standard method for estimating agglomeration benefits in an economic appraisal and then with variable land-use. The objective of the chapter is to determine if the inclusion of localisation benefits and changes in specialisation would be high enough to significantly affect the Present Value of Benefits (PVB) of an inter-city connectivity scheme. Sensitivity tests are undertaken to determine under what conditions localisation benefits are likely to be more and less important. The results are compared to those from the dynamic modelling in earlier chapters to see how and why they are similar and different.

In Chapter 8 a case study is undertaken of the proposed Northern Powerhouse Rail (NPR) scheme in the north of England. A similar method is used to the abstract modelling in Chapter 7 and the results are compared to see if the real world case gives similar relative benefits to the abstract case and if they confirm the other findings from Chapter 7. The case study is also used to determine if there are any differences between undertaking analysis at the detailed and abstract levels.

In Chapter 9 the conclusions of the research are presented. This includes an overview of the findings from each chapter, original research contributions and the implications of the research for modelling and appraisal and for policy. The chapter concludes with recommendations for future work in this research field.

2 Literature Review

2.1 Introduction

In this chapter a review is provided of the literature which has been identified as being most relevant to the research. The review is divided into three broad categories. Firstly, the theories of the how inter-city transport can impact on the economy are discussed. This includes an overview of the different mechanisms through which transport can impact on productivity and a discussion of which of these mechanism are most likely to provide a source of additional benefits in an economic appraisal. Secondly, the methods which are currently used to model transport economy linkages are discussed with a focus on the extent to which they take account of the potential for additional benefits such as through changes in trade and specialisation. Thirdly, an overview is provided of the empirical evidence in the relevant fields. This is followed by a summary of the literature and the identification of the key research gaps.

2.2 Theory

There are several theories which explain how transport schemes can impact on the economy. These are discussed in this section beginning with the neoclassical and endogenous theories of economic growth. The different mechanisms through which transport can impact on productivity are then presented including the theories behind them such as comparative advantage and new economic geography. The section concludes with a discussion of which of the mechanisms provide the most likely source of additional benefits in an economic appraisal of an inter-city connectivity scheme.

2.2.1 Neo-Classical and Endogenous Theories of Economic Growth

Theories of economic growth have been developed to explain how economies grow over time. The neo-classical theory of economic growth was established during the 1950s (Abreu, 2014) which included the development of the Solow-Swan exogenous growth model of long-run economic growth (Solow, 1956, Swan, 1956). The model is based on a production function of capital and labour and technological progress is exogenous. The Solow-Swan model predicts that in the long-run an economy will reach a steady state at which capital per worker is constant as investment in capital per worker will be equal to the effective depreciation of capital per worker. At this equilibrium the growth in economic output is given by the population growth rate only and increased capital per worker can only be achieved through an increase in technological progress.

The Solow-Swan model predicted that GDP per capita growth would be higher for countries which are furthest away from their steady states. This was due to the assumption of diminishing returns to capital which meant countries with lower capital per worker than in their long-run steady state would be expected to have higher rates of return on capital and therefore grow more quickly (Barro and Sala-i-Martin, 2004). This prediction, however, was found not to hold in subsequent decades as developed countries continued to grow more quickly than many developing economies. This led to extensions to the Solow-Swan model to include an endogenous savings rate, exogenous human capital and migration between countries which improved the explanatory power of the model (Abreu, 2014).

While such extensions improved the fit of the model they did not explain the sources of long-term economic growth as technological progress was assumed to be exogenous. This led to the development of endogenous growth theory in the 1980s which incorporated the change in technological progress in growth models based on literature such as Romer (1986) and Lucas (1988). This theory explains how the long-run growth rate of the economy is determined by the rate of knowledge accumulation (Acs and Sanders, 2014). These can be influenced by factors such as investment in research and development, education and knowledge spill overs. Endogenous growth theory suggests that through continuing technological progress advanced economies can continue to grow more quickly than developed countries and convergence across countries can be slow and won't necessarily happen (Martin and Sunley, 1998).

Transport infrastructure also can be included in economic growth models which was explored by Straub (2011). He demonstrated that transport infrastructure can be incorporated in the production function of an economy using the following equation[5]:

$$Q = A(\theta, K_I) \cdot F\big(K, L, I(K_I)\big) \tag{1.1}$$

In this function the output of an economy, Q, is determined by the inputs of the stock of non-infrastructure capital K, the number of labour hours L, and $I(K_I)$ is the impact of the stock of infrastructure capital (K_I) on intermediate inputs. The efficiency through which these inputs are used to produce output is determined by A which is Total Factor Productivity (TFP). This captures the impacts of externalities in production which give rise to efficiency gains both from infrastructure, K_I, and, θ,

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[5] This equation is from Straub (2011), p686

which represents other sources of externalities in the economy such as internal economies of scale.

In this framework transport infrastructure can impact on economic output in two distinct ways (Straub, 2011). Firstly, improvements in transport in infrastructure reduce the cost of intermediate inputs for firms through the infrastructure capital term in equation (1.1). This leads to a fall in firms' unit costs and allows them to expand their production. Secondly, a transport scheme can increase productive efficiency through the externalities term. Some of the effects due to transport are intertwined with other sources of externalities in the economy. For example, the creation and sharing of knowledge from endogenous growth theory is an externality which can boost productivity and improved connectivity could potentially facilitate this. There are several other possible sources of externalities related to transport improvements including agglomeration effects and increased trade and specialisation and these are discussed in detail in Section 2.2.2 below.

Economic growth models have important implications for the impact of transport projects on the economic growth rate according to Straub (2011). They suggest that transport projects can raise the level of the steady state of the economy leading to higher GDP but this will only involve a temporary increase in the economic growth rate. This doesn't mean such schemes are not worthwhile as productivity will be higher at the new steady state and the temporary increase in the growth rate may last several years. Secondly, transport can impact on the long-term economic growth rate only through externalities which can generate endogenous growth. This is more contentious but a series of transport improvements to support increases in productive capacity due to technological progress over time may assist in increasing the long-term growth rate of an economy (Venables et al, 2014).

In the following section the different mechanisms through which inter-city connectivity can impact on productivity are outlined. This is followed in Section 2.2.3 with a discussion about which of these may provide a source of additional benefits which are not included currently in standard economic appraisal guidance.

2.2.2 Transport Economy Linkages

One of the bases for inter-city connectivity schemes is improved economic performance through increased productivity, jobs and output. In this research the main focus is on how inter-city connectivity can impact on productivity and there are several different mechanisms through which it can achieve this. These mechanisms can be divided between direct effects and economy channels and are listed in Table 2.1.

The clearest direct effect of inter-city connectivity is travel cost savings for business and freight users. These savings arise as improvements in inter-city connectivity reduce the costs associated with travelling including journey times and vehicle operating costs. These savings boost productivity through lowering firms' unit costs of production. An important aspect of these savings is that although they are initially realised by freight and business users they may be borne by other economic agents (Venables, et al., 2014). For example, firms' operating in a competitive market may pass reduced travel costs to other firms or consumers.

Another of the direct effects of inter-city connectivity is that it can reduce monopoly power in local markets. Such power arises if there are too few firms operating in a market which can lead to inefficiencies as firms are able to charge higher prices and produce less output than is socially optimal. Improved inter-city transport links can alleviate this through opening up the market to firms based in other locations. In a similar way to travel costs savings the impacts of reduced monopoly power can be realised in secondary markets if the effects of increased competition are passed on to other firms through lower prices.

Table 2.1 Inter-city Connectivity & Productivity Linkages

Direct Effects	Economy Channels[6]
Freight & Business Travel Cost Savings	Technology Diffusion
Reductions in Monopoly and Monopsony Power	Coordination Device
Increased Competition in Supplier Markets => Lower Input Prices	Gains from Trade
Increased Market Access => Internal Economies of Scale	Agglomeration Gains (Urbanisation and Localisation Effects)
Reorganisation Benefits	
Logistical Adjustments	
Reduced Commuting Costs	

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[6] The economy channels listed in this table are from Lakshmanan (2011).

Inefficiencies can also be present in a market due to monopsony power which is when there are too few buyers. This lack of competition can lead to an inefficient allocation of resources as it can force suppliers into pricing at below the socially optimal level. Improved inter-city transport connectivity can mitigate this through increasing access to local markets for buyers located in other places.

The increase in access to markets of firms located in other places can also generate higher productivity if it leads to the realisation of internal economies of scale. These economies occur when firms achieve lower per unit costs through expanding production. The sources of internal economies of scale include spreading management costs over higher levels of output and the ability to invest in new technology which may only be viable at higher levels of production. Firms may also be able to derive economies of scale if an inter-city connectivity scheme allows them to reorganise their activity in fewer locations. This was explored by Mohring and Williamson (1969) who showed that a multi-plant monopolist can become more efficient by rationalising production in fewer plants if transport costs fall. The combination of internal economies of scale over geographic space are called spatial monopolies (Laird & Mackie, 2014).

Other direct productivity effects of improved inter-city connectivity include enhanced logistical arrangements and reduced commuting costs. Improvements to logistical practices include adopting just-in-time production techniques which allow firms to minimise their on-site inventory requirements (Laird, et al, 2014, Anderson and Lakshmanan, 2002). Reductions in commuting costs can increase productivity through lowering the compensation firms pay to workers as part of their wages to cover the cost of travelling to and from work (Laird et al, 2014). This effect is likely to be more relevant for inter-city connectivity schemes over shorter distances as over longer distance the number of commuting trips will be more limited.

In addition to these direct effects Lakshmanan (2011) outlines how inter-city connectivity can also impact on productivity through four economy channels. Firstly, improved inter-city connections can allow technology to be transferred from more to less productive regions leading to efficiency gains. Lakshmanan (2011) highlights the example of countries in East Asia which enhanced their productivity through adopting technology from advanced economies in the second half of the twentieth century. Secondly, inter-city connectivity schemes can act as a coordination device between firms with trade linkages based in different locations. Improved connections can incentivise both firms to invest and expand production at the same time leading to higher productivity through the realisation of economies of scale. There is also a spatial variation of this effect in which transport improvements can incentivise firms in sectors with linkages to locate together leading to lower transport costs and economies of scale (Laird et al., 2014).

There are two further economy channels put forward by Lakshmanan (2011): gains from trade and agglomeration gains. These have particular relevance to this research and each are discussed in more detail in the following two sub-sections.

2.2.2.1 Gains from Trade

Reductions in trade barriers can lead to efficiency gains through allowing places to become more specialised in particular sectors and there are two main mechanisms through which these can be realised (Lakshmanan, 2011). Firstly, reductions in trade barriers can allow places to switch more productive resources into the sectors in which they are more efficient. This is called the Theory of Comparative Advantage which was developed in the early 19th century by English economist David Ricardo (Ricardo, 1817).

To explain his theory Ricardo used the example of the production of cloth and wine in Portugal and England. He demonstrated that if Portugal was more efficient at producing wine than cloth and England was more efficient at producing cloth than wine then if trade barriers were reduced between the countries then both could gain by becoming more specialised in the sector in which it is more efficient. Ricardo showed that there is a net welfare gain to society of these structural changes as the efficiency gains allow consumers in both countries to increase their consumption of both goods.

The second mechanism for increased trade and specialisation due to inter-city connectivity is that it can lead to the realisation of economies of scale. This is a key feature of the theory of new economic geography (Krugman, 1991b, Fujita et al. 1999) which was developed to explain why economic activity in the real world is unevenly distributed (Lafourcade and Thisse, 2011). This theory introduces spatial dimensions into the neoclassical economic framework (Wilson, 2011) and suggests that the observed concentration of economic activity can be explained by the interaction of transport costs, market size and economies of scale.

In new economic geography models the equilibrium spatial distribution of sectors is determined by the relative strength of centripetal and centrifugal forces (Fujita, 2007). For firms one of the most important centripetal forces is the greater access to markets of locating in concentrated locations. The resulting increased proximity to customers reduces firms' transport costs and allows firms to expand production and realise internal economies of scale[7]. For workers the centripetal forces include higher wages due to economies of scale in concentrated areas and access to more differentiated products and services. The centrifugal forces for both firms and workers include higher land prices in urban areas and firms can also benefit from less competition in less concentrated regions. Over time new economic geography modelling suggests that there can be a process of cumulative causation in which workers and firms become clustered together in a location which increase its attractiveness to other firms and workers to relocate there (Redding, 2009).

One of the main results of new economic geography is that there is a bell-shaped curve of spatial concentration of economic activity in relation to transport costs (Lafourcade and Thisse, 2011). This result derives from the finding that if transport costs fall from an initially high level such as before the Industrial Revolution then production will become concentrated in a few locations to benefit from increasing returns to scale. If transport costs continue to fall, however, production will start to disperse again as centrifugal forces start to dominate such as congestion and higher land rents and wages in cities. This bell-shaped curve is supported by evidence from France (Combes et al., 2011) and the USA (Kim et al., 2003) which showed that manufacturing industries became more concentrated in specific regions in the 19th century but dispersed again during the 20th century.

2.2.2.2 Agglomeration Gains

Agglomeration gains are based on a finding from the empirical literature that there is a positive relationship between city size and productivity. The sources of agglomeration effects can be characterised as sharing, matching and learning (Duranton and Puga, 2004) and the evidence suggests that doubling economic mass leads to a 3 to 8 per cent increase in productivity (Rosenthal and Strange, 2004). Agglomeration effects are an example of external economies of scale as the effects are not internal to firms but derive from interactions between them.

There is an important distinction between agglomeration gains deriving from urbanisation and localisation economies. The former stem from the productivity gains of greater density of overall economic activity whereas the latter derive from higher density of firms within the same sector. Urbanisation economies are a function of labour market pooling, supply chain linkages and inter-industry knowledge spill overs

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[7] In the first models developed based on the theory of new economy geography such as Krugman (1991b) the centripetal forces were based on pecuniary externalities. However, later modelling in the field has incorporated external economies of scale such as knowledge spillovers and innovation from endogenous growth theory (Baldwin and Forslid, 2000, Hirose, 2008).

(Combes and Overman, 2004). Localisation economies arise as increased proximity of firms can lead to the development of a specialised labour market pool, sharing of inputs and own-industry knowledge spill overs (Rosenthal and Strange, 2003).

A pertinent aspect of agglomeration economies for inter-city connectivity schemes is that the evidence suggests that the effects can decay quickly over distance (Melo et al., 2016). Melo and Graham (2009) calculated that an increase in 100,000 jobs in a location led to an increase in average wages of 1.19% within 5km but only 0.15% between 10 and 20km. Rice et al. (2006) estimated that urbanisation effects drop rapidly beyond a 40-minute driving time and are insignificant beyond 80 minutes. Fewer studies have estimated the speed of decay of localisation effects but the evidence suggests that the effects may decline even more rapidly than for urbanisation. Graham (2009) estimated that in many sectors localisation economies are not significant beyond 5km and Arzhagi and Henderson (2008) estimated localisation effects were not significant beyond 750 metres for the advertising sector in Manhattan. Taking all of this evidence together suggests that with fixed land-use there may be a tipping point related to the travel time between places over which agglomeration benefits will not be significant. The empirical evidence on elasticities and decay factors for urbanisation and localisation economies by sector is discussed in detail in Section 2.4.1 later in this chapter.

While the decay of the effects over distance may limit the scope for localisation benefits due to inter-city schemes it has been suggested that they could be more significant if such schemes can promote increased specialisation (Rosewell and Venables, 2013). This was explored by Venables (2017) who built a theoretical model of two regions in which a final good is produced with two intermediate goods. He found that the combination of inter-city transport improvements and localisation effects could lead to each region becoming more specialised in the production of one of the intermediate goods. He estimated that the welfare gains could be potentially large but also found that improved inter-city links was a necessary but not sufficient condition to realise all of the benefits. To maximise the benefits other coordination policies to further specialisation would be required such as investment to develop the areas around inter-city transport nodes (Venables, 2017).

In this section the different mechanisms in which inter-city connectivity can impact on productivity have been outlined. In the next section consideration is given to the most likely sources of additional benefits which are not currently included in economic appraisal guidance.

2.2.3 Additionality of Benefits

An established methodology for measuring changes in welfare due to a transport project is Cost Benefit Analysis (CBA). This is based on microeconomic theory and involves evaluating the social welfare impact of a transport scheme by comparing the monetised benefits and costs. Techniques for estimating the direct cost savings from transport schemes such as time saving benefits are well established and in the absence of any market failures these capture all of the economic benefits. In reality, however, market failures are present in most markets such as imperfect competition and externalities which mean not all benefits are captured in a standard CBA (Venables et al., 2014). This raises an important question around what types of market failure are most likely to give rise to additional benefits due to improvements in inter-city connectivity.

One potential source of market failure which has been investigated in relation to inter-city connectivity improvements is the combination of market power and internal economies of scale. Mohring and Williamson (1969) explored this using the example of a multi-plant monopolist which is able to choose where to locate production subject to a budget constraint. The authors showed that in response to a transport improvements the monopolist can realise efficiency gains from concentrating their production in fewer locations. However, they found that these benefits are not additional to a conventional CBA as the benefits are captured by the area under the demand curve in the transport market (Small, 1999).

The potential for additional benefits due to market power was also explored by Jara-Díaz (1986) who analysed the production and trade of a good between two locations varying the level of competition. He found that with perfect competition or pure monopoly the welfare changes are fully captured by the consumer surplus in the transport market but with monopolistic competition this result may not hold as firms are able to exercise market power and set prices above marginal cost. The level of welfare change not captured in a standard CBA was found to increase in market power and decrease with the elasticity of demand in the market for the good. Minken (2014) undertook a similar analysis to Mohring and Williamson (1969) but examined both a perfect competitively market structure as well as a multi-plant monopolist. Minken (2014) found that it is not if prices are above marginal cost which is crucial in determining if benefits are additional but if the market is at a socially sub-optimal equilibrium.

Vickerman and Ulied (2012) considered the literature in the context of HSR schemes and concluded that the overall impact on social welfare of market power is likely to be unpredictable. While an inter-city transport scheme could allow firms easier access to other markets resulting in increased competition and therefore reduced market power it could also drive the exit of firms from markets which may lead to increased monopoly power. Vickerman and Ulied (2012) suggest that the effects may vary by sector and efficiency gains in some sectors may be offset by reductions in others and the overall net benefit could be negligible.

Another potential source of market failure which could give rise to additional benefits from inter-city connectivity schemes are external economies of scale through agglomeration effects. These were discussed in Section 2.2.2.2 above and encompass the productivity gains from an increase in overall economic density (urbanisation economies) or within specific sectors or tasks (localisation economies). Several studies have investigated the potential for urbanisation[8] effects due to transport projects. These included Venables (2007) and several papers authored and co-authored by Daniel Graham (Graham, 2005, Graham, 2006, Graham, 2007 and Graham, Gibbons & Martin, 2009). These studies showed that transport improvements can generate welfare gains which are additional to those in a standard CBA and that the scale of the benefits can be significant. This research subsequently formed the basis for the inclusion of urbanisation benefits in the UK's DfT appraisal guidance (DfT, 2018c). Urbanisation benefits are now regularly included in the economic appraisals of transport schemes in the UK and several other countries such as Australia, New Zealand and Sweden (Mackie & Worsley, 2013).

The main focus of the development of methods for estimating urbanisation benefits was intra-urban rather than inter-city transport projects (Melo and Graham, 2010). As highlighted in Section 2.2.2.2 it has been suggested that for inter-city projects there may be potential for significant localisation benefits if such schemes can generate increased specialisation (Rosewell and Venables, 2013). This was investigated by Venables (2017) using a theoretical model who showed that the welfare gains could be potentially significant (Venables, 2017). In contrast to urbanisation effects the benefits from localisation effects are not typically included in economic appraisals[9]. It

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[8] In some of the literature these effects are referred to as agglomeration effects. While changes in overall economic density will also include some changes in the density of sectors the effects primarily arise due to the former. In the remainder of this thesis these are referred to as urbanisation effects and productivity gains due to changes in the density of sectors are referred to as localisation effects.

[9] Localisation benefits have been included in the latest DfT's WebTAG Guidance (DfT, 2018c). In contrast to the guidance on urbanisation benefits no parameters are recommended for

has been suggested that these benefits have the potential to have a material impact on the business cases of inter-city transport schemes if they were included (Rosewell and Venables, 2013).

In addition to market power and external economies of scale there are other types of market failure which have the potential to lead to additional benefits from transport projects. This was explored by Venables et al. (2014) who concluded that market failures will be context-specific and different for intra- and inter- city connectivity schemes. For inter-city connectivity schemes the authors suggest another potential market failure could be barriers to development. These could arise from monopoly power of local property developers or coordination failure such as when firms with trade linkages are based in expensive regions and could realise efficiency gains from relocating together in less expensive places. Venables et al. (2014) also suggest that there could also be market failures present in the labour market giving rise to additional benefits such as the movement of workers from less to more productive locations[10].

The UK's DfT has been at the forefront of the development of guidelines for the economic appraisal of transport schemes (Venables et al. 2014). These guidelines initially focussed on direct cost savings but over the last 10 to 15 years methods have been developed to assess some of the benefits arising from the presence of market failures which are known as Wider Economic Impacts (WEIs). The WEIs now included in the UK DfT's appraisal guidelines (DfT, 2018b) are market power in imperfectly competitive markets, labour supply impacts, urbanisation effects and the impacts of jobs moving from less to more productive locations.

The inclusion of these WEIs in economic appraisals in the UK has had a significant impact on the estimated total benefits of some major transport infrastructure schemes. In the appraisal of Crossrail, which is a new underground railway line currently under construction in London, the WEIs were estimated at 30.8% of the total present value of benefits (PVB). Urbanisation benefits have also been found to be significant for inter-city schemes. In the appraisal of HS2 which is a high speed rail network currently under construction in the UK WEIs were estimated at 19.1% of the total present value of benefits.

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localisation effects. In addition, there is no detailed guidance for how to model changes in specialisation.

[10] These benefits are different to agglomeration benefits and arise from increased tax revenue on workers' incomes due to the increased wage rates of those who relocate.

In the appraisal of both of these schemes urbanisation benefits were estimated to be one of the largest sources of WEIs. In the appraisal of Crossrail urbanisation benefits accounted for 43.2% of WEIs (Crossrail Ltd., 2005) and for HS2 urbanisation benefits accounted for 62.5% of WEIs (DfT, 2017a). These results demonstrate that the inclusion of urbanisation effects has had a material impact on the appraisal of transport projects. This finding suggests that the localisation benefits arising from higher densities due to increased specialisation may also have the potential to impact on the present value of benefits of transport schemes. The magnitude of these benefits may potentially be significant and their omission from current appraisal guidelines is a gap and may be leading to sub-optimal decision-making.

In this research it was decided to focus on developing methods to assess the potential for changes in specialisation due to inter-city connectivity improvements and to estimate the scale of additional benefits due to localisation effects. It will be key to determine if the benefits would be high enough to significantly affect the Present Value of Benefits (PVB) of a scheme and under what conditions localisation benefits are likely to be more and less significant. In Section 2.3 an assessment is made of the extent to which current modelling methods include these effects. This is followed in Section 2.4 with a discussion of the empirical evidence on the parameters for localisation effects and on changes in land-use in response to inter-city transport improvements.

2.3 Transport Economy Modelling

A variety of modelling tools have been developed to assess the impacts of transport on land-use. One of the most commonly used methods are Land-Use Transport Interaction (LUTI) models which were first developed in the late 1950s in the USA (Iacono et al., 2008). In LUTI models transport and land-use interact so that changes in land-use impact on transport and vice versa (MVA/ITS, 2013). The first LUTI models were focussed on urban areas (Wegener, 2004) but a number of multi-regional LUTI models have now been developed. These include SASI (Spatial and Socio-economic Impacts of Transport Investments and Transport System Improvements) of Europe (Wegener, 2008) and TIGRIS-XL of The Netherlands (Zondag et al., 2015).

There are several drawbacks of LUTI models for modelling the impacts of inter-city connectivity on specialisation. In contrast to alternative approaches such as Spatial Computable General Equilbrium (SCGE) models LUTI models are not based on economic micro-foundations. This means simplifying assumptions are often required in LUTI models such as that markets clear with prices equal to marginal cost and that all markets are perfectly competitive (Vickerman, 2012). Another weakness of LUTI models is that most are based on determining equilibria rather than modelling continuous dynamic processes (Swanson, 2007). This has particular relevance to the modelling of changes in specialisation as modelling based on new economic geography theory suggests that the relocation of firms and workers occurs due to a process of cumulative causation and structural changes take place over several years (Krugman, 1991b, Fujita et al., 1999).

Dynamics have been incorporated into some LUTI models through the application of the system dynamics approach which was developed by Jay W. Forrester in the USA in the 1950s. This approach is a framework for modelling complex non-linear systems which can incorporate interdependent relationships between variables, feedback loops and lagged effects[11]. A key aspect of this method is that the structure of a system including the feedback loops between variables is crucial whereas in contrast individuals tend to think in short causal chains between a limited number of variables (Sterman, 2006). System dynamics is commonly used in the real world in many fields including economics, transport, education, environment and health.

Several LUTI models been developed based on the system dynamics approach including the UDM (Urban Dynamic Model) (Swanson, 2007) and MARS (Metropolitan Activity Relocation Simulator) (Pfaffenbichler et al., 2008). These models were originally developed to focus on effects within cities or city regions but more recently versions have been developed of wider areas including a UDM of the North of England and a MARS model of Austria. In both models transport changes feed through into changes in the attractiveness of zones for residential and commercial use. Residents and firms can relocate subject to constraints which then feeds back into which impacts on conditions on the transport network. In both models the land within a zone can be reallocated between residential and commercial use but the models do not take account of changes in trade and specialisation or localisation effects.

The system dynamics approach was also used in the development of ASTRA (Assessment of Transport Strategies) (Schade et al., 2000). This is a model of the countries in the European Union, Norway and Switzerland which was developed to determine the impact of transport policies and strategies (Fermi et al., 2014). In ASTRA there are 25 sectors which are linked together in a sector interchange sub-

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[11] The system dynamics approach is outlined in detail in Section 3.3 of Chapter 3.

model. In this sub-model there is an input-output framework and changes in transport costs impact on the spending of households and businesses which drives changes in demand and sectoral employment (Schade et al., 2018). ASTRA can therefore represent some aspects of changes in specialisation due to inter-city connectivity but localisation effects are not included.

Although localisation effects have not been incorporated into dynamic LUTI models there have been several attempts to model agglomeration processes within clusters using the system dynamics approach. These studies show how the interdependence of variables can lead to efficiency gains due to proximity within a geographical area which over time can lead to the development of comparative advantage. Some of these studies (Buendia, 2005 and Dangelico et al., 2010) focus on the importance of knowledge spill overs rather than pecuniary externalities and the role of transportation has not been central to the analysis. A recent exception to this is Diaz et al. (2016) who modelled the interactions of transport infrastructure, population and GDP within regions but inter-city connectivity was not considered in the study.

Buendia (2005) outlines how economic clusters are dynamic systems and how they arise and evolve over time. A model is developed using system dynamics based on increasing returns to spatial concentration of economic activity which includes both pecuniary and knowledge spill overs. Reinforcing and balancing feedback loops are shown to interact leading to the development of clusters over time until a steady state is achieved. The author identified two significant weaknesses in Krugman’s (1991b) formalised model of new economic geography in relation to the development of clusters. Firstly, the model is based on only a few variables such as transport costs and economies of scale and other important variables such as knowledge spill overs and research and development investment are excluded. Secondly, clusters are complex systems and it is the mutual causality between many variables which leads to pecuniary externalities but these are assumed rather than explained in Krugman’s model.

Another common method for modelling transport and economy linkages are SCGE (Spatial Computable General Equilibrium) models. These model are based on micro-foundations and were originally developed from the input-output framework established by Leontief (1936) (Charalampidis et al., 2019). SCGE models can model agglomeration effects and incorporate spatial elements of new economic geography such as centrifugal and centripetal forces but the majority of the models are static. Examples of multi-regional SCGE models include CGEurope (Bröcker, 2004) and PINGO (Prediction of regional and Inter-regional freight transport) of Norway (Vold and Jean-Hansen, 2007).

There have been efforts to incorporate dynamics into SCGE models such as RAEM 3.0 (Relative Acculturation Extended Model) (Ivanova and Tavasszy, 2007) and REMI (Regional Economic Models, Inc.) (Treyz et al., 1991). Although RAEM 3.0 and REMI produce forecasts over time they are recursive-dynamic which means that static equilibria are forecast for each point in time rather than modelling the dynamics explicitly (Ivanova and Tavasszy, 2007). Forward-looking dynamic SCGE models have also been developed such as CGEurope-R based on the condition that individuals have perfect foresight but this is an unrealistic assumption (Bröcker and Korzhenevych, 2013).

In summary there is no complete method currently available for modelling the impact of inter-city connectivity on changes in specialisation and localisation effects. Many of the impacts are likely to take place over long timeframes which are currently modelled coarsely in modelling tools such as LUTI models. Some dynamic LUTI models have been developed based on the system dynamics approach but they do not incorporate changes in specialisation based on localisation effects. SCGE models can take account of the micro-foundations such as changes in trade and specialisation and include elements of new economic geography theory such as centripetal and centrifugal forces. SCGE models, however, are based on static rather than dynamic frameworks and models based on new economic geography suggests that transitional dynamics are important in the modelling of changes in trade and specialisation.

2.4 Empirical Evidence

In this section the evidence from the empirical literature which is relevant to the research is reviewed. The evidence on urbanisation and localisation economies is discussed first in Section 2.4.1 followed by the evidence on land-use changes due to inter-city connectivity improvements in Section 2.4.2.

2.4.1 Urbanisation and Localisation Economies

One of the first studies to estimate the scale of agglomeration effects was Sveikauskas (1975). He used data for 14 manufacturing industries in the USA and estimated an agglomeration elasticity with respect to city size of 0.06. There have been many subsequent studies and Rosenthal and Strange (2004) summarise that the evidence suggests that the impact of doubling employment in a city is a 3 to 8 per cent increase in productivity which equates to an elasticity range of 0.04 to 0.11.

Many of the empirical studies on agglomeration economies do not distinguish between the effects which are due to urbanisation and localisation which can vary considerably. This can lead to biased estimates which overstate the scale of the productivity effects (Graham, 2005). This can be seen in the meta-analysis of studies on agglomeration effects (Melo et al., 2009) which found that including localisation effects reduced the size of the estimated urbanisation elasticities by 0.025. To understand the relative scale of localisation and urbanisation economies it is therefore important to focus on studies in which they have been estimated simultaneously to avoid any bias (Graham, 2005). A summary of the elasticities from studies which simultaneously estimated localisation and urbanisation effects on productivity is shown in Table 2.2. As can be seen only a few studies have undertaken a simultaneous estimation of both types of elasticity.

One of the first studies that simultaneously determined estimates for both types of agglomeration effect was Nakamura (1985) using data from 1979 for manufacturing firms in Japan. Using a translog production function he estimated higher elasticities for localisation effects (0.046) than urbanisation (0.034). Supporting the results of subsequent studies he found that the results varied significantly by sector and he estimated higher elasticities for urbanisation than localisation for lighter industries such as Printing & Publishing. He concluded that the differences for manufacturing industries are likely to be determined by the extent to which a sector is dependent on access to markets for urbanisation economies or to materials and equipment for localisation economies.

Using data from Brazil Henderson (1986) analysed data for 11 manufacturing industries using a production function with a flexible functional form. He estimated significant positive localisation elasticities for all of the industries except Printing & Publishing. The elasticity estimates were greater than 0.1 for five of the ten sectors with positive elasticities ranging from 0.03 in Apparel to 0.21 in Chemicals with a mean value of 0.105. He found significant evidence for positive urbanisation economies only for Printing & Publishing (0.177) and limited evidence for the manufacture of non-metallic products and furniture.

Henderson (1986) also used US data to estimate elasticities across 16 industries and estimated significant positive localisation economies in nine of sixteen industries ranging from 0.09 (Pulp & Paper) to 0.45 (Petroleum) with a mean value of 0.19. He estimated significant positive urbanisation economies only for the manufacture of non-metallic products. Unlike Nakamura (1985) he found some evidence of diseconomies but only for one sector for urbanisation effects and three sectors for localisation and he did not put forward an explanation for these results.

Table 2.2 Evidence on Urbanisation and Localisation Elasticities

Study	Time Period	Country	Sectors	Localisation Elasticities	Urbanisation Elasticities
Nakamura (1985)	1979	Japan (Cities)	Manufacturing	Mean = 0.046	Mean = 0.034
Henderson (1986)	1970	Brazil (SMSAs)	Manufacturing	0.03 to 0.21, Mean = 0.105	0.05 to 0.18, Mean = 0.098†
	1972	USA (SMSAs)	Manufacturing	0.09 to 0.45, Mean = 0.19†	0.022 to 0.074, Mean = 0.049†
Moomaw (1988)	1977	USA (SMAs)	Manufacturing	0.039 to 0.170, Mean = 0.087	0.04 to 0.123, Mean = 0.075
Brülhart & Mathys (2008)	1980-2003	EU (NUTS-2)	Manufacturing	0.00	0.17
	1980-2003	EU (NUTS-2)	Financial Services	0.23 to 0.26	-0.17‡
Graham (2009)	1995-2002	UK (Wards)	Manufacturing	0.026 to 0.074, Mean = 0.046†	0.06 to 0.39, Mean = 0.208†
	1995-2002	UK (Wards)	Services	0.042 to 0.124, Mean = 0.076†	0.13 to 0.38, Mean = 0.251†

† Only positive and significant results included. ‡ Overstated due to inclusion of localisation effects within estimate. There are no values included in the table from Wetwitoo and Kato (2017), Marrocu et al. (2013) and Foster and Stehrer (2009) as specific elasticity values are not stated in their papers.

Using a different approach Moomaw (1988) estimated the impact of employment density on productivity using a labour demand equation rather than a production function. He estimated elasticities for 18 manufacturing industries in the US and found positive urbanisation elasticities in seven industries with a mean of 0.075 and positive localisation elasticities in nine industries with a mean of 0.087. He found no evidence for urbanisation and localisation effects in 8 of the 18 sectors. He also found some evidence to support the finding in Henderson (1986) that there may be urbanisation diseconomies by sector with negative values estimated for Primary Metals and Chemicals.

More recent studies have estimated elasticities for a wider range of sectors than only manufacturing. This is important as only 10% to 20% of jobs are in manufacturing industries in more developed economies (World Bank, 2018). Brülhart and Mathys (2008) used a production function with NUTS-2 region data for 20 European countries to estimate urbanisation and localisation elasticities for seven sectors including Financial Services, Wholesale/Retail, Hotel/Restaurants and Transport/Communications. They found evidence for urbanisation economies in most sectors with a mean estimate of 0.13. For localisation economies they found most effects were negative including manufacturing industries which they suggest may be due to congestion diseconomies. Financial services is the only sector they estimated significant positive localisation economies for of 0.23 to 0.26 and they also found evidence for limited urbanisation economies in the same sector.

The impacts have also been estimated using data for Japan. Using a regional production function Wetwitoo and Kato (2017) estimated the productivity effects of inter-city transport in Japan between 1981 and 2006. They estimated elasticities for eleven broad groups of sectors including four service sectors (Finance & Insurance, Real Estate, Transport & Communication, Services). They found evidence that localisation effects are higher than urbanisation effects overall but the results varied by sector. They estimated both positive urbanisation and localisation economies for Finance & Insurance and Real Estate and higher localisation than urbanisation effects for Transport & Communications.

The estimated elasticities have been found to hold at a more disaggregate level of geographic data. Using a translog production function Graham (2009) estimated localisation and urbanisation elasticities for 27 sectors by distance band up to 50km using data from Great Britain at ward level. He found evidence for positive localisation effects in several service sectors including Finance & Insurance (0.06), Architecture & Engineering (0.08) Advertising (0.09), Computers (0.10) and Business & Management Consultancy (0.12). He found evidence of even stronger urbanisation economies for most service sectors with average estimates of 0.22 for Business & Management Consultancy, 0.25 for Land, Water & Air Transport, 0.26 for Finance & Insurance, 0.37 for Media and 0.38 for Public Admin. Only a few service sectors were found to have higher localisation elasticities than urbanisation: Computers, Architecture & Engineering and Advertising. In contrast to many of the studies discussed above Graham (2009) found limited evidence for positive localisation elasticities in manufacturing industries except for Food & Beverages and effects over short distances in the manufacture of Chemicals, Rubber & Plastics, Motor Vehicles & Transport Equipment. He also estimated positive urbanisation economies for four manufacturing industries ranging from 0.06 for the manufacture of Metal Products to 0.13 for Publishing & Printing.

Graham (2009) produced negative elasticity estimates for localisation effects for several sectors. He suggested that these results could be due to price competition and also due to the importance of access to customers rather than firms for sectors such as retail and public services. This latter effect is supported by his finding of higher urbanisation effects than localisation for such sectors. Graham (2009) also estimated negative urbanisation elasticities and inconsistent values across different distance bands for a few sectors. He attributes these to identification issues due to multicollinearity between localisation and urbanisation effects. In a study (Graham, 2006) estimated that for many sectors the elasticities decline once a certain threshold of effective density has been reached. He concluded that this suggests that many sectors are better suited to being based on smaller urban areas and elasticities can be negative for very high densities. The exception to this was found to be Business Services for which the productivity benefits from continued to increase even at high levels of density.

The estimated elasticities have been found to vary significantly between countries with different economic characteristics. Foster and Stehrer (2009) estimated localisation effects across the European Union (EU) at 0.04 but they found much stronger localisation effects in newer member states in Eastern Europe (0.20) than member states in Western Europe (0.01). Brülhart and Mathys (2008) also found elasticity estimates for Europe which were significantly higher when Eastern European countries were included. This may be explained by the history of concentration of economic activity in those countries dating back to when they were Socialist Republics (Brülhart and Koenig, 2006). Marrocu et al. (2013) also found significant differences in elasticity estimates for Western and Eastern Europe by sector. They found evidence for localisation economies for low-tech manufacturing sectors in Eastern Europe but diseconomies in Western Europe and they also estimated positive urbanisation effects for knowledge-intensive sectors within large urban areas in Western Europe but not in Eastern Europe.

Similar evidence for these findings has been found for other parts of the world. Combes et al. (2015) estimated that doubling city size in China increased wages by 8.7 per cent which the authors note is around three times the equivalent estimates for North America and Europe. In a meta-analysis Melo et al. (2009) also found higher estimates for Brazil than the USA and Canada. This evidence suggests that middle-income countries may be more likely to realise higher benefits from agglomeration effects than more developed economies.

There is strong evidence from the literature that productivity impacts of changes in economic density are greater closer to where the changes occur than places further away (Combes and Gobillon, 2015). The degree of this spatial decay of the effects is incorporated in the calculation of agglomeration benefits using distance decay factors. The speed of decay is the inverse of the square of the factor (as shown in Equations (1) & (2)). For example, a decay factor of 2 would mean that the benefits of density at twice the distance are quarter of the amount. Higher decay factors mean the effects diminish more rapidly over distance and a decay factor of zero would imply no decay of the effects over distance.

The decay of localisation and urbanisation economies by sector are not consistent. This is because the different aspects of the economies such as market access, supplier access, knowledge spill overs and access to labour will decay at different speeds (Combes and Gobillon, 2015) and will vary by sector. For example, to benefit from urbanisation or localisation economies deriving from market access it may be enough for a firm to be located within the same city as its customers but to benefit from knowledge spill overs a firm may need to be based in the same neighbourhood as other firms.

The evidence suggests that urbanisation effects attenuate rapidly with distance but there have been only a limited number of studies (Melo et al., 2017). Melo and Graham (2009) calculated that an increase in 100,000 jobs at a location led to an increase in average wages of 1.19% within 5km but only 0.38% between 5 and 10km and 0.15% for 10 to 20km. Using Great Britain data Rice et al. (2006) estimated that urbanisation effects diminish rapidly with travel time and found no evidence for any effects beyond 80 minutes. Evidence for Italy found no significant effect beyond 12km but the authors note this is likely to reflect the relatively small size of local labour markets in the country (Di Addario and Patacchini, 2008). Melo et al. (2017) summarise that the evidence suggests that urbanisation benefits can be present up to the extent of the local labour market.

Localisation effects have been found to typically decay more rapidly over distance than urbanisation effects. Graham (2009) estimated that localisation effects diminished more rapidly than urbanisation effects and that in some sectors they are not significant beyond 1km in some manufacturing industries and beyond 5km in Finance & Insurance and Business & Management Consultancy. Localisation effects can sometimes be present over very short distances. Arzhagi and Henderson (2008) estimate that all localisation effects for advertising in Manhattan in New York are realised within 750m where 24% of all advertising agency receipts in the US are made. Duranton and Overman (2005) estimated that all localisation effects dissipate within 50km.

There is relatively limited evidence for the values of decay factors and particularly by sector (Graham and Melo, 2010). Rice et al. (2006) estimated the rate of decay for urbanisation effects equivalent to a decay factor of between 1.37 and 1.51 depending on the specification. Amiti and Cameron (2007) estimated decay factors for supplier and market access on productivity in Indonesia of 1.8 and 2.8 respectively. Graham et al. (2010) estimated decay factors for urbanisation for broad sector groups of 1.0 for manufacturing, 1.6 for construction, 1.7 for consumer services and 1.8 for business services with an economy average of 1.7. These subsequently became the recommended values in the UK transport appraisal guidance (DfT, 2018c). The higher values for services is likely to be due to these effects being related to knowledge spill overs which take place over short distances whereas market access may be more important in other sectors (Combes and Gobillon, 2015).

2.4.2 Impact of Inter-city Connectivity on Land-Use Change

In the previous sections in this chapter the theories behind changes in land-use due to inter-city transport have been discussed. In this section the empirical literature on how inter-city transport can impact on land-use is reviewed. The section begins with a review of the evidence on how inter-city transport can generate changes in sectoral composition before discussing the extent to which any resulting changes in employment are likely to be due to net changes or displacement.

2.4.2.1 Changes in Sectoral Composition

Inter-urban transport schemes have been found to promote specialisation in manufacturing industries. One of the most studied inter-city transport projects is the US inter-state highway network which was developed from 1956 and was largely completed by the 1990s. Bougheas et al. (2000) analysed its local economic impacts and found that highways and specialisation in manufacturing industries were positively correlated but they did not quantify the extent of specialisation changes due to transport. Duranton and Turner (2012) estimated that a 10% increase in a city's stock of interstate highways led to an increase in employment of 1.5% within 20 years.

The spatial effects of the US inter-state network on manufacturing industries appears to have declined in more recent years. Using data from between 1969 and 1993 Chandra and Thompson (2000) estimated that after ten years of a highway improvement wages increased by 6.2% in Services, 6.2% in Retail and 9.3% in Finance, Insurance and Real Estate (FIRE) but they found no significant change in manufacturing and a decline in farming. They didn't estimate the changes in employment but suggest that the wage changes are likely to partly reflect changes in employment by sector. They found that the changes were due to reallocation of activity from other areas and there was no net increase in overall economic activity.

The impact of changes in US inter-state lane density has been found to have different impacts on employment growth by sector. Jiwattanakulpaisarn et al. (2010) analysed the period between 1984 and 1997 and found significant positive results for services and construction. They found that these changes were all accounted for by redistribution of jobs from nearby states but the results for manufacturing industries were insignificant. The lower impacts found in manufacturing sectors in the later studies may reflect that much of the changes had already taken place by that time. Duranton et al. (2014) estimated that all specialisation changes in manufacturing industries due to inter-state highways within cities from 1956 onwards had taken place by 1997 and that the majority of the impacts had taken place by 1987.

The impact of inter-city transport on sectoral composition may be considered at the level of tasks as well as sectors. Tasks are functions below the level of sectors such as the manufacture of sub-components or the headquarters, designers or finance workers within different service sectors. Different functions may benefit from different locations and good transport and communications can allow these to gain scale in different locations. Duranton and Puga (2005) found evidence that cities in the US have changed from being specialised in sectors to tasks and the evidence for this was particularly strong in the first decades of the 20th century when they note transport and communications links improved significantly. Michaels et al. (2013) found evidence of increased specialisation in tasks in the US due to improved accessibility over a longer period of study from 1880 to 2000. They estimated that the changes were largest in the early decades of the 20th century during which time there was a rapid improvement in inter-urban transport and communication links.

Evidence for changes in employment with respect to accessibility improvements has been found in Europe. Using data for Great Britain Gibbons et al. (2019) analysed the impact of highway improvements on sectoral employment and wages between 1986 and 1997. They estimated that a 1% increase in accessibility led to an increase in the number of jobs and firms with an elasticity of 0.3 to 0.5. Average accessibility increased by 0.34% over the study period which suggests that the resulting employment increase was 0.12% to 0.17%. Their estimates by sector were found to be less robust but they found evidence that employment increased most in producer, administrative and transport services. The authors also note that they did not examine the extent to which the employment changes were due to displacement. Gibbons et al.'s (2019) elasticity estimates are higher than those estimated for urban transport in the US such as Ozbay et al. (2006) who estimated an elasticity of employment to accessibility of 0.046 in the New York/New Jersey metropolitan area and Berechman and Paaswell (2001) who estimated an elasticity of 0.044 for South Bronx, New York.

The introduction of HSR lines between cities has also been found to foster changes in sectoral composition. Qin (2017) analysed the impacts of the introduction of HSR services in China in the 2000s and found that in the counties which did not receive HSR services GVA and GVA per capita fell by 3% to 5% and fixed capital investment by 9% to 10% relative to counties which did receive HSR stations. He found that GVA in service sectors were most negatively affected in these areas (-3%) and that there were no significant changes in manufacturing. This suggests service activity moved from rural areas to the cities served by HSR.

In another study of the impact of HSR in China Lin (2017) analysed the introduction of HSR services in 81 cities between 2003 and 2014 on 16 sectors. He estimated that the presence of an HSR station in a city increased employment by 7% and he found that the effects were highest in sectors where face-to-face interactions are most important such as in finance, retail and medical services. He found no positive impact of HSR on manufacturing industries but he did find positive effects of highway improvements. Dong (2018) found that HSR increased sectoral employment in retail/wholesale and hotel/food industries but he did not find any significant effects for other sectors. He found that all of the employment changes which took place were due to displacement of jobs from nearby cities which did not benefit from the scheme.

The evidence on the spatial impacts of HSR in more developed economies is more mixed. In one of the earliest studies of the impacts of HSR Plaud (1977) evaluated the impact of the opening of the original Shinkansen line from Tokyo to Osaka in

1964 which was the world’s first HSR line (Albalate et al., 2012). He found that between 1955 and 1972 employment increased significantly in Tokyo and Osaka but it fell by 30% in Nagoya as service sectors became increasingly concentrated in Tokyo and Osaka although the process of increased concentration in Tokyo and Osaka was happening anyway. In a more recent study Chen et al. (2019) found that the New Yokohama HSR station in Japan led to the development of a sub-centre specialised in IT services around the station.

The evidence on the spatial impact of the first HSR line in France between Paris and Lyon which opened in 1981 was reviewed by Blanquart and Koning (2017). They cite Charnoz et al. (2018) who found evidence that the opening of the line allowed multi-office firms based in Paris to open regional offices such as Lyon. However, others have suggested that these changes were happening anyway and the presence of an HSR station only assisted in the Lyon benefiting at the expense of other potential locations which did not receive an HSR station (Ollivier et al., 2014). The effects on the HSR line at stations in smaller towns such as Le Creusot and Mâcon-Loché was found to be limited (Marti-Henneberg, 2000) which is explained by their locations outside the urban areas and a lack of economic activity (Albalate et al., 2012). Further evidence from firm surveys (Mannone, 1995, Mannone, 1997) showed that the presence of the HSR station in Dijon affected the location choice of only 33% of its firms and it was only a key factor for 0.6% of its firms. The spatial impacts of other new HSR lines in Europe is more difficult to determine as most of them have opened relatively recently but some evidence has been found for relocation of activity from Seville to Madrid due to the opening of an HSR line between the cities (Gourvish, 2010).

The impact of HSR level on dispersion may also be a function of the relative changes in accessibility of places rather than absolute changes. Sasaki et al. (1997) modelled the spatial impacts of different segments of the Shinkansen network on the regions of Japan. They found that the full Shinkansen network did not lead to dispersion of activity between regions but the development of the first Shinkansen corridor between Tokyo and Okayama did lead to dispersion through attracting activity away from areas not served by HSR. This evidence suggests that HSR can cause dispersion from less to better connected regions if it creates imbalances in accessibility.

The location of an airport has also been found to impact the level of sectoral composition in local labour markets. Sheard (2014) analysed the impact of the presence of an airport on local economies in the US and found that the impact of the size of an airport on employment in the local metropolitan area was practically zero but that it did have an impact on specialisation in the service sector. He estimated that a 10% increase in the airport traffic would increase employment in tradable service sectors with an elasticity of 0.22. Percoco (2010) analysed the effects of airports in Italy and estimated an elasticity of service sector employment to airport traffic in the local area of 0.045 and in nearby locations of 0.017.

In addition to changing the sectoral composition of locations evidence has also been found for inter-city transport schemes impacting on economic density around them through attracting firms to benefit from the higher levels of accessibility. In a study using data from Portugal Holl (2004) analysed the impact on firm births by sector of the expansion of the country's motorway network from approximately 200km in 1986 to approximately 1,300km in 1997. He found evidence that the highways led to reduced firm growth 10-50km from the highway relative to within 10km in 8 of 9 service sectors and 6 of the 12 manufacturing industries. He also estimated that the movement of firms led to higher firm births overall in the manufacture of non-metallic minerals (0.103), textiles & footwear (0.093), food & beverages (0.075) and construction (0.064) which he concluded was evidence for geographical concentration resulting from the highway expansion in these sectors.

In a similar study Niu et al. (2015) estimated the impact of interstate highways on firm birth in four sectors (Construction, Finance & Insurance, Professional Services, Administrative Services) in the Washington-Baltimore Corridor. They found that proximity to interstate highways increased the rate of firm birth in all four sectors and particularly in Construction and Finance & Insurance. Similar evidence has also been found for intermediate stations on high-speed rail lines. Ahlfeldt and Fedderson (2017) examined the exogenous shock to accessibility on two small cities (Limburg and Montabaur) located on a high-speed rail (HSR) line between Frankfurt and Koln in Germany. They estimated an employment elasticity to accessibility of 0.038 for the cities but they did not analyse changes by sector. They don't discuss the extent to which it is displacement but it is likely these changes are due to jobs moving from nearby areas.

The location of an HSR station has also been found to foster increased economic density in urban areas as firms locate near to the station to take advantage of the high connectivity. Shen et al. (2014) analysed the impacts of the introduction of HSR services from 1992 at Madrid's Atocha station on the local area up to 20km between 1990 and 2006. They found that economic density increased around the station over the study period and that the HSR services may have contributed to the changes. In another study Marti-Henneberg (2000) found little evidence of new firm growth next to HSR stations in Spain although he did find it enhanced existing firms and many of the changes are likely to take place over long timeframes. Chen et al. (2019) survey the literature and found that factors required for spatial impacts of HSR stations include the availability of affordable land (Mohino et al., 2014) and other factors such as local economic characteristics, image and level of public support (Yin et al., 2015).

Evidence for increased concentration around stations has also been found for intra-urban rail networks. Niu et al. (2015) analysed the spatial impact of metro stations in the Washington-Baltimore Corridor in the US and found that the presence of a metro station within one mile boosted firm births in all of the four sectors they analysed. They found that the evidence for higher firm birth was particularly strong in Professional Services (0.006) and Administrative Services (0.003). Mayer and Trevien (2012) examined the impacts on the labour market of the development of the Regional Express Rail (RER) network which links central Paris and outlying sub-centres and opened in 1970. They estimated that between 1975 and 1990 municipalities with an RER station realised an approximately 10% reduction in journey times and an increase in employment of 8.8% relative to municipalities without a station. They also found evidence for a gentrification effect with a higher proportion of skilled workers locating near to the RER stations in Paris’s inner suburbs. They found no impact on total population around the stations which implied that it was all due to redistribution.

There is evidence that the effects of new inter-city infrastructure on land-use change may be greater in developing countries than in more developed economies. Ghani et al. (2016) estimated the effects on manufacturing industries of the Golden Quadrilateral (GQ) project which involved major upgrades to the highways linking Delhi, Chennai, Mumbai and Kolkata which took place between 1995 and 2007. They found that the project led to a 25-45% increase in employment in manufacturing within 10km of the highways ten years after scheme opening. These estimates are an order of magnitude greater than the studies in the US and Europe which were discussed above. This indicates that the effects of inter-city transport improvements have more potential for changes in land-use in developing countries where new inter-state infrastructure represent more of a step change in levels of accessibility compared to schemes in more developed countries.

Research examining the dynamics of inter-sectoral migration in response to changes in trade costs has been relatively limited (Dix-Carneiro, 2014). One of the few studies in this area by Dix-Carneiro (2014) explored the impacts on the labour market in Brazil of trade liberalisation. It was found that 95 per cent of labour market effects take place within 9 years with no physical capital mobility but up to 30 years with imperfect physical capital mobility. Dix-Carneiro (2014) highlighted important needs for future research including a need for greater understanding what effects the reallocation of labour between sectors. In addition, there is also a need for greater understanding of the mobility and accumulation of physical capital which were found to significantly impact on the dynamics of adjustment to a new steady state in their model formulation.

The estimated adjustment times to a trade shock in the literature vary depending on the situation analysed and the assumptions made. Using a dynamic trade model Artuc et al. (2010) estimated that the removal of a 30% tariff on manufacturing products lead to a reallocation of labour between sectors based on wage differentials and 95% of the impacts took place within 8 years. Ashournia (2015) used data from Denmark to find that 95% of labour reallocation between sectors took place over a period of just over 10 years following a trade liberalisation shock. Artuc and McLaren (2015) found switching costs between sectors can be significant and using a dynamic model estimated that sectoral redistribution of jobs due to a reduction in trade costs can take longer than 10 years. In a more global context Pessoa (2016) estimated that a 25% reduction in trade costs between China and the rest of the world would lead to a 90% real income adjustment within 25 years.

2.4.2.2 Displacement and Employment Growth

Several of the studies discussed in the previous section have highlighted that their estimated increase in jobs due to a transport scheme are due to displacement another location. This includes when a scheme leads to displacement from one area to another (Chandra and Thompson 2000, Duranton and Turner, 2012, Qin, 2017, Dong, 2018) and also when it increases concentration along the length of transport infrastructure (Jiwattanakulpaisarn et al., 2010, Holl, 2004).

Many of the other studies which were discussed estimated increases in employment due to a scheme but without determining the extent to which it represents new employment or displacement from other locations. An increase in employment can be included in an economic appraisal of a transport scheme when it is shown to occur under a market failure in the labour market. Examples of this include when transport links improve accessibility to the labour market from residential areas with high levels of structural unemployment. The transport scheme could allow people to access jobs and training which they would not otherwise have done and increase their chances of employment. Another example of a market failure in the labour market is when a high growth location is constrained as it cannot access sufficient labour. Improving transport links could allow workers to take advantage of improved job opportunities which may not be available in other locations.

The extent to which inter-city schemes can generate employment growth will be a function of how they can bring about these effects. There may be some potential for highways and conventional rail to improve access to employment of areas with high structural employment but the effects are likely to be limited in comparison to urban transport which improve links within local labour markets. The effects are likely to be even more limited for high-speed rail which typically only serves major cities. An exception to this may be if an HSR scheme diverts services away from conventional rail networks allowing additional commuter services which is one of the stated benefits of the HS2 network in the UK (HS2, 2012). Such changes will typically only involve enhancements to services on existing lines though with limited new infrastructure for improving links to less well-served areas.

Inter-city networks are also unlikely to significantly relieve constrained local labour markets. Most commuting takes place over relatively short distances and usually within the extent of local labour markets. In addition, commuting over long distances can be expensive which reduces the potential for the impacts. In addition, if people do switch jobs to other locations there may not be unemployed people with skills to replace them in their current role and so their employment is displaced rather than represent a new job at the aggregate level.

In summary the potential for net employment growth resulting from an inter-city connectivity scheme are likely to be limited in most contexts. As a result most, if not all, the employment changes will be due to displacement.

2.5 Summary

In this chapter the literature fields relevant to the economic impacts of inter-city connectivity have been discussed. Economic growth models based on neo-classical theory were developed in which economic output is a function of labour, capital and technological progress. These models suggest that in the long-run economies reach a steady state at which capital per worker is constant and increases in the long term growth rate can only be achieved through an increase in the population growth rate or technological progress. In these models technological progress was assumed to be exogenous which led to the development of endogenous growth theory in the 1980s. This theory suggested that knowledge and innovation are fundamental to explaining how economies grow over time and models based on this theory were able to explain the observed slow convergence between developed and developing countries. Economic growth models suggest that transport schemes can move an economy to a new steady state at which productivity will be higher but it is more difficult for transport improvements to affect the long-term growth rate.

There are several mechanisms through which inter-city connectivity can impact on productivity. These include direct effects such as travel cost savings and the impacts of increased access to markets which can lead to reductions in monopoly power and the realisation of internal economies of scale. There are also several economy channels through which inter-city connectivity can impact on productivity. These include the diffusion of technology between locations and reductions in coordination failure which allow firms in different places to coordinate their investment. Another economy channel is productivity gains due to increased density of economic activity of which there are two types. Urbanisation economies stem from an increase in overall economic density and localisation economies derive from increased density of individual sectors or tasks. Finally, inter-city connectivity schemes can also realise productivity gains through promoting increased specialisation.

Cost Benefit Analysis is the common method for assessing the economic impacts of transport schemes. This method initially focussed on direct cost savings but over the last 10 to 15 years methodology has been developed to evaluate wider economic impacts (WEIs). These impacts exist in the presence of market failures and give rise to additional benefits which are not captured in a standard CBA. In the UK the WEIs now included in economic appraisals of transport schemes include urbanisation economies, reduced monopoly power, movement of workers to more productive locations and changes in the supply of labour.

There are several other market failures which could give rise to additional benefits due to an inter-city connectivity scheme but are not typically included in economic appraisals. These include barriers to development, induced investment and coordination failure. Another potential sources of additional benefits are localisation economies arising from increased specialisation. Using a theoretical model Venables (2017) showed that inter-city connectivity improvements can generate increases in specialisation and the associated localisation benefits are potentially large and additional to those in a standard CBA. While the theoretical basis for these effects has been studied there is no understanding of the impact their inclusion could have on an economic appraisal of an inter-city connectivity scheme and under what conditions they will be more or less important. The omission of changes in specialisation and localisation effects from economic appraisals is a gap which could be leading to sub-optimal decision-making.

There is no complete method currently available for modelling the impact of inter-city connectivity on changes in specialisation and localisation effects. The theories of economic growth and new economic geography suggest that many of the impacts are likely to take place over long timeframes but these are modelled coarsely in LUTI models. There are some dynamic LUTI models but most do not include changes in sectoral employment due to transport schemes and those that do such as ASTRA do not take account of localisation effects. An alternative tool for modelling changes due to transport are SCGE models. These models can take account of the micro-foundations of trade and specialisation and incorporate elements of new economic geography such as centrifugal and centripetal forces. However, these are typically based on static frameworks and the few dynamic versions do not model the dynamics explicitly or are based on unrealistic assumptions.

Many of the empirical studies on agglomeration economies do not distinguish between urbanisation and localisation effects which can lead to biased estimates of the elasticities. There have been only a few studies which have estimated the elasticities simultaneously and the results suggests that localisation effects will be strongest in manufacturing and business service sectors but more limited in other service sectors. The evidence also suggests that localisation effects decay over distance more quickly than urbanisation effects which may limit the potential for localisation benefits over longer distance if no changes in land-use take place.

While there is a well-founded theoretical basis for changes in specialisation due to inter-city improvements there have been relatively few empirical studies examining the extent of the land-use changes and the evidence is mixed. There is some evidence of changes in sectoral composition due to inter-city connectivity schemes but other studies found no changes occurred. There is also evidence for other types of land-use change in response to inter-city schemes such as the movement of jobs towards locations which realise the greatest increases in accessibility. The evidence suggests that land-use changes by sector will vary depending on the transport modes affected with manufacturing industries more likely to be affected by highway projects and service industries by public transport improvements. The empirical studies also suggest that it may take several years to realise land-use changes due to inter-city transport improvements and any changes in employment are more likely to be due to redistribution than a net change in the number of jobs.

3 Methodology

3.1 Introduction

In this chapter the methods which are used in the analysis in this thesis are presented. In Section 3.2 an overview of the method for estimating agglomeration benefits is provided. This consists of an outline of a method for estimating localisation and urbanisation benefits and includes an overview of the differences between assessing the impacts with fixed and variable land-use. A worked example using a simple two city model is then used to illustrate how the method is applied in the context of an inter-city connectivity scheme.

The theory of new economic geography discussed in Section 2.2 of Chapter 2 suggests that the impacts of inter-city transport on specialisation are likely to take place in a process of cumulative causation over long timeframes. This is supported by the empirical evidence discussed in Section 2.4.2 of Chapter 2 which showed that changes in land-use due to the removal of trade barriers can take several decades to be fully realised. These findings were used to inform some of the objectives of the research including the need to understand the dynamics of how inter-city connectivity impacts on changes in specialisation and how different transition elements within the system interact with one another.

For the purpose of meeting these objectives the system dynamics approach has been chosen. This is the method which is also used in other dynamic models of the interaction of transport and land-use such as the Urban Dynamic Model (UDM), MARS (Metropolitan Activity Relocation Simulator) and ASTRA (Assessment of Transport Strategies) which were discussed in Section 2.3 of Chapter 2. This system dynamics approach is used in this thesis to develop dynamic models of how inter-city transport impacts on specialisation which are presented in Chapters 4 to 6. An overview of this method is presented in Section 3.3 and example models are used to demonstrate the key concepts of the approach.

3.2 Evaluation of Agglomeration Benefits

The recommended approach for evaluating transport schemes in the UK is provided in the Department for Transport's (DfT) Transport Analysis Guidance (WebTAG) (DfT, 2014). The aim of the guidance is to provide a consistent basis for evaluating transport projects which can be used to inform decision-making (DfT, 2014). The guidance presented in WebTAG have been developed over several decades and it has also been used to inform the transport appraisal guidelines of several other countries (Mackie and Worsley, 2013).

In WebTAG the recommended method for assessing transport schemes is Cost-Benefit Analysis (CBA) (DfT, 2018a). Using this approach the monetised costs and benefits of a transport scheme are estimated and compared to determine the scheme's overall value for money. The outputs from the CBA are then used alongside the qualitative analysis of impacts which cannot be monetised to provide an overall assessment of a transport scheme (DfT, 2018a).

As discussed in Section 2.2.3 of Chapter 2 the techniques initially developed to assess the economic benefits of transport schemes focussed on the direct cost savings such as time saving benefits. When markets are perfectly competitive markets all economic benefits are captured by direct cost savings but in the real world there are market failures present in most markets (Venables, et al., 2014). The presence of market failures means that direct cost savings may not capture all of the economic impacts of a scheme and there may be additional benefits or disbenefits which are known as Wider Economic Impacts (WEIs).

Over the last 10 to 15 years methods have been developed to assess the scale of WEIs in economic appraisals of transport schemes. One of the main sources of WEI which have been identified are agglomeration economies. These are a type of external economy of scale and are based on a consistent finding from the empirical literature that productivity increases with respect to the scale of economic density. The productivity gains from agglomeration derive from increased matching, sharing and learning (Duranton and Puga, 2003). There are two different types of agglomeration effect: urbanisation and localisation. Urbanisation effects are productivity gains which arise from the increased density of overall economic activity and localisation effects are gains in productivity which derive from higher density at the level of an individual sector or task.

The benefits from agglomeration effects resulting from a transport scheme will vary depending on the extent to which it fosters changes in land-use. If no changes in land-use take place the situation is known as static clustering and the agglomeration gains derive from reduced travel times which promotes a higher number of interactions between economic agents (DfT, 2018b). A transport scheme may lead to further agglomeration gains if it brings about land-use changes which is known as dynamic clustering. The agglomeration gains from dynamic clustering stem from the closer proximity of economic agents which further increases the number of interactions between them (DfT, 2018b).

The remainder of this section is organised in follows. In Section 3.2.1 the method used for estimating agglomeration benefits is outlined and in Section 3.2.2 a worked example of the method is presented using a simple two zone model.

3.2.1 Method

Advice for estimating the agglomeration benefits of a transport scheme is provided in the UK's WebTAG Guidance (DfT, 2018c). In WebTAG the recommended approach for assessing agglomeration benefits is to first estimate the level of effective density with and without the transport scheme. Effective density is a measure of the density of employment which is used as a proxy for the scale of agglomeration for which there is no direct measure.

The advice in WebTAG is to estimate agglomeration benefits in a core scenario without separating out the effects from urbanisation and localisation but these effects can be estimated as a sensitivity test. The following formula is used to estimate the level of effective density for agglomeration effects[12]:

$$d_i^{S,n,f} = \sum_j \sum_m \frac{E_j^{S,f}}{\left(g_{i,j}^{S,m,f}\right)^{\beta A^n}} \tag{3.1}$$

where $d_i^{S,n,f}$ is the effective density of sector *n* in zone *i* in situation *S* in forecast year *f*, $E_j^{S,f}$ is total employment in destination zone *j* in situation *S* in forecast year *f*, $g_{i,j}^{S,m,f}$, is generalised cost between zone *i* and destination zone *j* by mode *m* in situation *S* in forecast year *f* and βA^n is a distance decay factor for agglomeration effects in sector *n*.

Agglomeration benefits are estimated based on the proportional change in effective density. The situations with and without the transport scheme are known as the do-something (DS) and do-minimum (DM) respectively and agglomeration benefits are estimated using the following formula:

$$AGG_i^{n,f} = \left[\left(\frac{d_i^{DS,n,f}}{d_i^{DM,n,f}}\right)^{\rho A^n} - 1\right] GDPW_i^{DM,n,f} E_i^{DS,n,f} \tag{3.2}$$

where $AGG_i^{n,f}$ is the agglomeration benefits in zone *i* in sector *n* in forecast year *f*, $d_i^{DS,n,f}$ is the effective density in the do-something situation in sector *n* in forecast year *f*, $d_i^{DM,n,f}$ is the effective density in the do-minimum situation in sector *n* in forecast year *f*, ρA^n is an agglomeration elasticity in sector *n*, $GDPW_i^{DM,n,f}$ is the

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[12] Equations (3.1) ad (3.2) are based on those in the UK's WebTAG Guidance (DfT, 2018c).

GDP per worker in the do-minimum situation in sector *n* in forecast year *f* and $E_i^{DS,n,f}$ is total employment in the do-something situation in sector *n* in zone *i* in year forecast year *f*.

In the UK's WebTAG Guidance it is suggested that if localisation impacts are expected to be important in the economic appraisal of a transport scheme then localisation and urbanisation impacts can be estimated separately as a sensitivity test. As highlighted in Section 2.4.1 of Chapter 2 it is important when doing this that the elasticities for urbanisation and localisation are from a source in which they were estimated simultaneously to avoid any bias in the estimates (Venables et al. 2014).

Urbanisation benefits are estimated using a similar method to agglomeration benefits which was outlined above. The effective density for urbanisation effects, $dU_i^{S,n,f}$, for zone *i* in situation *S* in sector *n* in forecast year *f* is given by:

$$dU_i^{S,n,f} = \sum_j \sum_m \frac{E_j^{S,f}}{\left(GC_{ij}^{S,m,f}\right)^{\beta U^n}} \tag{3.3}$$

where $E_j^{S,f}$ is the total employment in destination zone j in situation *S* in forecast year *f*, $GC_{ij}^{S,m,f}$ is the generalised cost between zone *i* and destination zone *j* in situation *S* for mode *m* in forecast year *f* and βU^n is the distance decay factor for urbanisation effects in sector *n*[13]. The effective density for localisation effects is estimated based on the density of jobs in an individual sector only and does not take account the location of employment in other sectors. The effective density for localisation effects, $dl_i^{S,n,f}$, in zone *i* in Situation *S* in sector *n* in forecast year *f* is estimated using the following formula:

$$dL_i^{S,n,f} = \sum_j \sum_m \frac{E_j^{S,n,f}}{\left(GC_{ij}^{S,m,f}\right)^{\beta L^n}} \tag{3.4}$$

where $E_j^{S,n,f}$ is employment in destination zone *j* in sector *n* in Situation *S* in forecast year *f*, $GC_{ij}^{S,m,f}$ is the generalised travel costs between zone *i* and destination zone *j* in situation *S* for mode *m* in forecast year *f* and βL^n is the distance decay factor for localisation effects in sector *n*.

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[13] The distance decay factors used in the analysis in this thesis are based on those estimated in Graham, Gibbons & Martin (2009) which are the recommended values in the UK DfT's WebTAG Guidance (2018d). These factors were estimated based on distance between locations but the authors note that variations in distance are a good proxy for differences in average travel times or costs.

The benefits from urbanisation and localisation are estimated based on the change in effective densities between the do-minimum and so-something situations. Urbanisation benefits, URB_i^n, in zone *i* in sector *n* are estimated using the following formula:

$$URB_i^n = \left[\left(\frac{dU_i^{DS,n}}{dU_i^{DM,n}}\right)^{\rho U^n} - 1\right] GDPW_i^{DM,n} E_i^{DS,n} \tag{3.5}$$

where $dU_i^{DS,n}$ and $dU_i^{DM,n}$ are the effective densities for urbanisation effects in zone *i* in sector *n* in the do-something and do-minimum situations respectively, ρU^n is the urbanisation elasticity in sector *n*, $GDPW_i^{DM,n}$ is the GDP per worker in zone *i* in sector *n* in the do-minimum situation and $E_i^{DS,n}$ is employment in zone *i* in sector *n* in the do-something situation.

Localisation benefits, LOC_i^n, in zone *i* in sector *n* are estimated in a similar way to urbanisation benefits using the following formula:

$$LOC_i^n = \left[\left(\frac{dL_i^{DS,n}}{dL_i^{DM,n}}\right)^{\rho L^n} - 1\right] GDPW_i^{DM,n} E_i^{DS,n} \tag{3.6}$$

where $dL_i^{DS,n}$ is the effective density for localisation effects in zone *i* in sector *n* in the do-something situation, $dL_i^{DM,n}$ is the effective density for localisation effects in zone *i* in sector *n* in the do-minimum situation and ρL^n is the elasticity for localisation effects in sector n.

Equations (3.3) to (3.6) are used to estimate urbanisation and localisation benefits for both static clustering when land-use is fixed and dynamic clustering when land-use is variable. With dynamic clustering the changes in land-use need to be estimated. There is no standard single method for estimating land-use changes due to transport improvements and the UK's WebTAG suggests that when land-use changes are likely to be significant the changes should be estimated using a spatial model (DfT, 2018c).

3.2.2 Worked Example

The method outlined in the previous section for estimating urbanisation and localisation benefits with static and dynamic clustering can be demonstrated using a worked example. Figure 3.1 shows the structure of a simple model of two zones (A, B). In the model there is only one transport mode which people use to travel between the two zones. It is assumed that there is a generalised journey time (GJT) between the two zones of 100 minutes and the intra-zonal journey time is assumed to be 5 minutes within each zone. An inter-city connectivity scheme is introduced which reduces journey times on the inter-city link by 40 minutes to 60 minutes and the urbanisation and localisation benefits are estimated to determine the scale of the impacts.

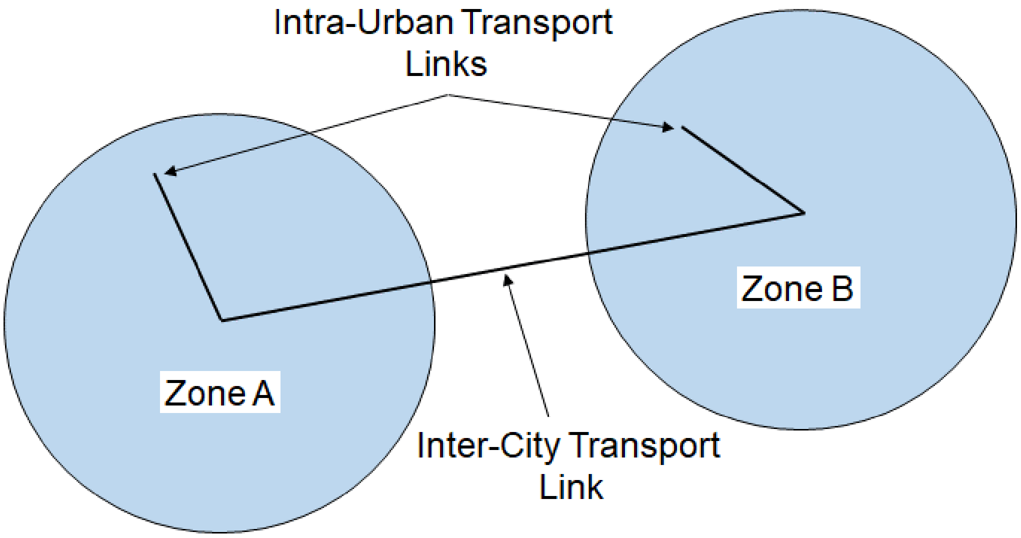

Figure 3.1 Structure of Two Zone Model

In the model for simplicity it is assumed that the economy is divided between only two sectors (S1, S2). The number of jobs in each sector are divided unevenly between the two zones and are shown in Table 3.1. Zone A has more jobs in Sector 1 (35,000) than Sector 2 (15,000) while in Zone B there are more jobs in Sector 2 (90,000) than in Sector 1 (10,000). It is assumed that in each zone the sector with the highest number of jobs has the highest GDP per worker. This means the highest GDP per worker in Sector 1 is in Zone A and in Sector 2 it is in Zone B.

Table 3.1 Economic Inputs for the Do-Minimum situation

	Zone A		Zone B		
Economic Variable	S1	S2	S1	S2	All Zones
Number of Jobs	35,000	15,000	10,000	90,000	150,000
GDP per Worker (£)	60,000	40,000	30,000	80,000	-

The equations for the estimation of urbanisation and localisation effects (equations (3.3)-(3.6)) require elasticities and distance decay factors. The assumptions which were used for these parameters by sector are shown in Table 3.2 and are based on the empirical evidence which was discussed in Section 2.4.1 of Chapter 2[14].

Table 3.2 Elasticities and Distance Decay Factors for Urbanisation and Localisation Effects by Sector

	Elasticity		Distance Decay Factor	
Type of Effect	S1	S2	S1	S2
Urbanisation	0.10	0.04	1.8	1.2
Localisation	0.05	0.08	2.0	1.5

In the following sub-sections the urbanisation and localisation benefits are estimated first for the situation with static clustering when land-use is fixed (Section 3.2.2.1) and then with dynamic clustering when land-use is variable (Section 3.2.2.2).

3.2.2.1 Static Clustering

The urbanisation and localisation benefits are estimated through inserting the economic inputs and parameters from Tables 3.1 and 3.2 respectively into the equations (3.3) to (3.6). The effective densities of Zones A and B for urbanisation effects in the do-minimum situation can be estimated first using equation (3.3)[15]:

$$EDU_A^{DM,S1} = \frac{50{,}000}{(5)^{1.8}} + \frac{100{,}000}{(100)^{1.8}} = 2{,}784.6 \tag{3.7}$$

$$EDU_A^{DM,S2} = \frac{50{,}000}{(5)^{1.2}} + \frac{100{,}000}{(100)^{1.2}} = 7{,}645.9 \tag{3.8}$$

$$EDU_B^{DM,S1} = \frac{100{,}000}{(5)^{1.8}} + \frac{50{,}000}{(100)^{1.8}} = 5{,}531.5 \tag{3.9}$$

$$EDU_B^{DM,S2} = \frac{100{,}000}{(5)^{1.2}} + \frac{50{,}000}{(100)^{1.2}} = 14{,}694.6 \tag{3.10}$$

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[14] In the modelling undertaken in Chapter 7 conservative elasticity ranges by sector are selected from the literature discussed in Chapter 2. The values in Table 3.1 are within the ranges selected in Chapter 7 which are presented in Table 7.4. The elasticities chosen for S1 and S2 to illustrate the calculations are based on the evidence for business services and heavy manufacturing respectively.

[15] In the analysis in this thesis for simplicity the effective densities for both urbanisation and localisation effects use generalised journey times rather than generalised costs. This means the scale of the resulting productivity impacts are likely to be slightly overestimated.

The effective density of a sector in a zone is calculated by dividing total employment in the two zones by the generalised journey time from the current zone to the power of the distance decay factor and then summing them together. Equation (3.7) shows the calculation of the effective density for urbanisation effects in Sector 1 in Zone A in the do-minimum situation. This is estimated by first dividing the number of jobs in Zone A (50,000) by the intra-zonal generalised journey time in Zone A (5) to the power of the distance decay factor in Sector 1 (1.8). The number of jobs in Zone B are then divided by the generalised journey time between Zones A and B (100) to the power of the distance decay factor in Sector 1 (1.8). The results of these two calculations are then summed together to give the total effective density for Sector 1 in Zone A of 2,784.6.

The results from equations (3.7) to 3.10) show that for both sectors S1 and S2 the effective density in Zone B (equations (3.9) & (3.10)) is higher than in Zone A (equations (3.7) & (3.8)). This is as expected given that total employment is twice as high in Zone B as in Zone A which leads to higher overall economic density in Zone B. These results also show that the effective densities are higher for Sector 2 (equations (3.8) & (3.10)) than for Sector 1 (equations (3.7) & (3.9)). This is due to the lower distance decay factor specified for Sector 2 of 1.2 compared to 1.8 in Sector 1. The difference between these assumptions means that the decay of density effects over distance diminishes more slowly over distance in Sector 2 than Sector 1 which means the effective densities in Sector 2 in both zones are higher than in Sector 1.

To estimate the urbanisation benefits of the reduction in inter-city journey times the effective densities first need to be calculated with the generalised journey times for the do-something situation. The effective density calculations for urbanisation effects for each combination of zone and sector in the do-something situation are given by:

$$EDU_A^{DS,S1} = \frac{50{,}000}{(5)^{1.8}} + \frac{100{,}000}{(60)^{1.8}} = 2{,}822.5 \tag{3.11}$$

$$EDU_A^{DS,S2} = \frac{50{,}000}{(5)^{1.2}} + \frac{100{,}000}{(60)^{1.2}} = 7{,}982.7 \tag{3.12}$$

$$EDU_B^{DS,S1} = \frac{100{,}000}{(5)^{1.8}} + \frac{50{,}000}{(60)^{1.8}} = 5{,}550.4 \tag{3.13}$$

$$EDU_B^{DS,S2} = \frac{100{,}000}{(5)^{1.2}} + \frac{50{,}000}{(60)^{1.2}} = 14{,}863.0 \tag{3.14}$$

Comparing these estimates with those for the do-minimum situation above shows that as expected the effective density of all combinations of sector and zone have increased due to the lower journey times between the two zones. The economic benefits from urbanisation effects can now be calculated by inserting the estimated effective densities for the do-minimum and do-something situations into equation (3.5) along with the economic inputs and urbanisation elasticity by sector. These are given by:

$$URB_A^{S1} = \left[\left(\frac{2822.5}{2784.6}\right)^{0.10} - 1\right] * £60{,}000 * 35{,}000 = £2{,}839{,}342.05 \tag{3.15}$$

$$URB_A^{S2} = \left[\left(\frac{7982.7}{7645.9}\right)^{0.04} - 1\right] * £40{,}000 * 15{,}000 = £1{,}035{,}392.13 \tag{3.16}$$

$$URB_B^{S1} = \left[\left(\frac{5550.4}{5531.5}\right)^{0.10} - 1\right] * £30{,}000 * 10{,}000 = £102{,}561.31 \tag{3.17}$$

$$URB_B^{S2} = \left[\left(\frac{14863.0}{14694.6}\right)^{0.04} - 1\right] * £80{,}000 * 90{,}000 = £3{,}282{,}217.46 \tag{3.18}$$

These results show that the reduction in travel times leads to positive urbanisation benefits in all combinations of sectors and zones. Total urbanisation benefits sum to £7.3mn per annum but there is a wide variation in the results which range from £0.1mn per annum in Sector 1 in Zone B to £3.3mn per annum in Sector 2 in Zone B. These differences are explained by variations in the proportional increase in effective density, urbanisation elasticity, initial GDP per worker and employment which all increase with the scale of the benefits.

As outlined in Section 3.2.1 the benefits from localisation effects are estimated in a similar way to urbanisation effects but the effective densities for localisation are based only on employment in the sector rather than the overall economy. The effective density for localisation effects for each combination of sector and zone for the do-minimum situation are estimated by inputting in the assumptions from Tables 3.1 and 3.2 into equation (3.4) for each combination of zone and sector and are given by:

$$EDL_A^{DM,S1} = \frac{35{,}000}{(5)^2} + \frac{10{,}000}{(100)^2} = 1{,}401.0 \tag{3.19}$$

$$EDL_A^{DM,S2} = \frac{15{,}000}{(5)^{1.5}} + \frac{90{,}000}{(100)^{1.5}} = 1{,}431.6 \tag{3.20}$$

$$EDL_B^{DM,S1} = \frac{10{,}000}{(5)^2} + \frac{35{,}000}{(100)^2} = 403.5 \tag{3.21}$$

$$EDL_B^{DM,S2} = \frac{90{,}000}{(5)^{1.5}} + \frac{15{,}000}{(100)^{1.5}} = 8{,}064.8 \tag{3.22}$$

These results show that the effective density for localisation effects are significantly lower than the effective densities for urbanisation effects in the do-minimum situation calculated in equations (3.7) to (3.10). This is due to two reasons. Firstly, employment in each individual sector is lower than overall employment across the economy. Secondly, the assumed distance decay factors are higher for localisation effects than urbanisation which means that for a sector in a zone the number of jobs in the same sector in the other zone has less impact on the scale of its effective density.

The effective densities for localisation effects in the do-something situation are estimated in the same way as in the do-minimum situation but with the reduced journey times between the zones and are given by:

$$EDL_A^{DS,S1} = \frac{35{,}000}{(5)^2} + \frac{10{,}000}{(60)^2} = 1{,}402.8 \tag{3.23}$$

$$EDL_A^{DS,S2} = \frac{15{,}000}{(5)^{1.5}} + \frac{90{,}000}{(60)^{1.5}} = 1{,}535.3 \tag{3.24}$$

$$EDL_B^{DS,S1} = \frac{10{,}000}{(5)^2} + \frac{35{,}000}{(60)^2} = 409.7 \tag{3.25}$$

$$EDL_B^{DS,S2} = \frac{90{,}000}{(5)^{1.5}} + \frac{15{,}000}{(60)^{1.5}} = 8{,}082.1 \tag{3.26}$$

These results show that as expected the lower generalised journey times have led to an increase in effective density in all combinations of sector and zone. The estimated effective densities from equations (3.19) to (3.26) can now be used to estimate the economic benefits from localisation effects by inserting them into equation (3.6) along with the economic inputs and localisation elasticities from Tables 3.1 and 3.2 respectively. These are estimated as the following:

$$LOC_A^{S1} = \left[\left(\frac{1402.8}{1401.0}\right)^{0.05} - 1\right] * £60{,}000 * 35{,}000 = £133{,}157.92 \tag{3.27}$$

$$LOC_A^{S2} = \left[\left(\frac{1535.3}{1431.6}\right)^{0.08} - 1\right] * £40{,}000 * 15{,}000 = £3{,}364{,}505.42 \tag{3.28}$$

$$LOC_B^{S1} = \left[\left(\frac{409.7}{403.5}\right)^{0.05} - 1\right] * £30{,}000 * 10{,}000 = £229{,}631.87 \tag{3.29}$$

$$LOC_B^{S2} = \left[\left(\frac{8082.1}{8064.8}\right)^{0.08} - 1\right] * £80{,}000 * 90{,}000 = £1{,}232{,}575.41 \tag{3.30}$$

These results show that localisation benefits are positive in all four combinations of sector and zone and sum to £5.0mn per annum. There is wide variation in the scale of the benefits which range from £0.2mn per annum in Sector 1 in Zone B to £3.4mn per annum in Sector 2 in Zone A. The scale of the benefits estimates increase with the scale of the proportional increase in effective density, localisation elasticity, initial GDP per worker and employment.

Equations (3.27) to (3.30) show that the benefits are highest for each sector in the zone in which it has the fewest number of jobs. For example, in Sector 1 there are 35,000 jobs in Zone A and 15,000 in Zone B but localisation benefits are £0.1mn per annum in Zone A and £3.3mn per annum in Zone B. This result seems counter-intuitive but is explained by the different impacts on density of the reductions in GJTs. The zone with the fewest jobs in the sector gains a greater proportional increase in effective density as it benefits from reduced journey times to zone with more jobs in that sector. This is in contrast to the zone with the most jobs in the sector which has improved links to a zone with a small number of jobs in the sector. The higher initial GDP per worker in the sector with the most workers is not enough to counterbalance this and localisation benefits are highest for the sector in the zone with the fewest jobs in the sector.

3.2.2.2 Dynamic Clustering

With dynamic clustering the estimation of urbanisation and localisation benefits needs to include the impacts of any changes in land-use. In this worked example it is assumed that the reduced journey times between the zones will foster increased trade and allow both zones to become more specialised in the sector in which it is most productive. In the do-minimum economic inputs outlined in Table 3.2 above Zone A has higher employment and GDP per worker in Sector 1 and Zone B has higher employment and productivity in Sector 2. It is assumed that the inter-city transport scheme will lead to land-use changes within the two zones with each becoming more specialised in the sector in which it initially had higher productivity and employment. It is assumed that there is no migration between the zones and the total number of jobs in each zone remains constant. The assumed number of jobs in the do-something scenario and how they compare to the do-minimum situation are shown in Table 3.3.

Table 3.3 Number of Jobs in each Sector and Zone in the Do-Minimum and Do-Something Situations

	Zone A		Zone B		
Scenario	S1	S2	S1	S2	All Zones
Do-Minimum	35,000	15,000	10,000	90,000	150,000
Do-Something	38,000	12,000	5,000	95,000	150,000
Change	+3,000	-3,000	-5,000	+5,000	0

These assumptions can now be used to estimate the benefits from urbanisation and localisation effects with dynamic clustering. The urbanisation benefits with dynamic clustering are given by:

$$URB_A^{S1} = \left[\left(\frac{2822.5}{2784.6}\right)^{0.10} - 1\right] * £60{,}000 * 38{,}000 = £3{,}082{,}714.23 \tag{3.31}$$

$$URB_A^{S2} = \left[\left(\frac{7982.7}{7645.9}\right)^{0.04} - 1\right] * £40{,}000 * 12{,}000 = £828{,}313.70 \tag{3.32}$$

$$URB_B^{S1} = \left[\left(\frac{5550.4}{5531.5}\right)^{0.10} - 1\right] * £30{,}000 * 5{,}000 = £51{,}280.65 \tag{3.33}$$

$$URB_B^{S2} = \left[\left(\frac{14863.0}{14694.6}\right)^{0.04} - 1\right] * £80{,}000 * 95{,}000 = £3{,}464{,}562.88 \tag{3.34}$$

Due to the assumption that the total number of jobs in each zone remains constant the effective densities for urbanisation effects in the do-something situation are the same as they were with static clustering (which were shown in equations (3.15) to (3.18)). Although the effective densities don't change with dynamic clustering the scale of the estimated urbanisation benefits are different as the number of jobs in each sector within each zone has changed and the elasticities and distance decay factors vary by sector. Total urbanisation benefits with dynamic clustering sum to £7.4mn per annum which is slightly higher than the £7.3mn per annum estimated in with static clustering.

The effective densities for localisation effects with dynamic clustering in the do-something situation are calculated as:

$$EDL_A^{DS,S1} = \frac{38{,}000}{(5)^2} + \frac{5{,}000}{(60)^2} = 1{,}521.4 \tag{3.35}$$

$$EDL_A^{DS,S2} = \frac{12{,}000}{(5)^{1.5}} + \frac{95{,}000}{(60)^{1.5}} = 1{,}277.7 \tag{3.36}$$

$$EDL_B^{DS,S1} = \frac{5{,}000}{(5)^2} + \frac{38{,}000}{(60)^2} = 210.6 \quad (3.37)$$

$$EDL_B^{DS,S2} = \frac{95{,}000}{(5)^{1.5}} + \frac{12{,}000}{(60)^{1.5}} = 8{,}522.9 \quad (3.38)$$

These estimated show that in contrast to urbanisation effects the assumed land-use changes significantly affect the scale of effective densities for localisation effects in each combination of sector and zone. Compared to the estimates with static clustering (shown in equations (3.23) to (3.26)) the effective densities have increased in the sectors in which each zone has gained jobs and decreased in the sectors in which each zone has lost jobs.

These estimates can now be used in combination with the estimated effective densities for localisation effects for the do-minimum situation from equations (3.17) to (3.20) to estimate localisation benefits which are given by:

$$LOC_A^{S1} = \left[\left(\frac{1521.4}{1401.0}\right)^{0.05} - 1\right] * £60{,}000 * 38{,}000 = £9{,}417{,}257.82 \quad (3.39)$$

$$LOC_A^{S2} = \left[\left(\frac{1277.7}{1431.6}\right)^{0.08} - 1\right] * £40{,}000 * 12{,}000 = -£4{,}347{,}953.05 \quad (3.40)$$

$$LOC_B^{S1} = \left[\left(\frac{210.6}{403.5}\right)^{0.05} - 1\right] * £30{,}000 * 5{,}000 = -£4{,}799{,}732.20 \quad (3.41)$$

$$LOC_B^{S2} = \left[\left(\frac{8522.9}{8064.8}\right)^{0.08} - 1\right] * £80{,}000 * 95{,}000 = £33{,}660{,}023.12 \quad (3.42)$$

The localisation benefits with dynamic clustering sum to £33.9mm per annum. This is significantly higher than the estimated total localisation benefits with static clustering of £5.0mn per annum. The reason for this large difference is that with dynamic clustering workers move into a sector with a significantly higher initial GDP per worker. As workers move between sectors this impacts on localisation effects in each sector leading to further impacts on GDP per worker. As workers move to a sector within a zone this increases GDP per worker through enhanced localisation effects and in the sector the worker leaves localisation effects become lower which reduces GDP per worker.

Despite the increase in total localisation benefits due to the land-use changes there are significant disbenefits in Sector 2 in Zone A of £4.3mn per annum and Sector 1 in Zone B of £4.8mn per annum. These disbenefits are caused by the workers leaving those sectors and switching to the other sector in the same zone. Overall, however, both zones realise positive benefits from the scheme as the disbenefits are outweighed by the increases in localisation benefits in the sector in each zone which gains jobs. Overall, localisation benefits are £5.1mn per annum in Zone A and £28.9mn per annum in Zone B. The significantly higher benefits in Zone B are due to the higher elasticity used for localisation effects in Sector 2 which is the sector Zone B is assumed to become more specialised in and also the greater difference between GDP per worker in the two sectors than in Zone A. In addition, there are a total of 100,000 workers in Zone B compared to only 50,000 in Zone A.

The benefit estimates for localisation and urbanisation effects can be used to estimate the relative contribution of each to total benefits. In the dynamic clustering scenario total localisation benefits (£33.9mn per annum) are 82% of the total benefits from urbanisation and localisation effects (£41.3mn per annum). This compares to the static clustering scenario outlined in the previous sub-section in which localisation benefits (£5.0mn per annum) were 41% of the total benefits from urbanisation and localisation effects (£12.3mn per annum). This shows that the introduction of the land-use changes in this worked example has led to higher benefits from localisation effects as a proportion of the total. This results from the assumed land-use changes in which each zone became more specialised in the sector which it had higher initial employment and GDP per worker while total employment in each zone remained constant.

3.3 System Dynamics Approach

The system dynamics approach is a framework for modelling complex non-linear systems which includes interactive relationships between variables, feedback loops and time lags. It was developed in the 1950s by Jay W. Forrester (Morecroft, 2020) who initially applied it to corporate problems but subsequently he realised it could also be employed to analyse social problems (Moody, 1970). This began with the development of the Urban Dynamic Model (Forrester, 1969) which he used to evaluate policy responses to tackle urban decay in Boston in the USA.

A key aspect of the system dynamics approach is that the structure of a system including the feedback loops between variables is crucial whereas in contrast individuals tend to think in short causal chains between a limited number of variables (Sterman, 2006). As a result policymakers’ mental models of a system can be deficient which can lead to policy resistance as the chosen course of action may lead to undesired outcomes (Sterman, 2006). System dynamics modelling can provide a holistic representation of a system which can be used to understand the key structures and improve policymaking.

Systems can be modelled using the system dynamics approach both qualitatively and quantitatively. A common output of the qualitative method are Causal Loop Diagrams (CLDs). These diagrams provide a schematic view of the key variables in a system and the interactions between them including the key feedback loops and time delays. The CLDs can also be used to form a dynamic hypothesis of how the structure of a system is determining its observed behaviour over time (Sterman, 2000). Quantitative modelling can also be undertaken based on the system dynamics approach using computer-based stock and flow models. These models are often developed from CLDs with the addition of equations to represent the relationships between variables. Stock and flow models allow different policies to be simulated to see which bring about the desired end state. An overview of Causal Loop Diagrams (CLDs) and stock and flow models are provided in the following two sub-sections in turn.

3.3.1 Causal Loop Diagrams (CLDs)

Causal Loop Diagrams provide a schematic view of the variables in a system and the interactions between them. The CLDs are constructed using a standardised set of elements which are presented in Table 3.4.

The variables in CLDs are known as entities and the relationship between two entities are represented by causal links. These links indicate the direction of causation between two entities and also include a sign of polarity. If a causal link from entity A to entity B has a positive polarity it means an increase in A leads to an increase in B. If the causal link from A to B has a negative sign it means that an increase in A leads to a decrease in B. Delays in the cause-and-effect relationship between two variables can also be incorporated which are represented by the addition of two slanted lines through the causal link.

An important aspect of system dynamics models are feedback loops. These loops are formed by a sequence of entities and causal links in a system which means that a change in the scale of an entity subsequently causes itself to grow or decline. There are two different types of feedback loop. Firstly, a reinforcing feedback loop amplifies the effects within a system over time and is represented by a circular arrow with an ‘R’ or a ‘+’ in the centre. In this type of feedback loop an increase (decrease) in an entity leads to a further increase (decrease) in its value. Secondly, a balancing feedback counters the effects within a system and is represented by a ‘B’ or ‘-’ in the centre of a circular arrow. In a balancing feedback loop an increase (decrease) in an entity subsequently leads to a decrease (increase) in its value. Reinforcing feedback loops contain an even number of causal links with negative polarity and a balancing feedback loop contains an odd number of causal links with negative polarity. System dynamics models typically contain many feedback loops which interact to determine how the state of the system changes over time.

Table 3.4 Elements used in Causal Loop Diagrams

Element	Symbol
Entity	**Rail Demand**
Causal links	$A \xrightarrow{+} B$ $A \xrightarrow{-} B$
Time Lag	$\longrightarrow\!\!\!\!\!\!\!\!\!/\!/\quad$
Feedback Loops	

The key concepts of CLDs can be illustrated using some simple example models. A basic model of a CLD and the behaviour over time of the relationship between chickens and eggs is shown in Figure 3.2.

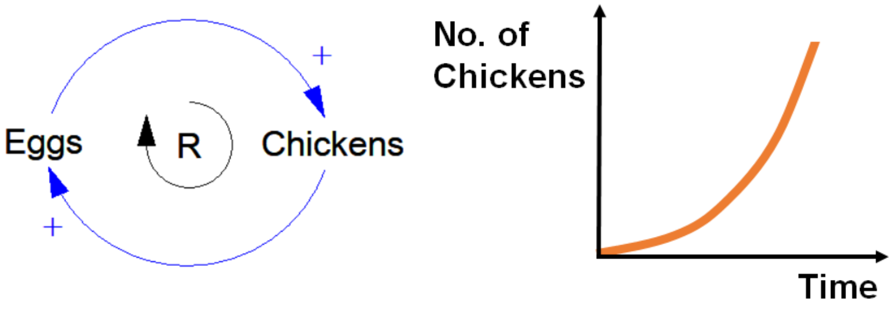

Figure 3.2 CLD and Behaviour over Time for a model of Chicken and Eggs (Source: Sterman (2000), p14)

In the example in Figure 3.2 there are only two variables: chickens and eggs. There is a positive causal link from chickens to eggs which means that an increase in the number of chickens leads to an increase in the number of eggs. There is also a positive causal link from eggs to chickens which signifies that an increase in eggs leads to a growth in the number of chickens. Both of the causal links in this system have a positive sign of polarity which means there is a reinforcing feedback loop.

This leads to the exponential growth in the number of chickens over time as more chickens lay more eggs which leads to more chickens.

The chicken and eggs example can be extended to include road crossings for which the updated CLD and behaviour over time are shown in Figure 3.3. The updated CLD now has three variables with the introduction of road crossings which is connected to chickens with two causal links. Firstly, there is a positive causal link from chickens to road crossings as a greater number of chickens leads to more chickens crossing the road. Secondly, there is a negative causal link from road crossings to chickens as a higher number of road crossings reduces the number of chickens. These two causal links form a balancing feedback loop as if the number of chickens increases this will increase the number of road crossings which will reduce the number of chickens. The behaviour over time chart shows that introducing a balancing feedback loop into the structure leads to oscillation over time rather than exponential growth.

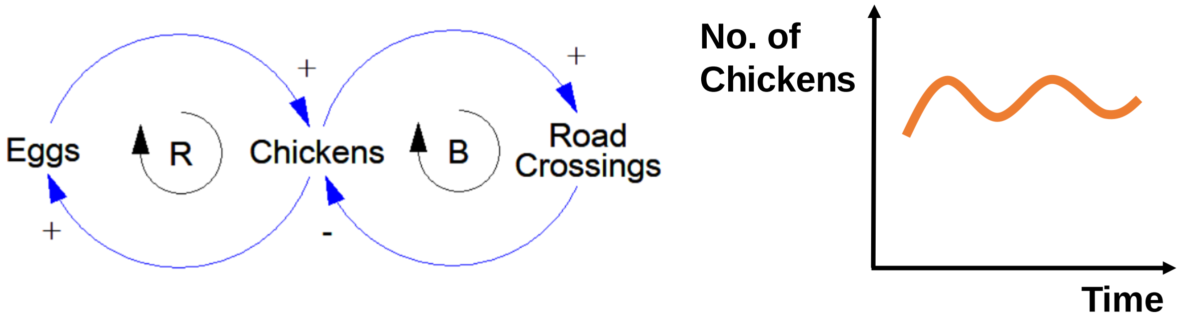

Figure 3.3 CLD and Behaviour over Time for a model of Chicken and Eggs with Road Crossings

The behaviour of system dynamic models become more complex when they include multiple feedback loops. Figure 3.4 shows a CLD and behaviour over time of a firm's sales over time taking into account the response of a direct competitor.

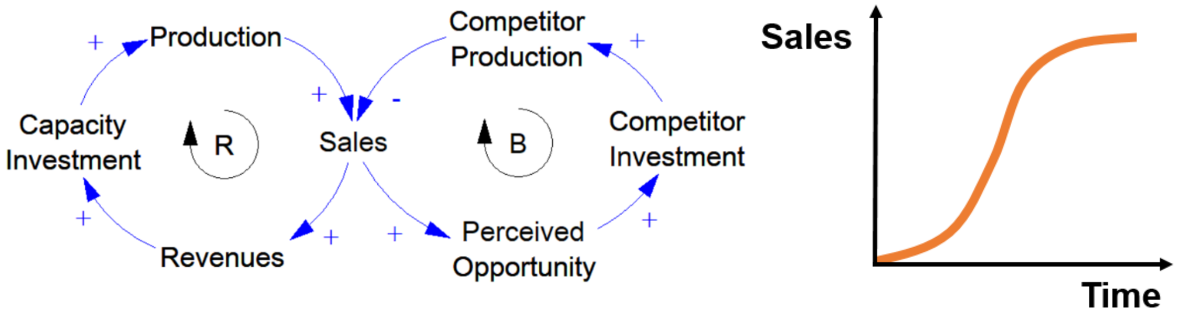

Figure 3.4 CLD and Behaviour over Time for a model of a Firm's Sales (Source: Tzafestas (2017), p98)

In the CLD in Figure 3.4 there are two feedback loops. In the loop on the left hand side of the CLD an increase in the sales of a firm generates higher revenues. This feeds through into higher investment by the firm in capacity which drives sales higher which is a reinforcing feedback loop. On the right hand side of the CLD there is another feedback loop which represents the response of a competitor in the market. As the sales of the firm grow this highlights to its competitor that there is a further opportunity in the market. The competitor responds to this by increasing investment in its own capacity which increases its production and reduces the sales of the original firm. This is a balancing feedback loop as in increase in the firm's sales leads to increased competition which reduces the level of its future sales.

The chart of the behaviour of the firm's sales over time in Figure 3.4 shows that there is an S-shaped growth pattern. Initially there is a rise in the firm's sales which leads to an increase in capacity and production which drives further sales but this is mitigated when its competitor responds by increasing production itself. The behaviour over time of the firm's highlights an important aspect of system dynamics models which is loop dominance. In this example the reinforcing feedback loop dominates to begin with but over time the balancing feedback loop comes to dominate and the system stabilises at a new equilibrium.

In system dynamics there are model structures which are present in many different models which are called common modes of behaviour or system archetypes. Examples of system archetypes include the exponential growth and S-shaped growth patterns shown in the two previous examples discussed above. There are several other system archetypes (see Wolstenholme (2003) for an overview) including S-shaped growth with overshoot, oscillation and overshoot and collapse.

Another common mode of behaviour which is found in many system dynamics models is the goal-seeking archetype. This archetype is also used in the models developed in this thesis in Chapters 4 to 6. The CLD and behaviour of the system over time for this archetype are shown in Figure 3.5.

The goal-seeking archetype functions by bringing a current state into balance with a desired state. It does this by using the discrepancy between the current state of the system and the desired state to move the current state towards the desired state. The goal-seeking archetype is a balancing feedback loop. This is observed in the behaviour over time chart in Figure 3.5 in which the change in the state over time gets smaller as the current state gets closer to the desired state.

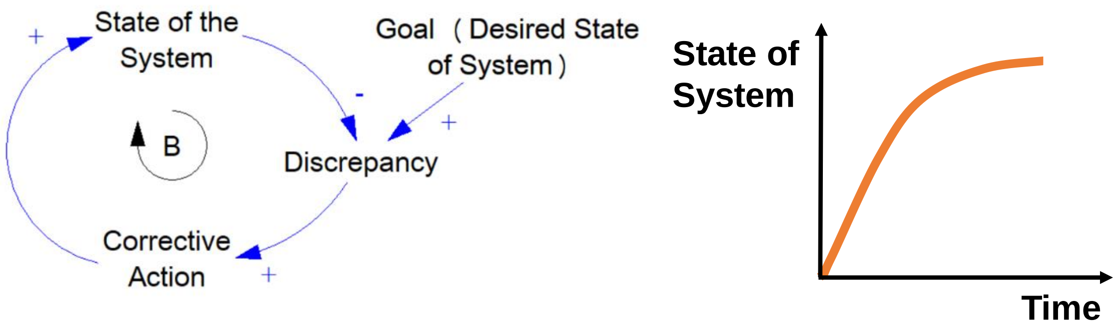

Figure 3.5 CLD and Behaviour over Time for Goal-Seeking Archetype (Source: Sterman (2000), p111)

3.3.2 Stock and Flow models

Quantitative modelling is undertaken in system dynamics using computer-based stock and flow models. These models are often developed from CLDs with the addition of equations to represent the relationships between variables. Stock and flow models use the same elements as outlined for CLDs above with a few additions. The basic structure of a stock and flow model is shown in Figure 3.6.

Figure 3.6 Basic Stock and Flow model

In stock and flow models there are different types of variables. Firstly, there are stocks which are illustrated by a rectangular box. Stocks are defined as variables which can accumulate over time. Stock and flow models also include inflows and outflows representing the rate of change of a stock over time. The external world is represented by small clouds which are shown on the extreme left and right of Figure 3.6. Inflows from the external world are represented by sources which are input into the model and outflows to the external world are represented by sinks which are an output from the model into the external world. Other variables included in a stock and flow model that are not stocks or flows which are called auxiliary variables.

The value of a stock over time is calculated using integration. The level of the stock in Figure 3.6 is estimated using the following formula[16]:

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[16] This equation is from Sterman (2000), p194.

$$Stock(t) = \int_{t_0}^{t} [Inflow(s) - Outflow(s)]\, ds + Stock(t_0) \qquad (3.43)$$

where *Stock(t)* is the level of the stock at time *t*, *Stock(t_0)* is the initial level of the stock at time zero (t_0), *Inflow(s)* is the rate of inflow at time *s* and *Outflow(s)* is the rate of outflow at time *s*. This equation represents that a stock will accumulate over time based on in its initial level and how the rate of inflow compares to the rate of outflow.

The functioning of stock and flow models can be illustrated using a basic example. A common type of model used in system dynamics is the adoption of a new product or idea. The stock and flow model and behaviour over time of a representation of this system is shown in Figure 3.7.

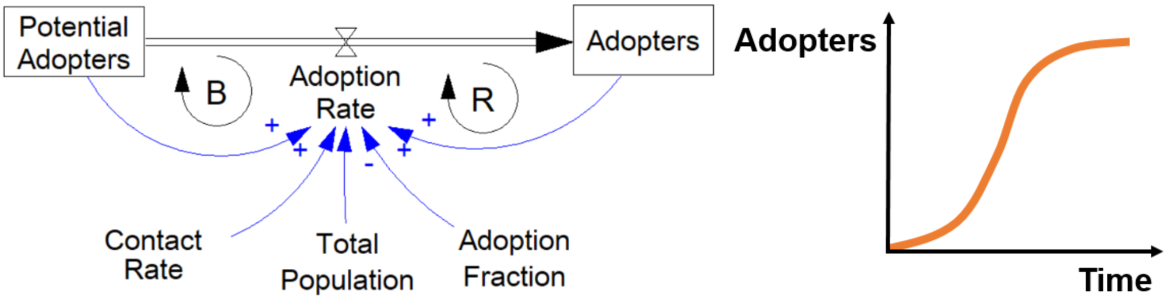

Figure 3.7 Stock and Flow model and Behaviour over Time for Adoption of a New Product (Source: Based on Sterman (2000), p325)

There are two stocks in Figure 3.6. Firstly, there is the stock of potential adopters who are the total number of customers in the population who have not yet purchased the product. Secondly, there are the adopters who are the number of people who have bought the product. The number of potential adopters who purchase the product are determined by the adoption rate which is a function of three auxiliary variables. These are the total population, the contact rate of people and the adoption fraction which is the proportion of potential adopters who adopt the product.

There are two feedback loops in the stock and flow model in Figure 3.7. Firstly, the number of adopters positively impacts on the adoption rate which then leads to an increase in the flow of adopters. This is a reinforcing feedback loop and represents positive word of mouth. Secondly, there is a balancing feedback loop as if the number of adopters increases this limits the number of potential adopters in later time periods. This feedback loop restricts the growth of the system and is therefore a balancing feedback loop. The projected behaviour over time is an S-shaped growth pattern and is similar to the CLD of a firm’s sales outlined in Figure 3.4. This is due to the similar structure of feedback loops in the two models with one reinforcing and one balancing feedback loop.

3.4 Summary

In this chapter the methodology used in the analysis in this thesis has been outlined. The method for estimating the urbanisation and localisation benefits was presented in Section 3.2. This is used in all of the analysis chapters in this thesis which are Chapters 4 to 8. In Chapters 4 a dynamic model of the impacts of inter-city connectivity on specialisation is developed based on the system dynamics approach which was outlined in Section 3.3. In Chapter 4 the CLDs and stock and flow representation of the model are outlined. A two city model is then used to determine the impact of inter-city connectivity improvements on land-use changes. This model is used to determine the final endpoint, to estimate the length of transition to the new steady state and to estimate the magnitude of benefits of increased specialisation due to inter-city transport. In Chapter 5 the dynamic model is extended to include mobility costs for switching sectors and in Chapter 6 the model is further extended to allow mobility of labour and capital between zones.

In Chapter 7 a static approach is used to estimate the impact of the inclusion of localisation effects and changes in specialisation on the economic appraisal of inter-city connectivity schemes. An abstract model is developed which is used to assess if the introduction of these effects are likely to be great enough to significantly affect the total Present Value of Benefits (PVB) of a scheme and under what conditions localisation benefits will be more important. In Chapter 8 a case study is undertaken of the proposed Northern Powerhouse Rail (NPR) scheme in the north of England. A similar method is used to the abstract modelling in Chapter 7 to see if the real world case supports the findings from Chapter 7. The case study is also used to determine if there are any differences between undertaking an analysis of changes in specialisation due to inter-city connectivity in the detailed real world case and the abstract case.

4 Dynamic Modelling of the Impacts of Inter-city Connectivity on Specialisation: First Stage Model

4.1 Introduction

In this chapter a stylised stock and flow model of the cities of Leeds and Manchester is developed using the system dynamics approach to investigate the impacts of inter-city transport on specialisation. In the model there are two business service sectors and a 20-minute reduction in rail travel times is introduced to determine the barriers to localisation impacts and to understand the extent to which they can be unlocked through inter-city transport. The objectives of the analysis undertaken in this chapter are to:

- Determine the final endpoint;
- Understand the dynamic processes over time;
- Determine the length of time for transition to a new steady state; and,
- Estimate the magnitude of benefits of increased specialisation due to inter-city transport.

This remainder of this chapter is organised as follows. In Section 4.2 the structure of the dynamic model which has been developed is outlined including the Causal Loop Diagrams (CLDs) and stock and flow model. The data inputs used in the model simulations are presented in Section 4.3 and the results are outlined in Section 4.4. The model is simulated in the first instance with mobile labour between sectors within a zone but with capital fixed and then with both mobile capital and labour between sectors within a zone. Finally, the conclusion is presented in Section 4.5.

4.2 Model Structure

The modelling analysis is undertaken using a stylised model of two cities which has been developed for this research. The cities are connected by inter-city rail and road links and each city has a core and periphery zone with intra-urban transport links. The structure of the model is shown in Figure 4.1.

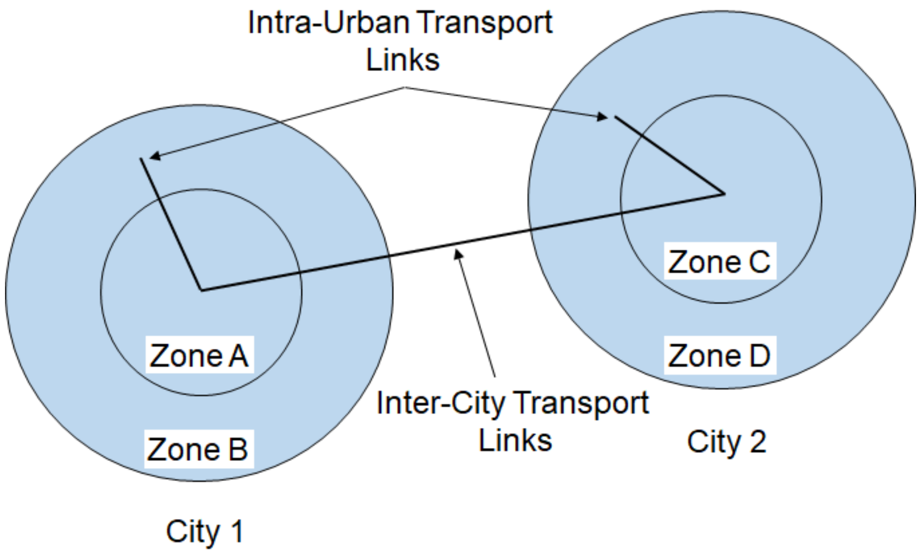

Figure 4.1 Diagram of Stylised Two-City Dynamic Model

The model has been developed based on the theories from the literature which are well developed in this field and were discussed in Chapter 2. These include the theories of comparative advantage and new economic geography and agglomeration effects due to changes in economic density. Based on the review of this literature a list of the most relevant variables and processes for the modelling was drawn up which is shown in Table 4.1. The first two columns show the endogenous and exogenous variables which were selected for the model and the third column shows the variables which were considered for inclusion but excluded.

Table 4.1 Variables and Processes Selected for Modelling

Endogenous	Exogenous	Excluded
Labour Stock	Transport Scheme	Zonal Migration
Capital Stock (Variable Capital Simulations)	Capital Stock (Fixed Capital Simulations)	Vertical Linkages
Wages	Prices	Population Growth
Capital Rents	Income Shares of Capital and Labour	Labour Skills/Human Capital
Sectoral Migration Within Zones	Labour Supply	Capital Accumulation
Total Factor Productivity		Capital Depreciation
Urbanisation Impacts		Demand for Products
Localisation Impacts		Factor Substitution

It was decided to keep the model simple so as to understand the importance of the key model structures and parameter assumptions. Only the variables considered most likely to be important in evaluating the impacts of inter-city connectivity on specialisation were therefore included in the first-stage model presented in this chapter. There were several endogenous variables selected for inclusion in the model. Labour and wage rates were included so that workers could choose between different options based on maximising their financial returns which is a commonly used method in new economic geography models (Krugman, 1991b, Fujita et al., 1999). Although capital was not included in many of the original new economic geography models such as Krugman (1991b) it was subsequently incorporated in some more recent variants (Martin & Rogers, 1995, Commendatore et al., 2007). Capital and capital rents were selected for inclusion in the model as it was expected that the decisions of capital owners and not only labour will be important for understanding changes in specialisation due to transport.

The inclusion of both labour and capital in the model also allowed the use of the Cobb-Douglas production function for estimating economic output in each sector. In this function economic output is determined by labour, capital and total factor productivity (TFP) which represents how efficiently labour and capital are used in production[17]. The Cobb-Douglas production function is commonly used in economic modelling due to its attractive mathematical properties (Zhao, 2019). These include characteristics which are useful for the modelling of changes in specialisation such as diminishing marginal returns[18]. Urbanisation and localisation effects were also included in the model which were discussed in Section 2.4.1 of Chapter 2. These stem from increased productivity due to a higher level of economic density of the overall economy and individual sectors respectively.

There were also several exogenous variables selected for inclusion in the first-stage model. These were specified as exogenous variables as changes in their value over time were not expected to be crucial for understanding the impact of inter-city transport on specialisation. The inter-city connectivity scheme is applied in the model as a one-off reduction in journey times between the two cities. The total labour

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[17] The formula for the Cobb-Douglas production function is shown in equation (4.5). This function includes the income shares of labour and capital which are included in Table 4.1. These variables represent the increase in output if the level of each of these variable were increased.

[18] The other properties of the Cobb-Douglas production function include constant returns to scale, both labour and capital are essential and if one of the factors of production declines towards zero the marginal product of the other tends towards infinity (Abreu, 2014).

supply was assumed to be fixed with each worker supplying a fixed annual number of hours of labour per year. Prices for the output of each sector were included in the model equations but they were set equal to one as demand linkages were not incorporated into the model and prices were therefore effectively excluded.

Other variables which were considered for the first-stage model include population growth, capital accumulation and capital depreciation which have been incorporated in dynamic representations of economic growth models (Kunte & Damani, 2016). These variables, however, were not considered essential for determining the impact of inter-city transport on changes in specialisation and it was decided to hold the total amount of labour and capital constant to focus on the impacts of the transport scheme only. Vertical linkages between sectors which are often modelled using input-output frameworks in transport and land-use interaction models such as ASTRA (Schade et al., 2000), the demand for products, and substitution between labour and capital in production were also considered for inclusion in the model but they were excluded for the same reasoning. The mobility of labour and capital between zones was excluded from the first-stage model but they were incorporated in an extended version of the model which is presented in Chapter 6.

A diagram of the stock and flow model which was developed based on the endogenous and exogenous variables shown in Table 4.1 is presented in Figure 4.2[19]. In the model there are two business service sectors (S1, S2) and the inter-city transport scheme is introduced to test the impact on land-use. The stock of labour and capital in each sector in each zone is determined by its initial value and by inward and outward migration from and to the alternative sector within the zone. The total number of workers and amount of capital in each zone are fixed and both can move between sectors within a zone in response to differences in wages and capital rents respectively.

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[19] The equations used in the model are outlined in Sections 4.2.1, 4.2.2 and 4.2.3 later in this chapter.

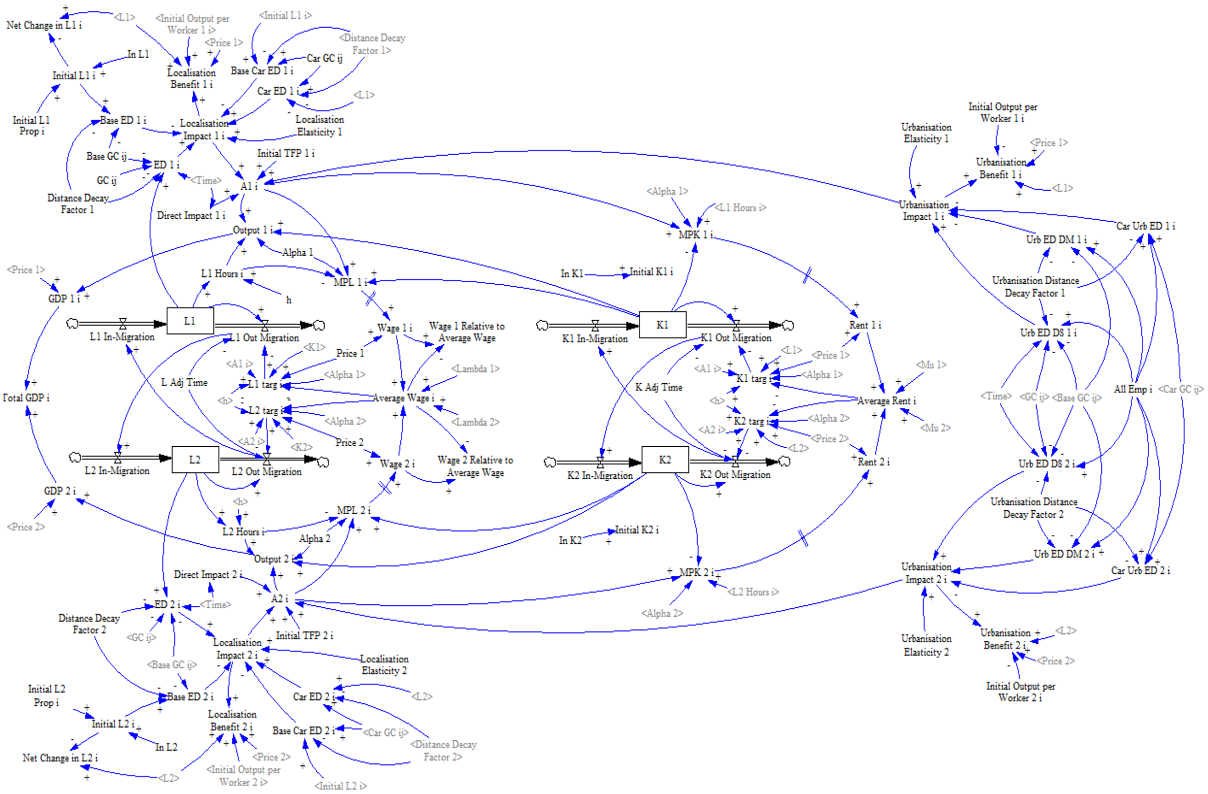

Figure 4.2 Stock and Flow Model Diagram

The main feedback loops in the model for the labour market in Sector 1 are shown in Figure 4.3. In reinforcing feedback loop R1 an increase in the number of workers in Sector 1 (*L1 (state of the system))* in a zone increases the effective density in that sector (*Sector Effective Density 1)* which increases the productivity of the workers through localisation impacts (*Localisation Impact 1*). This feeds through into a higher Total Factor Productivity (TFP) in the sector (*Total Factor Productivity 1*) which raises the implied steady state level of labour (*L1 Target (Goal)*) which then increases the incentive for more workers to move into that sector. There is another reinforcing feedback loop in the labour market (R2) through which an increase in the number of workers in Sector 1 (*L1 (state of the system)*) lowers the marginal product of labour (MPL) (*MPL 1*). This leads to a lower average wage (*Average Wage*) which raises the target level of labour in the sector (*L1 Target (Goal)*) in the zone.

There are also two balancing feedback loops in the labour market. The goal-seeking archetype is used to move the current number of workers in the sector (*L1 (state of the system)*) towards the target number (*L1 Target (Goal)*) in feedback loop B1. In feedback loop B2 an increase in the number of workers in Sector 1 (*L1 (state of the system)*) generates localisation impacts (*Localisation Impact 1*) which feed through into increasing the average wage (*Average Wage*) which reduces the implied steady state level of labour in Sector 1 (*L1 Target (Goal)*).

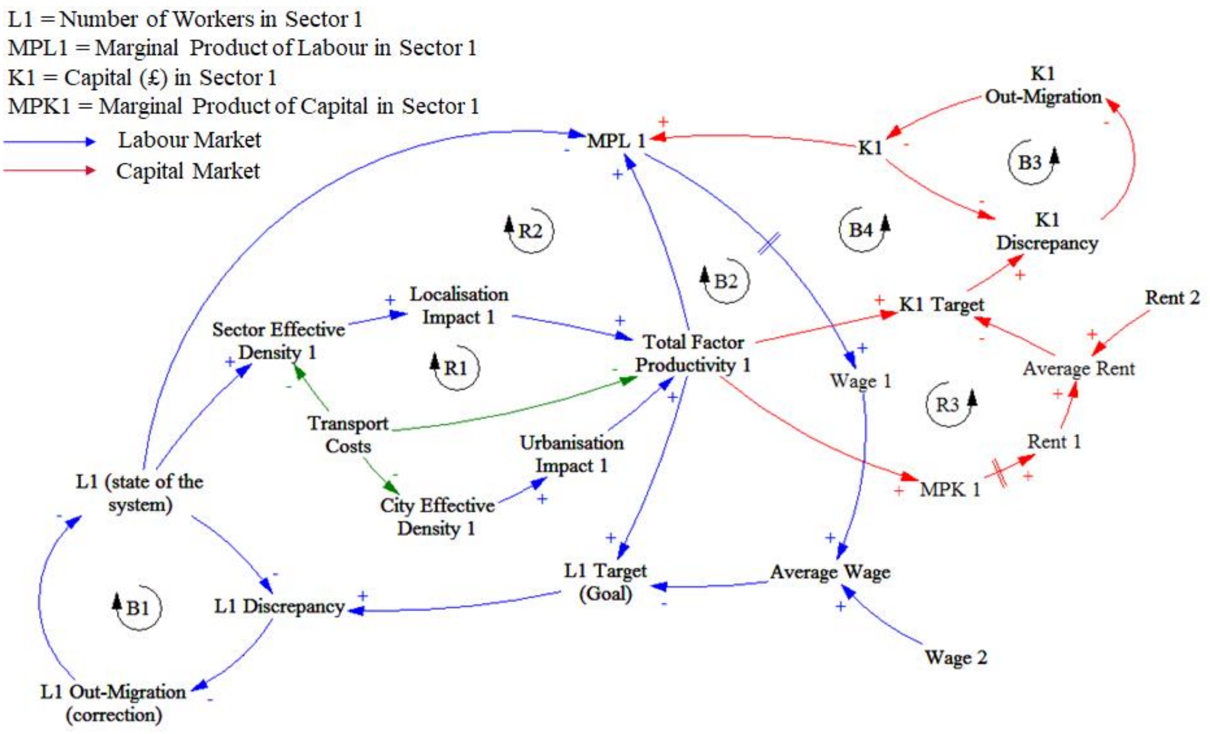

Figure 4.3 Main Feedback Loops in the Labour Market for Sector 1

Labour can also impact on the capital market through two feedback loops. Firstly, there is reinforcing feedback loop R3 in which an increase in labour in Sector 1 (*L1 (state of the system)*) leads to localisation impacts (*Localisation Impact 1*) which feed through into an increase in TFP (*Total Factor Productivity 1*). This leads to a higher marginal product of capital (MPK) (*MPK 1*) which increases the average rent (*Average Rent*) which lowers the implied steady state level of capital (*K1 Target*) through the goal-seeking archetype loop for capital (B3). This feeds through into a lower MPL (*MPL 1*) and average wage (*Average Wage*) which raises the implied steady state level of labour (*L1 Target (Goal)*). Secondly, there is a balancing feedback loop (B4) through which a rise in the number of workers (*L1 (state of the system)*) increases TFP (*Total Factor Productivity 1*) which leads to a higher implied steady state level of capital (*K1 Target*) and then MPL (*MPL 1*) leading to a lower implied steady state level of labour (*L1 Target (Goal)*).

The main feedback loops in the capital market for Sector 1 are shown in Figure 4.4. In addition to the feedback loops discussed previously there is a reinforcing feedback loop R4 through which an increase in capital in Sector 1 (*K1*) in a zone leads to a lower MPK (*MPK 1*) and then average rent (*Average Rent*) which increases the implied steady state level of capital in Sector 1 (*K1 Target*). In contrast to the labour stocks, the capital stocks do not feed directly into the effective densities for localisation impacts as these are a function of the number of workers in each zone and travel costs. This means that the reinforcing feedback loop for labour in which an increase in the number of workers in a sector increases TFP leading to further in-migration is not present for capital.

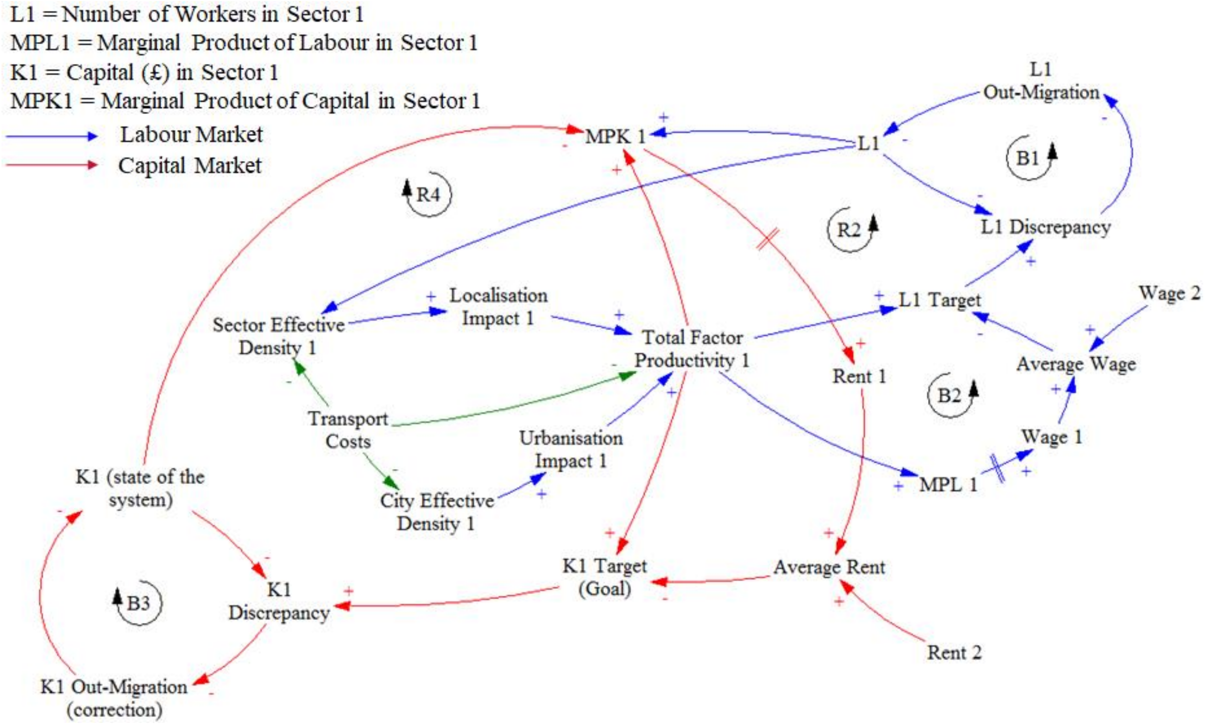

Figure 4.4 Main Feedback Loops in the Capital Market for Sector 1

In the remainder of Section 4.2 the equations which are used in the model are outlined. These are divided into the following sub-sections which are discussed in turn: labour market; capital market; and, economics impacts. All the terms used in the equations are defined in the table of notation which is shown in Table 4.2.

4.2.1 Labour Market

The labour stock in Sector 1 (S1) and Sector 2 (S2) in each zone is determined by its initial value and migration to and from the other sector within the same zone. The stock of labour in Sector 1, $L_i^{S1}(t)$, is given by the following integral formula for zone *i* at time *t*:

$$L_i^{S1}(t) = \int_{t_0}^{t} \left[L\ In\ Migration_i^{S1}(s) - L\ Out\ Migration_i^{S1}(s)\right] ds + L_i^{S1}(t_0) \qquad (4.1)$$

where $L\ In\ Migration_i^{S1}(s)$ is the inflow into the stock of labour in Sector 1 in zone *i* at time s, $L\ Out\ Migration_i^{S1}(s)$ is the outflow from the stock of labour in Sector 1 in zone *i* at time *s*, and $L_i^{S1}(t_0)$ is the initial level of the labour stock in Sector 1 in zone *i* when *t* is equal to zero. The labour stock in Sector 2, $L_i^{S2}(t)$, is given by:

$$L_i^{S2}(t) = \int_{t_0}^{t} \left[L\ In\ Migration_i^{S2}(s) - L\ Out\ Migration_i^{S2}(s)\right] ds + L_i^{S2}(t_0) \qquad (4.2)$$

where $L\ In\ Migration_i^{S2}(s)$ is the inflow into the stock of labour in Sector 2 in zone *i* at time *s*, $L\ Out\ Migration_i^{S2}(s)$ is the outflow from the stock of labour in Sector 2 in zone *i* at time *s*, and $L_i^{S2}(t_0)$ is the initial level of the labour stock in Sector 2 in zone *i* when *t* is equal to zero.

Table 4.2 Table of Notation

Symbol	Description
i	Zone
j	Destination zone
n, $S1$, $S2$	Sector, Sector 1, Sector 2
t, s	Time
L_i^n	Labour (number of workers) in sector *n* in zone *i*
$(L^*)_i^n$	Implied steady state value of labour in sector *n* in zone *i*
$L\ Out\ Migration_i^n$	Outflow of Workers from sector *n* in zone *i*
$L\ In\ Migration_i^n$	Inflow of Workers into sector *n* in zone *i*
K_i^n	Capital sector *n* in zone *i*
$(K^*)_i^n$	Implied steady state level of capital in sector *n* in zone *i*
$K\ Out\ Migration_i^n$	Outflow of capital from sector *n* in zone *i*
$K\ In\ Migration_i^n$	Inflow of Capital into Sector *n* in zone *i*
h	Average annual number of hours worked per worker
A_i^n	Total Factor Productivity (TFP) in sector *n* in zone *i*
α_i^n	Income share of capital in sector *n* in zone *i*
$1 - \alpha_i^n$	Income share of labour in sector *n* in zone *i*
Y_i^n	Number of units of output in sector *n* in zone *i*
λ_i^n	Proportion of labour in sector *n* in zone *i*
μ_i^n	Proportion of capital in sector *n* in zone *i*
w_i^n	Wage rate (£) per hour in sector *n* in zone *i*
$\overline{w_\iota}$	Average wage in zone *i*

r_i^n	Capital rent (£) in sector *n* in zone *i*
$\overline{r_i}$	Average capital rent in zone *i*
MPL_i^n	Marginal Product (number of units of output) of labour in sector *n* in zone *i*
MPK_i^n	Marginal Product (number of units of output) of capital in sector *n* in zone *i*
P^n	Price (£) per unit in sector *n*
$TAdjL$	Time of adjustment for labour
$TAdjK$	Time of adjustment for capital
BUB_i^n	Business User Benefits (£)sector *n* in zone *i*
DIR_i^n	Direct uplift to TFP due to business user benefits sector *n* in zone *i*
EDU_i^n	Effective Density for urbanisation effects in sector *n* in zone *i*
EDL_i^n	Effective Density for localisation effects in sector *n* in zone *i*
E_j	Number of jobs in destination zone *j*
E_j^n	Number of jobs in destination zone *j* in sector *n*
GJT_{ij}^m	Generalised Journey Time (£) between zone *i* and destination zone *j* using mode *m*
m	Transport Mode
βu^n	Distance decay factor for urbanisation impacts in sector *n*
βl^n	Distance decay factor for localisation Impacts in sector *n*
URB_i^n	Change in productivity (%) due to urbanisation impacts
LOC_i^n	Change in productivity (%) due to localisation impacts
ρu^n	Urbanisation elasticity in sector *n*
ρl^n	Localisation elasticity in sector *n*
$Initial\ GDP_i^n$	GDP at time (t) equal to zero in sector *n* in zone *i*
WBU_i^n	Wider Economic Benefits (£) due to urbanisation in sector *n* in zone *i*
WBL_i^n	Wider Economic Benefits (£) due to localisation in sector *n* in zone *i*
$GDPW_i^{DM,n}$	GDP (£) per worker in the do-minimum situation in sector *n* in zone *i*

$E_i^{DS,n}$	Employment in the do-something situation in sector *n* in zone *i*
TB_i^n	Total economic benefits (£) in sector *n* in zone *i*

For ease of presentation time subscripts are omitted in the equations outlined below which are auxiliary variables where the calculation involves quantities in the same time step.

A goal-seeking structure is used to determine the pathway to the final equilibrium level of labour in a sector within a zone as described in Sterman (2000). Labour can only move in one direction at each time step and the number of workers who migrate out of a sector is determined by the following formula for Sector 1:

$$L\ Out\ Migration_i^{S1} = \left(\frac{L_i^{S1} - (L^*)_i^{S1}}{TAdjL}\right) \qquad if\ w_i^{S2} > w_i^{S1} \tag{4.3}$$

where $L\ Out\ Migration_i^{S1}$ is the number of workers who leave Sector 1 in zone *i*, L_i^{S1} is the current number of workers in Sector 1 in zone i, $(L^*)_i^{S1}$ is the implied steady state value of labour in Sector 1 in zone *i*, $TAdjL$ is the adjustment time for labour, and w_i^{S1} and w_i^{S2} are the wage rates per hour in zone *i* in Sector 1 and Sector 2 respectively. Workers only migrate from Sector 1 to Sector 2 in zone *i* if the wage rate in Sector 2 is greater than the wage rate in Sector 1.

A higher adjustment time leads to a slower speed of adjustment and an adjustment time for labour of 1.5 years was specified to achieve adjustment to 98% of the initial gap in 6.5 years with fixed capital. This value was based on defining a slightly quicker speed of adjustment to Dix-Carneiro (2014) who undertook one of the most in-depth analyses of the dynamics of inter-sectoral migration. He estimated that in response to reduced inter-regional trade barriers 95% of the adjustment in sectoral employment took place within 9 years with fixed capital but with the inclusion of human capital which accumulates with experience in a sector over time which slows down the transition to a new steady state. The estimated length of adjustment of 6.5 years with fixed capital is just outside four times the adjustment time suggested as a rule-of-thumb in Sterman (2000) and the reason for the longer adjustment is the six months delay applied between changes in productivities and wage rates.

The number of workers who migrate out of sector 2 in zone *i*, $L\ Out\ Migration_i^{S2}$, is calculated in a similar way using the following formula:

$$L\ Out\ Migration_i^{S2} = \left(\frac{L_i^{S2} - (L^*)_i^{S2}}{TAdjL}\right) \qquad if\ w_i^{S1} > w_i^{S2} \tag{4.4}$$

where $L\ Out\ Migration_i^{S2}$ is the number of workers who leave Sector 2 in zone *i*, L_i^{S2} is the current number of workers in Sector 2 in zone i, $(L^*)_i^{S2}$ is the implied steady state value of labour in Sector 2 in zone *i*. Labour only moves from Sector 2 to Sector 1 if the wage rate in Sector 1 in zone *i*, w_i^{S1} , is greater than the wage rates in Sector 2 in zone *i*, w_i^{S2}.

The number of units of output produced in each zone *i* in sector *n*, Y_i^n, is determined using a Cobb-Douglas Production Function:

$$Y_i^n = A_i^n (hL_i^n)^{1-\alpha_i^n} (K_i^n)^{\alpha_i^n} \tag{4.5}$$

where A_i^n is Total Factor Productivity (TFP) in sector *n* in zone *i*, *h* is the average annual number of hours worked per worker each year, L_i^n is the number of workers in sector *n* in zone *i*, K_i^n is capital (£) in sector *n* in zone *i*, α_i^n is the income share of capital in sector *n* in zone *i* and $1 - \alpha_i^n$ is the income share of labour in sector *n* in zone *i*. The nominal wage rate per hour for workers in sector *n* in zone *i*, w_i^n, is given by:

$$w_i^n = MPL_i^n P^n \tag{4.6}$$

where P^n is price (£) per unit in sector *n* which is set to 1 and MPL_i^n is the marginal product of labour in sector *n* in zone *i* which is determined by:

$$MPL_i^n = (1 - \alpha_i^n) A_i^n (K_i^n / hL_i^n)^{\alpha_i^n} \tag{4.7}$$

It is assumed that productivity changes do not feed through into changes in wages immediately. This is modelled through introducing a delay between a change in the marginal product of labour in a sector and the wage rate. This is applied using a third order exponential delay with a time delay of six months based on the assumption that workers have annual pay reviews and so, on average, productivity changes are reflected in wage rates six months later[20].

The implied steady state value of labour in sector *n* in zone *i*, $(L^*)_i^n$, is determined by setting the wage rate given by the combination of equations (4.6) and (4.7) equal to the average wage across the two sectors within a zone *i*, $(\overline{w_i})$, and rearranging to express in terms of the number of workers which gives:

$$(L^*)_i^n = 1 \Big/ \Big(\big(\overline{w_i} / (1 - \alpha_i^n) P^n \, A_i^n\big)^{1/\alpha_i^n} (h_i^n / K_i^n) \Big) \tag{4.8}$$

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[20] For an overview of applying delays including third-order exponential delays in system dynamics modelling see Kirkwood (1998).

4.2.2 Capital Market

The formulae for capital stocks are similar to those outlined in the previous sub-section for labour stocks. The capital stock for Sector 1 in zone *i* at time *t*, $K_i^{S1}(t)$, is given by:

$$K_i^{S1}(t) = \int_{t_0}^{t} \left[K\ In\ Migration_i^{S1}(s) - K\ Out\ Migration_i^{S1}(s)\right] ds + K_i^{S1}(t_0) \qquad (4.9)$$

where $K\ In\ Migration_i^{S1}(s)$ is the inflow of capital into Sector 1 in zone *i* in time *s*, $K\ Out\ Migration_i^{S1}(s)$ is the outflow of capital from Sector 1 in zone in time s and $K_i^{S2}(t_0)$ is the amount of capital in Sector 2 in zone *i* at time equals zero. Similarly, the formula for the capital stock in Sector 2 in zone *i* at time *t*, $K_i^{S2}(t)$, is given by:

$$K_i^{S2}(t) = \int_{t_0}^{t} \left[K\ In\ Migration_i^{S2}(s) - K\ Out\ Migration_i^{S2}(s)\right] ds + K_i^{S2}(t_0) \qquad (4.10)$$

where $K\ In\ Migration_i^{S2}(s)$ is the inflow into the stock of capital in Sector 2 in zone *i* at time *s*, $K\ Out\ Migration_i^{S2}(s)$ is the outflow from the stock of capital in Sector 2 in zone *i* at time *s*, and $k_i^{S2}(t_0)$ is the initial level of the capital stock in Sector 2 in zone *i* when *t* is equal to zero. The migration of capital between sectors within a zone is based on the same structure as labour. The amount of capital leaving Sector 1 in zone *i*, $K\ Out\ Migration_i^{S1}$, is given by:

$$K\ Out\ Migration_i^{S1} = \left(\frac{K_i^{S1} - (K^*)_i^{S1}}{TAdjK}\right) \qquad if\ r_i^{S2} > r_i^{S1} \qquad (4.11)$$

where K_i^{S1} is the amount of capital in sector 1 in zone *i*, $(K^*)_i^n$ is the implied steady state value of capital in Sector 1 in zone *i*, $TAdjK$ is the adjustment time for capital, r_i^{S2} is the capital rent (£) in Sector 2 in zone *i*, and r_i^{S1} is the capital rent in Sector 1 in zone *i*. Capital only switches from Sector 1 to Sector 2 in zone *i* if r_i^{S2} is greater than r_i^{S1}. As in the labour market the adjustment time for capital was set to 1.5 years. Similarly, the amount of capital leaving Sector 2 in zone *i*, $K\ Out\ Migration_i^{S2}$, is given by:

$$K\ Out\ Migration_i^{S2} = \left(\frac{K_i^{S2} - (K^*)_i^{S2}}{TAdjK}\right) \qquad if\ r_i^{S1} > r_i^{S2} \qquad (4.12)$$

The nominal rent for capital in sector n in zone *i*, r_i^n, is given by:

$$r_i^n = MPK_i^n P^n \qquad (4.13)$$

where MPK_i^n is the marginal product of capital in sector *n* in zone *i* and P^n is the price per unit in sector *n*. The marginal product of capital in sector *n* in zone *i*, MPK_i^n, is calculated for sector *n* in zone *i* using the formula:

$$MPK_i^n = \alpha_i^n A_i^n (K_i^n)^{\alpha_i^n - 1} (hL_i^n)^{1-\alpha_i^n} \qquad (4.14)$$

There is a delay between changes in productivity which feed into the MPK and then rent. The delay between productivity changes and rents are modelled in the same way as in the labour market with a third order exponential delay with a time delay of six months.

The implied steady state value of capital in sector *n* in zone i,$(K_i^n)^*$, is determined across each sector and zone by equating the monetary value of MPK with the average rent within zone *i,* ($\overline{r_i}$), and rearranging to express in terms of capital which gives:

$$(K^*)_i^n = \left(\overline{r_i}/(h_i^n L_i^n)^{1-\alpha_i^n}\ \alpha_i^n P^n A_i^n\right)^{1/(\alpha_i^n - 1)} \qquad (4.15)$$

4.2.3 Economic Impacts

The business user benefits of the transport scheme and the localisation and urbanisation impacts are used to estimate TFP which feeds into the calculation of the wage rate and capital rent through equations (4.7) and (4.14) respectively. The value of TFP in sector *n* in zone *i*, A_i^n, is given by:

$$A_i^n = Initial\ A_i^n * DIR_i^n * (1 + URB_i^n) * (1 + LOC_i^n) \qquad (4.16)$$

where $Initial\ A_i^n$ is the initial level of TFP at time equal to zero in sector *n* in zone *i*, DIR_i^n is the proportional increase in productivity from business user benefits in sector *n* in zone *i*, $(1 + URB_i^n)$ is the increase in TFP from urbanisation effects in sector *n* in zone *i* and $(1 + LOC_i^n)$ is the increase in TFP from localisation effects in sector *n* in zone *i*.

The business user benefits (BUB) are calculated using the standard rule-of-a-half formula. These are then used to calculate the direct impact on TFP in sector *n* in zone *i*, DIR_i^n, using the following formula for zone *i* for e.g. Sector 1:

$$DIR_i^{S1} = \left(\left(\frac{Initial\ GDP_i^{S1}}{Initial\ GDP_i^{S1} + Initial\ GDP_i^{S2}}\right) BUB_i^{S1} + Initial\ GDP_i^{S1}\right) \Big/ Initial\ GDP_i^{S1} \qquad (4.17)$$

where $Initial\ GDP_i^{S1}$ and $Initial\ GDP_i^{S2}$ are the initial GDP in zone *i* in Sector 1 and 2 respectively and BUB_i^{S1} are the business user benefits in Sector 1 in zone *i*. The values of the initial GDP in each combination of sector and zone are calculated using the number of jobs and GDP per worker at time equal to zero. The direct impact is calculated for the scheme opening year and then applied in all subsequent years.

The effective densities for urbanisation and localisation effects in sector *n* in zone *i*, EDU_i^n and, EDL_i^n respectively are given by:

$$EDU_i^n = \sum_j \sum_m \frac{E_j}{\left(GJT_{ij}^m\right)^{\beta U^n}} \tag{4.18}$$

$$EDL_i^n = \sum_j \sum_m \frac{E_j^n}{\left(GJT_{ij}^m\right)^{\beta L^n}} \tag{4.19}$$

where GJT_{ij}^m is the generalised journey time of a trip between zone *i* and destination zone *j* by transport mode *m*, E_j is total employment in destination zone j, E_j^n is employment in destination zone *j* in sector *n* and βU^n and βL^n are the distance decay factors for urbanisation and localisation effects in sector *n* respectively. The productivity impacts are calculated separately at each time step for urbanisation (URB_i^n) and localisation (LOC_i^n) effects for each sector *n* in zones *i* based on the effective density in the do-minimum (DM) and do-something (DS) situations using the following formulae respectively:

$$URB_i^n = \left[\left(\frac{EDU_i^{DS,n}}{EDU_i^{DM,n}}\right)^{\rho U^n} - 1\right] \tag{4.20}$$

$$LOC_i^n = \left[\left(\frac{EDL_i^{DS,n}}{EDL_i^{DM,n}}\right)^{\rho L^n} - 1\right] \tag{4.21}$$

where ρU^n and ρL^n are the elasticities for urbanisation and localisation effects in sector *n* respectively.

The economic benefits from urbanisation (WBU_i^n) and localisation (WBL_i^n) effects in sector *n* in zone *i* are calculated using the formulae respectively:

$$WBU_i^n = URB_i^n GDPW_i^{DM,n} E_i^{DS,n} \tag{4.22}$$

$$WBL_i^n = LOC_i^n GDPW_i^{DM,n} E_i^{DS,n} \tag{4.23}$$

where $GDPW_i^{DM,n}$ is the GDP per worker in the do-minimum situation in sector *n* in zone *i* and $E_i^{DS,n}$ is employment in sector *n* in zone *i* in the do-something situation. Total benefits in sector *n* in zone *i*, TB_i^n, at each time step are given by:

$$TB_i^n = BUB_i^n + WBU_i^n + WBL_i^n \tag{4.24}$$

4.3 Data Inputs

The analysis in this chapter is based on a stylised model of the UK cities of Manchester and Leeds. The study area is a closed system and all of the economic impacts are realised within the two cities. The data inputs used for the number of jobs, capital, TFP and GDP per worker for Sector 1 are shown in Table 4.3. The Sector 2 inputs are symmetrical to those for Sector 1 but with the higher GDP per worker in Zones C (£82,000) and D (£61,500) rather than in A (£78,000) and B (£58,500). This set up implies that Cities 1 and 2 have a comparative advantage in Sectors 1 and 2 respectively and it is expected that at a new steady state the cities will be more specialised in the sector in which they have the comparative advantage.

Table 4.3 Economic Inputs for Sector 1

	City 1		City 2		
Economic Variable	Zone A	Zone B	Zone C	Zone D	All Zones
Number of Jobs	50,000	20,00	50,000	20,000	140,000
Total Jobs	-	-	-	--	1,000,000
Capital Inputs (£mn)	£2,050	£615	£1,950	£585	-
TFP	12.67	10.72	12.31	10.42	-
GDP per Worker (£)	82,000	61,500	78,000	58,500	-
GDP (£mn)	£4,10	£1,230	£3,900	£1,170	-

The sectors which have been selected for the analysis are based on business services such as finance media, high-tech in which firms are known to cluster together (Venables, Laird and Overman, 2014). The two sectors are presumed to require similar skills and workers are assumed to be able to move between sectors without further training. An income share for capital of 0.42 was used for both sectors based on the UK's Office for National Statistics (ONS) estimate for real estate activities, professional and scientific activities and administrative and support activities (ONS, 2020)[21].

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[21] The ONS estimates in 2016 Q1 for the income share of capital for producer services were 0.40 (Information and Communication), 0.38 (Financial & Insurance), 0.42 (Real Estate, Professional, Scientific & Technical Activities, and, Administrative and Support Services).

The economic inputs were based around data for GDP per capita for producer services in the north of England (DfT, 2018d). The GDP in each sector in each zone was estimated by multiplying the GDP per worker by the assumed number of workers. A capital-output ratio of 0.5 based on the estimated value for Professional and Scientific Activities in the UK (ONS, 2016) was then used to estimate the amount of capital in each sector and zone. An average number of hours worked per worker of 1,700 was then used to calculate the annual number of labour hours. These and the amount of capital were then used to calculate the level of output in each sector and zone using the formula for the Cobb-Douglas production function. The value of TFP was then specified so that the level of output estimated in the Cobb-Douglas production function equated to the product of GDP per worker and the number of workers.

In Sector 1 an urbanisation elasticity of 0.083 and distance decay factor of 1.746 were used. These are the agglomeration[22] parameters for producer services from Graham et al. (2009) which the recommended values in the UK's WebTAG Guidance (DfT, 2018c) are based on. There are no localisation elasticities recommended in WebTAG and an elasticity of 0.03 was used in Sector 1 to reflect the evidence from Graham (2009) that localisation elasticities are lower than urbanisation elasticities for business service sectors. A distance decay factor of 2 was used based on the evidence that localisation effects decay more rapidly over distance than urbanisation impacts (Graham, 2009). For Sector 2 elasticities of 0.05 and 0.01 were used for urbanisation and localisation effects respectively to test how the effects compare for a sector which is less disposed to urbanisation and localisation effects. The same distance decay factors were used in Sector 2 as in Sector 1.

The Do-Minimum journey times for public transport (PT) and car are shown in Tables 4.4 and 4.5 respectively. The PT journey times are based on the current rail average in-vehicle journey time in the inter-peak of 52 minutes between Manchester and Leeds. The journey times also include 5 minutes for access and egress time at each station, a 10 minute walk to and from each station and assume that passengers arrive 5 minutes before their departure. It is assumed that business trips between the core and periphery are undertaken by taxi which takes 15 minutes and this is also

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[22] Agglomeration elasticities will include some localisation effects and applying them as urbanisation elasticities may slightly overstate the effects. For the modelling in Chapter 7 a range for urbanisation elasticities for business services of 0.04 to 0.20 (see Table 7.4) is selected based on the empirical evidence and the value used in this chapter is at the lower end of this range.

assumed for trips within the periphery. The car in-vehicle times are based on an estimated uncongested journey time of 66 minutes using Google Maps in the inter-peak. It is assumed that there is a 10 minute access/egress time for trips starting or ending in the city centre and 5 minutes for trips starting or ending in the periphery.

Table 4.4 Do-Minimum Public Transport Journey Times (minutes)

		City 1		City 2	
	Zone	A	B	C	D
City 1	A	10	15	87	102
	B	15	15	102	107
City 2	C	87	102	10	15
	D	102	107	15	15

Table 4.5 Car Journey Times (minutes)

		City 1		City 2	
	Zone	A	B	C	D
City 1	A	10	25	86	91
	B	25	20	81	91
City 2	C	86	81	10	25
	D	91	91	25	20

4.4 Results and Discussion

4.4.1 Business User Benefits

The business user benefits were first estimated using the standard rule-of-a-half formula (DfT, 2019). The business values of time were estimated using the distances for each O-D pair using the method outlined in the UK DfT's WebTAG guidelines (DfT, 2019). With this method the values of time vary by distance with higher values for longer trips and the estimated values are shown in Table 4.6.

The rail demand data was approximated from rail ticket sales data and an elasticity for rail demand with respect to GJT of -0.8 was used to estimate the number of new trips between zones[23]. The 20-minute journey time improvement was estimated to lead to a 21.3% increase in the number of inter-city rail trips across the two sectors. Total business user benefits were calculated as £2.1mn in the scheme opening year and the results by sector and zone are shown in Table 4.7[24].

Table 4.6 Business Rail Passenger Values of Time (£/hr, 2021 Values and 2010 Prices)

		City 1		City 2	
	Zone	A	B	C	D
City 1	A	8.32	8.38	18.45	19.01
	B	8.38	8.38	19.01	19.58
City 2	C	18.45	19.01	8.32	8.38
	D	19.01	19.58	8.38	8.38

Table 4.7 Business User Benefits (£mn, 2021 Values and 2010 Prices) in the Scheme Opening Year

	Zone	Sector 1	Sector 2	Total
City 1	A	0.39	0.37	0.75
	B	0.15	0.14	0.30
City 2	C	0.37	0.39	0.75
	D	0.14	0.15	0.30
	Total	1.05	1.05	2.10

4.4.2 Simulations with Fixed Capital

The model was simulated first with fixed capital by both sector and zone but with labour mobile between sectors within a zone using the economic inputs in Table 4.3.

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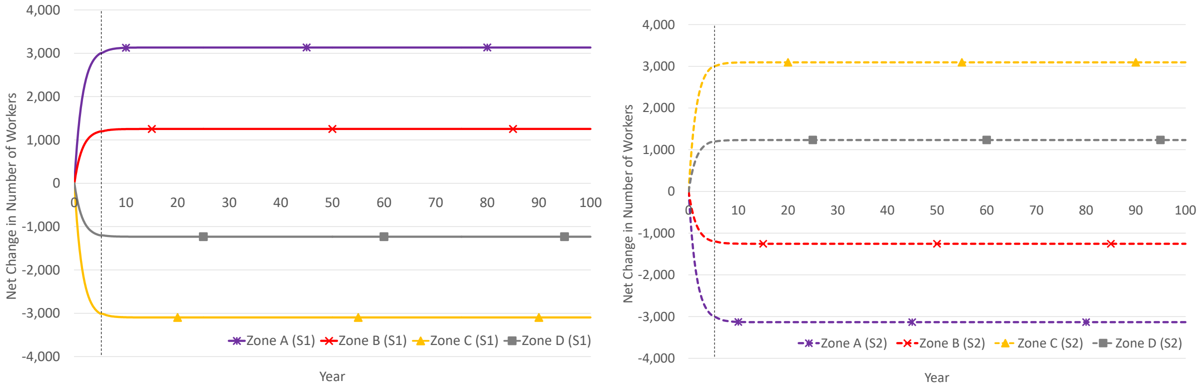
[23] This was based on a conservative assumption from an meta-analysis of rail elasticities with respect to GJT using UK data which estimated a long-run (annual) rail elasticity with respect to GJT ranging from –0.66 (for a 2 mile distance) to -1.67 (for a 200 mile distance) (Wardman, 2012).

[24] The business user benefits were estimated using numbers of inter-city trips for the two sectors which were approximated from rail ticket sales data between Manchester and Leeds.

The net change in the number of workers in each sector is shown in Figure 4.5. There is no consistent equilibrium at the initial starting point as the inputs are based on real data and the aim is to test how the model settles down.



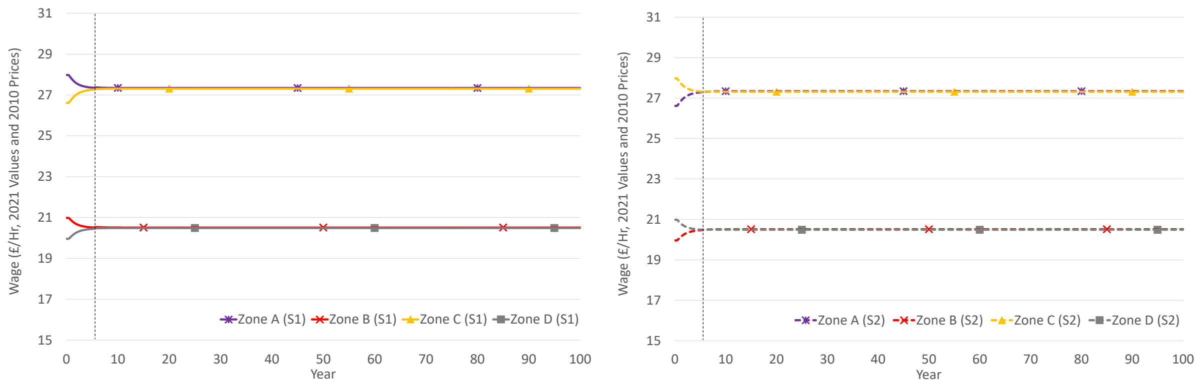
(a) Sector 1 **(b) Sector 2**

Figure 4.5 Net Change in Number of Workers Relative to Year Zero

At the start of the analysis period workers move towards Sector 1 in Zones A and B and towards Sector 2 in Zones C and D and the opening of the transport scheme in Year 5 accentuates these movements. The labour stock adjusts to 98% of the initial gap in 6.5 years which is just outside four times the adjustment time suggested as a rule-of-thumb in Sterman (2000) and the reason for this is the six months delay applied between changes in productivities and wage rates.

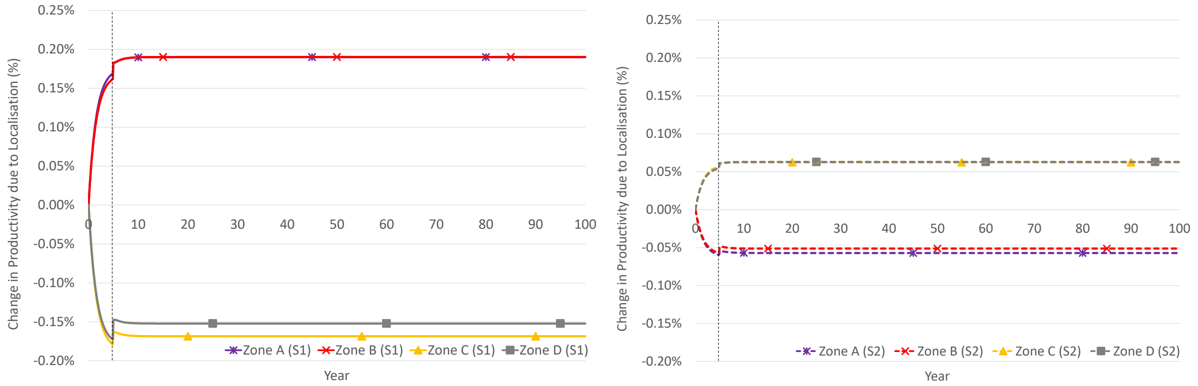
Figure 4.6 shows how the wage rates change over the study period. Initially wages are higher in Sector 1 in City 1 and in Sector 2 in City 2 which explains the sectoral migration patterns in Figure 4.5 Over time the wage differential between the sectors narrows until it approaches zero which corresponds to the reduced net change in number of workers in Figure 4.5. The reason for this is the productivity changes are subject to diminishing returns to labour within the Cobb-Douglas production function as capital is fixed. As workers move sectors the marginal productivity in the sector declines and similarly it rises in the sector which the workers are leaving. These effects limit the level of specialisation which can be achieved and the model reaches a new steady state where 53.1% of the number of workers in each city are in the sector in which the city has the comparative advantage.

The localisation impacts are shown in Figure 4.7. In the first few years the workers switch between sectors to achieve a higher wage which changes the density of each sector in each zone. The transport scheme opening in Year 5 leads to a similar increase in the impacts in all zones as the elasticities used are the same within each sector and all locations benefit from the reduced transport costs. The changes are higher in Sector 1 than Sector 2 due to the higher elasticity used in Sector 1.



(a) Sector 1 **(b) Sector 2**

Figure 4.6 Wage (£/hr, 2021 Values and 2010 Prices)



(a) Sector 1 **(b) Sector 2**

Figure 4.7 Localisation Impacts (%)

Figure 4.8 shows the urbanisation impacts. There are no impacts before the transport improvement as overall employment and transport costs remain constant. Following the transport improvement there is an immediate increase for both sectors in all zones[25]. The increases are greatest in the peripheral zones as firms there realise a higher proportional increase in effective density than firms in the core

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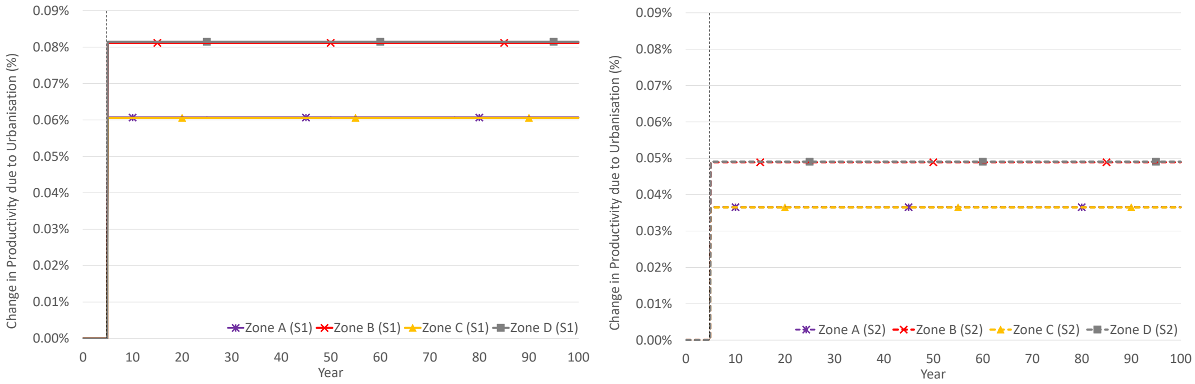
[25] The three sources of agglomeration effects are matching, sharing and learning (Duranton and Puga, 2003). In the model the residential location of workers and commuting trips are not considered. If commuting between the cities is limited urbanisation and localisation effects between the two cities due to the transport scheme would derive from knowledge spill overs and improved supply chain linkages rather than expanding the labour market pool. This implies that in the modelling the scale of the urbanisation and localisation impacts may be slightly overestimated. Compared to the elasticity ranges identified for business services in the modelling undertaken in Chapter 7 the elasticities used in this chapter were conservative which slightly compensates for this. The scale and length of time for different aspects of agglomeration effects are discussed in Tveter & Laird (2018).

zones. This is because the peripheral zones have fewer workers and benefit from reduced journey times to zones where the number of jobs are higher[26].

The transport scheme leads to an increase in annual output per worker of £55 (0.07%) which across the 280,000 workers in the two sectors sums to an annual increase in output of £7.7m. This compares with the Frontier Economics' (2016) estimate of an increase in earnings of £21.6m (2014 Values and Prices) in Leeds and Manchester resulting from a 20-minute reduction in rail times between the two cities using an agglomeration elasticity of 0.03. The estimate in the current research is lower due to the focus on only two sectors and the analysis of the two cities only and not their wider city regions as in the Frontier Economics (2016) study[27].

Figure 4.9 shows how the changes in output per worker vary by sector and zone. As workers move from Sector 2 to 1 in City 1 the output per worker increases in Sector 1 and declines in Sector 2 due to the productivity changes outlined above. At the new steady state the output per worker of both sectors in each zone are the same which ties in with the equalised wage rates between sectors within each zone in Figure 4.6



(a) Sector 1 **(b) Sector 2**

Figure 4.8 Urbanisation Impacts (%)

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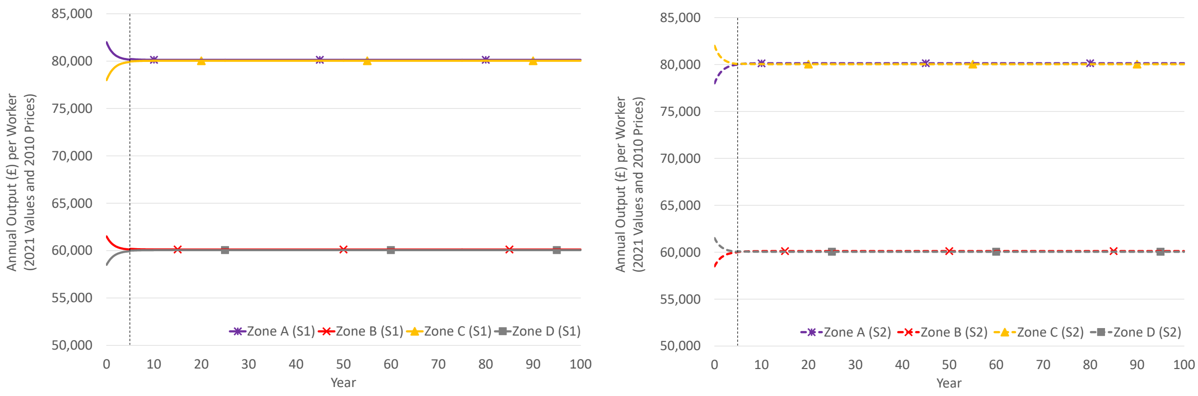
[26] The result that there are greater proportional increases in effective density in peripheral areas was discussed in Section 3.2.2 of Chapter 3. This arises as places with fewer jobs gain a greater proportional increase in effective density as a result of reduced travel times between places with more jobs. This suggests that cities with different economic structures might be affected differently by changes in accessibility. For example, in polycentric urban areas which have a more even distribution of employment such as Los Angeles or the San Francisco Bay Area there are likely to be less differences in the scale of productivity changes over space than in the monocentric structure used in this chapter.

[27] The Frontier Economics (2016) study was based on a static analysis and land-use changes were not included.



(a) Sector 1 **(b) Sector 2**

Figure 4.9 Output per Worker (£mn, 2021 Values & 2010 Prices)

The discounted economic benefits of the inter-city transport scheme are shown in Figure 4.10[28]. The urbanisation and localisation benefits are estimated using the method outlined in Section 3.2.1 of Chapter 3. The business user, urbanisation and localisation benefits are discounted in line with the advice in the UK DfT's WebTAG to reflect that people value benefits in the near future more than later (DfT, 2018a). The discount factors used those recommended in the UK DfT's WebTAG (DfT, 2017b).

Total benefits are estimated at £261.6m which are comprised of £35.6m business user benefits, £185.5m urbanisation benefits and £40.5m benefits from localisation. Localisation benefits are only 22% of urbanisation benefits and both are concentrated in the sectors and zones where employment is highest. The benefits from urbanisation and localisation appear relatively high in comparison to the business user benefits but it should be noted that the analysis has focussed on sectors which are particularly disposed to agglomeration effects and consumer and leisure benefits have not been estimated. If the analysis was extended to other sectors of the economy and the other user benefits were calculated then the user benefits would be expected to make up a higher proportion of the overall benefits.

The undiscounted annual total economic benefits in Year 50 once the model is near to the new steady state are £15.4m which consist of £2.1m business user benefits, £10.9m urbanisation benefits and £2.4m localisation benefits. These are lower than

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[28] The economic benefits estimated over the appraisal period in this chapter and the dynamic modelling undertaken in Chapters 5 and 6 do not include background economic growth over time. The reason for this is that in the dynamic modelling it was assumed that there was no background growth in productivity so the impact of the transport scheme only could be focussed on. This means the benefits estimates in Chapters 4, 5 and 6 underestimate the full scale of the benefits.

the estimates in two other studies which have evaluated the impacts of a 20-minute reduction in rail journey time between Leeds and Manchester. Centre for Cities (2007) estimate benefits from the scheme of £14.7m annual business user benefits and £26.7m annual agglomeration benefits across Leeds, Huddersfield and Manchester (2016 Values, 2010 Prices) and Frontier Economics (2016) estimate annual agglomeration benefits across the six Northern Travel to Work Areas (TTWAs) of £28m (2014 Values, 2010 Prices). The lower estimates in the current study are explained by the focus in the current study on two sectors and not the cities' wider regions and the exclusion of the user benefits of business travellers making through trips between the cities.

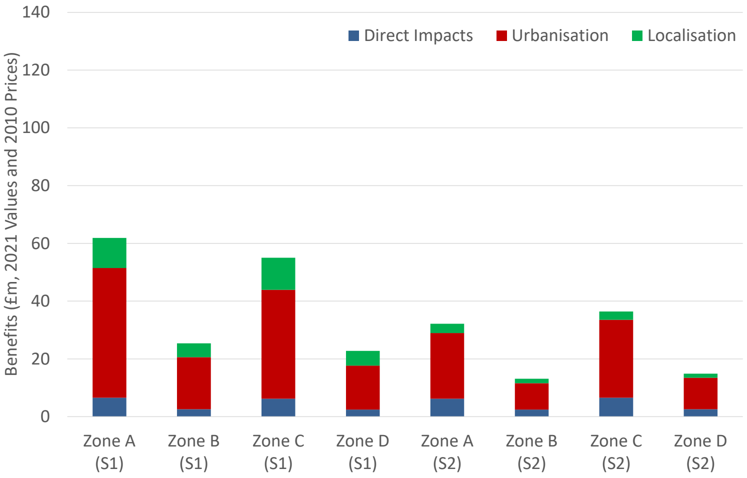
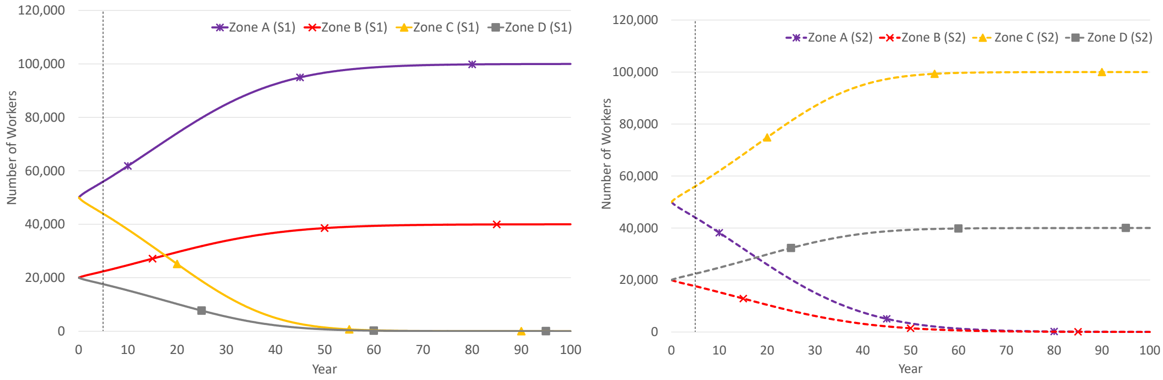


Figure 4.10 Discounted Benefits (£mn, 2021 Values & 2010 Prices)

4.4.3 Simulations with Variable Capital

The assumption of fixed capital by sector in each zone was relaxed to understand the impact on the results. The total labour and capital in each zone are fixed but both can move between sectors to achieve a higher return. In contrast to the labour stocks, the capital stocks do not feed directly through into changes to the effective densities for localisation impacts as these are a function of the number of workers in each zone and travel costs only (as shown in equation 3.19). This means that the reinforcing feedback loop for labour in the fixed capital model outlined above in which an increase in labour in a sector increases TFP and the relative attractiveness of the sector leading to further in-migration is not present for capital.

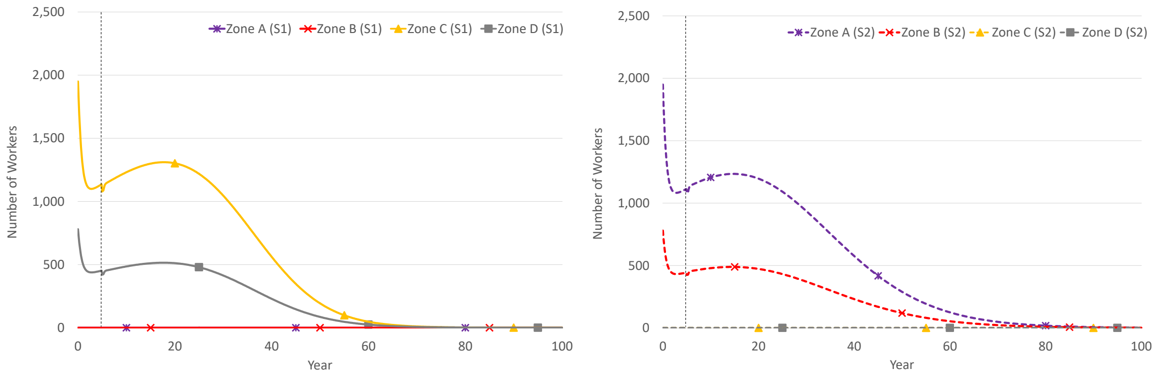
All of the other inputs were maintained and Figure 4.11 shows how the number of workers in each sector in each zone changes over time. This shows that labour becomes fully specialised in Sector 1 in City 1 and in Sector 2 in City 2. This result is in contrast to the model run with fixed capital where reallocation between sectors was limited and is due to the mobility of both capital and labour. Now if workers or capital move sector there is no longer the restriction of diminishing returns and capital and labour continue to migrate in the same direction until each zone is fully specialised in one sector.



(a) Sector 1 **(b) Sector 2**

Figure 4.11 Output per Worker (£mn, 2021 Values & 2010 Prices)

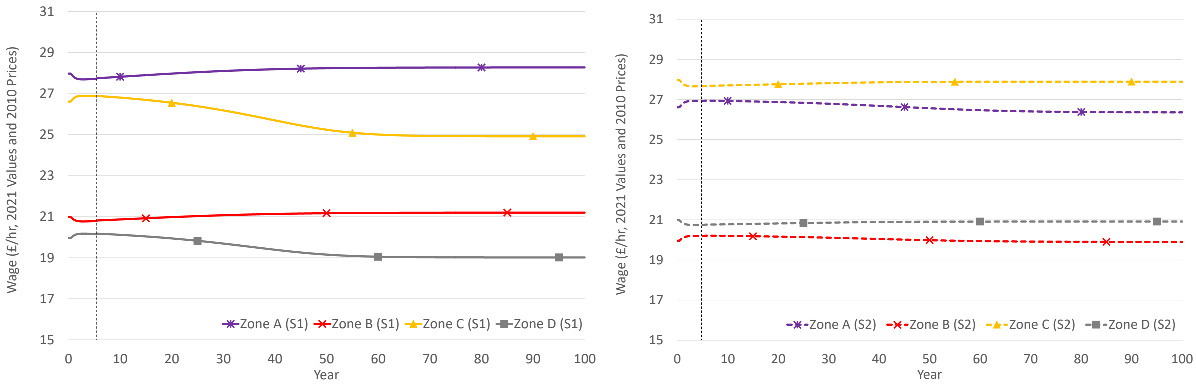
Figure 4.12 shows the out-migration of workers by sector. This shows that the migration of workers from Sector 1 to 2 in City 2 is quicker than from Sector 2 to 1 in City 1. Sector 2 reaches 99% of employment in both zones in City 1 by Year 54 which is 13 years earlier than Sector 1 in City 1 which it is reached by Year 67.



(a) Sector 1 **(b) Sector 2**

Figure 4.12 Out-migration of Workers from Sector with Capital Mobility

Driving the changes in sectoral migration are the relative wage rates between sectors which are shown in Figure 4.13. This shows that the wage rate differential in Sector 1 between the two cities is smaller than in Sector 2. This leads to a greater incentive for workers to concentrate in Sector 2 in City 2 than in Sector 1 in City 1 which explains the differences in the speed of migration shown in Figure 4.12.



(a) Sector 1 **(b) Sector 2**

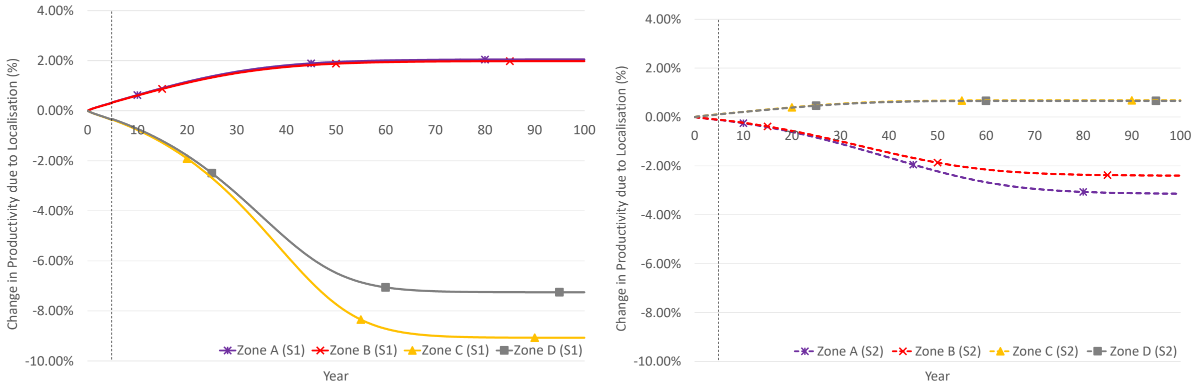
Figure 4.13 Wage Rates with Capital Mobility

The differences in wage rates are driven by productivity changes. The productivity impacts due to urbanisation are the same as in the simulation with fixed capital as the total employment by zone has not changed. The localisation impacts which are shown in Figure 4.14, however, are much greater than when capital was fixed. This is due to the more significant changes in specialisation which lead to additional gains in productivity through the increased concentration of Sector 1 in City 1 and Sector 2 in City 2.

There are large differences in the magnitude and pattern of localisation impacts across sectors and zones. Due to the larger elasticities in Sector 1 the positive productivity increases in Sector 1 in City 1 are greater than for Sector 2 in City 2. The differences in elasticities also explain why the productivity reductions in Sector 1 in City 2 are greater than the reductions in Sector 2 in City 1. The reductions in the declining sectors are also greater in absolute terms than the increases in the expanding sectors. This is because when one worker moves from a sector to the other the reduction in average productivity in the sector they are leaving is greater than the increase in average productivity in the sector they are joining. It should be noted that while the decreases in productivity impacts due to localisation can be greater than the increases in the expanding sector there are a smaller number of workers in the declining sectors and there are therefore still positive impacts overall. The localisation impacts lead to a higher wage differential in zones where Sector 2 is expanding than in zones where Sector 1 is increasing and drive the changes in migration and wage rates shown in Figures 4.12 and 4.13 respectively.

It was found that the transport scheme leads to changes in localisation impacts which slightly slow down the rate of changes in specialisation. This is because the effective density increase is greater in zones with a smaller number of jobs as they are brought closer to zones with a higher number of jobs (larger increases in Zones

C and D). This reduces the wage differential between the increasing and declining sectors over time and therefore slows the rate of changes in specialisation.

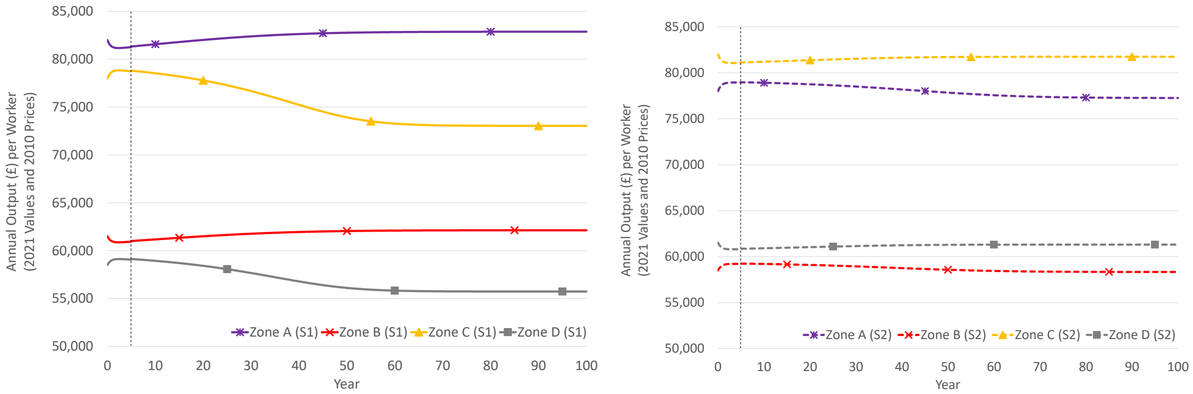


(a) Sector 1 **(b) Sector 2**

Figure 4.14 Localisation Impacts (%) with Capital Mobility

The output per worker increases by £2,007 (2.7%) from £74,286 in Year Zero to a new steady state value of £76,427. This end point is £2,052 (2.8%) higher than the simulation with fixed capital. The time taken to reach a new steady state with mobile capital is significantly longer due to the move to full specialisation and the time required to reach 98% of the initial gap has increased from 6.6 years with fixed capital to 60.5 years.

Figure 4.15 shows how output by worker by sector and zone changes over time. The output per worker increases over time in Sector 1 in City 1 and in Sector 2 in City 2 but the growth is more significant in the former due to the higher localisation and urbanisation elasticities used for Sector 1. The changes in output per work are similar to the localisation impacts shown in Figure 4.14 which shows the greater influence of localisation effects on productivity when capital is mobile between sectors.



(a) Sector 1 **(b) Sector 2**

Figure 4.15 Output per Worker (£, 2021 Values & 2010 Prices) with Capital Mobility

The economic benefits of the transport scheme are shown in Figure 4.16. Total economic benefits are £249.2m. The largest benefits overall are in Sector 1 in Zone A and Sector 2 in Zone C where the cities are specialising in the sectors in which they have a comparative advantage. There are, however, negative localisation benefits in both zones in City 2 for Sector 2. This is because although the transport scheme increases the localisation effective density in each sector it increases by more in zones with a fewer number of workers in the sector. This leads to slower growth in specialisation and this is not outweighed by the increase in effective density as a result of the transport scheme due to the low localisation elasticity in Sector 2 of 0.01.

The estimated total benefits of the transport scheme are £12.4m (4.8%) lower than when capital was fixed. This is due to the £14.2m reduction in total localisation benefits to £26.3m which outweighs a smaller increase in urbanisation benefits which are £1.8m higher at £187.2m. The reason why localisation benefits are lower with variable capital is that the transition to a full specialisation endpoint would occur without the transport scheme. The transport scheme slows down the change in specialisation as locations with a smaller number of jobs in a sector gain greater accessibility to locations with higher employment with the scheme. This reduces the incentive for workers to shift sector and leads to lower localisation benefits. The total localisation benefits with variable capital are 18.8% of urbanisation benefits compared to 22% when capital was fixed.

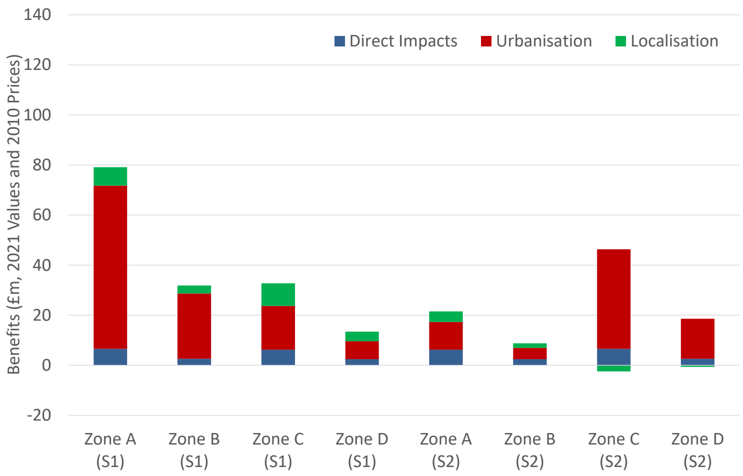


Figure 4.16 Discounted Benefits (£mn, 2021 Values and 2021 Prices) with Capital Mobility

Figure 4.17 shows how the potential benefits from localisation relative to Year Zero evolve over time[29]. This shows that the benefits from specialisation can be significant and full specialisation leads to a 2.9 per cent increase in total GDP which is much higher than when capital was fixed (0.12%). The reason for this is that now both labour and capital are mobile between sectors and the gains from specialisation are no longer limited by diminishing returns. In the real world, however, these benefits are unlikely to be fully realised due to factors such as lack of available skills, further shocks before equilibrium is reached and inertia to change. The transport improvement leads to benefits through increasing economic density earlier in the analysis period but the scheme also slows down the rate of specialisation. This is because as the increase in effective density for the sector which is declining in a zone is greater than in zones where the sector is expanding which reduced the incentive for workers to move to the expanding sector within a zone. The transport scheme also does not affect the end point as the model will gravitate to full specialisation when labour and capital are both mobile if there are any sectoral differences in the initial rates of wages and rents.

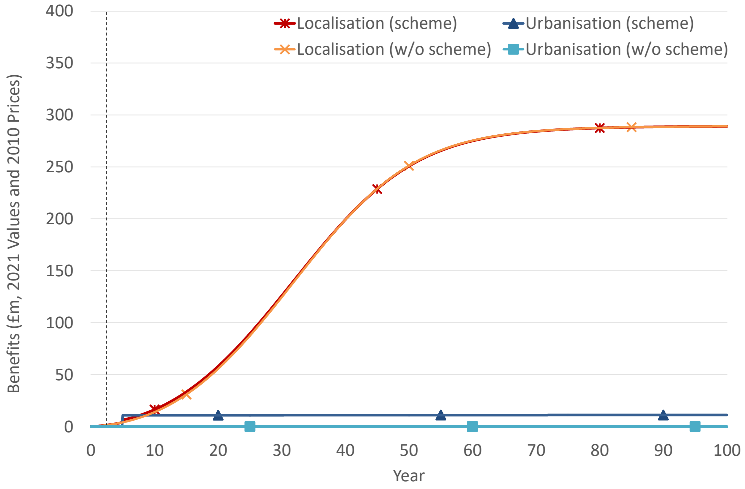


Figure 4.17 Undiscounted Potential Localisation and Urbanisation Benefits (£mn, 2021 Values and 2021 Prices) Relative to Year Zero (not between the DS and DM) with Capital Mobility

4.5 Conclusion

In this chapter a stylised dynamic model of the UK cities Manchester and Leeds has been developed to understand the magnitude of the impacts and transition to a new

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[29] In this figure the urbanisation and localisation benefits are not discounted so how the two types of benefit evolve over time can be compared more easily.

steady state resulting from a 20-minute inter-city rail journey time improvement between the two cities. The model was built using the system dynamics approach and incorporated elements of the theories of comparative advantage, new economic geography and agglomeration effects due to changes in economic density. The model includes labour, wage rates, capital, capital rents, total factor productivity and urbanisation and localisation effects.

The model simulation results showed that when labour is mobile between zones but capital is fixed the inter-city transport scheme has only a marginal impact on movement between sectors. The extent of changes in specialisation are limited by fixed capital in each sector which leads to diminishing returns to labour which over time reduces the incentive for workers to migrate to the expanding sector. While the land-use changes are limited there are still some productivity gains which result from the higher density of workers due to the reduced journey times.

With both mobile labour and capital between sectors significant potential benefits are unlocked and it is found that the model tends towards the corner solution with full specialisation. The speed of adjustment is slower compared to the fixed capital end point due to the move to full specialisation and the new steady state is reached only after several decades. The potential benefits from full specialisation are shown to be large and inter-city transport can support the realisation of localisation impacts more quickly through increasing the density of the sectors. The results also showed that negative localisation benefits due to the transport scheme are possible as the scheme can slow down the move to increased specialisation time as the localisation impacts are higher for sectors in zones with fewer number of workers. This also explains why the economic benefits from the transport scheme are higher in the fixed capital case (£261.6m) than with mobile capital (£249.2m).

In both simulations the urbanisation benefits due to the inter-city transport scheme were estimated to be approximately four times the size of localisation benefits. This suggests that other policies to promote specialisation may have more impact on localisation benefits such as investing in local labour skills and direct policies to promote cluster growth. Transport, however, can still play a role by providing support to maximise the potential gains.

The analysis in this chapter has highlighted some improvements which could be made to the model structures. Firstly, the model predicts an endpoint of full specialisation but this is unrealistic as cities are unlikely to have zero jobs in any business service sector. This suggests that something needs to be added the model to dampen or constrain the final endpoint. In addition, in the model it has been assumed that workers and capital can move sector without any cost. With zero costs of moving sector this means workers and capital move for any small increment in their monetary returns. However, this is unrealistic as there are costs associated with moving sector such as the time and monetary costs[30]. This suggests that the model needs to be updated to include sectoral mobility costs and these should be taken into account in labour and capital owner's decisions on whether to move sector. These changes are implemented in an extended version of the model which is outlined in Chapter 5.

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[30] The empirical literature on mobility costs for labour and capital of switching sector is discussed in Section 5.2.2 of Chapter 5.

5 Extension of Dynamic Model to Include Factor Mobility Costs and Limits to Specialisation

5.1 Introduction

In this chapter the dynamic model is extended to take account of the implications for its structures identified in Chapter 4. Mobility costs of switching sector for labour and capital are introduced to reflect that there are costs associated with moving between sectors and that labour and capital would be unlikely to move between sectors for marginal returns. In addition, limits on the level of specialisation in each zone are introduced to reflect that in the real world cities do not become fully specialised in some sectors with zero employment in others.

Updates are also made to several of the data inputs used in the model. The economic inputs are revised so that the sector in which each zone initially has a comparative advantage is based on the effective density of each sector by location rather than an exogenous assumption as in Chapter 4. Further updates to the data inputs have also been made to simplify the assumptions to compensate for the increased complexity of the model.

The updated model is simulated to investigate the impact of the model updates. The objectives of this chapter are to:

1. Evaluate the extent to which barriers to localisation impacts due to factor mobility costs can be unlocked through inter-city transport;
2. Estimate the length of time adjustment to a new steady state; and,
3. Estimate the relative size of urbanisation and localisation benefits.

The remainder of this chapter is organised as follows. The updates to the model structure and data inputs for the model are outlined in Section 5.2. In Section 5.3 the results and discussion are outlined and this is followed by the conclusion in Section 5.4.

5.2 Updates to Model

There are costs for labour and capital of moving sector which may potentially limit changes in specialisation and the associated productivity benefits through increased localisation effects. Sources of costs for inter-sectoral labour mobility include the time and monetary costs of searching for a new job (Fuller et al., 2014). Other costs for labour of changing sector include the potential loss of human capital accumulated in the previous sector (Lee and Wolpin, 2006) and there may also be psychological costs of switching sector (Dix-Carneiro, 2014). There are also mobility costs incurred in moving capital between sectors such as time and resource costs (Morshed & Turnovsky, 2004). Grossman (1983) highlights Neary (1978) and Mussa (1978) who suggest there may be a loss of efficiency initially if capital is moved between sectors but this diminishes over time. This suggests that there is a cost of moving capital between sectors in the short-run but in the long-run capital is perfectly mobile (Grossman, 1983).

The model has been updated so that the costs associated with switching labour and capital between sectors are taken into account. The formulae for sectoral migration used in Chapter 4 (equations (4.3)-(4.4) for the labour market and (4.11)-(4.12) for the capital market) require modification to take account of this. In the labour market the out-migration from Sector 1 in zone *i*, $L\ Out\ Migration_i^{S1}$, and the out migration from Sector 2 in zone *i*, $L\ Out\ Migration_i^{S2}$, are now based on the following equations respectively:

$$L\ Out\ Migration_i^{S1} = \left(\frac{L_i^{S1} - (L^*)_i^{S1}}{TAdjL}\right) \qquad if\ w_i^{S2} - w_i^{S1} > cL \tag{5.1}$$

$$L\ Out\ Migration_i^{S2} = \left(\frac{L_i^{S2} - (L^*)_i^{S2}}{TAdjL}\right) \qquad if\ w_i^{S1} - w_i^{S2} > cL \tag{5.2}$$

where L_i^{S1} and L_i^{S2} are the number of workers in zone *i* in Sector 1 and 2 respectively, $(L^*)_i^{S1}$ and $(L^*)_i^{S2}$ are the implied steady state levels of labour in Sector 1 and 2 respectively, w_i^{S1} and w_i^{S2} are the wage rates in Sector 1 and 2 respectively, $TAdjL$ is the adjustment time for labour and cL is the cost of switching between sectors. In this new setup workers only move between sectors if the increase in the wage rate is greater than the cost of switching sectors.

Similar updates were made to the conditions for out-migration in the capital market. Out-migration from Sector 1 in zone *i*, $K\ Out\ Migration_i^{S1}$, and the out migration from Sector 2 in zone *i*, $K\ Out\ Migration_i^{S2}$, are based on the following equations respectively:

$$K\ Out\ Migration_i^{S1} = \left(\frac{K_i^{S1} - (K^*)_i^{S1}}{TAdjK}\right) \qquad if\ r_i^{S2} - r_i^{S1} > cK \tag{5.3}$$

$$K\ Out\ Migration_i^{S2} = \left(\frac{K_i^2 - (K^*)_i^2}{TAdjK}\right) \qquad if\ r_i^{S1} - r_i^{S2} > cK \tag{5.4}$$

where K_i^{S1} and LK_i^{S2} are the amount of capital in zone *i* in Sector 1 and 2 respectively, $(K^*)_i^{S1}$ and $(K^*)_i^{S2}$ are the implied steady state levels of capital in Sector 1 and 2 respectively, r_i^{S1} and r_i^{S2} are the capital rents in Sector 1 and 2 respectively, $TAdjK$ is the adjustment time for capital and cK is the costs incurred in switching between sectors. Similarly to the labour market capital only switches between sectors if the increase in capital rent is greater than the cost of switching. With this revised model setup for inter-city transport to induce increases in specialisation the gains to labour and capital must outweigh any costs associated with switching sector.

A further change to the model was made to limit the level of specialisation which can be attained within each zone. This was to reflect that in major cities it is found that there is usually a minimum proportion of a sector located in a city to serve the local market. The specialisation of capital in one sector within a zone was specified as a minimum of 20% of the total of both sectors[31]. This was applied in the model by specifying a fixed amount of capital in each sector in each zone which could not switch between sectors[32]. The updated stock and flow model is shown in Figure 5.1 with the introduction of mobility costs for labour and capital and fixed capital highlighted in red.

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[31] The limit on the level of specialisation was applied to capital rather than labour on the basis that demand for a firm's output from local markets is likely to be one of the most important factors in preventing the realisation of very high levels of specialisation.

[32] The equations outlined for the capital market in Chapter 4 still function in the same way but the capital stocks only include the proportion of capital which is mobile between sectors.

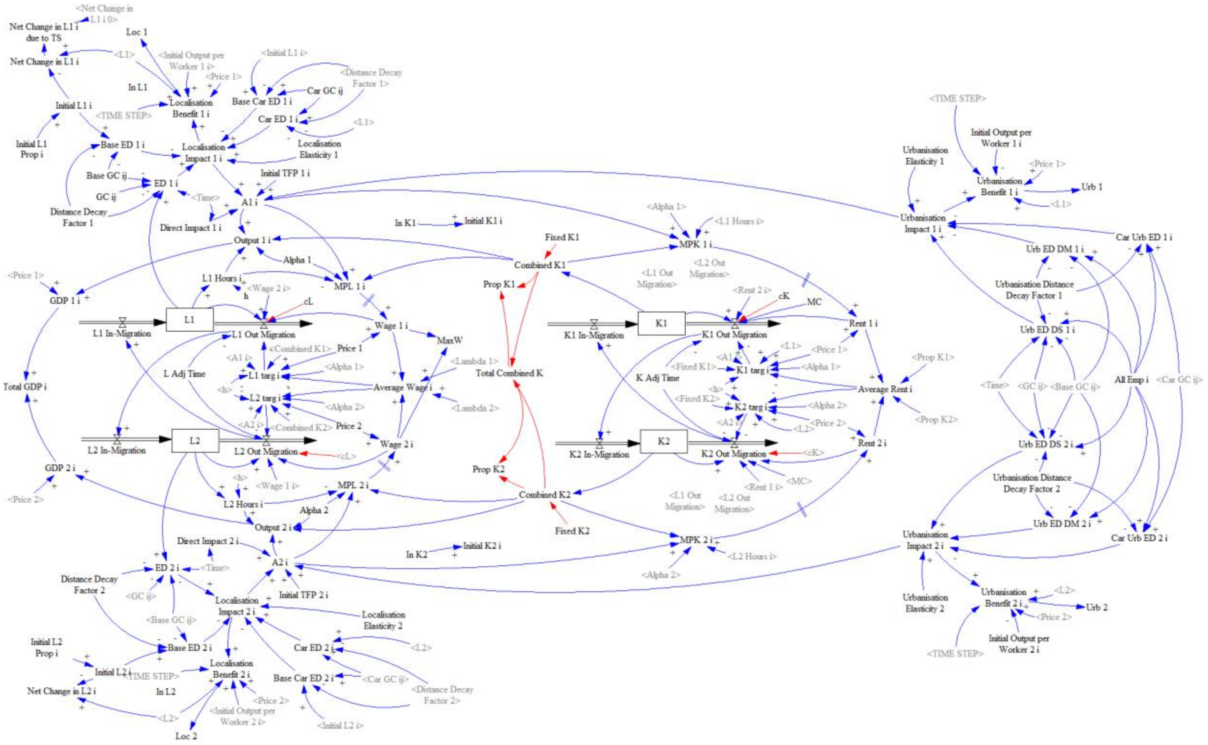

Figure 5.1 Updated Stock and Flow Model Diagram (changes from the diagram shown in Figure 4.2 in Chapter 4 are highlighted in red)

5.3 Updates to Data Inputs

Some of the data inputs used in the dynamic model were updated from those used in Chapter 4. The initial economic inputs were adjusted so that the productivity differences between sectors within each zone were based on differences in the density of employment rather than an exogenous assumption as in Chapter 4. The updated economic inputs are shown in Table 5.1.

To base the productivity differences on the density of employment higher levels of employment were specified in Sector 1 in City 1 and in Sector 2 in City 2. This meant that as in Chapter 4 Cities 1 and 2 are assumed to have a comparative advantage in Sectors 1 and 2 respectively. These numbers of jobs were used to estimate differences in the scale of productivity due to localisation effects. This was achieved by estimating the change in productivity in each sector in each zone due to localisation effects by comparing the effective density using a base value of 1,000 workers to the number of workers shown in Table 5.1. The estimated increases in productivity were then used to estimate the increase in TFP and GDP per worker from the situation with 1,000 workers using equation (4.16) in Chapter 4[33]. The amount of capital in each sector and zone were then estimated so the annual output of each combination of sector and zone was equivalent to the multiplication of the number of workers and GDP per worker shown in Table 5.1[34].

Table 5.1 Economic Inputs for Sector 1[35]

	City 1		City 2		
Economic Variable	Zone A	Zone B	Zone C	Zone D	All Zones
Number of Jobs	60,000	24,000	40,000	16,000	140,000
Total Jobs	-	-	-	-	1,000,000
Capital Inputs (£mn)	£4,833	£1,933	£3,222	£1,289	-
TFP	11.25	11.16	11.12	11.03	-
GDP per Worker (£)	£73,107	£72,539	£72,257	£71,718	-
GDP (£mn)	£4,386	£1,741	£2,890	£1,147	-
Wage per hour (£)	£28.35	£28.13	£28.02	£27.81	-
Annual Capital Rent (£)	£0.318	£0.315	£0.314	£0.312	-

Changes were made to some of the other input assumptions used in Chapter 4 to compensate for the model becoming more complex. In Chapter 4 the urbanisation and localisation parameters were assumed to be different in the two sectors but in

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[33] These estimated increases were applied to a base value of TFP of 10 and £65,000 for GDP per worker. These values were chosen to give similar wage rates to Chapter 4 for the core zone in the sector in which it has the comparative advantage. In Chapter 4 the wage rate in this combination of zone and sector was £27.98 per hour.

[34] The level of capital in each sector and zones was estimated in two steps. Firstly, the estimated productivity increases were applied to a base value of GDP per worker of £65,000 per annum to give output values which are at a similar level to those for producer services in the north of England (DfT, 2018d). The Cobb-Douglas function was then used with labour, TFP and the income shares for capital and labour to estimate the level of capital required to generate GDP equal to the number of jobs multiplied by the GDP per worker.

[35] In these inputs the wage rates are higher in the core of cities than in the periphery. This is supported by evidence such as Gale (1998) which showed that in the U.S. wages are on average 6.7% higher in the core of large metropolitan areas than in the periphery. Wage differences between locations have been shown to be explained by differences in economic density (Melo, Graham & Noland, 2009).

this chapter the same values are applied. An urbanisation elasticity of 0.03 was used in both sectors and a distance decay factor of 1.746 with the latter the value estimated for producer services in Graham et al. (2009) which is recommended in the UK's WebTAG Guidance (DfT, 2018c). For localisation impacts an elasticity of 0.03 was used for both sectors and a distance decay factor of 2 to represent that these effects decay more rapidly over distance than urbanisation impacts (Graham, 2009).

Some of the other input data assumptions were updated to reflect the sourcing of new data. The average number of hours worked per worker in the UK of 1,676 (OECD, 2018) was used rather than the assumption of 1,700 in Chapter 4. In addition, an income share for capital of 0.35 was used for both sectors rather than 0.42 in Chapter 4[36].

Minor revisions were made to simplify the public transport journey times which were used in Chapter 4. The new journey times were based on an average in-vehicle travel time between the cities of 60 minutes and also include 5 minutes for access and egress time at each station, a 10 minute walk to the destination from the station and assume that passengers arrive 5 minutes before their departure. It was assumed that business trips between the core and periphery take 15 minutes and this trip time was also assumed for trips within the periphery zone of each city. For simplicity in this updated version of the model the do-minimum journey times for public transport and car were assumed to be the same and are shown in Table 5.2.

Table 5.2 Do-Minimum Public Transport and Car Journey Times (minutes)

		City 1		City 2	
	Zone	A	B	C	D
City 1	A	15	20	95	105
	B	20	20	105	115
City 2	C	95	105	15	20
	D	105	115	20	20

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[36] This is slightly lower than the value of 0.42 which was used in Chapter 4. It was updated to reflect that in some service sectors the capital share is lower than 0.42 such as 0.25 in Professional, Scientific and Technical Activities and 0.33 in Administrative and Support Service Activities (ONS, 2020).

5.4 Results and Discussion

5.4.1 Business User Benefits

The 20-minute journey time improvement on the inter-city rail link was introduced in Year 5. Using the same elasticity for inter-urban rail demand with respect to GJT used in Chapter 4 (-0.8) this was estimated to lead to a 19.5% increase in the number of rail trips. Total business user benefits were calculated as £64.3m over the 60-year appraisal period using a 2010 discount base year and discount rates from UK Department for Transport appraisal guidelines (DfT, 2017a)[37]. The results for each combination of sector and zone are shown in Table 5.3.

Table 5.3 Present Value of Business User Benefits (£mn, 2021 Values and 2010 Prices) over 60 Years

	Zone	Sector 1	Sector 2	Total
City 1	A	13.89	9.15	23.03
	B	5.50	3.62	9.12
City 2	C	9.15	13.89	23.03
	D	3.62	5.50	9.12
	Total	32.15	32.15	64.31

5.4.2 Simulations with Equal Trip Rates per Job

The model was run first under the assumption that the business user benefits of the transport scheme are split between sectors in a zone based on the same trip rate per job. This led to a productivity uplift from business user benefits of 0.19% which was applied to each sector in each zone. The mobility costs were set at 1% higher than the initial wage and rent differentials between sectors in the core zones giving a mobility cost of moving sector for labour of £558 per worker and for capital of 0.37p

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[37] Business user benefits were estimated using a rail business user value of time of £32.76 per hour (2021 Values, 2010 Prices) from the UK's WebTAG Guidance (DfT, 2017b). These values are higher than those estimated using the method based on distance in Chapter 4. This was to reflect that the combination of the significant scale of the two cities, the short distance between them and the current relatively low number of business rail trips means that the method of estimating the value of time based on distance could be leading to an underestimate of the value of time for business trips.

per £1 of capital per year[38]. Due to the inclusion of mobility costs there is now a consistent equilibrium with no movement of labour and capital between sectors before the transport scheme opens in Year 5.

The wage differential between Sector 1 and Sector 2 in City 1 for this model simulation is shown in Figure 5.2. It was found that with the 0.19% increase in productivity the transport scheme did not generate any changes in specialisation. This is because although the transport scheme leads to productivity gains through user benefits, localisation and urbanisation effects it does not lead to a higher wage or rent differential than the labour and capital mobility costs respectively.

Figure 5.2 shows that the gap between the wage in Sector 1 and 2 decreases in both zones in City 1 after the transport scheme improvement in Year 5. These changes are driven by localisation impacts as the business user and urbanisation impacts lead to the same relative productivity impact for each sector within each zone. The localisation effect is positive in both sectors but approximately twice as high for the less productive sector in each zone. This is because the sector with fewer workers in a zone gains a greater proportional increase in effective density as the workers are brought in closer proximity to zones with a higher number of workers in the same sector. This leads to a greater increase in the wage rate in the less productive sector in each zone which explains the slight narrowing of the wage differential between the more and less productive sectors.

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[38] This gives a mobility cost equal to 1.2% of the wage rate in the core zone in the sector with the comparative advantage. This is lower than in empirical estimates such as Ashournia (2015) who estimated that in Denmark the cost of moving into one of six broad sectors ranged from 9.8% of the annual wage in construction to 18.9% in service sectors excluding any loss of human capital of switching sector. For the US estimates of inter-sectoral mobility costs based on a proportion of average annual wages include 54 to 67% (Lalé, 2016) and 50 to 75% per cent (Lee and Wolpin, 2006). The assumption in the current analysis is lower than these estimates as in the model decisions around switching sectors are only considered in the immediate time horizon whereas in reality workers absorb inter-sectoral mobility costs over longer timeframes. In addition, in the current analysis movements are only considered between business service sectors for which for many workers the costs of switching are likely to be lower than for movement between broad sectors. There is sparse evidence on the cost of moving capital between sectors.

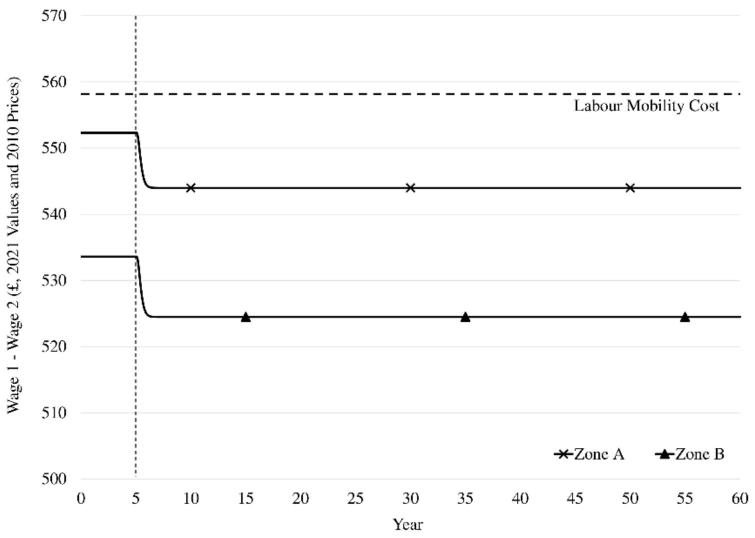

Figure 5.2 Wage 1 - Wage 2 (2021 Values & 2010 Prices) in City 1 with Equal Trip Rates per Job

The scale of the business user benefits were then increased to understand how significant the transport scheme would need to be to generate changes in specialisation. It was estimated that business user benefits would need to be multiplied by approximately 140 to generate a high enough increase in wages and rents in the more productive sector in each zone to move to a new steady state with maximum specialisation. Such high business user benefits are unrealistic which suggests that under the assumptions of the model distributing business user benefits based on an equal trip rate per job will result in no changes in specialisation due to an inter-city transport scheme.

5.4.3 Simulations with Uneven Trip Rates per Job

In reality the impacts on sectors in different locations are unlikely to be symmetric. In particular, it might be expected that more productive sectors in each location may benefit more from an inter-city transport scheme as they may be able to use their productive advantage to increase their market share in the other city. This scenario was tested in the model through adjusting how the user benefits were split between sectors in each zone by assuming that workers in the more productive sector make twice as many trips per job as in the less productive sector. This meant that the productivity increase in the more productive sector (0.232%) was twice the increase in the less productive sector (0.116%) in each zone.

Under these assumptions the impact of the business user benefits on the wage and rent differentials between sectors were again found not to be great enough to exceed the mobility costs of moving sector and the cities remained in their initial steady states. The model was then used again to calculate the size of business user benefits which would be required to move away from the initial steady state and it was estimated that they would need to be multiplied by 2.5. This is significantly less than the level required when the user business benefits were based on equal trip rates as outlined above.

The wage differential between Sectors 1 and 2 and localisation impacts for City 1 with uneven trip rates and business user benefits multiplied by 2.5 are shown in Figures 5.3 and 5.4 respectively. Figure 5.3 shows that the transport scheme initially leads to an increase in the wage differential between sectors. This is due to the higher business user benefits in the more productive sector which outweigh the higher localisation effects in the less productive sector. These impacts lead to a higher increase in TFP in the more productive sector which increases the wage and rent differentials to just above the mobility costs and a small amount of labour and capital moves into the more productive sector. There are also links between changes in the labour and capital markets. An increase in capital in a sector increases the MPL in the sector which increases the attractiveness of the sector to workers. Similarly, as labour moves into the sector this increases TFP which increases the rent differential which leads to more capital moving into the sector. As labour and capital become concentrated in the more productive sector in each zone this leads to higher localisation impacts in the more productive sector (as shown in Figure 5.4) which accentuates the process of increased specialisation.

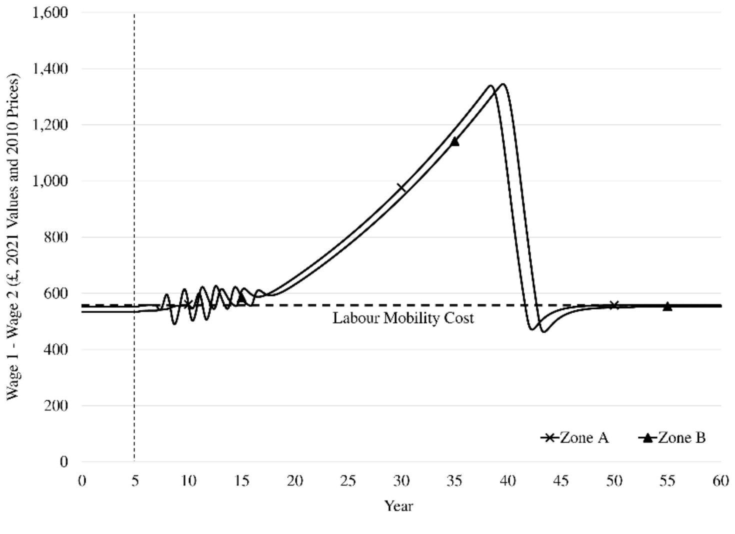

Figure 5.3 Wage 1 – Wage 2 (2021 Values & 2010 Prices) with Uneven Trip Rates per Job & BUB x2.5

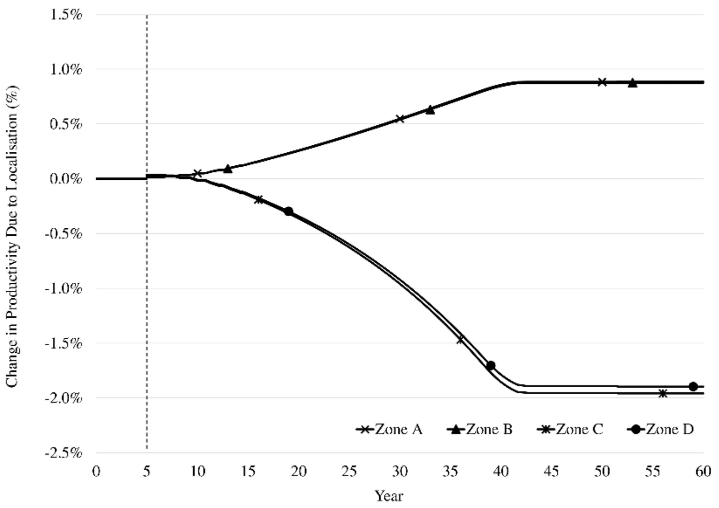

Figure 5.4 Localisation Impacts in Sector 1 with Uneven Trip Rates per Job & BUB x2.5

The delays on changes in the wage rates and rents lead to oscillation of the wage and capital differentials around the mobility costs between Years 8 and 14. This is because when the gap between the differential and the mobility cost is small only a limited amount of capital and labour moves sector in each time step. If the other factor remains constant there will be diminishing marginal returns which leads to a falling wage or rent differential which explains the fluctuations. To move beyond the tipping point both labour and capital need to switch sector in a reinforcing feedback loop and the gap between the differentials and mobility costs aren’t high enough between Years 8 and 14 to sustain this. The back and forth between the capital and labour markets continues until the changes in localisation impacts lead to wage and rent differentials which are high enough to generate a sustained movement of both labour and capital into the more productive sector.

After Year 38 and 39 for Zone A and B respectively there is a sudden fall in the wage differential. This is because at this point the proportion of capital in the less productive sector reaches the minimum limit of 20% and no more capital migration occurs. At this point the wage is still higher than the labour mobility cost in the more productive sector and workers continue to move into it. Capital no longer migrates in response which means the MPL falls in the sector due to diminishing marginal returns to labour. Similarly, in Sector 2 the MPL and therefore the wage rate increase as workers leave the sector. This leads to a narrowing of the wage differential between the sectors until it is below the labour mobility cost and no further migration between the sectors takes place.

The transition to the new steady state endpoint for the number of workers is shown in Figure 5.5. The opening of the transport scheme leads to workers moving towards

Sector 1 in Zones A and B (City 1) and Sector 2 in Zones C and D (City 2) which is in line with comparative advantage as expected. The number of workers adjusts to 95% of the initial gap in 34 years of the transport scheme opening. This speed of adjustment is slightly slower than Dix-Carneiro (2014) who estimated that 95% of labour market changes due to a trade liberalisation took place in 30 years.

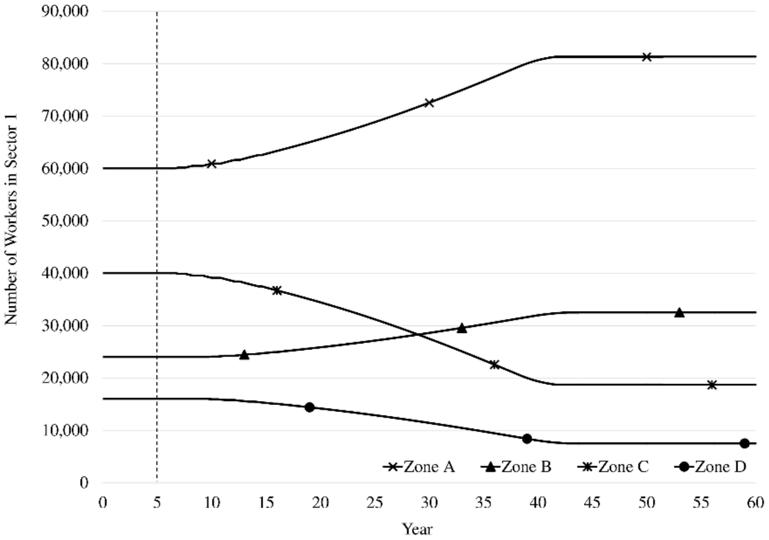

Figure 5.5 Number of Workers in Sector 1 with Uneven Trip Rates per Job & BUB x2.5

5.4.3 Sensitivity Tests Varying the Mobility Costs of Labour and Capital

It has been assumed up to this point that the mobility costs for labour and capital are at a similar relative level. In reality, however, there may be differences in the costs incurred for each factor in moving sector. To test the impact of this simulations were undertaken with different levels of mobility costs for capital and labour to test their impact on the level of specialisation changes. Holding the mobility cost for labour constant it was estimated that if the capital mobility cost was increased to 0.43p per £1 of capital per year (17% higher than the rent differential in the core zones) another type of steady state was possible where there is a limited change in specialisation. It is easier to show these effects with an even higher capital mobility cost and Figure 5.6 shows the wage differential over time in Sector 1 in City 1 of 0.48p per £1 of capital per year.

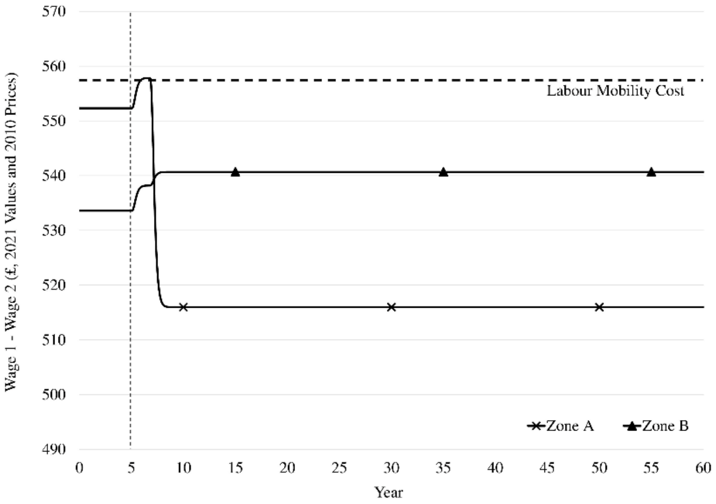

Figure 5.6 Wage 1 – Wage 2 (2021 Values & Prices) in City 1 with Uneven Trip Rates per Job, BUB x2.5 & K Mobility Cost of 0.48p per £1 of Capital

Figure 5.6 shows that following the opening of the transport scheme the business user benefits lead to an increase in the wage differential between Sector 1 and 2 to just above the labour mobility cost in Year 6. This leads to workers moving from Sector 2 to 1 in Zone A which increases TFP in Sector 1 due to localisation impacts but not enough to induce a movement of capital which remains constant. As workers move into Sector 1 its wage rate falls due to diminishing marginal returns to labour and the wage rate in Sector 2 increases which leads to a reduction in the wage differential. The differential falls below its initial level due to the delay on wage rate changes which leads to an overshooting of the number of workers moving into Sector 1. It should be noted that there are no specialisation changes in the periphery (i.e. Zone B) as the change in the wage differential between the sectors isn't great enough to exceed the labour mobility cost.

Figure 5.7 show the localisation impacts which are impacting on these changes. The initial increase in effective density in Year 5 is greater for the less productive sector in each zone as there are fewer workers in these sectors and a greater increase in effective density is therefore realised. As workers move to the more productive sector this partially offsets this pattern of localisation effects which leads to a small increase in the wage differential at the end of Year 6 which can be seen visibly for Zone B in Figure 5.5. This effect is also occurring in Zone A but it is not great enough to reverse the direction of the wage differential in this zone which stabilises at £516 per worker at the new steady state.

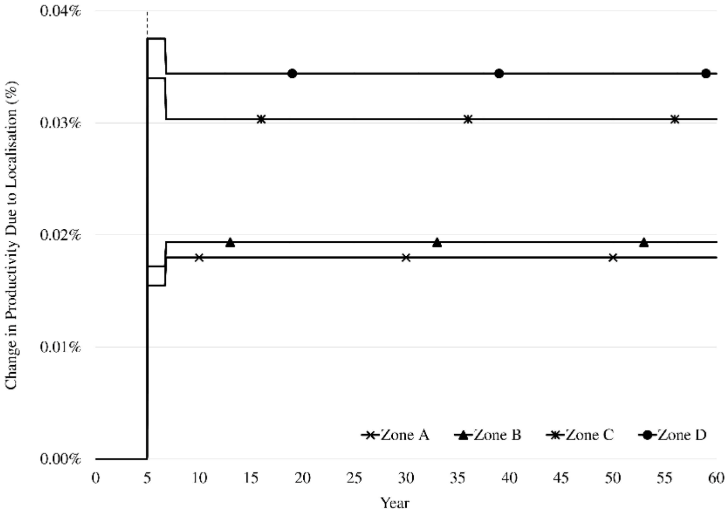

Figure 5.7 Localisation Impacts (%) in Sector 1 with Uneven Trip Rates per Job, BUB x2.5 & K Mobility Cost of 0.48p per £1 of Capital

The estimated steady state number of workers in Sector 1 in Zone A for this simulation is shown in Figure 5.8. This shows that there is no change in the requirement for business user benefits to be multiplied by 2.5 for the transport scheme to generate changes in specialisation but the requirement for maximum specialisation has increased to 3.4 times business user benefits.

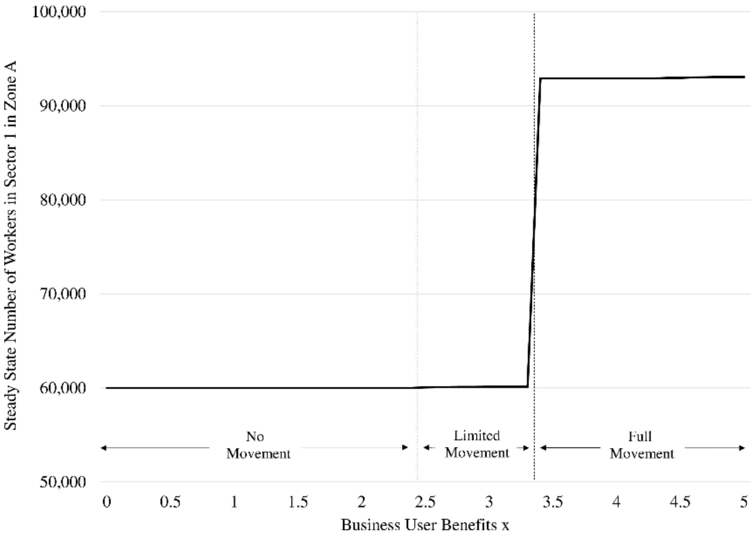

Figure 5.8 Steady State Number of Workers in Sector 1 in Zone A with Uneven Trip Rates per Job & K mobility cost of 0.48p per £1 of Capital

The model was also run with a higher mobility cost for labour than capital but it was found that this could not generate a limited specialisation endpoint under the assumptions of the model.

The present value of economic benefits of the transport scheme for the three types of steady state with a higher mobility cost for capital from Figure 5.8 are shown in Table 5.4. Although these results are for the sensitivity tests the benefits estimates for the first and third tests shown in the table are equivalent to those for the equal and uneven trip rates per job simulations respectively which were outlined in Sections 5.4.2 and 5.4.3 above.

Table 5.4 Present Value of Benefits (£m, 2021 Values and 2010 Prices) of Transport Scheme with Uneven Trip Rates per Job & K Mobility Cost of 0.48p per £1 of Capital[39]

	BUB x1			BUB x2.5			BUB x5		
Zone	BUB	Urb	Loc	BUB	Urb	Loc	BUB	Urb	Loc
A (S1)	17.3	22.9	11.5	43.3	22.9	13.2	86.6	26.3	364.7
B (S1)	6.9	9.3	5.1	17.1	9.3	5.7	34.3	10.6	142.3
C (S1)	5.7	15.1	16.6	14.3	15.1	14.9	28.5	11.7	-203.8
D (S1)	2.3	6.1	7.3	5.7	6.1	6.7	11.3	4.8	-78.9
A (S2)	5.7	15.1	16.6	14.3	15.1	14.9	28.5	11.7	-203.8
B (S2)	2.3	6.1	7.3	5.7	6.1	6.7	11.3	4.8	-78.9
C (S2)	17.3	22.9	11.5	43.3	22.9	13.2	86.6	26.3	364.7
D (S2)	6.9	9.3	5.1	17.1	9.3	5.7	34.3	10.6	142.3
Total	64.3	106.8	80.9	160.8	106.8	81.0	321.5	106.9	448.7

These results show that if the impacts of the transport scheme are high enough then it can induce changes in specialisation which can lead to significant localisation impacts. These benefits give an indication of the maximum level of the impact but in reality labour and capital won’t necessarily always move sector to achieve a higher return and the realisation of all of these potential benefits may not be possible. This is because some people and capital owners are likely to have preferences for working in particular sectors and capital owners may also be tied to long-term contracts.

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[39] This shows the benefits only for Sectors 1 and 2. There will also be benefits in other sectors across the economy but these are not included in this table. As in the present value of benefit presented in Chapter 4 these estimates do not include background economic growth.

To achieve these changes in specialisation an inter-city rail scheme would need to be significant to generate large enough time savings and/or be implemented on a route which is used for a high number of business trips. This would suggest that specialisation changes are more likely to occur when there are trade linkages between sectors in different cities which could be expected to lead to higher trip rates. In addition, changes in specialisation could potentially be realised for longer distances between cities where the time savings may be more significant although the distance decay of urbanisation and localisation effects may limit the scope of the impacts and there may also be fewer business trips over longer distances.

As highlighted in Chapter 4 there may also be a role for other direct policies to realise the potential benefits from increased specialisation. Such policies could include investment in local labour skills in specific sectors and direct policies to promote cluster growth. For example, the BBC moved several of its departments to Salford in Greater Manchester in 2012 which significantly promoted the MediaCityUK cluster located there. Policies such as these could be used alongside inter-city transport connectivity schemes to realise the full potential for localisation benefits. This is supported by the finding in Venables (2017) who found that inter-city transport connectivity is a necessary but not sufficient condition to realise the benefits from localisation effects due to increased specialisation.

5.5 Conclusion

In this chapter the dynamic model was extended to include factor mobility costs and limits on the level of specialisation in each zone. With factor mobility costs included there is a consistent starting point and transport improvements are the catalyst for generating changes in land-use. The results show that changes in specialisation don’t happen easily with factor mobility costs but they are more likely to arise when the effects differ between sectors and between cities. When the business user benefits lead to the same increases in productivity in both sectors in a zone then the transport improvement required to induce further specialisation needs to be significant. Based on a 20 minute reduction in rail journey times between the two cities it was forecast that an unrealistic level of business user benefits would be required to move the cities towards further specialisation.

When higher trip rates are assumed in the more productive sector in each location the scale of benefits required to change the level of specialisation is smaller but still significant. This suggests that investment in transport links between cities for which there is potential for significant time savings could generate changes in specialisation such as when there are trade linkages between sectors in different cities and therefore a high number of business trips. There may also be scope for investing in links between cities which are further away for which time savings may be greater but there may be fewer business trips using such links and there is also the distance decay of urbanisation and localisation effects to consider. In addition, specialisation changes may result from an inter-city transport improvement if the existing links are poor and transport is acting as a constraint on business trips.

The length of time of adjustment to a new steady state of maximised specialisation was estimated at 34 years. This is slightly longer than in other studies which have estimated sectoral adjustment times to changes in trade costs such as Dix-Carneiro (2014). Based on the parameter assumptions the urbanisation benefits due to the transport scheme were estimated as 32% greater than localisation benefits if the scheme does not generate further changes in specialisation. If the scheme leads to maximised specialisation the potential localisation benefits were shown to be large and several times the level of urbanisation benefits.

In Chapter 6 the dynamic model is extended further to include the mobility of labour and capital between zones. The updated model is used to determine the impact of the introduction of zonal mobility on the dynamics, length of transition, final endpoint and the relative benefits from localisation and urbanisation effects.

6 Extension of Dynamic Model to Include Mobility of Labour and Capital Between Zones

6.1 Introduction

In the dynamic modelling presented in Chapters 4 and 5 it was assumed that the total amount of labour and capital within each zone was fixed. In the real world, however, labour and capital are mobile and can move between locations. In this chapter the assumption of the immobility of labour and capital between zones in the dynamic model is relaxed to test its impact. The objectives of this chapter are to determine the impact of the introduction of zonal mobility on the:

1. final endpoint;
2. speed of transition to the new steady state;
3. conditions required for an inter-city transport scheme to generate changes in specialisation; and,
4. magnitude of urbanisation and localisation benefits.

The chapter is organised as follows. In Section 6.2 the background literature on the theory and evidence of the mobility of labour and capital between locations are discussed. In Section 6.3 the updates to the model are outlined and in Section 6.4 the simulation results are presented. Simulations are undertaken in Section 6.4.1 without zero mobility costs between sectors and zones and in Section 6.4.2 with non-zero mobility costs. The conclusion is provided in Section 6.5.

6.2 Background Literature

The economic modelling of inter-regional labour mobility was reviewed by Etzo (2008). He cited Hicks (1932) as the first to define the concept of workers maximising their utility when making a decision to move location through comparing the costs and benefits. This was the basis of subsequent modelling such as (Sjaastad, 1962) and Harris & Todaro (1970) in which workers move to realise a higher wage if the increase covers the cost of moving which then leads to a new market equilibrium (Tarasyev & Jabbar, 2018). Endogenous growth theory (Romer, 1986) has also been incorporated in some models such as in Reichlin & in Rustichini (1998) in which wages increase through scale effects. Reichlin & Rustichini (1998) demonstrated that if the migration of skilled workers is primarily in one direction it can lead to significant divergence over time as human capital becomes concentrated in one location leading to higher wages and attracting further in-migration (Etzo, 2008). Later work has led to migration decisions based on family rather individual decision-making (Stark and Bloom, 1985) and the development of migrant support networks in labour-importing locations (Massey, 2002) which can incentivise further immigration (Tarasyev & Jabbar, 2018).

The mobility of factors of production is one of the key assumptions in the theory of New Economic Geography (Krugman, 1991b, Fujita et al., 1999). The core-periphery model (Krugman, 1991b) showed that factor mobility, transport costs and increasing returns to scale can interact leading to the concentration of different sectors in different locations. In the core-periphery model labour is the only mobile factor of production but subsequent variations of the model have been developed which incorporate capital mobility such as the footloose capital model (Martin and Rogers, 1995). In the footloose capital model capital is perfectly mobile and labour is fixed by location but it is mobile between sectors. The model has been used to investigate the impacts of transport infrastructure and it has been found that the level of concentration by location at long-run equilibrium is sensitive to the scale of transport costs (Commendatore, et al., 2007).

The evidence suggests that level of inter-regional labour migration within countries can be significant. Labour mobility within countries is typically represented using internal migration rates which are estimated as the proportion of labour which leaves a location within a given timeframe. Over five year periods the internal migration rate has been estimated at 2.5% for the 32 regions of Mexico (2006-2010), 2.7% for the 31 administration regions of China (1996-2000), 4.4% for the 8 states and territories of Australia (2006-2010), and 8.9% for 51 states of the USA (1996-2010) (UN DESA, 2013). The internal migration rates are even higher when a finer disaggregation of geographical units is used. In Canada for 2005-2010 the internal migration rate was 2.9% for the 13 states and provinces but 11.3% for the 293 census geographical units (UN DESA, 2013).

The evidence on capital mobility is that it is significantly more mobile between regions within the same country than between countries based on analysis of Canada (Helliwell & McKitrick, 1999) and Japan (Dekle, 1996). Similarly, Collier & Vickerman (2001) found that capital mobility between Northern France and Kent in south east England was relatively low despite their close geographical proximity and good transport links. The higher mobility of capital within countries is explained by capital owners’ lesser knowledge of markets in other countries and the risks of exchange rate movements (Feldstein, 1994). There is also evidence that the mobility of capital both at the national and international level has increased significantly over the last few decades since reforms in financial market to increase liquidity were introduced which began in the USA in the 1970s (Corpataux & Crevoisier, 2005).

6.3 Updates to Model

The version of the dynamic model presented in Chapter 5 has been extended to allow movement of labour and capital between zones. The variables which are included in the updated version of the model are shown in Table 6.1 with changes from the previous version of the model highlighted in bold.

Table 6.1 Variables and Processes Selected for Modelling

Endogenous	Exogenous	Excluded
Labour Stock	Transport Scheme	Vertical Linkages
Capital Stock	Prices	Population Growth
Wages	Income Share of Capital	Labour Skills/Human Capital
Capital Rents	Labour Supply	Capital Accumulation
Sectoral Migration Within Zones		Capital Depreciation
Total Factor Productivity		Demand for Products
Urbanisation Impacts		Factor Substitution
Localisation Impacts		
Zonal Migration (previously excluded)		

As in Chapters 4 and 5 the model is an abstract representation of the cities of Leeds and Manchester in the north of England. There are two zones in each city representing the core and the periphery and the two cities are of equal size. There are rail and highway links between the cities and the inter-city rail journey time of 60 minutes is reduced by 20 minutes to test under what conditions it can generate changes in specialisation and to estimate the economic benefits.

6.3.1 Updates to Methodology

The structure of the model was updated so that labour and capital can move between zones as well as sectors. To achieve this the target-based approach used in Chapters 4 and 5 was retained but the formulae for the target levels of labour and capital were modified. In the previous chapters the implied steady state value of labour, $(L^{*})_i^n$, was estimated by setting the wage rate equal to the average wage across the two sectors within a zone ($\overline{w_i}$) and rearranging in terms of labour but with mobility between zones workers face a wider choice set of moving to another sector, zone or both. To reflect this the formula for the implied steady state of labour in sector *n* in zone *i*, $(L^*)_i^n$, used in the previous two chapters (equation (4.8)) was modified to be expressed as:

$$(L^*)_i^n = 1/\Big((MAX(w_I^N)/(1-\alpha_i^n)P^n\,A_i^n)^{1/\alpha_i^n}(h_i^n/K_i^n)\Big) \qquad (6.1)$$

where $MAX(w_I^N)$ is the maximum wage across both sectors (*N*) in all four zones (*I*), $1-\alpha_i^n$ is the income share of labour in sector *n* in zone *i*, α_i^n is the income share of capital in sector *n* in zone *i*, P^n is the price in sector *n*, A_i^n is total factor productivity in sector *n* in zone *i*, h_i^n is the annual number of hours worked in sector n in zone *i* and K_i^n is the amount of capital in sector *n* in zone *i*.

The maximum rather than the average wage across all sectors and zones was used in equation (6.1) as it was found that otherwise it could be possible for workers to potentially gain from moving zone but not being able to do so. The reason for this is that it was possible for the wage rate in a sector in a zone to be below the maximum in the study area but above the average if there was a significantly higher wage in some locations in the study area. This means that in these combinations of sectors and zones the target level of labour would be above the current number of workers and no out-migration would take place even though workers could gain from moving. To avoid this the formula for the target level of labour was modified to be based on the maximum wage rate across the study area so that workers can always move if they can achieve a higher return elsewhere[40].

As in the previous versions of the model in Chapters 4 and 5 the level of out-migration from a sector in a zone is determined by comparing the current level of labour to the implied steady state level. Labour migrates from its current sector and zone if the current level of labour is greater than its target level. The number of workers who migrate from sector *n* in zone *i*, $L\ Out\ Migration_i^n$, is given by:

$$L\ Out\ Migration_i^n = \left(\frac{L_i^n - (L^*)_i^n}{TAdjL}\right) \qquad if\ MAX(w_I^N) - w_i^n > cL \qquad (6.2)$$

where L_i^n is the number of workers in sector n in zone *i*, $w_i^n$is the wage rate in sector *n* in zone *i*, $TAdjL$ is the adjustment time in the labour market and cL is the cost of

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[40] Changing from using the average wage rate within the zone to the maximum wage rate across the study area had no impact on the final endpoint.

moving to a different combination of sector and zone. Workers are assumed to move to the combination of sector and zone with the highest return if the net increase in wages is greater than the cost of switching. If more than combination of sector and zone has the maximum wage rate available then the number of migrating workers are divided evenly between those alternatives.

Similar adjustments to those made in the labour market were also carried out in the capital market. The formula for the implied steady state of capital in sector *n* in zone *i*, $(K^*)_i^n$, was updated so that the average rent within a zone ($\overline{r_i}$) used in Chapter 4 (equation (4.15)) was replaced with the maximum rent across all combinations of sectors and zones $MAX(r_I^N)$:

$$(K^*)_i^n = \left(MAX(r_I^N)/(h_i^n L_i^n)^{1-\alpha_i^n}\ \alpha_i^n P^n A_i^n\right)^{1/(\alpha_i^n-1)} \tag{6.3}$$

There is out-migration of capital from its current combination of sector and zone if the current level is greater than the target level. Capital migrates to the combination of sector and zone where the capital rent is highest taking into account any costs of switching (*cK*). The amount of capital which leaves sector *n* in zone *i*, $K\ Out\ Migration_i^n$, is given by:

$$K\ Out\ Migration_i^n = \left(\frac{K_i^n - (K^*)_i^n}{TAdjL}\right) \qquad if\ MAX(r_I^N) - r_i^n > cK \tag{6.4}$$

where r_i^n is the capital rent in sector *n* in zone *i* and $TAdjK$ is the adjustment time in the capital market. As in the labour market if more than one combination of zone and sector has the highest return taking into account mobility costs the capital which migrates is split evenly between the alternatives.

The model was simulated to test the impact of these changes and it was found that they led to a quicker transition to the new steady state. This transpired because the amount of migration of labour and capital in each time step is determined by the difference between the current wage and rent and the maximum available across the study area which are greater than the difference between the current wage and rent and the average within each zone used in the model in Chapters 4 and 5. This led to more labour and capital moving in each time step in the updated version of the model and the new steady state was therefore reached more quickly. The quicker speed of adjustment was unrealistic and to adjust the model to take account of this the model without zonal mobility in Chapter 5 was re-run using the maximum wage and rent rather than the average and the adjustment parameters ($TAdjL$, $TAdjK$) were selected so that adjustment to 90% of the initial gap took the same length of time as using the average wage and rent. This led to the adjustment parameter for both labour and capital increasing from 1.500 to 1.915. These parameters were used in the simulations both with and without mobility between zones which are outlined in Section 6.4.

A further potential update to the model was identified which was replacing the DELAY3 function which determines the speed with which wages and rents adjust in response to changes in productivity with the DELAY1 function. The model without zonal mobility was tested with this change and the wage differential between Sector 1 and 2 in Zone A is shown in Figure 6.1.

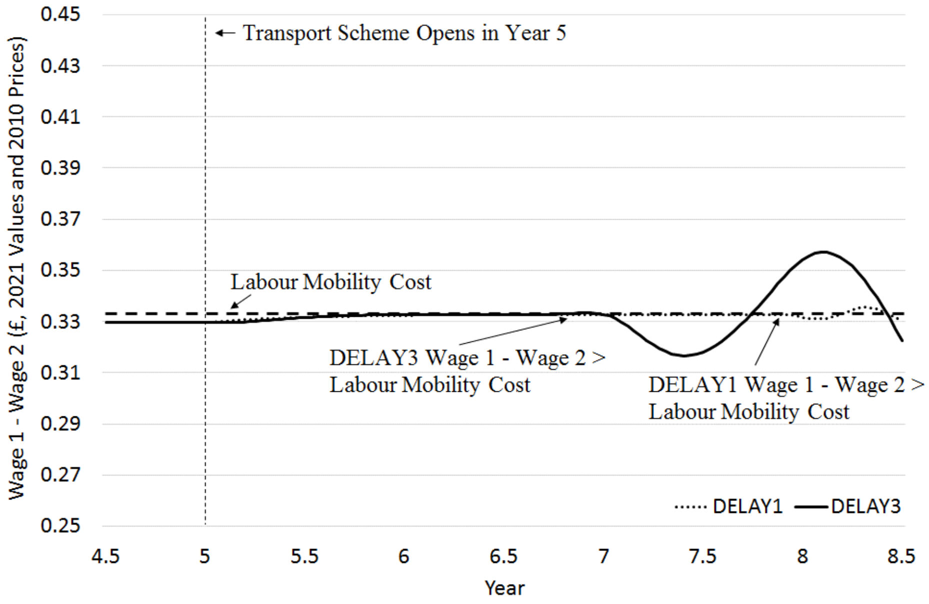

Figure 6.1 Wage 1 – Wage 2 in Zone A (£/hr, 2021 Values and 2010 Prices)

It was found that using the DELAY1 function made no difference to the minimum requirements for changes in specialisation due to the transport scheme but it led to the threshold for changes in specialisation being reached 1.2 years later than previously at 7.9 rather than 6.7 years as shown in Figure 6.1. This was due to the different responses with larger fluctuations in the wage differentials using the DELAY3 function which leads to them rising above the cost of moving sector more quickly which led to changes in land-use sooner. The DELAY1 function was taken forward in the modelling and used for the analysis in the remainder of this chapter as it removes the sharp oscillations of wages and rents which are not realistic.

6.3.2 Updates to Data Inputs

The baseline economic input data used for Sector 1 in the model simulations is shown in Table 6.2. There were some minor adjustments made to the economic inputs from those used in Chapter 5. The initial level of Total Factor Productivity (TFP) in each combination of sector and zone were updated to take account of both urbanisation and localisation effects rather than localisation effects only as in Chapter 5. This was achieved by first assuming that below 1,000 workers in each zone there are no agglomeration effects in a similar way to Chapter 5. The specified number of jobs in each sector and zone (shown in Table 6.2) were then used to calculate the increase in productivity from both urbanisation and localisation effects to calculate the updated wage rates and GDP per worker[41].

Table 6.2 Economic Inputs for Sector 1

	City 1		City 2		
Economic Variable	Zone A	Zone B	Zone C	Zone D	All Zones
Number of Jobs	60,000	24,00	40,000	16,000	140,000
Total Jobs	-	-	-	-	1,000,000
Capital Inputs (£m)	£4,860	£1,944	£3,240	£1,296	-
TFP	11.25	11.13	11.04	10.92	-
GDP per Worker (£)	£73,282	£72,452	£71,905	£71,114	-
GDP (£m)	£4,397	£1,739	£2,876	£1,138	-
Wage per hour (£)	£28.42	£28.10	£27.89	£27.58	-
Annual Capital Rent (£)	£0.317	£0.313	£0.311	£0.307	-

The elasticities and distance decay factors for urbanisation and localisation effects were updated from those used in Chapter 5. The elasticities in this chapter are based on the central case assumptions used for the static modelling in Chapter 7 (shown in Table 7.4) which were based on a review of the empirical evidence. The elasticities used for both sectors were 0.05 for localisation effects and 0.12 for urbanisation effects. The distance decay factors used in this chapter were also based on the central case assumptions used in the static modelling in Chapter 7. In both sectors a distance decay factor of 1.9 was used for localisation effects and 1.7 for urbanisation effects.

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[41] The wage rate in the core zones in which it has a comparative advantage are similar to the wage rate used in Chapter 5. The wage rates for the sectors in other zones are also similar in Chapter 5 but there are larger differences in wages and rents across the study area due to the inclusion of urbanisation effects and the higher elasticities and lower distance decay factors for localisation effects.

As in the economic inputs used in Chapters 4 and 5, City 1 has higher wages and capital rents in Sector 1 and City 2 in Sector 2 and it is expected that an inter-city transport scheme will increase the differences between wages and rents in each city leading to further specialisation in the sector each is most specialised in. All of the other data inputs such as journey times and rail demand remained the same as in Chapter 5.

6.4 Results and Discussion

Model simulations were undertaken to determine the impact of introducing zonal mobility into the model. Simulations were carried out both with and without zonal mobility so the results could be compared using the following assumptions:

- Zero sectoral and zonal mobility costs;
- Non-zero sectoral and zonal mobility costs; and,
- Non-zero sectoral and zonal mobility costs with lower zonal mobility costs within cities.

The first of set of assumptions was used so that the dynamic processes over time with and without zonal mobility could be compared and to determine any difference in the natural equilibrium endpoints. These simulations are similar to the format of the model simulations without zonal mobility with variable capital in Chapter 4 and the results are outlined in Section 6.4.1.

A more realistic assumption of non-zero sectoral and zonal mobility costs was then used in the model runs outlined in Section 6.4.2. These simulations are a similar format to the model runs with sectoral mobility costs undertaken in Chapter 5. A simulation was first undertaken without zonal mobility which is then compared to two different simulations with zonal mobility. In the first of these it is assumed that zonal mobility costs are the same between all zones in the model and in the second zonal mobility costs are lower for movements within cities. The latter simulation is to reflect the evidence which is discussed in Section 6.4.2 which shows that labour and capital may be more likely to move location within a city or region than move between them.

6.4.1 Zero sectoral and zonal mobility costs

Model simulations were undertaken with and without zonal mobility so the effects of the inclusion of zonal mobility could be determined. As in Chapter 4 no minimum level of capital by sector and zone was specified and business user benefits were applied based on even trip rates[42]. The number of workers in Sector 1 over time for both models with zero sectoral and zonal mobility costs are shown in Figure 6.2[43]. As with all the charts in this section the simulation without zonal mobility is shown on the left hand side of Figure 6.2(a) and the simulation with zonal mobility is shown on the right hand side of Figure 6.2(b).

Figure 6.2(a) shows that as expected without zonal mobility there is a transition towards a full specialisation endpoint in each zone based on comparative advantage with Sector 1 fully concentrated in the zones in City 1 and Sector 2 in the zones in City 2. This is the same pattern for the without zonal mobility model run with variable capital in Chapter 4. Figure 6.2(b) shows that with zonal mobility the final endpoint is different. In this simulation at the new steady state all jobs in Sector 1 are in City 1 and all Sector 2 jobs are in City 2 but all workers are now concentrated in the core zones only with no jobs in the two sectors in the periphery.

Figure 6.2 also shows that there is a significant difference between the speeds of transition in the two simulations. The speed of transition is quicker without zonal mobility and the labour stock adjusts to 98% of the initial gap taking place in 44 years compared to more than 100 years with zonal mobility. Although there is a slower transition to the final endpoint in the simulation with zonal mobility the core zone of each city reaches 100,000 workers in the sector which it has a comparative advantage more quickly. With zonal mobility this takes only 18 years compared to several decades without zonal mobility.

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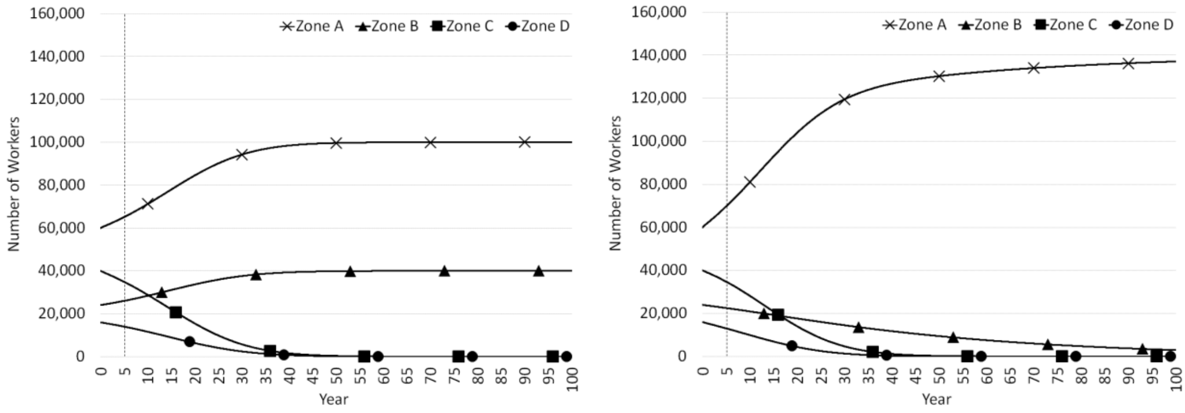
[42] This means that the business user benefits were split between sectors based on the number of workers in each sector and zone. This means the proportional increase in productivity is the same in each combination of sector and zone.

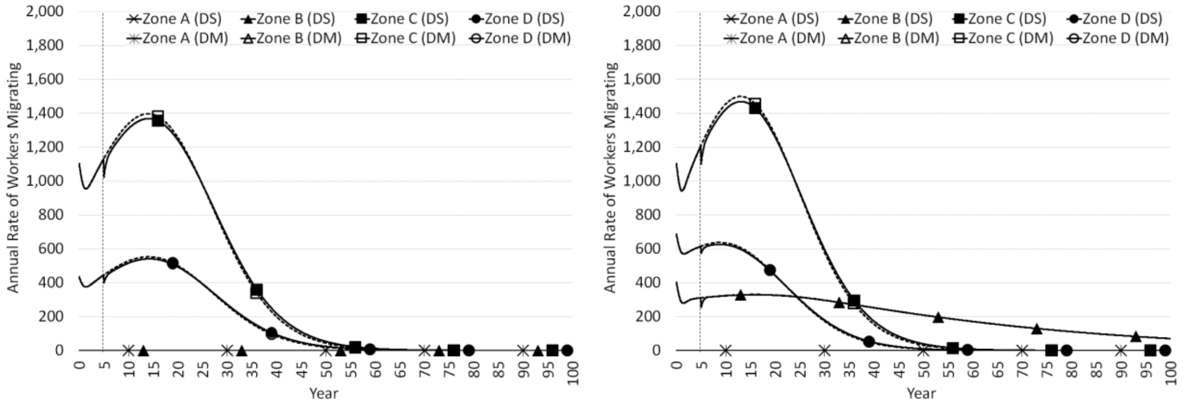
[43] The two cities are symmetrical but with a high number of jobs in Sector 1 in City 1 and in Sector 2 in City 2 and the parameters used for elasticities and distance decay factors are the same in both sectors. This means in this chapter the results for Sector 2 are the same as those presented for Sector 1 but reversed in each city.



(a) Without zonal mobility **(b) With zonal mobility**

Figure 6.2 Number of Workers in Sector 1 with Zero Mobility Costs[44]

In Figure 6.2 the speed of the fall in the number of workers in Zones C and D is similar in both simulations. What drives the slower speed of adjustment in the simulation with zonal mobility is the slower fall in the number of workers in Zone B which takes more than 100 years. The reasons driving the differences in final endpoints and speed of transition in the two simulations can be investigated through plotting the variables driving these changes. The out-migration from Sector 1 and in-migration into Sector 1 are shown in Figures 6.3 and 6.4 respectively. The results are shown for the Do-Something (DS) and Do-Minimum (DM) in both simulations so the impact of the inter-city transport scheme can be seen.



(b) Without zonal mobility **(b) With zonal mobility**

Figure 6.3 Out-Migration of Workers from Sector 1 with Zero Mobility Costs

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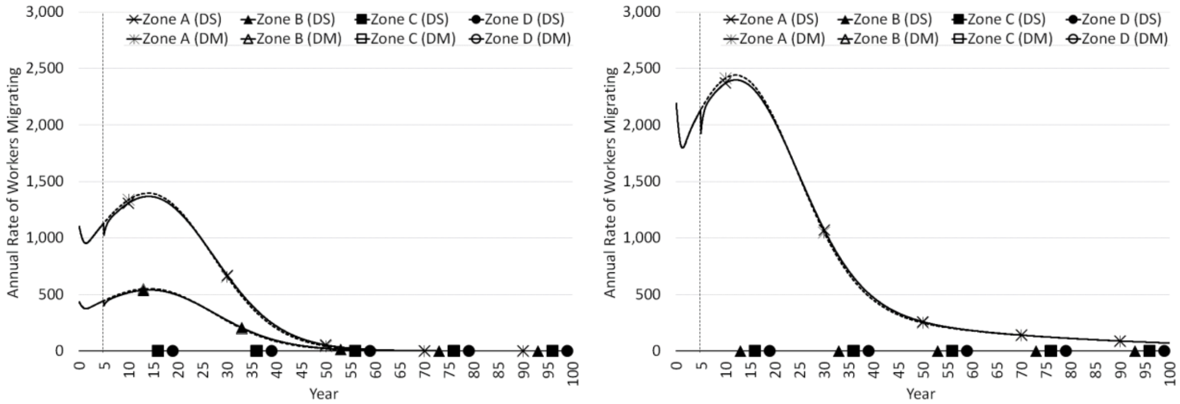
[44] There is some movement before the transport scheme opens in Year 5 as with zero mobility costs workers and capital can move to the destination with the highest return with no cost. The more realistic case of non-zero mobility costs is presented in Section 6.4.2 in which there is no movement before the transport scheme opens in Year 5.



(a) Without zonal mobility **(b) With zonal mobility**

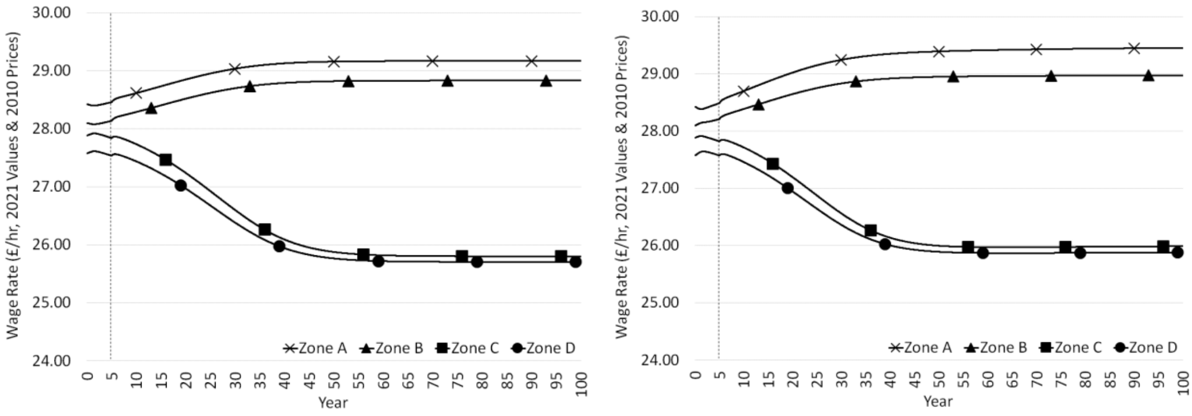
Figure 6.4 In-Migration of Workers into Sector 1 with Zero Mobility Costs

Figure 6.3 shows that in both models there is out-migration from Sector 1 in City 2 (Zones C and D) as workers move to where wage rates are highest. In the simulation without zonal mobility workers move within each zone to the sector with the comparative advantage as shown in Figure 6.4(a). In the simulation with zonal mobility the migration patterns are different. As shown in Figure 6.3 (a) workers not only leave Sector 1 in Zones C and D but also Zone B. This is because with zonal mobility workers can move to the combination of zone and sector with the highest return which are Sector 1 in Zone A and in Sector 2 in Zone B. This is shown by the significant in-migration into Sector 1 in Zone A but none of the other three zones in Figure 6.4(b).

There are other notable differences in the pattern of migration between the models. Figure 6.3 shows that there is a higher level of out-migration from Zone D over the first few years in the model with zonal mobility than without. This is because with mobility workers can leave Sector 1 in this zone and switch to working in the comparative advantage sectors in each core zone. This is a larger wage differential than moving to Sector 2 in Zone D and so there is higher level of migration. In addition, it can also be seen in Figure 6.3 that the out-migration from Zone B in Sector 1 with zonal mobility occurs more slowly than from any other location. The reason for this can be seen through looking at the urbanisation and localisation effects which are discussed below. This slower rate of migration explains why it takes longer to reach a new steady state with zonal mobility in Figure 6.2 (b).

The impact of the transport scheme on the speed of transition can be shown by comparing the DM and DS simulations. In both models initially the journey time improvement in Year 5 slows down the migration away from Sector 1 in Zones A and B. This is due to the counter-intuitive reason discussed in Chapter 4 in which the transport scheme generates a larger proportion increase in the effective density of locations with fewer jobs. This is because locations with a small number of jobs gain proportionally more from the changes in effective density as they brought closer to locations with more jobs whereas locations with more jobs gain less from being brought close to locations with fewer jobs[45]. Later in the analysis period the migration is higher with the transport scheme as less migration took place in the earlier years. Even though the speed of transition is different with the transport scheme the endpoints in the DM and DS are the same in both models.

The labour migration patterns are driven by changes in wage rates over time which are shown for Sector 1 in Figure 6.5. This shows that in both models the wage rates increase in Zones A and B and decline in Zones C and D as the number of jobs in Sector 1 increases in City 1 and falls in City 2. Figure 6.5 also shows that the wage rates in Sector 1 are higher in all four zones in the simulation with zonal mobility including in Zones C and D.



(a) Without zonal mobility **(b) With zonal mobility**

Figure 6.5 Wage Rate (£/hr, 2021 Values and 2010 Prices) in Sector 1 with Zero Mobility Costs

As in Chapter 4 the differences in the changes in the wage rates over the analysis period are driven by differences in urbanisation and localisation effects only and not business user benefits. This is because with even trip rates the business user benefits generate the same proportional increase in productivity in both sectors in all zones and therefore their impact on differences in wage rates cancel out. The urbanisation impacts are shown first in Figure 6.6.

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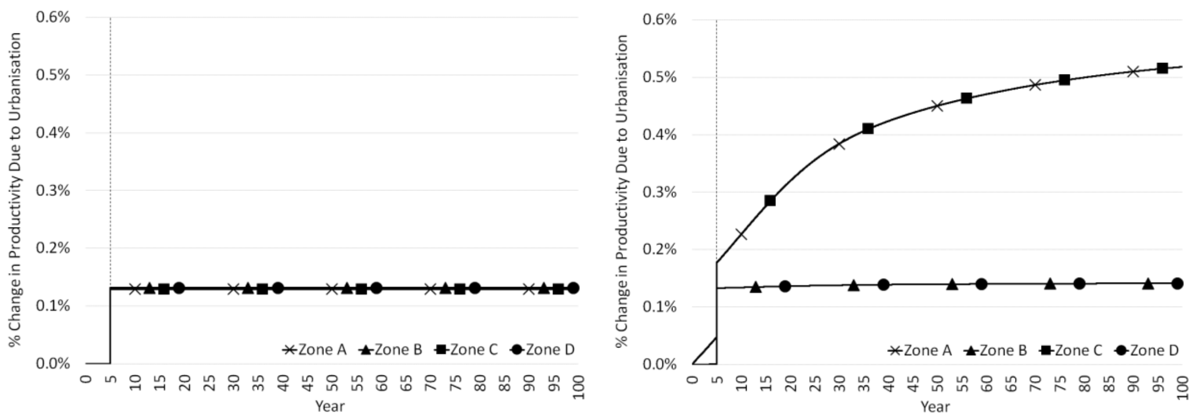
[45] This also explains the immediate fall in the migration from Sector 1 in Zones A and B when the transport scheme opens in Year 5.



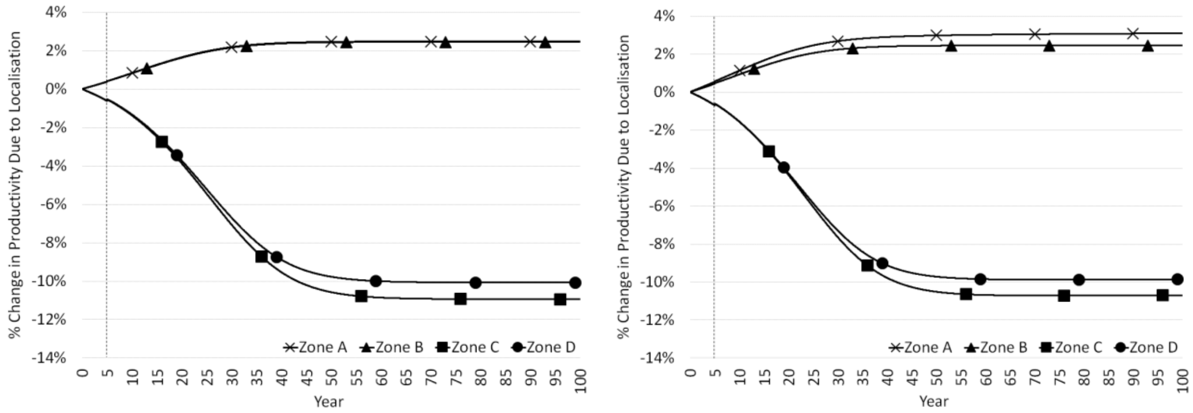
(a) Without zonal mobility **(b) With zonal mobility**

Figure 6.6 Urbanisation Impacts (%) in Sector 1 with Zero Mobility Costs

Figure 6.6 (a) shows that in the simulation without zonal mobility the urbanisation impacts in Sector 1 are similar in all zones. This is because urbanisation impacts are calculated based on the effective density across all sectors and without mobility between cities the number of jobs in each zone is fixed. This means that only the reduced transport costs in Year 5 generate any urbanisation effects. In the simulation with mobility between zones in Figure 6.6(b) the urbanisation impacts vary by zone over time. In the core zones there are some urbanisation effects from the start of the analysis period. This is because the number of workers in the core zones increases as workers migrate there to achieve a higher wage which increases the effective density of these zones. When the transport scheme opens in Year 5 there is then a further increase in urbanisation impacts as productivity increases. This is due to the lower journey times between zones which increases the effective density of overall economic activity. These effects continue to grow over time as more workers move to working in the core zones which leads to even higher effective density.

In the peripheral zones there are no change in urbanisation impacts until the transport scheme opens in Year 5. Following the opening of the scheme there is a slight increase in urbanisation impacts over time. This results from the small increase in the overall effective density of the study area as jobs in the two sectors become concentrated in the core zones.

The localisation impacts of the two schemes are shown in Figure 6.7. This shows that the scale of the changes are more significant than the urbanisation effects shown in Figure 6.6. This is because the proportional changes in sectoral employment which drives localisation impacts are greater than for overall employment across the economy which drive urbanisation effects.

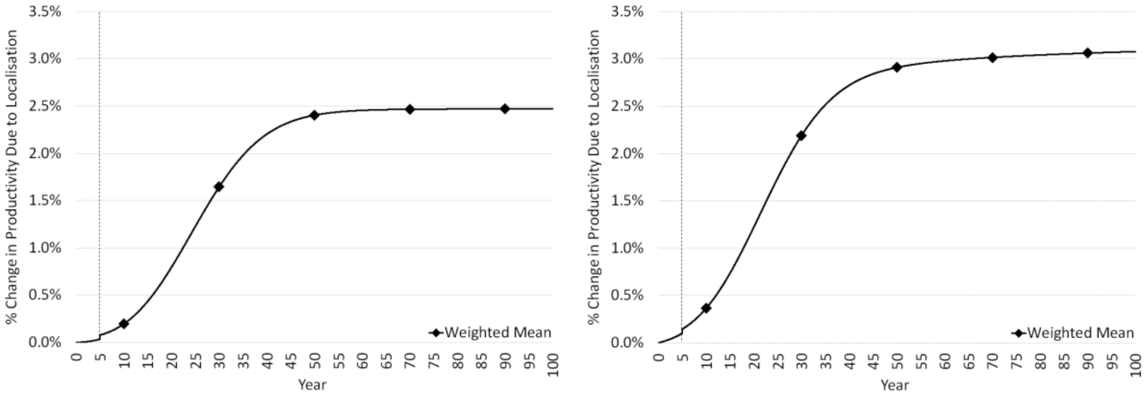


(a) Without zonal mobility **(b) With zonal mobility**

Figure 6.7 Localisation Impacts (%) in Sector 1 with Zero Mobility Costs

With zonal mobility the increase in localisation effects for Sector 1 in the core zone (Zone A) is higher than without zonal mobility. This occurs because with mobility between zones the number of workers in the sector in the core zone increases generating higher localisation effects. Despite no in-migration into Sector 1 in Zone B there are also increasing localisation impacts over time in this zone. The reason for this is that workers switch from Sector 2 into Sector 1 in Zone A and workers also move from City 2 (Zones C and D) to Sector 1 in Zone A. This increases labour in Sector 1 in Zone A in City 1 which increases the effective density of the Sector 1 across the whole city. This leads to a smaller wage differential between Sector 1 in Zone B and A which means only a few workers move from Zone B to Zone A in each time step. This explains the reason for the longer transition to the new steady state in the simulation with zonal mobility highlighted in the discussion around Figure 6.2.

Whilst in Figure 6.7 the negative effects are larger than the positive effects the impacts overall are positive because the number of workers is increasing over time in the zones in which localisation effects are positive and falling where the effects are falling. This is demonstrated in Figure 6.8 which shows the weighted mean for localisation effects in Sector 1 across all four zones. Localisation effects increase more quickly and reach a higher level with zonal mobility due to the higher densities realised as the sector becomes more highly concentrated in Zone A in City 1.



(a) Without zonal mobility **(b) With zonal mobility**

Figure 6.8 Weighted Mean Localisation Impacts (%) in Sector 1 with Zero Mobility Costs

In the analysis in this chapter so far the focus has been only on the impacts within two sectors. It is important to note, however, that other sectors in the study area would also be potentially affected by an inter-city transport improvement. Firstly, the changes in the two sectors that have been modelled could also be expected to impact on other sectors. For instance, increased concentration of the two business service sectors in the core zones could potentially lead to higher land rents which would affect the rents paid by firms in other sectors and incentivise some to move to less expensive locations. On the other hand the change in location of firms in the two modelled sectors could induce firms in other sectors to move to be closer to their suppliers or customers in those sectors.

Changes in land-use can also be expected to take place in other sectors in the economy as a result of the transport scheme. The effects could be similar to those that have been modelled although wage rates and localisation and urbanisation parameters may be different in other sectors. Changes in other sectors could also impact on business service sectors through their impact on land prices and they may alter the distances between business service firms and their customers and suppliers. There could also be movements in workers and capital between the two sectors and the rest of the economy.

These considerations about other sectors across the economy are also relevant to the model simulations with non-zero sectoral and zonal mobility costs which are outlined in the following section.

6.4.2 Non-zero sectoral and zonal mobility costs

The assumption of zero mobility costs is unrealistic and there are costs to both labour and capital of moving between sectors and between zones. The mobility costs of moving sector were discussed in Chapter 5 and for labour these include the costs of training and reskilling (Larch & Lechthaler, 2011). For capital there are the time and resource costs of moving sector (Morshed & Turnovsky, 2004) and the efficiency of capital may initially decline after moving sector (Neary, 1978, Mussa, 1978). As shown in Chapter 5 these costs of moving sector create barriers to changes in specialisation.

There are several costs to labour and capital of moving between locations. For labour the financial costs of moving will be important including the time and resource costs and workers who rent maybe more likely to move location than homeowners (Andrews, et al., 2011). There are also the personal costs of moving such as moving away from family and friends (Iregui, 2005) and the need to care for sick relatives and the feelings of partners and children who may not want to move (Morissette, 2017). There is evidence from the European Union (EU) that labour migration both between and within countries is lower than would be expected given the wage differentials (Decressin and Fatás, 1995). Belot and Ederveen (2012) estimate that for 22 OECD countries migration between them is 0.6% lower for every 100km increase in distance between capital cities and they found that cultural differences were better at explaining the differences in migration flows between EU countries than economic variables. While cultural differences are likely to be less significant within countries they may still be present to an extent due to differences between regions.

For capital the cost of moving location includes the time and resource cost of physically moving equipment but there are also several other costs for firms to consider. Based on survey evidence from the Netherlands Weterings & Knoben (2013) divide factors for firms’ relocation decisions into short- and long-distance factors. They found that for short distances internal issues such as the need for space are likely to be the most important but over long-distances they found factors such as access to markets and agglomeration economies (McCann & Folta, 2008) are more important. Weterings & Knoben (2013) highlight evidence that diseconomies of agglomeration can incentivise firms to leave their current location such as competition between firms and inputs such as land and access to skilled labour (Pouder & St. John, 1996, Flyer & Shaver, 2003, and, Stuart & Sorenson, 2003).

Many firms are relatively small and the decision to relocate to another city or region may depend on personal reasons in a similar way to worker decisions in the labour market (Niedomsyl et al., 2018). There is also likely to be some inertia to change as firms make decisions about location for the long-term and not only for small changes in rents which could prove to be temporary. All of these reasons suggest that capital is only likely to be moved to a new location if there are clear benefits which could be expected to be sustained over a number of years.

The impact of including zonal mobility costs in addition to those for moving sector were tested in the model using the baseline economic inputs from Table 6.2. To obtain an equilibrium starting point the sectoral mobility costs for labour and capital were set in the same way as in Chapter 4 at 1% above the wage and rent differential respectively between the sectors in the core zones. In a similar way the costs of moving zone were set at 1% above the largest wage and rent differentials respectively between zones[46][47]. As in Chapter 5 a 20% minimum amount of capital was also specified for both sectors within each zone to prevent full specialisation in each zone.

So that the impact of introducing zonal mobility with mobility costs could be identified the model without zonal mobility was simulated first. With non-zero mobility costs the inter-city transport scheme is now the catalyst for changes in land-use if the changes in productivity are great enough to incentivise worker and capital to move sector. As in the simulations in Chapter 5 it was found that with even trips rates the scale of business user benefits were insufficient to generate any changes in specialisation[48]. It was found that the minimum BUB required to generate changes in land-use was 4.2 times the baseline with uneven trip rates[49].

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[46] These were estimated for labour as £0.54/hour for movements between sectors within the same zone, £0.85/hour for movements between zones but not sector and £1.39/hour for movements between sectors and zones. For capital the mobility costs were estimated as £0.0060/£ of capital for movements between sectors within the same zone, £0.0095/£ of capital for movements between zones but not sector and £0.0155/£ of capital for movements between sectors and zones.

[47] In the model the choice of residential location is not considered only workplace location. For capital this will include the physical cost of moving capital between cities. Many business service firms could have offices in both cities which would lower the level of zonal mobility costs as moving capital may only involve expanding one office and reducing the size of the other.

[48] Even trip rates mean that the business user benefits are split between sectors and zones based on the proportion of workers in each sector. This means that the proportional increase in productivity in each sector and zone are the same and BUB alone cannot incentivise any workers to move sector or zone.

[49] This is higher than the requirement of 2.6 times the BUB for the without zonal mobility simulations in Chapter 5. This is because the wage differentials are greater now due to the inclusion of urbanisation effects in the initial wages and the higher elasticities used for urbanisation and localisation effects.

The number of workers in Sector 1 for this simulation is shown in Figure 6.9. Following the opening of the transport scheme in Year 5 the number of workers in Sector 1 in City 1 (Zones A and B) increases and the number of workers in City 2 (Zones C and D) declines. This is as expected as workers and capital in each zone shift into the sector in which it has a comparative advantage. It takes approximately 21 years following the opening the transport improvement to achieve adjustment to 98% of the initial gap.

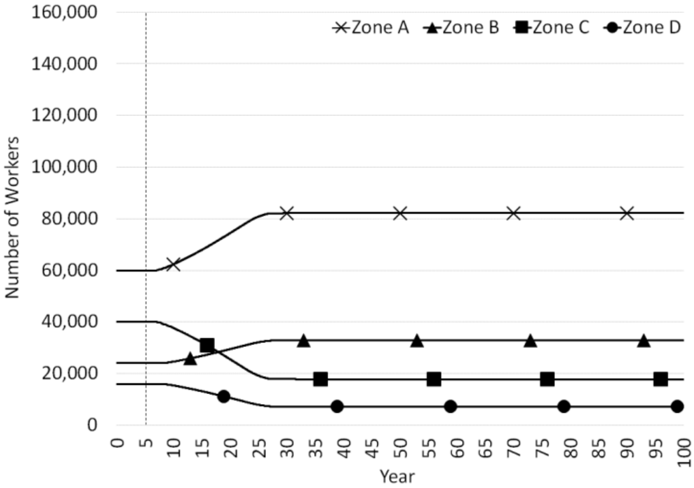

Figure 6.9 Number of Workers in Sector 1 without Zonal Mobility and Non-Zero Sectoral Mobility Costs

The model was then simulated with mobility between zones and equal zonal mobility costs within and between cities. It was found that introducing zonal mobility had no impact on the minimum conditions required for changes in land-use due to the transport scheme which remained uneven trip rates and 4.2 x baseline BUB. The number of workers in Sector 1 in each zone over time is shown in Figure 6.10. This shows that following the journey time improvement the number of workers increases in Sector 1 in the core zone of City 1 which has the comparative advantage in the sector. This is because workers move from Sector 2 in the core zone and also from Sector 2 in City 2. However, the number of workers in the peripheral zone (Zone B) in Sector 1 remains constant. This is because as the number of workers in Sector 1 increases in Zone A this increases the effective density of the sector in Zone B. This increases the wage in Zone B and the wage differential to Zone A is not great enough for workers to overcome the mobility cost. The number of workers in Sector 1 in the peripheral zone in City 2 (Zone D) declines as workers migrate to the sector with the comparative advantage in the core zones of both cities. This leads to an increase in the proportion of jobs in the core zones in both cities.

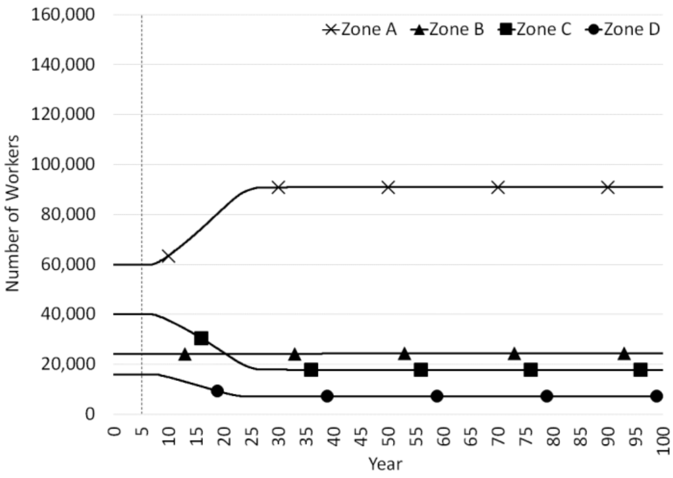

Figure 6.10 Number of Workers in Sector 1 with Zonal Mobility and Non-Zero Mobility Costs

It takes a similar length of time to reach 98% adjustment to the initial gap as in the simulation without zonal mobility at approximately 20 years. The number of workers in the core zone with the comparative advantage is higher though with 90,891 workers in Zone A in Sector 1 compared to only 81,184 without zonal mobility. This shows that with zonal mobility a higher proportion of Sector 1 is in the core as workers are attracted to the core zones to achieve a higher wage.

It might be expected in the real world that the cost of moving location within a city would be lower than moving to another city for both labour and capital. This is because if workers move to a job in another city it may involve moving property and leaving behind family and friends and for capital moving city may involve moving away from regular customers and suppliers. For these reasons it might be expected that labour and capital would require higher compensation for moving to a workplace in another city than to another location with their current city. This is supported by evidence from the Netherlands highlighted by Hospers (2011) which shows that only 6% of migrating firms move to another region (Van Oort et al, 2007) and only 14% of migrating people move more than 100km (Feijten and Visser, 2005).

Lower mobility costs for labour and capital between zones within each city were tested in the model. The costs for moving between zones within each city were based on assuming 1% above the current wage differential between the core and periphery of each city[50]. The costs of moving sector and moving zone between cities remained the same as the inputs used in the previous simulation.

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[50] For labour this gave a mobility cost between zones within each city of £0.33/hour and for capital of £0.0036 per £ of capital.

In this simulation it was found that again there was no change to the minimum requirement for changes in land-use of uneven trip rates and BUB of 4.2 times the baseline assumptions. The number of workers in Sector 1 over time is presented in Figure 6.11 which shows that there is a different pattern in changes in labour when zonal mobility costs are lower within cities. Unlike in the previous simulation there is no barrier to workers in Sector 1 in Zone B moving to Zone A as the wage differential is now greater than the cost of moving. This leads to a higher endpoint with 107,306 workers in Sector 1 in Zone A.

The speed of transition to the new steady state is much slower in this model run compared to the previous two simulations and it takes 70 years to reach the new steady state. This slower transition is because the movement away from Sector 1 in Zone B takes longer to realise. This is due to the same reasoning outlined in Section 6.4.1 for the simulation with zero mobility costs in which the movements into the core zone in the sector with the comparative advantage also increases the effective density of that sector in the periphery zone. This leads to only a small increase above the wage differential between Zone B and the two core zones and their comparative advantage sector and therefore only a few workers move from Zone B in each time step.

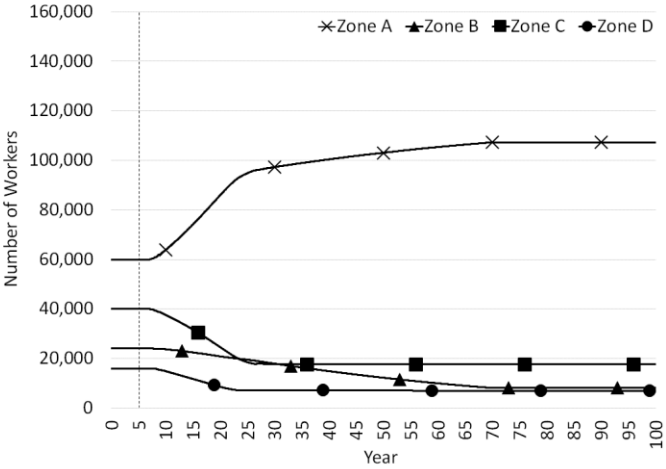

Figure 6.11 Number of Workers in Sector 1 with Zonal Mobility and Non-Zero Mobility Costs with Lower Mobility Costs for Within City Movements

6.4.3 Economic Benefits

The present value of benefits for the three simulations presented in Section 6.4.2 were estimated using the discount rates and base discount year of 2010 from the

DfT WebTAG guidelines (DfT, 2017b)[51]. The estimated benefits for each simulation by zone for Sector 1 (S1) and Sector 2 (S2) are shown in Table 6.3.

Table 6.3 PV Benefits (£m, 2021 Values and 2010 Prices) of Inter-City Transport Scheme[52]

	Without Zonal Mobility			Zonal Mobility With Equal Zonal Mobility Costs Between Zones			Zonal Mobility & Lower Intra-City Mobility Costs		
Zone	BUB	Urb	Loc	BUB	Urb	Loc	BUB	Urb	Loc
A (S1)	77.3	126.3	1018.0	77.3	208.0	1296.5	77.3	291.8	1544.1
B (S1)	30.6	50.6	395.6	30.6	42.1	315.7	30.6	33.5	222.9
C (S1)	25.5	43.9	-511.1	25.5	60.3	-528.9	25.5	73.2	-528.3
D (S1)	10.1	18.0	-196.9	10.1	17.1	-195.5	10.1	17.2	-196.0
A (S2)	25.5	43.9	-511.1	25.5	60.3	-528.9	25.5	73.2	-528.3
B (S2)	10.1	18.0	-196.9	10.1	17.1	-195.5	10.1	17.2	-196.0
C (S2)	77.3	126.3	1018.0	77.3	208.0	1296.5	77.3	291.8	1544.1
D (S2)	30.6	50.6	395.6	30.6	42.1	315.7	30.6	33.5	222.9
Total	286.8	477.6	1411.0	286.8	654.8	1775.4	286.8	831.5	2085.4

The results show that the lowest total benefits across the three model runs are for the simulation without zonal mobility. In this simulation localisation benefits are £1,411mn compared to £478mn for urbanisation[53]. In the model run with zonal mobility and equal mobility costs between zones localisation benefits are £1,775mn and urbanisation benefits are £655mn which represent increases from the previous

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[51] To ensure consistency with the modelling results in Chapter 5 it was assumed that the year of appraisal was 2018 which meant a discount rate of 0.035 was applied up to 2048 and then 0.03 to the end of the appraisal period in 2080.

[52] This shows the benefits only for Sectors 1 and 2. There will also be benefits in other sectors across the economy but these are not included in this table. As in the present value of benefit presented in Chapters 4 and 5 these estimates do not include background economic growth.

[53] These results are greater than the benefit estimates presented without zonal mobility in Chapter 5. This is due to the higher level of business user benefits required to generate changes in land-use and the higher parameters assumed for urbanisation and localisation effects.

simulation of 26% and 37% respectively. The increase in urbanisation benefits are greatest as with mobility between zones there is an increase in concentration across the economy whereas with location fixed they are only affected by changes in travel times. Localisation benefits are also higher as with zonal mobility a higher concentration of the sectors is able to develop with the comparative advantage in the core zones of each city.

In the last simulation with zonal mobility and lower mobility costs within cities both urbanisation and localisation benefits are even higher than in the previous two simulations at £832mn and £2,085mn respectively. Compared to the model run without zonal mobility benefits from localisation have increased by 48% and from urbanisation by 74%. The benefits in this model run are the highest across the three simulations as at the final endpoint there is the greatest concentration of the sector with the comparative advantage in the core of each city. This leads to greater effective densities of each sector and the economy as a whole which leads to higher localisation and urbanisation benefits respectively.

In reality the full scale of the benefits of the simulations in Table 6.3 are unlikely to be realised. As discussed in Chapter 5 the maximum potential changes in sectoral composition within a location are unlikely to be fully achieved as people are likely to have preferences for working in particular sectors and capital owners may be tied to long-term contracts and there may be inertia about moving sectors. Similarly, there are likely to be limits to the potential for increased concentration within cities. This is due to the effects of increased competition for land, skilled labour and other inputs density (McCann & Folta, 2008, Pouder & St. John, 1996, Flyer & Shaver, 2003, and, Stuart & Sorenson, 2003). This is supported by evidence of lower and even negative agglomeration elasticities estimates in some sectors at high levels of effective density (Graham, 2006).

There is recent ex-post evidence from the north of England that transport improvements can significantly increase land prices. Nellthorp et al. (2019) estimated that the opening of a new tram station increased land prices in Manchester by an average of 6.3% within 1km which is similar to other studies of other transport improvements (Gibbons & Machin, 2005, Ahlfeldt, 2013). This suggests that land rents could increase around inter-city transport nodes which could act as a barrier to movements of capital from low to higher density locations such as the core of cities. This is supported by evidence from HSR stations in Europe that cities with plentiful available and affordable land particularly around inter-city transport nodes are best placed to realise the benefits from increased concentration in Central Business Districts (Mohino et al., 2014).

Limits to the benefits from increased concentration suggest that movements of labour and capital between zones is likely to be more limited than in the model outlined in this chapter which future research could investigate. These could include the introduction of land prices and competition for labour and allowing firms to operate from more than one location. In addition, a stochastic choice model could be introduced to calibrate or slow down movements between locations.

6.5 Conclusion

In this chapter the impact of extending the dynamic model to allow mobility of labour and capital between zones was tested. The results showed that introducing zonal mobility is important as it leads to a different final endpoint. With zero mobility costs a new steady state is reached in which each city is fully concentrated in the core zone only in the business service sector in which it has a comparative advantage. Whilst the introduction of zonal mobility led to increased productivity the speed of transition to the new steady state was found to take longer. With zero mobility costs the transition takes over 100 years compared to 44 years without zonal mobility. The slower transition is due to the slow speed of migration away from the peripheral zone in the sector with the comparative advantage. This occurs because workers can achieve the highest return by moving to the sector with the comparative advantage in the core zone of both cities and as workers migrate there this has a positive localisation impact on the peripheral zone in the same sector. This limits the scale of the wage differential between the periphery and core zone in the comparative advantage sectors and therefore only a few workers move away from core zone each time step which increases the length of the transition to the new steady state.

Introducing zonal mobility into the model was also tested in the more realistic case of mobility costs of moving sector and zone and a maximum specialisation endpoint. When mobility costs are included the transport scheme is needed to generate changes in land-use and it was found zonal mobility had no impact on the minimum level of business user benefits required for changes in land-use to occur. It was found that zonal mobility unlocks more benefits than in the case with no zonal mobility with both higher localisation and urbanisation benefits due to the increased density of activity in the core zones of each city.

The modelling results also suggest that the relative cost for labour and capital of moving within rather than between cities will also impact on the final endpoint. With equal zonal mobility costs within and between cities a final endpoint is reached in which there is a higher concentration of the sector with the comparative advantage in the core zone. However, the number of workers in the same sector in the peripheral zone does not change as the wage differential is not high enough to induce workers to leave. With lower mobility costs for zonal movements within cities a new steady state is reached with maximum concentration in the core zone as there is a lower barrier for movements of labour and capital from the periphery to the core.

The impact of zonal mobility was found to generate higher benefits from both localisation and urbanisation effects. In reality, however, the full realisation of the benefits due to increased concentration in the core of cities is unlikely. Factors such as increased competition for land and labour skills and other inputs are likely to restrict the gains to capital and labour of moving to the core. In addition, workers and capital owners may have preferences for working and living in particular locations.

7 Static Modelling: Abstract Scenarios

7.1 Introduction

In the preceding three chapters a dynamic approach was used to model the impact of inter-city rail improvements on land-use in two business service sectors. In this chapter analysis is undertaken using a static approach which is the standard method for estimating agglomeration benefits in an economic appraisal. In this approach agglomeration benefits are typically estimated with fixed land-use and for urbanisation effects only. In this chapter this method is extended to include localisation benefits and changes in land-use deriving from inter-city connectivity improvements.

The main aim of this chapter is to determine the relevance of localisation economies to the economic appraisal of inter-city transport schemes. The analysis is undertaken using an abstract model of two cities to estimate the scale of localisation and urbanisation benefits resulting from a 10% reduction in in-vehicle times on highway and public transport links between the cities. The urbanisation and localisation parameters by sector and assumptions on the scale of land-use changes are based on the empirical evidence which was reviewed in Chapter 2. The objectives of this chapter are to determine:

- The relative benefits from localisation and urbanisation effects with fixed and variable land-use;
- The conditions under which localisation benefits are likely to be more or less important; and,
- If the impact of the inclusion of localisation benefits and land-use changes due to changes in specialisation are likely to be great enough to significantly affect the total Present Value of Benefits (PVB) of an inter-city connectivity scheme.

The remainder of this chapter is organised as follows. In Section 7.2 the structure of the model is outlined including the base economic data and in Section 7.3 the method used for the fixed and variable land-use scenarios is presented. In Section 7.4 the parameters for the analysis are sourced from the review of the empirical evidence in Chapter 2. This includes the parameters for localisation and urbanisation economies and land-use change due to inter-city transport improvements and in this section the fixed and variable land-use scenarios are also defined. The results and discussion are provided in Section 7.5 and a comparison to the dynamic modelling results is presented in Section 7.6. Finally, the conclusion is presented in Section 7.7.

7.2 Model Structure

The localisation and urbanisation benefits are estimated using an abstract model of two cities and the structure of the model is shown in Figure 7.1. Each of the two cities (A and B) is divided into five zones with a core zone and four peripheral zones. The cities are linked by highway and railway infrastructure and the economic benefits are estimated for a reduction in in-vehicle journey times of 10 per cent.

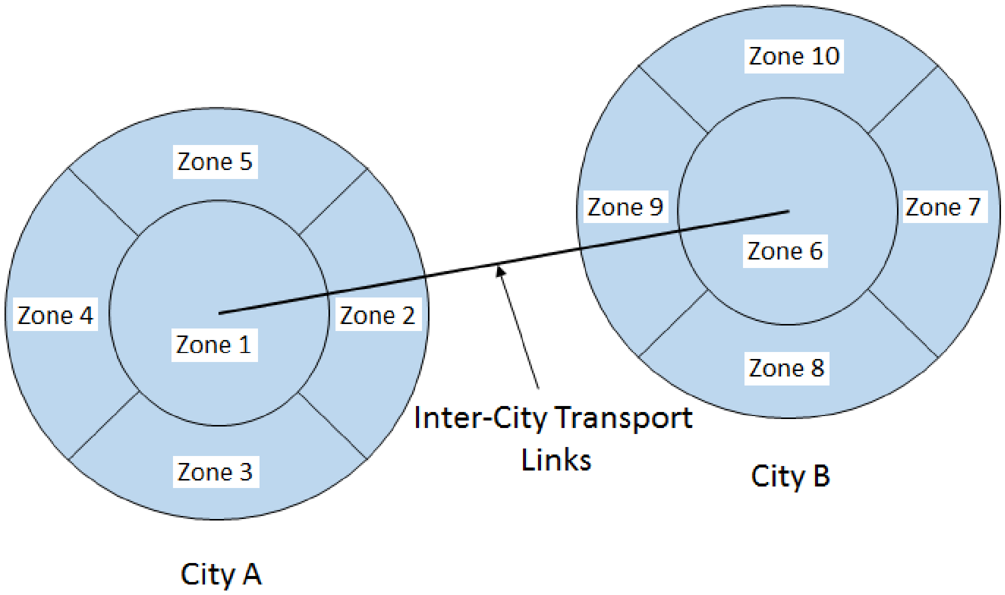

Figure 7.1 Structure of Two-City Model

In the modelling the distance between the two cities is varied to test whether the impacts differ if the city pairs are closer together or further apart. The distances between the centre of the cities tested are 20km, 150km and 400km. The in-vehicle journey times for each of these distances for rail trips are based on an average speed of 120km per hour. It is assumed that passengers arrive 10 minutes before their departure and there are 5 minutes each for access and egress. The journey time from the city centre station to the origin or destination in the core zone is assumed to be 7.5 minutes. There is a 15 minute journey time between the core and peripheral zones of each city and 25 minutes between the peripheral zones on opposite sides of the city. Intra-zonal journey times are assumed to be 10 minutes. For simplicity the journey times are assumed to be the same for highway trips. The generalised journey times between all of the zones with a distance of 400km are shown in Table 7.1. The GJTs for the 20km and 150km distances between the cities are presented in Tables A.5 and A.6 respectively in Section A.2 of Appendix A.

Table 7.1 Baseline Journey Times (minutes) for 400km distance between cities

Zone	1	2	3	4	5	6	7	8	9	10
1	10	15	15	15	15	235	243	243	243	243
2	15	10	15	25	15	243	250	250	250	250
3	15	15	10	15	25	243	250	250	250	250
4	15	25	15	10	15	243	250	250	250	250
5	15	15	25	15	10	243	250	250	250	250
6	235	243	243	243	243	10	15	15	15	15
7	243	250	250	250	250	15	10	15	25	15
8	243	250	250	250	250	15	15	10	15	25
9	243	250	250	250	250	15	25	15	10	15
10	243	250	250	250	250	15	15	25	15	10

In the analysis the economy is divided into 16 sector groups which are defined in Table 7.2. They are based on six broad sector groups of heavy manufacturing (HM), urban manufacturing (UM), construction (CN), producer services (PS), consumer services (CS) and other[54]. The manufacturing sector is split into two separate groups based on the review of the empirical evidence in Section 2.4.1 which suggested that some industries such as printing and publishing and the manufacture of office machinery and equipment are likely to have urbanisation and localisation elasticities which are more similar to those of service sectors than heavy manufacturing industries. These sectors were split out from heavy manufacturing in the modelling so the appropriate elasticities could be applied and are referred to as urban manufacturing in this chapter.

The six broad sector groups were split between sectors which could realise land-use changes due to inter-city journey time improvements and others which were less likely

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[54] The ‘other’ sector is made up of employment which could not be assigned to any of the other sectors. It includes public administration, primary industries, health, education and social services.

to. The latter are referred to as non-tradable (NT) sectors and represent those which predominantly serve local markets such as health, education, social services, and consumer services such as retail and accommodation. The proportion of employment in the tradable sectors was assumed to vary between the cities due to differences in Ricardian comparative advantage. The jobs in each sector were split between the cities so City A was assumed to be specialised in some tradable sectors (T-A) and City B in other tradable sectors (T-B).

Table 7.2 Modelled Sectors

Sector	Description
HM (T-A)	Heavy Manufacturing (Tradable and City A specialism)
HM (T-B)	Heavy Manufacturing (Tradable and City B specialism)
HM (NT)	Heavy Manufacturing (Non-Tradable and not specialism of City A or B)
UM (T-A)	Urban Manufacturing (Tradable and City A specialism)
UM (T-B)	Urban Manufacturing (Tradable and City B specialism)
CN (T-A)	Construction (Tradable and City A specialism)
CN (T-B)	Construction (Tradable and City B specialism)
PS (T-A)	Producer Services (Tradable and City A specialism)
PS (T-B)	Producer Services (Tradable and City B specialism)
PS (NT)	Producer Services (Non-Tradable and not specialism of City A or B)
CS (T-A)	Consumer Services (Tradable and City A specialism)
CS (T-B)	Consumer Services (Tradable and City B specialism)
CS (NT)	Consumer Services (Non-Tradable and not specialism of City A or B)
Other (T-A)	Other Sectors (Tradable and City A specialism)
Other (T-B)	Other Sectors (Tradable and City B specialism)
Other (NT)	Other Sectors (Non-Tradable and not specialism of City A or B)

The two cities were assumed to be of equal size with 900,000 jobs in each city and the initial proportion of jobs by sector and zone are shown in Table 7.3. The employment splits by sector were informed from UK employment data for the north of England (DfT, 2018d) to give realistic values. The proportion of jobs in each city in the six broad sectoral groups was 10% in heavy manufacturing, 2% in urban manufacturing, 7% in construction, 20% in producer services, 24% in consumer services and 37% in other. The number of jobs in the tradable sectors was split so that 52% is in the city which has the comparative advantage in the sector and 48% in the other city. The baseline GDP per worker by sector and zone was assumed to be similar to values for the north of England in 2021 (DfT, 2018d) and are shown in Table A.3 in Section A.3 of Appendix A.

Table 7.3 Percentage of Jobs by sector in each zone: Baseline Scenario

	City A Zones					City B Zones				
Sector	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.3	5.8	7.6	6.4	7.4	3.1	5.3	7.0	5.9	6.8
HM (T-B)	3.1	5.3	7.0	5.9	6.8	3.3	5.8	7.6	6.4	7.4
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.0	1.4	1.2	0.9	1.2	1.0	1.3	1.2
UM (T-B)	0.9	1.2	1.0	1.3	1.2	1.0	1.3	1.0	1.4	1.2
CN (T-A)	3.6	3.6	4.3	3.3	5.1	3.3	3.3	4.0	3.0	4.7
CN (T-B)	3.3	3.3	4.0	3.0	4.7	3.6	3.6	4.3	3.3	5.1
PS (T-A)	10.1	3.9	4.2	6.2	3.9	9.3	3.6	3.9	5.7	3.6
PS (T-B)	9.3	3.6	3.9	5.7	3.6	10.1	3.9	4.2	6.2	3.9
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.3	0.8	0.4	0.4	0.2	0.2
CS (T-B)	0.8	0.4	0.4	0.2	0.2	0.9	0.5	0.4	0.2	0.3
CS (NT)	19.6	28.4	26.5	20.0	24.5	19.6	28.4	26.5	20.0	24.5
Other (T-A)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Other (NT)	37.4	36.7	36.4	31.9	38.2	37.4	36.7	36.4	31.9	38.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. of Jobs (k)	429.3	147.3	151.2	95.3	77.0	429.3	147.3	151.2	95.3	77.0

7.3 Method for Estimating Urbanisation and Localisation Effects

The urbanisation and localisation effects in this chapter are modelled based on the method outlined in Chapter 3. In this approach the scale of the impacts are assessed by measuring the change in effective density which is used as a proxy for access to economic mass. In this chapter a number of scenarios are undertaken with fixed and variable land-use. The method used for each are outlined in Sections 7.3.1 and 7.3.2 respectively.

7.3.1 Fixed Land-use Scenarios

With fixed land-use there are no changes in employment and urbanisation and localisation benefits are realised only from changes in generalised journey times. The method for estimating these benefits was outlined in Section 3.2 of Chapter 3.

7.3.2 Variable Land-use Scenarios

With variable land-use urbanisation and localisation effects can be realised both from changes in generalised journey times and the associated changes in land-use. Based on the model structure and the theories and evidence for land-use changes due to transport discussed in Section 2.4.2 in Chapter 2, two types of land-use have been selected for implementation in the scenarios in this chapter. Firstly, there may be changes in sectoral composition in a location based on the theory of comparative advantage (Ricardo, 1817). With this type of land-use change the total employment in a location remains fixed but jobs can be reallocated between sectors. Secondly, there is evidence from the literature that differences in the relative changes in accessibility can lead to transfers of jobs between locations (Chandra and Thompson 2000, Duranton and Turner, 2012, Qin, 2017, Dong, 2018). With this type of land-use change it can be expected that sectors which are most likely to benefit from the change in journey times will become more concentrated around the transport nodes with the greatest increases in accessibility.

The empirical literature discussed in Section 2.4.2 in Chapter 2 also highlighted that other types of land-use change may result from changes in inter-city connectivity. Firstly, there may be a transfer of jobs between rural and urban areas in response to the different changes in accessibility those locations. Secondly, there may also be transfers of jobs between urban areas which are more or less affected by a transport scheme. However, with the two-city model structure used in this chapter both of these effects are outside the scope of the analysis and are not modelled.

In the following two sections the method used to estimate the effects of the land-use changes are presented. The method for changes in sectoral composition are outlined in section 7.3.2.1 and for changes in sectoral concentration are outlined in Section 7.3.2.2. Scenarios are undertaken with either one or both of these types of land-use change and the scenario tests with variable land-use are defined in Section 7.4.2.

7.3.2.1 Changes in Sectoral Composition

For this type of land-use change it is assumed that the improved inter-city links will increase market access to firms and allow each city to become more specialised in the sectors in which it is initially more specialised. These changes involve jobs within each one switching between sectors but the number of jobs in each zone remains fixed. The cities are the same size which means the number of jobs in each sector across the study area remains constant. Figure 7.2 shows a diagrammatic representation of the employment changes in the study area.

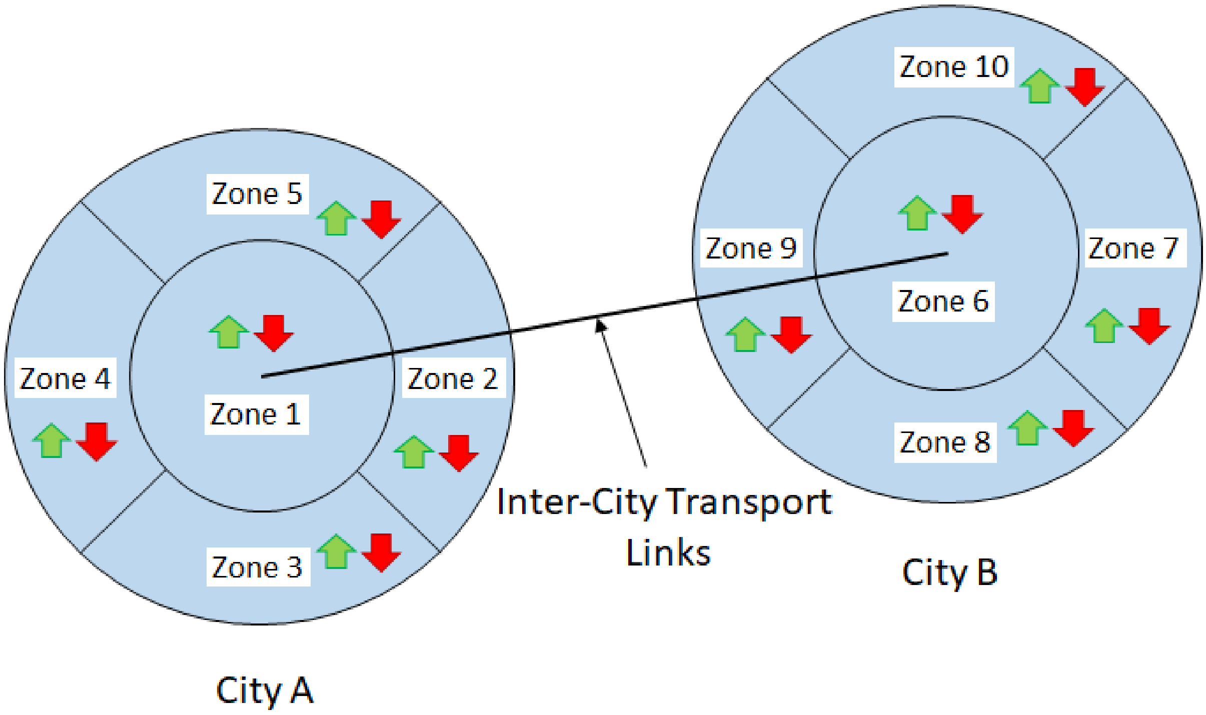

Figure 7.2 Diagram of Changes in Sectoral Composition

The employment changes are applied by first estimating the impact of the inter-city transport scheme on the number of jobs in the sectors with the comparative advantage in each zone. The changes in employment are estimated by applying an elasticity for land-use change with respect to change in GJT in those sectors. The formula for the estimated change in employment in zone i in the sector with the comparative advantage, $\Delta Employment_i^{nCA}$, is:

$$\Delta Employment_i^{nCA} = \left(\frac{GJT_{ij}^{DS}}{GJT_{ij}^{DM}}\right)^{-\eta} \tag{7.1}$$

where GJT_{ij}^{DM} is the generalised journey time without the scheme, GJT_{ij}^{DS} is the generalised journey time with the scheme and η is the elasticity for employment with respect to changes in generalised journey times.

There is no available data on demand for trips between the cities to use to estimate a weighted GJT for each zone and sector. The employment split between the core and all peripheral zones combined is approximately 50% in each. It was assumed that for core zones the proportional change in GJT for inter-city trips was the mean for trips between the two core zones and between the core zone and peripheral zones. For peripheral zones the proportional change in GJT was based on the average for trips between peripheral zones in different cities and between the core and periphery. The effect of doing this was that the proportional changes in GJTs are slightly greater in the core zones than in the peripheral zones.

In the scenario testing the distance between the two cities is varied to determine its impact on the scale of the benefits. The benefits are estimated over three distances: 20km, 150km and 400km. In some of the variable land-use scenarios it is assumed that the scale of the land-use changes declines with the distance between cities. This is based on the evidence for declining level of trade between locations (Disdier and Head, 2008, Overman et al., 2003, Guillemette, 2009, and Leamer and Levinsohn, 1995) which is discussed in detail in Section 7.4.2.

This is taken into account in some of the scenarios by assuming that the 20km distance between the centres of the cities represents the cities being adjacent. It is assumed that there is no decline in the scale of trade impacts for the 20km distance but for longer distances between cities the land-use changes are smaller. This is implemented by adjusting equation (7.1) for the estimation of the change in employment in the zone i in the sector with the comparative advantage, $\Delta Employment_{i}^{nCA,Dist}$, for the specified distance between the cities *Dist* to become:

$$\Delta Employment_{i}^{CA,Dist} = \left(\frac{GJT_{ij}^{DS}}{GJT_{ij}^{DM}}\right)^{-\eta} \times \left(\frac{20}{Dist}\right)^{\varphi} \tag{7.2}$$

where φ is the elasticity for the decline in trade over distance which is sourced from the literature.

It is assumed that the study area is a closed economy and that total employment remains constant. This implies that any increase in jobs in sectors within a zone need to be balanced by reductions in other sectors in the same zone. In the sectoral employment data outlined in Section 7.2 the number of jobs in each sectoral group was divided between tradable sectors which the zone did or did not have a comparative advantage and non-tradable sectors in which it was assumed that there were likely to be limited potential for trade impacts due to changes in inter-city connectivity. It is assumed that the reductions in jobs would be applied only in sectors in which the zone did not have a comparative advantage only and not in the non-tradable sectors.

This was implemented by reducing employment in sectors without the comparative advantage in each zone in proportion to their original number of jobs. For a distance *Dist* between the cities the change in employment in zone *i* in a sector without the comparative advantage *NCA*, $\Delta Emp_i^{NCA,Dist}$, is estimated using the following formula:

$$\Delta Emp_i^{NCA,Dist} = -\sum_{CA} \Delta Emp_i^{CA,Dist} \times \left(\frac{Emp_i^{NCA}}{\sum_{NCA} Emp_i^{NCA}} \right) \tag{7.3}$$

where $\sum_{CA} \Delta Emp_i^{CA,Dist}$ is the sum of increases in employment across all comparative advantage sectors *CA* in zone *i*, Emp_i^{NCA} is employment in each non-comparative advantage sector *NCA* in zone *i* and $\sum_{NCA} Emp_i^{NCA}$ is the sum of all employment in non-comparative advantage sectors *NCA* in zone *i*.

7.3.2.2 Changes in Sectoral Concentration

For this type of land-use change it is assumed that employment would be attracted towards the locations with the highest increases in accessibility. In the setup of the model initial generalised journey times are shorter between the core zones of each city. This means that the relative reduction in journey times due to the inter-city transport improvement are higher in those zones than the peripheral zones. Core zones of cities are typically focussed on producer and consumer services rather than manufacturing it was assumed that jobs would increase in those sectors only. A diagrammatic representation of the land-use changes are shown in Figure 7.3.

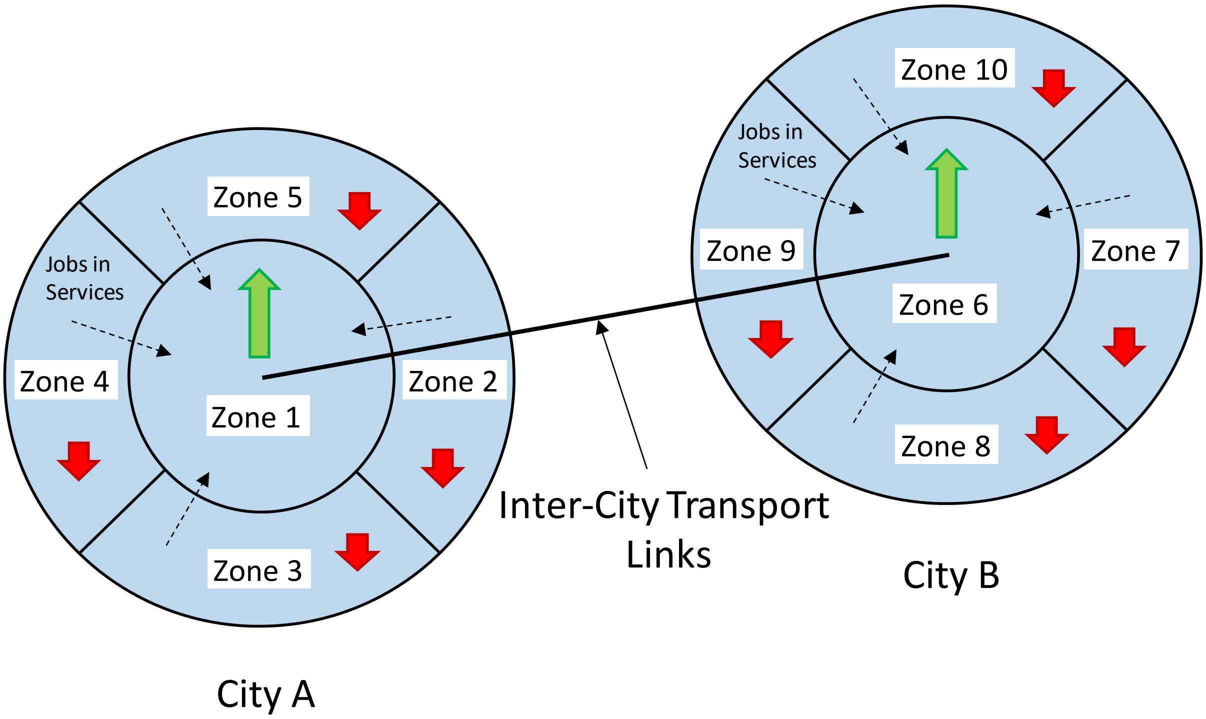

Figure 7.3 Changes in Sectoral Concentration of Producer and Consumer Services

The increase in concentration of producer and consumer services was undertaken using a similar formula as outlined for changes in sectoral composition in equation (7.5) above. The change in employment in each tradable service sector *TSS* in zone *i*, $\Delta Employment_{i}^{TSS,Dist}$, are given by:

$$\Delta Employment_{Core\ i}^{TSS} = \left(\frac{GJT_{ij}^{DS}}{GJT_{ij}^{DM}}\right)^{-\gamma} \tag{7.4}$$

where γ is an elasticity for increase in concentration with respect to changes in generalised journey times. Some scenarios are also undertaken taking into account that trade impacts decline with distance. In these scenarios the change in employment in each tradable service sector are similar to equation (7.6) for sectoral composition changes. The change in employment in tradable service sectors in the core zone *i* for distance between cities *Dist*, $\Delta Employment_{Core\ i}^{TSS,Dist}$, is given by:

$$\Delta Employment_{Core\ i}^{TSS,Dist} = \left(\frac{GJT_{ij}^{DS}}{GJT_{ij}^{DM}}\right)^{-\gamma} \times \left(\frac{20}{Dist}\right)^{\varphi} \tag{7.5}$$

To take account of these changes adjustments are required to ensure the total number of jobs in the study area remains constant. It was assumed that the increases in the core zones would be balanced by reductions in the four peripheral zones within the same city. The changes in employment in tradable service sectors in peripheral zone *i* in City *z*, $\Delta Emp_{Periphery\ i,City\ x}^{TSS,Dist}$, are given by:

$$\Delta Emp^{TSS,Dist}_{Periphery\ i,z} = -\sum\nolimits_{Core\ i,z} \Delta Emp^{TSS,Dist}_{Core\ i,z} \times \left(\frac{Emp^{TSS}_{Periphery\ i,z}}{\sum_z Emp^{TSS}_{Periphery\ i,z}}\right) \tag{7.6}$$

where $\sum_{Core\ i,z} \Delta Emp^{TSS,Dist}_{Core\ i,z}$ is the sum of the change in employment in tradable service sectors in the core zone *i* in City *z*, $Emp^{TSS}_{Periphery\ i,z}$ is employment in tradable sectors in the periphery zone *i* in City *z* and $\sum_z Emp^{TSS}_{Periphery\ i,z}$ is the total employment in tradable service sectors in peripheral zones *i* in City *z*.

7.4 Implications of Evidence for Modelling

There is now a need to source the values to use for the parameters in the equations outlined above and to define the scenarios. In the following sections a range of values are selected based on the empirical evidence discussed in Chapter 2. The elasticities and distance decay factors for urbanisation and localisation effects are discussed first in Section 7.4.1 followed by a consideration of the evidence on the degree of land-use change due to an inter-city transport improvement in Section 7.4.2. The fixed land-use scenarios are defined at the end of Section 7.4.1 and the variable land-use scenarios at the end of Section 7.4.2.

7.4.1 Evidence on Localisation and Urbanisation Economies

For the analysis values are required for elasticities and distance decay factors by sector for urbanisation and localisation effects. The empirical literature on these parameters was reviewed in Section 2.4.1 of Chapter 2. This showed that there have been only five studies (Nakamura, 1985, Henderson, 1986, Moomaw, 1988, Brülhart & Mathys, 2008 and Graham, 2009) in which localisation and urbanisation elasticities by sector have been estimated simultaneously to avoid any bias in the estimates and there is uncertainty around their precise value by sector. For the purpose of the analysis conservative elasticity ranges were selected from this evidence. Conservative ranges were used to reflect both that the estimated elasticities are lower in the more recent studies and that significant positive elasticities have not been estimated in all sectors. The selected ranges for the elasticities by sector are shown in Table 7.4.

The evidence from the studies suggests that heavy manufacturing industries are likely to benefit more from localisation effects than urbanisation. There are some manufacturing industries such as printing and publishing and the manufacture of office machinery and computers for which the evidence suggests that firms are likely to benefit most from access to customers and therefore they are likely to gain more from urbanisation effects than localisation. For these sectors it was assumed that the elasticity range is similar to those for service sectors.

Table 7.4 Urbanisation and Localisation Elasticity Ranges by Sector

	Elasticity Range	
Sector	Urbanisation	Localisation
Heavy Manufacturing	0.00 to 0.04	0.04 to 0.10
Service Sectors (excl. Business Services), Urban Manufacturing† & Construction	0.04 to 0.12	0.00 to 0.04
Business Services	0.04 to 0.20	0.04 to 0.12

† Urban Manufacturing is sectors which are focussed on serving urban areas such as printing & publishing and the manufacture of office equipment.

The evidence for service sectors and construction suggests that they are more likely to benefit from urbanisation effects than localisation. An exception to this are business service sectors for which there is evidence that localisation effects are strong and urbanisation effects are even greater. For public services the studies which have estimated elasticities use private sector wage data so there is limited evidence on the scale of elasticities in these sectors. Access to customers can be expected to be particularly important for these sectors and they are therefore likely to benefit more from urbanisation effects than localisation and similar elasticity ranges are specified to those for other service sectors.

Four fixed land-use scenarios (S1 to S4) were defined to estimate the urbanisation and localisation benefits under different situations and the assumptions used in each of these scenarios are shown in Table 7.5. The first three of the scenarios were based on varying the localisation parameters to take account of the range of values suggested by the empirical evidence. These three scenarios were based on low (S1), medium (S2) and high (S3) impact assumptions for localisation effects using values chosen from the ranges shown in Table 7.4. The urbanisation assumptions were held constant in each of these scenarios and are similar to the values suggested in the UK's appraisal guidelines (DfT, 2018c) in order to focus on the effects of varying the localisation assumptions. In Scenario S4 the proportion of initial manufacturing employment in both cities was doubled to test the impact of inter-city connectivity improvements on regions with a higher proportion of employment in manufacturing. In this scenario the employment in the other sectors was reduced in proportion so that total employment in each city remained constant and the localisation parameters used are the same as in Scenario S2. All four scenarios are undertaken for the three distances between the cities of 20km, 150km and 400km to test how this affects the scale of the benefits.

Table 7.5 Definitions of Fixed Land-Use Scenario Tests

	Scenario Test			
Variable	S1	S2	S3	S4
Localisation Parameters	Low	Medium	High	Medium
% Manufacturing employment	12%	12%	12%	24%
% Other Sectors employment	88%	88%	88%	76%
Initial Specialisation Level	52:48	52:48	52:48	52:48
Heavy Manufacturing Urb Elasticity	0.02	0.02	0.02	0.02
Heavy Manufacturing Loc Elasticity	0.04	0.07	0.10	0.07
Producer Services Urb Elasticity	0.12	0.12	0.12	0.12
Producer Services Loc Elasticity	0.02	0.05	0.08	0.05
CS, CN & Other Urb Elasticity†	0.04	0.04	0.04	0.04
CS, CN & Other Loc Elasticity†	0.01	0.02	0.03	0.02
Heavy Manufacturing Urb DDF†	1.0	1.0	1.0	1.0
Heavy Manufacturing Loc DDF†	1.8	1.5	1.2	1.5
Producer Services Urb DDF	1.7	1.7	1.7	1.7
Producer Services Loc DDF	2.0	1.9	1.8	1.9
CS, CN & Other Urb DDF	1.7	1.7	1.7	1.7
CS, CN & Other Loc DDF	2.0	1.9	1.8	1.9

CS = Consumer Services, CN = Construction. † Urban Manufacturing is assumed to have the same elasticities as Consumer Services, Construction & Other and the same distance decay factors as Heavy Manufacturing.

The distance decay factors used for urbanisation effects in each of the scenarios are based on similar values to those recommended in WebTAG (DfT, 2018c) with a distance decay factor of 1.7 for services and 1.0 for manufacturing. There is little evidence for the values for decay factors for localisation effects by sector but Graham (2009) estimated that localisation effects decay more quickly than urbanisation. This is reflected in the values selected for the medium localisation impacts scenario (S2) and the values were varied in the relevant direction for the low (S1) and high (S3) impact scenarios. In addition to these four scenarios several sensitivity tests were undertaken in which the elasticities, distance decay factors and other assumptions were varied and these are outlined in Section A.1.1 in Appendix A.

7.4.2 Ex-Post Evidence on the Impact of Inter-city Connectivity on Land-Use Change

As outlined in Section 7.3.2 there are two types of land-use change implemented in this chapter. Firstly, it is assumed that the inter-city journey time improvements will lead to changes in sectoral composition in which jobs switch between sectors within zones. Secondly, it is assumed that the journey time improvements will lead to changes in sectoral concentration in which service sector jobs move towards the core zones where the accessibility improvements are greatest. To assess these changes parameters are required to represent the land-use changes by sector.

The evidence on changes in land-use with respect to inter-city connectivity was reviewed in Section 2.4.2 of Chapter 2. This showed that the evidence is mixed and there are no studies which have estimated changes in sectoral composition by individual sector due to inter-city transport schemes. The studies which have been undertaken have estimated different aspects of the impact of transport on land-use such as changes in employment or firms births and different measures such as changes in accessibility or effects by different distance bands. In one of the most in-depth studies using UK data Gibbons et al. (2019) estimated an elasticity of increases in employment with respect to changes in accessibility of 0.5. Lower estimates have been found for urban transport in the US of 0.03 to 0.05 (Ozbay et al., 2006, and Berechman and Paaswell, 2001) and large estimates have been found in developing countries (Ghani et al., 2016). In the modelling the extent of the potential benefits from increased specialisation based on comparative advantage are tested using elasticities of -0.3 and -0.5 for land-use changes with respect to changes in GJT.

The evidence suggests that accessibility improvements at public transport nodes and highways can lead to increased concentration of jobs and firms around them (Gibbons et al., 2019, Holl, 2004, Mayer and Trevien, 2012, Niu et al., 2015, Ghani et al. 2016, Shen et al., 2014). Movements of jobs between zones are applied in the modelling by assuming that the inter-connectivity GJT reductions will lead to producer and consumer services employment becoming more concentrated in the locations in which the GJTs reductions are greatest. The potential extent of these effects are tested through applying elasticities of -0.3 and -0.5 for land-use change with respect to changes in GJT based on the estimates using UK data by Gibbons et al. (2019).

The evidence suggests that the majority of employment changes will be due to redistribution and the impact on overall employment from an inter-city scheme is likely to be limited and in most cases zero. This is reflected in the analysis through assuming that there is no change in the overall number of workers and all land-use changes are due to displacement within each city. The potential migration of workers into the study area to benefit from the increases in accessibility are also not considered.

There is strong evidence from the empirical literature that the level of bilateral trade between locations diminishes with distance due to higher transport costs (Bleaney and Neaves, 2013). The estimates of elasticities of bilateral trade with respect to distance are relatively consistent. Disdier and Head (2008) undertook a meta-analysis of 1467 estimates from 103 studies which gave a range of -0.28 to -1.55 with a mean of -0.9 which is similar to others who have summarised the evidence of the literature (Overman et al., 2003, Guillemette, 2009, and Leamer and Levinsohn, 1995). In one of the few studies which has produced estimates by sector Berthelon and Freund (2004) estimated a range of elasticities from -0.93 for Other Goods and -0.96 for Animals to -1.55 for Mineral Fuels with a mean of -1.21. Examining the impact of the US Inter-State Highways Duranton et al. (2014) found similar estimated changes with a 1% reduction in distance between 66 US cities found to lead to an increase in trade by value of 1.4% and in trade by weight of 1.9%.

This evidence suggests that the level of trade and therefore changes in land-use due to inter-city transport improvements can be expected to be lower for city pairs which are further apart. This is taken into account by assuming that in some scenarios the land-use changes decline with distance between city pairs. For the 20km distance between cities it is assumed that the two cities are close enough so that firms would be as likely to trade with firms in the other city as within their own and no decline over distance is specified. For the 150km and 400km distances the changes are estimated through first estimating the land-use changes due to the change in GJT and then applying an elasticity to take into account how the effects decline with distance.

Six variable land-use scenarios (D1 to D6) were undertaken which are defined in Table 7.6. To compare the impact of the two types of land-use change in D1 only the impact of changes in sectoral composition within zones was tested and in D2 only the impact of increased concentration of service sector employment in the core zones was tested. In both of these scenarios an elasticity of land-use change with respect to GJT of -0.5 was used and no elasticity for the decline in trade with distance elasticity so that the full potential extent of the benefits could be estimated.

Table 7.6 Definition of Variable Land-Use Scenarios

	Scenario Test					
Variable	D1	D2	D3	D4	D5	D6
Localisation Parameters	Med	Med	Low	Med	High	Med
% Manufacturing employment	12%	12%	12%	12%	12%	24%
% Other Sectors employment	88%	88%	88%	88%	88%	76%
Change in Sectoral Composition Elasticity	-0.5	0	-0.3	-0.5	-0.5	-0.5
Change in Concentration of Service Sectors in Core Zones Elasticity	0	-0.5	-0.3	-0.5	-0.5	-0.5
Elasticity of Trade w.r.t Distance	0	0	-1.2	-0.9	-0.5	-0.9

In Scenarios D4, D5 and D6 low, medium and high impact scenarios were defined respectively. These scenarios use the same localisation parameters as in the low, medium and high impact scenarios (S1 to S3) with fixed land-use with additional assumptions made on the degree of land-use change. In the medium assumptions test a land-use to GJT elasticity of -0.5 is used for both types of land-use change and an elasticity of trade impacts to distance of -0.9 based on the mean estimate from Disdier and Head’s meta-study (2008). For the low assumptions test the lowest elasticity for land-use changes with respect to GJT of -0.3 was used for both types of land-use change and the highest elasticity for the decline in trade impacts of -1.2. In the high impact assumptions test the same land-use to GJT elasticity is used as in the medium assumptions test but a lower elasticity for the decline of trade impact over distance of -0.5 is used. Scenario D6 is the same as Scenario D4 but with double the proportion of employment in manufacturing.

As with the fixed land-use scenarios the benefits are estimated for 20km, 150km and 400km distances between the two cities. There were also a number of sensitivity tests undertaken and the assumptions and results of these are outlined in Section A.1.2 in Appendix A.

The calculation of the land-use changes in each scenario with variable land-use is undertaken using the method outlined in Section 7.3.2. The change in GJT over each distance for trips between zonal pairs for the three types of trip in the 10-zone model which include an inter-city leg is shown in Table 7.7. In this table the percentage change in GJT is not consistent over each of the three distances between the cities. This is because the proportion of total GJT which is access, egress and waiting time is lower for the longer distances between the cities which means that the proportional reductions in GJT are greater than for the shorter distances.

Table 7.7 Changes in GJT by Inter-city Zonal Movement

Inter-City Zonal Movement	DM IVT (mins)	DM GJT (mins)	Change in IVT (mins)	Change in IVT (%)	Change in GJT (%)
Distance between cities: 20km					
Core to Core	10	45	-1.0	-10.0%	-2.2%
Core to Periphery	10	53	-1.0	-10.0%	-1.9%
Periphery to Periphery	10	60	-1.0	-10.0%	-1.7%
Distance between cities: 150km					
Core to Core	75	110	-7.5	-10.0%	-6.8%
Core to Periphery	75	118	-7.5	-10.0%	-6.4%
Periphery to Periphery	75	125	-7.5	-10.0%	-6.0%
Distance between cities: 400km					
Core to Core	200	235	-20.0	-10.0%	-8.5%
Core to Periphery	200	243	-20.0	-10.0%	-8.2%
Periphery to Periphery	200	250	-20.0	-10.0%	-8.0%

The proportional changes in average generalised journey times for the core and peripheral zones in the study area are shown in Table 7.8. As outlined in Section 7.3.2.1 these were estimated by taking an average of the relevant inter-city zonal movements for each of the two zone types. For core zones this is the average for the core to core and core to periphery movements and for periphery zones the average is estimated for the core to periphery and periphery to periphery movements. Table 7.8 shows that the proportional changes in GJT are slightly higher for core zones because the inter-city IVT (in-vehicle time) for trips between core zones is a greater proportion of total GJT than for trips between periphery zones.

Table 7.8 Estimated Average Change in Generalised Journey Times for Inter-City Trips by Zone

Zone Type	Average Change in GJT (%)
Distance between cities: 20km	
Core	-2.1%
Periphery	-1.8%
Distance between cities: 150km	
Core	-6.6%
Periphery	-6.2%
Distance between cities: 400km	
Core	-8.4%
Periphery	-8.1%

The estimated changes in land-use in the core zones by scenario are shown in Table 7.9. These values are used to represent the increase in employment for both of types of land-use change modelled in the analysis. Firstly, they are used to represent the increase in the number of jobs in zones in tradable sectors for which the city has a comparative advantage. These jobs are transferred from the tradable sectors for which the city does not have a comparative advantage. Secondly, they are used to represent the increase in concentration of producer and consumer services jobs in the core zone of each city which are transferred from the peripheral zones. Neither of the two types of land-use change impact on the total number of jobs in each city which remain constant.

As discussed in the methodology section for the 20km distance between the cities it is assumed that there is no decline in trade impacts due to distance as the cities. The land-use changes for the 20km distance are therefore calculated using only the land-use change with respect to change in GJT elasticity. For example, in the first row of Table 7.9 the -0.3 elasticity for land-use changes is applied to the 2.1% reduction in GJT (from Table 7.5) to calculate the change in land-use which is given by ((97.9/100)^-0.3)-1) = 0.63%.

Table 7.9 Estimated % Increase in Employment in Core Zones for Changes in Sectoral Composition based on Comparative Advantage and for Changes in Sectoral Concentration Scenarios for Tradable Service Sectors

		Distance between Cities			
Land-Use w.r.t GJT Elasticity	Trade w.r.t Distance Elasticity	20km	150km	400km	Scenario Test
-0.5	0	1.05%	3.47%	4.47%	D1 & D2
-0.5	-0.5	1.05%	1.27%	1.00%	D5
-0.5	-0.9	1.05%	0.57%	0.30%	D4 & D6
-0.3	-1.2	0.63%	0.18%	0.07%	D3

For the 150km and 400km distances between the cities in scenarios D3 to D6 it is assumed that there is a decline in the level of land-use changes with distance. The changes in land-use change for these two distances are calculated in two steps. Firstly, the land-use change with respect to the change in GJT with no decline over distance is estimated. For example, in the third row of Table 7.9 the change in land-use for the 150km distance between the cities is estimated by applying an elasticity of -0.5 to the -6.6% change in GJT (from Table 7.8) which gives ((93.4/100)^-0.5)-1 = 3.47%. Secondly, the elasticity for trade impacts with respect to distance of -0.9 is applied to this value based on the distance between the cities relative to 20km at which the cities are assumed to be adjacent to each other. This gives an estimated land-use change of 2.00% x (150/20)^-0.9 = 0.57%.

The estimated changes in land-use in the periphery zones were estimated using the same method and are shown in Table 7.10. The estimated changes in land-use are slightly lower than those in the core zones in Table 7.9 due to the lower average change in GJTs in the peripheral zones (as shown in Table 7.8).

Table 7.10 Estimated % Increase in Employment in Periphery Zones in Scenarios for Changes in Sectoral Composition based on Comparative Advantage

		Distance between the Cities			
Land-Use w.r.t GJT Elasticity	Trade w.r.t Distance Elasticity	20km	150km	400km	Scenario Test(s)
-0.5	0.0	0.90%	3.25%	4.33%	D1 & D2
-0.5	-0.5	0.90%	1.19%	0.97%	D5
-0.5	-0.9	0.90%	0.53%	0.29%	D4 & D6
-0.3	-1.2	0.54%	0.17%	0.07%	D3

As outlined in the methodology sections the increases in employment presented in Tables 7.9 and 7.10 are balanced by reductions in elsewhere so the total number of jobs in the study area remains constant. These changes are estimated for the changes in sectoral composition land-use changes using equation (7.3) and for the changes in sectoral composition scenarios using equation (7.6). The land-use inputs for all six of the variable land-use scenarios for all three distances between the cities are presented in Table A.10-A.27 in Appendix A.

The accessibility of each zone to other zones within the same city will not be affected by the inter-city transport improvement. Without detailed data on the origins and destinations of trips between the cities which could be expected to vary by sector it is difficult to know the precise overall change in accessibility for each zone and there may be different scales of impacts for changes in long and short-distance accessibility. The estimated land-use changes in Tables 7.9 and 7.10 therefore represent an upper estimate on the amount of land-use change that could be expected in order to test the potential scale of the benefits.

7.5 Results and Discussion

The results for the four fixed and six variable land-use scenarios are outlined in turn in the following sub-sections.

7.5.1 Fixed Land-Use

The results for the four fixed land-use scenarios (S1 to S4) are presented in Tables 7.11 and 7.12. In Table 7.11 the estimated annual benefits per annum are shown for urbanisation, localisation and the combined total for the three different distances between the two cities of 20km, 150km and 400km. In the lower portion of the table the proportion of total estimated benefits from localisation and urbanisation effects are given for each scenario. In Table 7.12 the estimated benefits for the 400km distance between the cities as a proportion of the estimated benefits for the 20km distance are shown for localisation and total benefits to show how the benefits vary between city pairs close together and far apart.

Table 7.11 Annual Benefits (£mn p.a., 2021 Values & Prices) by distance between cities for fixed land-use scenarios

Distance	20km			150km			400km		
Scenario	Loc	Urb	Total	Loc	Urb	Total	Loc	Urb	Total
S1	5.2	21.9	27.1	4.1	22.2	26.3	1.4	9.7	11.1
S2	11.9	21.9	33.9	11.0	22.2	33.2	4.4	9.7	14.1
S3	19.8	21.9	41.7	21.5	22.2	43.7	10.2	9.7	19.9
S4	14.9	21.1	36.0	15.1	23.1	38.1	6.4	11.0	17.4
% of Benefits									
S1	19%	81%	100%	16%	84%	100%	13%	87%	100%
S2	35%	65%	100%	33%	67%	100%	31%	69%	100%
S3	47%	53%	100%	49%	51%	100%	51%	49%	100%
S4	41%	59%	100%	40%	60%	100%	37%	63%	100%

Table 7.12 Proportion of Benefits for 400km distance between cities relative to the 20km distance for fixed land-use scenarios

Scenario	Loc Benefits 400km/20km	Total Benefits 400km/20km
S1	27%	41%
S2	37%	42%
S3	51%	48%
S4	43%	48%

The results in Table 7.11 for the scenario with the central case assumptions for localisation parameters (S2) show that for the shortest distance between the cities of

20km total benefits are £33.9mn per annum of which localisation benefits are £11.9mn per annum of the benefits and urbanisation benefits are £21.9mn per annum. Localisation benefits decline as the distance between the cities increases due to the decay of the density effects with benefits of £11.0mn per annum for the 150km distance and £4.4mn per annum for the 400km distance.

Due to the decay of benefits with distance urbanisation benefits are also higher for the 20km distance (£21.9mn per annum) than for the 400km distance (£9.7mn per annum) but they are highest overall for the 150km distance at £22.2mn per annum. This is because the distance decay factors used for urbanisation effects are lower than for localisation. This means the fall in benefits for the 150km distance compared to 20km are not as strong as for localisation effects and the decrease is outweighed by the greater proportional increase in the GJTs inputs for the longer distances (as shown in Table 7.7).

The results in Table 7.11 can be used to estimate localisation benefits as a proportion of urbanisation benefits. In S2 for the 20km distance between the cities localisation benefits (£11.9mn per annum) are 54% of urbanisation benefits (£21.9mn per annum). The estimated proportion decreases with distance between the cities with a value of 50% for the 150km distance and 45% for the 400km distance. This is due to the higher distance decay factors assumed for localisation effects compared to urbanisation. These results are reflected in Table 7.12 which shows that localisation benefits for the 400km distance are 37% of those for the 20km distance compared to 42% for total benefits. These results indicate that with fixed land-use localisation benefits are likely to have more impact on economic appraisals of inter-city schemes for short distances between cities than when cities are further apart.

Scenarios S1 and S3 show the impact of applying lower and higher localisation parameter assumptions from the empirical literature respectively. The urbanisation benefits are identical to those for S2 as the urbanisation parameter assumptions are held constant. The results show that the differences in the localisation assumptions have a significant effect on the scale of the benefits. For the 20km distance localisation benefits are more than three times higher in S3 (£14.9mn per annum) than in S2 (£5.2mn per annum). The differences increase with distance and for the 400km distance localisation benefits per annum are £6.4mn per annum in S3 compared to £1.4mn per annum in S1. These differences also impact on the relative benefits from localisation. With the low impact assumptions (S1) localisation benefits are 13% (400km) to 19% (20km) of urbanisation benefits. With the high impact assumptions (S3) the localisation and urbanisation benefits are roughly equivalent for the 20km and 150km distances and for 400km localisation effects account for the majority (51%) of total benefits. These results from Scenarios S1 and S3 indicate that the uncertainty around the localisation parameters has a significant impact on their relevance to economic appraisal and highlights the need for more consistent elasticity estimates.

Scenario S4 is based on the same assumptions as Scenario S2 but with double the proportion of manufacturing employment in the two cities. In S4 for the 20km distance localisation benefits are £14.9mn per annum which is higher than the £11.9mn per annum in S2. In contrast urbanisation benefits are slightly lower in S4 (£21.1mn per annum) compared to S2 (£21.9mn per annum) due to the lower urbanisation elasticities assumed for manufacturing industries. Due to the lower decay factors used for manufacturing industries compared to other sectors the decline of the benefits with distance is less pronounced in S4 compared to S2. In S4 total benefits for the 400km distance are 48% of those for the 20km distance compared to 42% in the baseline scenario. These results indicate that localisation benefits are likely to account for a higher proportion of benefits for transport schemes which improve connections between places with higher employment in manufacturing industries. This suggests that inter-city connectivity schemes in middle-income countries such as in Eastern Europe and East Asia countries which have higher levels of manufacturing employment than advanced economies are likely to generate higher localisation benefits.

Urbanisation benefits typically account for approximately 10% to 15% of the total Present Value of Benefits (PVB) for an inter-urban scheme transport with fixed land-use (Eddington, 2006, DfT, 2017a)[55]. This range can be used to estimate the impact the inclusion of localisation benefits would have on the overall PVB by comparing them to the scale of urbanisation benefits which were calculated using similar assumptions to those recommended in the UK's appraisal guidelines (DfT, 2018c). Based on the mid-point of the representative range for urbanisation benefits (i.e.

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[55] Eddington (2006) showed that the proportion of benefits due to wider economic impacts including urbanisation effects are higher for intra-urban transport schemes than inter-urban. In the latest HS2 business case (DfT, 2017a) urbanisation benefits are 12% of total benefits which is within the 10% to 15% range. This compares to the estimated urbanisation benefits as a proportion of total benefits for Crossrail in London of 26% for the mid scenario (Colin Buchanan & Volterra, 2007) and 26% for the Northern Line Extension in London (Volterra & ARUP, 2012). For ease of calculation it is assumed that the 10% to 15% range can be used for all three distances in the analysis.

12.5%) in the PVB the estimated increase in PVB due to the inclusion of localisation benefits are shown in Table 7.13 for Scenarios S1 to S3[56][57].

Table 7.13 Estimated % Increase in Total PVB in an Economic Appraisal due to inclusion of localisation benefits with fixed land-use

	Distance		
Scenario	20km	150km	400km
S1	2.9%	2.3%	1.8%
S2	6.8%	6.2%	5.6%
S3	11.3%	12.1%	13.1%

The results in Table 7.13 show that the inclusion of localisation benefits in an economic appraisal with fixed land-use is estimated to increase the total PVB of an inter-urban scheme by between 1.8% and 13.1%. With the low impact assumptions the estimated increase in total PVB is relatively small (1.8% to 2.9%) which would be unlikely to greatly affect the outcome of a business case but the increases are more significant for the medium impact assumptions (5.6% to 6.8%). With the high impacts the benefits from localisation (11.3% to 13.1%) are similar to those from urbanisation for all three distances between the cities and for the 400km distance the PVB from localisation (13.1%) are slightly greater than the assumption for urbanisation (12.5%).

The estimated increase in PVB for the 20km and 150km distances is greatest with the low and medium impact assumptions but for the 400km distance the high impact assumptions generate the largest increase. This is because the combination of a greater proportional reduction in GJT for the 400km distance (as shown in Table 7.5)

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[56] The increase in total PVB is estimated based on a comparison to urbanisation benefits which are calculated using similar parameters to those suggested in the DfT's Webtag Guidance (DfT, 2018c). For example, for the 400km distance between the cities with the low impact assumptions the localisation benefits are £1.4mn per annum. The urbanisation benefits for the same distance are £9.7mn per annum and based on the assumption that urbanisation benefits are 12.5% of total benefits then the total benefits per annum without localisation benefits can be estimated as 9.7*(100/12.5) = £77.5mn per annum. The percentage increase in total benefits due to the inclusion of localisation benefits (£1.4mn per annum) can then be estimated as 4.4/77.5 = 1.8%.

[57] The estimated changes in PVB in Table 7.13 and those for variable land-use in Table 7.16 do not take into account that the elasticities often used to estimate urbanisation benefits in economic appraisals include some localisation effects which means the scale of the increases may be slightly overestimated.

and higher assumptions on localisation effects outweigh the greater decay in the effects over longer distances between the cities. For the low and medium impact assumptions the scale of the effects are not great enough to exceed their decay over distance for the longer distances and the estimated increase in total PVB are higher when the cities are closer together.

7.5.2 Variable Land-Use

The results for the six variable land-use scenarios are shown in Tables 7.14. The second to tenth columns show the estimated annual benefits per annum for urbanisation, localisation and the combined total for the three distances between the cities. In the next three columns the localisation benefits as a proportion of the total benefits for the three distances between the cities are given. In the final two columns the estimated benefits for the 400km distance between the cities as a proportion of the estimated benefits for the 20km distance are shown for localisation and total benefits. In the lower portion of the table the proportion of benefits due to land-use changes in each scenario are provided[58]. The results for the fixed land-use scenario with medium parameter assumptions for localisation effects (S2) are also included so the impact of introducing land-use changes can be discerned.

In Scenario D1 the impact of introducing changes in sectoral composition based on Ricardian comparative advantage was tested with no decline in the level of trade impacts with distance applied between the cities. The results show that as expected the land-use changes lead to an increase in localisation benefits relative to Scenario S2 in which land-use was fixed but the localisation parameters are the same. Over the 20km distance the land-use change leads to a marginal increase in localisation benefits from Scenario S2 of £0.3mn to £12.2mn per annum. There are more significant increases from S2 for the 150km (£1.8mn to £12.8mn per annum) and 400km (£2.8mn to £7.2mn per annum) distances which is due to the higher proportional increase in GJT for the longer distances (as shown in Table 7.5) which generates greater changes in specialisation. The estimated urbanisation benefits in D1 are unchanged from S2 as sectoral employment in each zone remains constant so the overall economic density does not change.

In Scenario D2 the impacts of the increased concentration of producer and consumer service jobs in the core zones with no decline in impacts over distance

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[58] These were estimated by re-running the scenarios with the land-use changes but no changes in GJTs and then dividing the estimated benefits by those for the scenarios with both the changes in land-use and GJTs.

was tested. The results show that this type of land-use leads to higher localisation benefits than for changes in sectoral composition within zones in the previous scenario (D1). The increases in localisation benefits relative to Scenario S2 in which land-use was fixed are greatest for the longer distances between the cities and for the 400km distance localisation benefits (£18.2mn per annum) are more than quadruple their value in S2 (£4.4mn per annum). The increases are greater for the longer distances because the proportional reduction in GJTs are higher for those distances which leads to greater changes in land-use. As expected the increased concentration of service sector jobs in core zones in Scenario D2 also leads to an increase in urbanisation benefits as the land-use changes increase the overall density of employment. The increase in urbanisation benefits from S2 are less than for localisation benefits but are still significant and range from £2.5mn per annum (11%) for the 20km distance to £10.7mn per annum (100%) for the 400km distance.

The results for Scenarios D3, D4 and D5 show the impact of applying the low, medium and high impact assumptions for localisation effects and land-use changes respectively. Scenario D4 is the same as S2 but with the inclusion of the central case assumptions for land-use changes. For the 20km distance the increase in localisation benefits due to the inclusion of land-use changes is significant with estimated benefits of £15.3mn per annum in D4 compared to £11.9mn per annum in S2 which is a 29% increase. There are also increases in localisation benefits over the two longer distances but they are not as large due to the assumed decline of trade impacts over distance. Compared to S2 localisation benefits are £1.8mn per annum (16%) higher for the 150km distance and £0.9mn per annum (21%) higher for the 400km distance.

The inclusion of land-use changes also leads to higher urbanisation benefits but the scale of the increases are less significant than for localisation benefits. The increase in urbanisation benefits are greatest for the 20km distance which are £2.5mn per annum (11%) higher than in S2 and lowest for the 400km distance in which they are £0.7mn per annum (7%) higher. The smaller increases in urbanisation benefits resulting from the incorporation of land-use changes increases the proportion of total benefits due to localisation impacts. In D4 localisation benefits account for between 34% (400km) and 38% (20km) of total benefits compared to 31% and 35% for the same distances in S2 with no land-use changes.

Table 7.14 Estimated Annual Benefits £mn p.a. (2021 Values & Prices)

Distance	20km			150km			400km			% Localisation			Localisation Benefits 400km/20km	Total Benefits 400km/20km
Test	Loc	Urb	Total	Loc	Urb	Total	Loc	Urb	Total	20km	150km	400km		
S2	11.9	21.9	33.9	11.0	22.2	33.2	4.4	9.7	14.1	35%	33%	31%	37%	42%
D1	12.2	21.9	34.1	12.8	22.2	34.9	7.2	9.7	16.8	36%	37%	42%	59%	49%
D2	15.0	24.4	39.4	21.6	30.4	52.0	18.2	20.4	38.6	38%	41%	47%	121%	98%
D3	6.0	23.4	29.4	4.4	22.6	27.0	1.5	9.9	11.4	20%	16%	13%	25%	39%
D4	15.3	24.4	39.7	12.8	23.5	36.3	5.3	10.4	15.7	38%	35%	34%	35%	40%
D5	24.9	24.4	49.3	27.7	25.2	52.9	15.0	12.1	27.1	51%	52%	55%	60%	55%
D6	18.0	23.0	40.9	16.6	24.1	40.7	7.2	11.6	18.8	44%	41%	38%	40%	46%
% Benefits Due to Changes in Land-Use														
D1	2%	0%	1%	14%	0%	5%	39%	0%	17%					
D2	21%	10%	14%	49%	27%	36%	76%	53%	64%					
D3	14%	6%	8%	5%	2%	2%	6%	2%	2%					
D4	22%	10%	15%	14%	6%	8%	17%	7%	10%					
D5	21%	10%	15%	23%	12%	17%	32%	20%	27%					
D6	17%	8%	12%	9%	4%	6%	11%	5%	7%					

The results for Scenarios D3 and D5 show that as expected varying the assumptions on land-use changes and localisation parameters has a significant impact on the scale of localisation benefits. Compared to D3 localisation benefits for D5 range from £18.9mn per annum higher (315%) for the 20km distance to £13.5mn per annum (900%) higher for the 400km distance. The differences in assumptions on land-use changes in D3 and D5 also lead to urbanisation benefits varying between the two scenarios but not as significantly as localisation benefits. Compared to D3 urbanisation benefits in D5 range from £1.0mn per annum higher (4%) for the 20km distance to £2.2mn per annum higher (22%) for the 400km distance.

These benefit estimates impact significantly on the proportion of total benefits due to localisation effects. With the low impact assumptions (D3) this proportion ranges from 13% for the 400km distance to 20% for the 20km distance. For the high impact assumptions (D5) localisation benefits account for the majority of agglomeration benefits. The highest proportion estimated is for the 400km distance where localisation benefits account for 55% of the total benefits.

Scenario D6 uses the same assumptions as the medium impacts scenario (D4) but with double the proportion of initial employment in manufacturing. The localisation benefits were estimated as £18.0mn per annum for the 20km distance, £16.6mn per annum for 150km and £7.2mn per annum for 400km which are 18, 30% and 36% higher respectively than in D4. The increases rise with distance as the distance decay factors for manufacturing are assumed to be lower than services which means the effects decay less over distance. Although localisation benefits are higher than in Scenario D4 the urbanisation benefits are £1.4mn per annum lower for the short 20km distance due to the lower urbanisation elasticities assumed for manufacturing than services. For the 150km and 400km distances urbanisation benefits are slightly higher than in D4 as this effect is outweighed by the lower decay factors used for manufacturing. Overall the total benefits with double the proportion of employment in manufacturing are estimated to be higher than D4 for all three distances ranging from 3% (£1.2mn per annum) for the 20km distance to 20% (£3.1mn per annum) for the 400km distance.

The results from Scenario D6 suggest that schemes which improve links between places with a higher proportion of employment in manufacturing such as in Eastern Europe and Asia could realise more significant benefits from localisation effects than in advanced economies. In addition, there is evidence of more significant elasticities in middle-income countries (Foster & Stehrer, 2009, Brülhart & Mathys, 2008, Marrocu et al., 2013) and potentially greater changes in land-use (Ghani et al., 2016) and GJTs which suggests there may be potential for even higher localisation benefits than those estimated in this analysis.

There are some consistent results from across all Scenarios D3 to D6 which have implications for business cases of inter-city schemes. Firstly, total benefits from urbanisation and localisation effects are significantly higher for the two shorter distances between the cities than for the 400km distance. This suggests that the inclusion of localisation effects and changes in specialisation will have more impact on the total benefits for inter-city schemes between places which are closer together. Secondly, the results for these scenarios in the lower portion of Table 7.14 show that the land-use changes which were implemented have more impact on the scale of localisation benefits than urbanisation. This suggests that the inclusion of localisation benefits will have more impact on the business case of a transport scheme which improves links between places where there is high scope for changes in specialisation. Examples of such cases include instances where places have comparative advantages in different sectors or when places have strong supply chain linkages which a transport scheme could promote further.

The estimated benefits from Table 7.14 were used to calculate the impact on the PVB of the inclusion of localisation and urbanisation benefits with variable land-use using the same method as when land-use was held constant. Based on the mid-point of 12.5% of the typical range of urbanisation benefits for an inter-urban scheme (Eddington, 2006, DfT, 2017a) the estimated increases in total PVB for Scenarios D3 to D5 are shown in Table 7.15.

Table 7.15 Estimated % Increase in Total PVB in an Economic Appraisal with variable land-use[59]

Distance	20km			150km			400km		
Scenario	Loc	Urb	Total	Loc	Urb	Total	Loc	Urb	Total
D3	3.4%	0.8%	4.2%	2.5%	0.2%	2.7%	1.9%	0.2%	2.2%
D4	8.7%	1.4%	10.1%	7.2%	0.7%	7.9%	6.8%	0.9%	7.7%
D5	14.2%	1.4%	15.6%	15.6%	1.7%	17.3%	19.3%	3.0%	22.4%

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[59] The estimated increases in PVB for scenarios D4 to D6 were calculated using the same method as for the fixed land-use scenarios (S1 to S3) outlined above but based on a comparison to the estimated urbanisation benefits in S2 in which the central parameter assumptions for urbanisation effects were used and land-use was fixed.

The results in Table 7.15 show that the inclusion of land-use changes and localisation benefits is estimated to increase total PVB by between 2.2% and 22.4%. The increases in PVB are significantly higher than the results for the scenarios with fixed land-use (1.8% to 13.1%) which shows that as expected the inclusion of land-use changes further increased the impact on total PVB. The inclusion of localisation benefits accounts for the majority of the increase in PVB (1.9% to 19.3%) but urbanisation benefits also contribute to the rise (0.2% to 3.0%).

The scale of the estimated increases in PVB suggest that the overall value for money outcome of a greater number of schemes would be affected by the inclusion of land-use changes than when land-use was fixed. The scale of the increases are not significant enough to transform the case for a scheme which has an otherwise poor business case but they would be substantial enough to improve the value for money outcome of many inter-city schemes. The results show that there is uncertainty around the scale of the benefits and the estimated change in the PVB will vary depending on the context. The sectors which are most likely to realise significant additional benefits as a result of inter-city transport improvements will be those which are more dependent on inter-city trade and those with higher elasticities and lower decay factors for localisation effects.

There are some caveats around the results in this analysis. The estimated benefits for the variable land-use tests are dependent on the assumptions which were made about the degree of land-use change about which there is some uncertainty. It was assumed that specialisation in each city would increase with comparative advantage but this won’t necessarily always be the case such as when sectors are predominantly focussed on serving demand in their local market. In addition, only changes in land-use in the two cities have been tested but there may also be changes in rural areas and other urban areas as a result of an inter-city scheme which would impact on the benefits. The results have shown that localisation benefits are more dependent on changes in land-use than urbanisation but other research has shown though that inter-urban transport improvements are a necessary but not sufficient condition for land-use changes to take place (Venables, 2017). This means that inter-urban transport investment on its own may not be enough to bring about all of the potential changes in land-use. To realise the full potential for localisation benefits from land-use change, therefore, would require a business environment in which firms are able to invest and expand to maximise the potential opportunities (Rosewell and Venables, 2013).

7.6 Comparison to Dynamic Modelling Results

There are number of differences between the two methods which makes a direct comparison of the modelling results difficult. In the dynamic modelling only land-use changes in two sectors were considered whereas in the static modelling land-use changes in all sectors in the economy were considered. In addition, total employment in the study areas were not the same in the two methods and only inter-city rail improvements was considered in the dynamic modelling whereas both inter-city rail and highway improvements were introduced in the static model.

Despite these differences the results from the static modelling in this chapter were compared to those from the dynamic modelling presented in Chapter 6 to see how and why they are similar and different. The total urbanisation and localisation benefits from the three dynamic model runs in Chapter 6 are shown in Table 7.16 along with the percentage split between the two types of agglomeration benefit.

Table 7.16 Present Value of Benefits (£mn, 2021 Values and 2010 Prices) of Inter-City Rail Scheme from Dynamic Modelling Simulations in Chapter 6

	Without Zonal Mobility		Zonal Mobility		Zonal Mobility & Lower Intra-City Mobility Costs	
Variable	Urb	Loc	Urb	Loc	Urb	Loc
PVB (£mn)	477.6	1411.0	654.8	1775.4	831.5	2085.4
% Split	25.3%	74.7%	26.9%	73.1%	28.5%	71.5%

Table 7.16 shows that the proportion of benefits due to localisation effects in the dynamic model ranges from 71.5% to 74.7%. This is significantly higher than the estimates from the static modelling undertaken in this chapter in which with the medium assumptions and variable land-use localisation benefits accounted for 34% of total benefits per annum for a 150km distance between cities and 32% for the 400km distance. The proportion of benefits for localisation is higher in the dynamic model due to the greater degree of land-use change permitted. While the changes are high compared to the static modelling there is uncertainty around the scale of land-use changes due to transport and the impacts in different sectors could vary significantly.

There are some notable differences between the two methods which have implications for modelling and appraisal. One of the key differences between the methods is that in the dynamic model conditions have to be satisfied for changes in land-use to take place whereas in the static model land-use changes are assumed to take place automatically. This means that in the static model even a small journey time improvement will generate changes in specialisation but a more significant transport scheme is required in the dynamic model. This implies that when undertaking a static analysis it would be beneficial to analyse the level of trade linkages between places as two otherwise identical city pairs may have significantly more or less trade with each other which could affect the potential for changes in specialisation.

The dynamic modelling simulations showed that it can take a number of years or even decades to realise the full benefits from changes in specialisation. This suggests that care needs to be taken when applying elasticities for estimating changes in land-use in a static framework. If long-run elasticities for land-use changes with respect to GJT are applied the present value of benefits of a scheme could be overestimated if build-up factors are not applied to the benefits in each year.

7.7 Conclusion

This chapter set out to determine the importance of localisation benefits in the economic appraisal of inter-urban transport schemes. Localisation benefits are not typically included in economic appraisals and there is a limited evidence base both for localisation parameters and land-use changes due to inter-city transport improvements. To test the potential for localisation benefits resulting from inter-urban schemes an abstract model of two cities was constructed and a 10% reduction in travel times between the cities was introduced. With fixed land-use and the central case assumptions for localisation parameters the localisation benefits were estimated at approximately 50% of urbanisation benefits. Due to the assumed higher decay of localisation effects compared to urbanisation this proportion decreases with the distance between the cities with an estimate of 54% for the 20km distance and 45% for the 400km distance.

Simulations were also undertaken with variable land-use. In these model runs it was assumed that due to the inter-city journey time improvements cities would become more specialised and there would be increased concentration of service sectors in the core of each city. As expected the introduction of these impacts increased the estimated total localisation benefits ranging from 16% for the 150km distance to 20% for the 400km distance with the central case assumptions. There was also an increase in urbanisation benefits due to increased density of employment in the core zones although the increases were not as significant ranging from 6% for the 150km distance to 11% for the 20km distance. These changes meant that with the central case assumptions localisation effects as a proportion of urbanisation benefits were higher than in the fixed land-use scenarios ranging from 51% for the 400km distance to 63% for the 20km distance.

Scenarios were also undertaken assuming double the proportion of manufacturing employment as used in the base case. The total estimated benefits with variable land-use were up to 20% higher in these scenarios due to the higher localisation elasticities and lower distance decay factors in manufacturing compared to other sectors. These results indicate that localisation benefits may account for a larger share of benefits for inter-urban schemes in countries such as in Eastern Europe and East Asia which have higher levels of employment in manufacturing. In addition, there may be potential for more significant reductions in journey times and there is evidence for greater land-use changes in response to inter-urban schemes in such countries (Ghani et al., 2016) which could generate even higher localisation benefits.

Across all scenarios undertaken total benefits from localisation and urbanisation effects for the 20km and 150km distances between the cities were consistently higher than for the 400km distance. This suggests that the inclusion of localisation effects and changes in specialisation will have more impact on the total benefits of inter-city schemes which link places which are closer together. The benefits estimates also showed that the scale of localisation benefits are more dependent on land-use changes than urbanisation. This indicates that to realise higher localisation benefits from inter-urban transport the investment needs to be focussed on improving links between cities which are likely to maximise the potential for increased trading opportunities. This suggests that improving links between places which have different comparative advantages and/or integrated supply-chains would be most likely to realise significant localisation benefits. To facilitate these land-use changes would require a labour market in which workers have the required skills to move between sectors.

Based on the evidence that urbanisation benefits are approximately 10% to 15% of the total PVB of an inter-city transport scheme it was estimated that with land-use held constant the inclusion of localisation benefits would increase the total Present Values of Benefits (PVB) by 1.8% to 13.1%. These estimates increase with the scale of the assumed localisation parameters. With variable land-use the inclusion of localisation benefits and higher urbanisation benefits are estimated to increase the total PVB by between 2.0% and 22.4% which increase with the scale of the localisation impact parameters and the scale of land-use changes. These estimates suggest that the incorporation of land-use changes would be likely to affect the value for money outcome of a greater number of inter-urban schemes but the scale of the increase in benefits would still not be sufficient to transform an otherwise poor business case.

The variation in the benefits estimates between the low and high impact assumptions on localisation parameters and land-use changes shows that the uncertainty around these parameters is important. More research is needed on the scale of localisation and urbanisation elasticities and distance decay factors by sector. More evidence is is also needed on the extent of these effects which can be expected to vary by location, transport mode of scheme and sectoral composition of places affected by a transport scheme. Empirical work is also needed to estimate how these effects vary over time.

In the next chapter a similar analysis is carried out to this chapter using the real world case of the proposed Northern Powerhouse Rail (NPR) scheme between the cities of Leeds and Manchester in the north of England. A number of fixed and variable land-use scenarios are undertaken to test if the real world case gives similar relative benefits to the abstract case and if they confirm the other findings from this chapter. The case study is also used to identify if there are any differences in carrying out analysis at the detailed case compared to the abstract case.

8 Case Study of Inter-City Rail Improvements Between Greater Manchester and West Yorkshire in the UK

8.1 Introduction

In this chapter a case study is carried out of the proposed Northern Powerhouse Rail (NPR) scheme between the cities of Leeds and Manchester in the north of England. A similar method is used to the abstract modelling undertaken in Chapter 7 and localisation and urbanisation benefits are estimated for a number of fixed and variable land-use scenarios. The purpose of the case study is to answer the following research questions:

- What are the relative benefits from localisation and urbanisation in an appraisal of an inter-urban scheme with real world data? The results from the case study will be compared to the abstract modelling in Chapter 7 to see if the real world case gives similar relative benefits to the abstract case and if they confirm the other findings from Chapter 7.
- Are there any differences in undertaking analysis at the detailed level compared to the abstract level? The process of undertaking the case study will be used to determine if there are any differences between undertaking analysis with detailed real world data compared to the abstract case in Chapter 7.

This chapter has the following structure. In Section 8.2 an overview is provided of the study area. In Section 8.3 the base year data on journey times, GVA per worker and employment are outlined and in Section 8.4 the fixed and variable scenarios tests are defined. The results and discussion are outlined in Section 8.5 and the conclusion is presented in Section 8.6.

8.2 Overview of Study Area

A map of the study area is shown in Figure 8.1. There are 15 local authority districts (LADs) in the region which are divided between the two metropolitan counties of Greater Manchester and West Yorkshire.

Figure 8.1 The Metropolitan Counties and Local Authority Districts in the study area

A more detailed map of the study area including the major transport links is shown in Figure 8.2. The area of Greater Manchester is approximately 60% of the geographical size of West Yorkshire and Greater Manchester is more densely populated than West Yorkshire with fewer rural areas. There is a sparsely populated area on either side of the border between the two metropolitan counties which is due to the Pennines which are a chain of hills which run south-north through the study area. The Euclidean distance between the centre of Manchester and Leeds which are the largest cities in Greater Manchester and West Yorkshire respectively is 57 km (36 miles)[60].

Figure 8.2 shows that the two metropolitan counties are linked by the M62 motorway and several ‘A’ and other minor roads. There are two coach operators (National Express and Megabus) which provide services between the two cities with a quickest journey time of approximately 70 minutes[61]. There are also a few local bus services which traverse the border between the two metropolitan counties.

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[60] This was measured using Google Maps from Piccadilly Gardens in Manchester to City Square in Leeds.

[61] Source: The information on coach services operating between Leeds and Manchester was obtained from https://www.busbud.com/en-gb/bus-leeds-manchester/r/gcwfhc-gcw2jp.

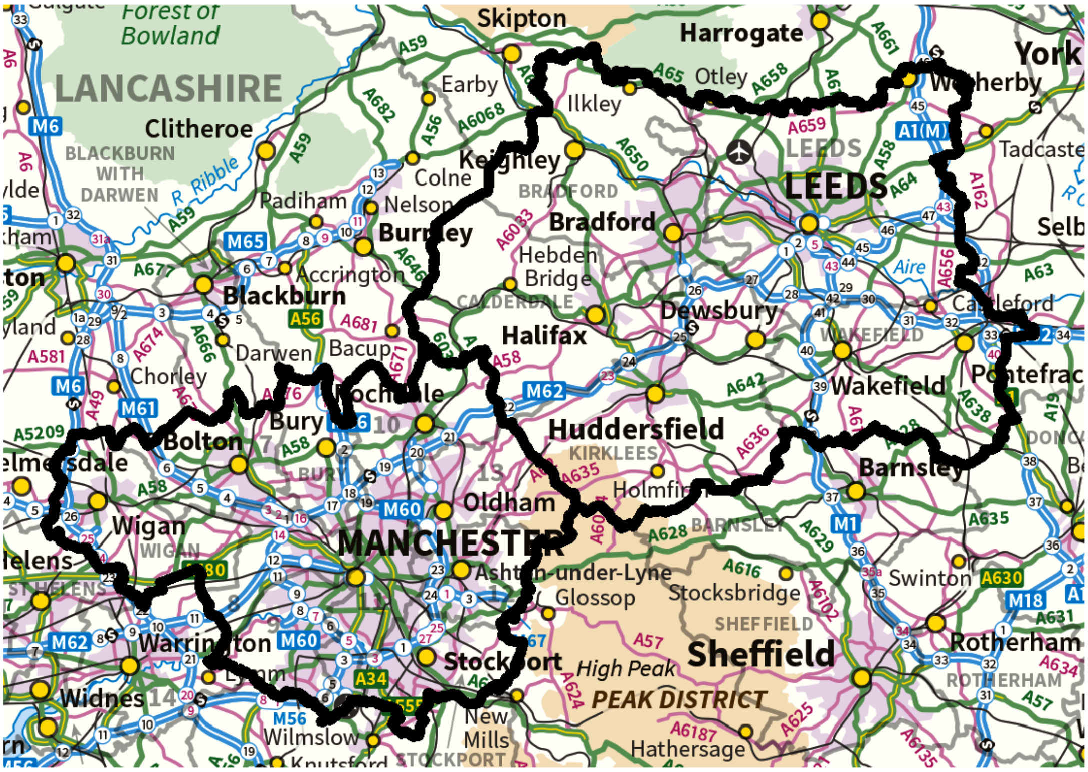

Figure 8.2 Map of the major transport links in Greater Manchester and West Yorkshire (Contains Ordnance Survey data © Crown copyright and database right 2019) [62]

A map of the railways in the study area including the proposed Northern Powerhouse Rail (NPR) line is shown in Figure 8.3. This shows that there are currently two main railway lines between Manchester and Leeds. The line which runs between the two cities via Huddersfield is called the TransPennine line and this route provides the shortest journey times and most frequent service. In the December 2016 timetable there were an average of 6 trains per hour (tph) running in each direction with an average journey time of 52 minutes between Manchester and Leeds[63].

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[62] The background map in this figure is the Ordnance Survey MiniScale sourced from: https://digimap.edina.ac.uk

[63] Source: TransPennine Express (2016). December 2016 Timetable for Liverpool & Manchester Airport to/from North East.

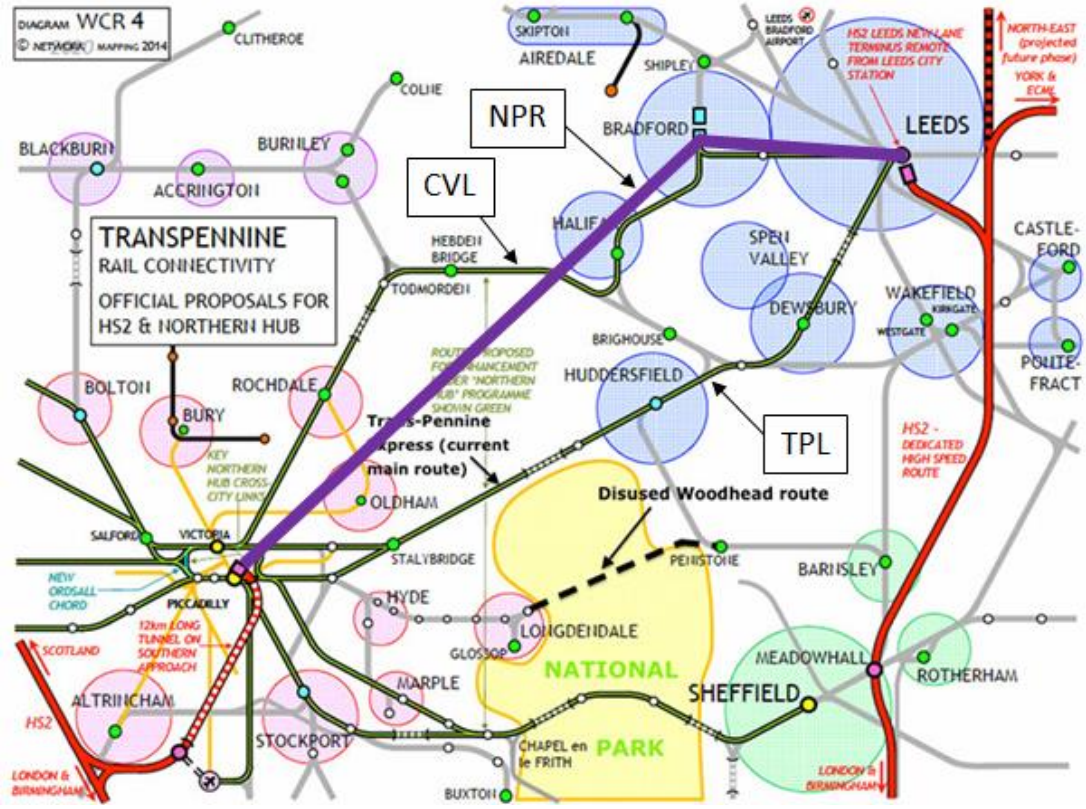

Figure 8.3 Map of NPR, TransPennine line (TPL) & Calder Valley line (CVL)[64][65]

The railway line which runs between Manchester and Leeds via Halifax is called the Calder Valley line. Services between Manchester and Leeds on this route are slower and less frequent than on the TransPennine line and in the December 2016 timetable the average journey time was approximately 92 minutes between Manchester and Leeds and there were 2 trains per hour (tph) in each direction[66]. This Calder Valley line is slower than the TransPennine line as the route is more circuitous and because there are more intermediate stops including at the city of Bradford and the market towns of Rochdale, Hebden Bridge and Todmorden.

The NPR line is still at the development stage but it is expected to reduce the quickest journey times between Manchester and Leeds by approximately 20 minutes

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[64] Additions made to map sourced from: https://www.tunneltalk.com/Discussion-Forum-29Oct2014-Examining-the-options-for-a-UK-east-west-high-speed-rail-link.php

[65] In the latest plans for HS2 the services will now stop at Sheffield via a spur from the HS2 mainline rather than at Meadowhall on the HS2 line (DfT, 2016). The route of HS2 in the north of England is still subject to final approval.

[66] Source: Arriva Rail North Ltd. (2016). December 2016 Timetable for Route 36: Leeds to/from Manchester via Dewsbury/Bradford Interchange.

to 32 minutes. An intermediate stop on the NPR line is planned at Bradford which will reduce journey times significantly to and from Manchester and there will also be journey time reductions between Bradford and Leeds. The services which operate on the NPR line may also extend to outside the study area to the west and east but these are outside the scope of the analysis in this chapter and only the impacts of the journey time reductions between Greater Manchester and West Yorkshire are considered.

8.3 Base Year Data

To estimate the localisation and urbanisation benefits of the NPR scheme there is a need to source base year data on generalised journey times (GJTs), employment and GVA (Gross Value Added) per worker. The year 2016 was selected as the base year for the analysis. This was chosen as there was a significant changes made to rail services in the study area from 2017 onwards when TransPennine line services were re-routed through Manchester city centre. This change extended journey times between Leeds and Manchester's main railway station Manchester Piccadilly by approximately 10 minutes. To avoid any impact of these changes on the base year land-use data which can take several years to fully realise 2016 was selected as the base year to focus on the impact of the NPR scheme only.

The benefits calculations are undertaken at the level of Mid-level Super Output Areas (MSOAs) of which there are 645 in the study area. The variables used in the benefits calculations along with the spatial level it was sourced are shown in Table 8.1. The data from 2016 for each of these variables are discussed in turn in the following sub-sections.

Table 8.1 Data used by level of spatial detail

Dataset	Spatial Detail
Generalised Journey Times	MSOA
Sectoral Employment	MSOA
Sectoral GVA per Worker	LAD

8.3.1 Generalised Journey Times

The generalised journey time (GJT) data between the MSOAs in the study area was sourced from the UK Data Service[67]. GJTs were obtained for highway and public transport trips in the AM Peak Hour for 2016. The highway GJTs from the city centres of Manchester and Leeds are shown in Figures 8.4 and 8.5 respectively. Highway GJTs were provided between all MSOAs except for MSOA E02001249 which is centred on Junction 1 of the M67 motorway in Greater Manchester. GJTs from and to this MSOA were generated by taking the average of the GJTs to and from the two MSOAs (E02001248 and E02001252) adjacent to this junction.

The public transport GJTs from Manchester and Leeds city centres to the other MSOAs in the study area are shown in Figures 8.6 and 8.7 respectively. The journey time data provided did not include public transport GJTs for 128,543 (31%) of the MSOA O-D pairs in the study area. Data was not available for these O-D pairs as MSOAs are relatively small and there is no data provided if public transport is not accessible from within the MSOA or if journeys require many interchanges.

Several assumptions were made to complete the PT GJT matrix. Firstly, it was assumed that if there was a GJT in only one direction between an OD pair this was also used for the opposite direction which reduced the number of missing values by 64,675. Secondly, there were 11 MSOAs with no public transport GJT data and 3 MSOAs with values for one OD movement only. For OD movements between these MSOAs the GJTs were estimated by measuring the distance between the zone centroids of the MSOA and an adjacent MSOA. Based on an assumed walking speed of 1 metre per second the access time to the adjacent MSOA was calculated which was then added to GJTs to and from the adjacent MSOA.

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[67] The UK Data Service provides data to researchers and policymakers such as UK census data and other government surveys.

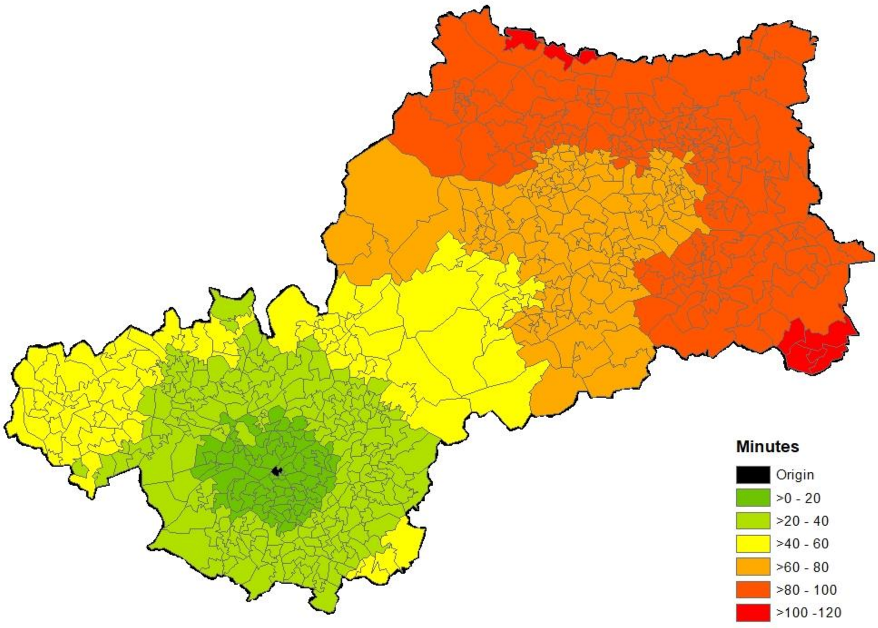

Figure 8.4 Highway Journey times (minutes) to Manchester city centre: 2016

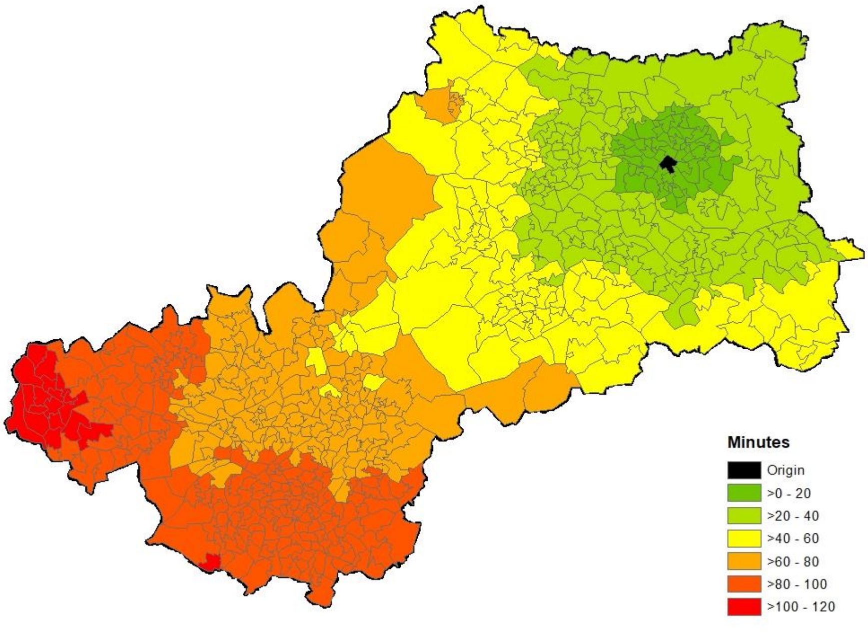

Figure 8.5 Highway Journey times (minutes) to Leeds city centre: 2016

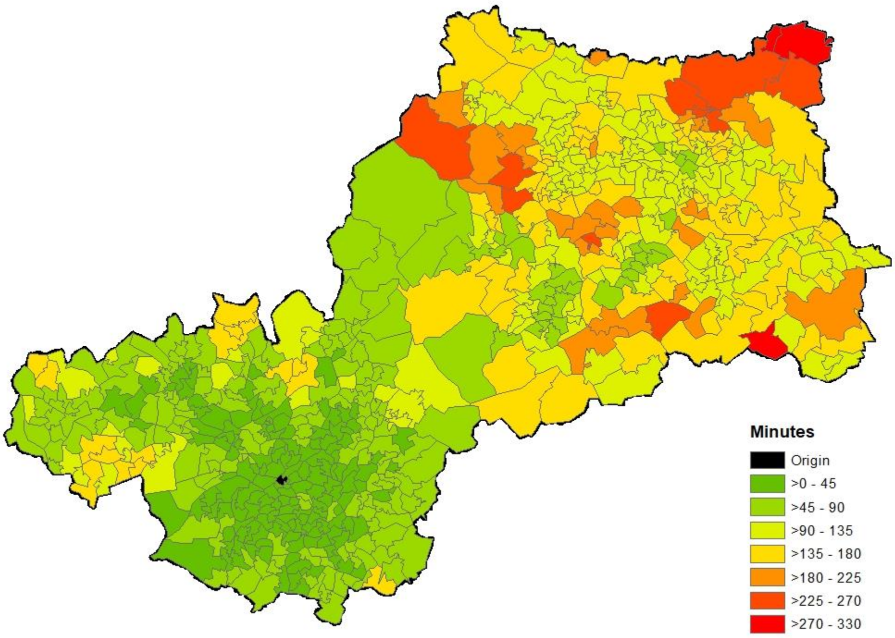

Figure 8.6 Public Transport Journey times (minutes) to Manchester city centre: 2016

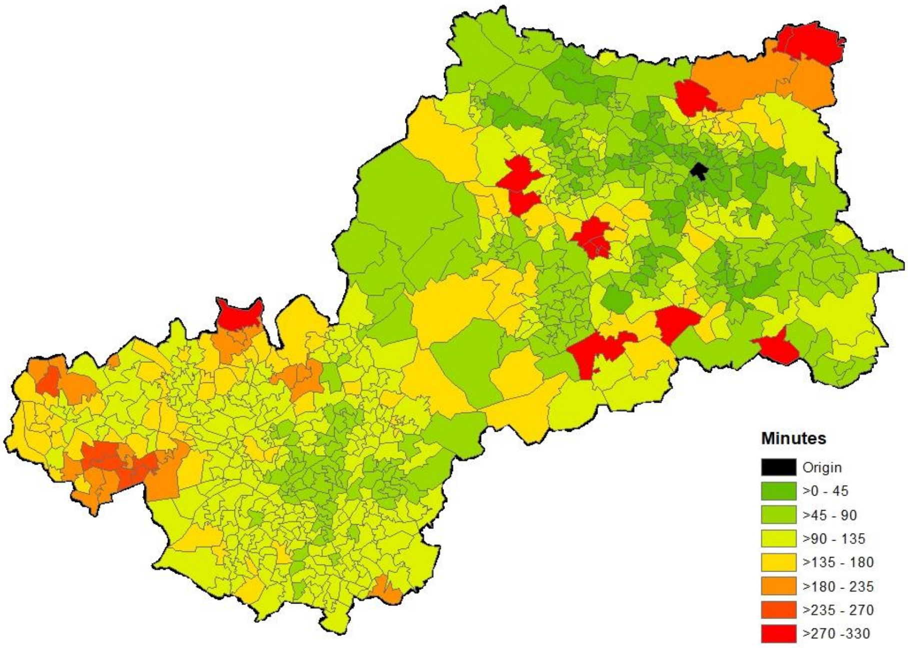

Figure 8.7 Public Transport Journey times (minutes) to Manchester city centre: 2016

The majority of the remaining 47,144 (11%) O-D pairs with no GJT data were to and from rural areas in West Yorkshire and Wigan in Greater Manchester. These areas are more sparsely populated than most of the LADs in the study area and are therefore less likely to have good public transport connections. For all of the remaining O-D pairs with no GJT the maximum GJT between the pairs of LADs in which the MSOAs are located were used.

8.3.2 Land-Use

For the purpose of forecasting potential changes in land-use due to the NPR scheme the levels of specialisation by location in the base year first need to be identified. There are many different methods available for determining the degree of specialisation in a location (see Kopczewska et al., 2017, for a review) and several of them have been developed following the increased interest in economic geography over the last thirty years (Franceschi et al., 2009). The most common method for estimating the level of specialisation by location is the Hoover-Balassa coefficient or Location Quotient (LQ) (Kopczewska et al., 2017). This coefficient was developed by Hoover (1936) and is estimated by dividing the proportion of employment in a sector in a location by the equivalent proportion across the country. The level of specialisation is calculated for each location using a location quotient, $LQ_{i,r}$, which for sector *i* and region *r* is estimated using the following formula[68]:

$$LQ_{i,r} = \frac{E_{i,r}}{E_r} \bigg/ \frac{E_i}{E} \qquad (8.1)$$

where $E_{i,r}$ is employment in sector *i* in region *r*, E_r is employment in region *r*, E_i is employment in sector *i* and *E* is total employment.

A location quotient of greater than one denotes that an area has a higher proportion of employment a sector than the national average and an LQ of less than one signifies a lower level of employment in the location relative to the national average. An LQ of greater than 1.25 indicates a sector which is part of the area's export base and an LQ of less than 0.75 indicates a sector which is being substituted for imports from other areas (McLean and Voytek, 1992).

There are other indices which are also commonly used to measure the level of specialisation by location such as the Krugman Specialization Index (Krugman, 1991a), Herfindahl-Hirschman Index (Herfindahl, 1950, Hirschman, 1964), Theil Index (Theil, 1967) and the Gini coefficient (Gini, 1912). For the purposes of the case study the Hoover-Balassa coefficient method is sufficient and in the following sub-sections the sectoral employment in the study area is analysed at LAD and MSOA

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[68] This equation is from ONS (2017).

level in turn to determine the level of specialisation across the study area in the base year.

8.3.2.1 Land-Use at Local Authority District (LAD) level

The UK's Department for Transport (DfT) provides employment data by LAD for four broad sectoral groups: manufacturing, construction, consumer services and producer services (DfT, 2018d). This dataset is based on firm level data and other sectors of the economy such as public services are not included and for the purposes of the analysis these were classified as 'Other'[69]. This dataset was used to calculate LQs for the 15 LADs in the study area using equation (8.1) and are presented in Figure 8.8[70]. The ten LADs in the study area which are in Greater Manchester are shown on the left and the five LADs in West Yorkshire on the right.

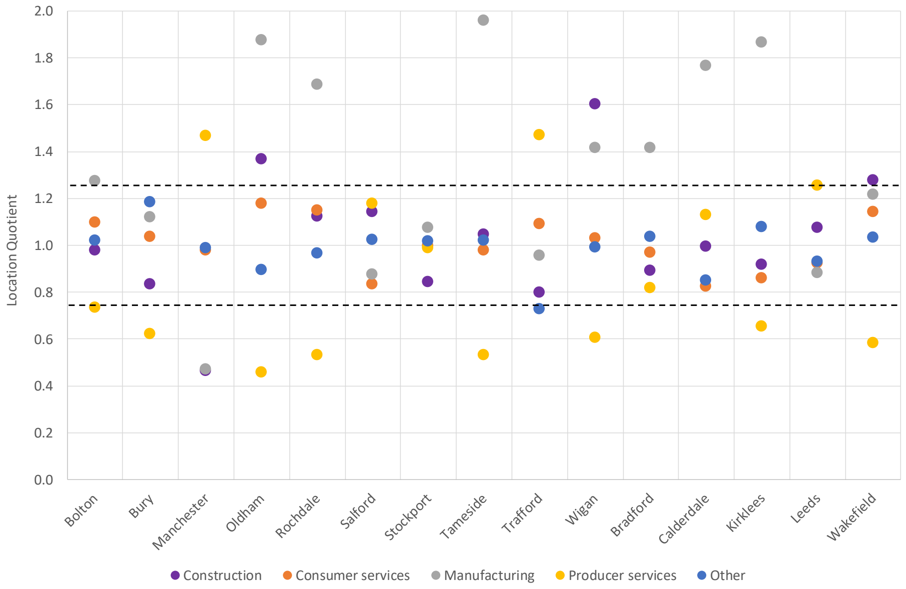

Figure 8.8 Location Quotients for Local Authority Districts by Sectoral Group (2016)

Figure 8.8 shows that across the study area it is predominantly producer services and manufacturing which lie outside the range of 0.75 and 1.25 which would suggest a level of employment similar to the national average. The three LADs of Manchester, Trafford and Leeds have an LQ in producer services which is greater

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[69] The number of jobs in this sector was estimated using the difference between the sum of employment across the four broad sectoral groups and the total number of jobs by LAD which are both provided in WebTAG (DfT, 2018d).

[70] These LQs and others presented later in this chapter were estimated relative to the proportion of sectoral employment across Great Britain rather than the whole of the United Kingdom as this data was not available.

than 1.25 but eight have an LQ of less than 0.75. There are eight LADs with an LQ of greater than 1.25 in manufacturing and only Manchester has an LQ of less than 0.75. The relatively high LQs for manufacturing and low values for producer services across the study area are likely to partly be a reflection of the influence of Greater London. In the dataset Greater London accounts for 17% of total employment in Great Britain and compared to the national average it has much higher employment in service sectors and much less in manufacturing industries[71]. The LQs for consumer services and other are more consistent across the study area and only the LQ for other in Trafford (0.73) lies outside the 0.75 to 1.25 range. The LQs for construction are also relatively consistent across the study area and only Wigan (1.60) and Oldham (1.37) lie outside this range.

To determine the potential for changes in specialisation at individual sector level due to the NPR scheme sectoral employment data was required at a more disaggregate level than broad industrial group. Data was sourced from the UK's BRES (Business Register and Employment Survey) for the 15 LADs at the 2-digit Standard Industrial Classification (SIC) (2007) level in which the economy is divided into 88 sectors. The review of the empirical literature in Section 2.4.2 of Chapter 2 highlighted that inter-city rail projects are more likely to impact on land-use in service sectors than manufacturing industries (Lin, 2017, Dong, 2018, Chen et al., 2019). Based on this evidence the sectors which were identified as having the most potential for realising land-use changes due to the NPR scheme were producer and consumer service sectors and publishing, media and real estate which also rely on face-to-face contact. In total 22 sectors were selected for potential land-use changes due to the NPR scheme and they are presented in Table 8.2[72].

The LQs for these 22 sectors were estimated for each LAD in the study area and are shown in Figure 8.9. This shows that Leeds and Manchester have an LQ of at least 0.5 in nearly all of the 22 sectors. In many of the other LADs in the study area there

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[71] The proportion of employment in Greater London in 2016 in manufacturing and producer services was 52% and 7% respectively compared to the averages across Great Britain of 33% and 16% respectively (DfT, 2018d). It should be noted that the dataset does not include employment in other sectors such as public services and all of these percentage values are higher than they would be if these sectors were included.

[72] The NPR scheme may abstract trips from highways. This could lead to changes in land-use in sectors which are more focussed on road freight such as manufacturing but these effects were not considered in this analysis.

are high levels of specialisation in a few of the 22 sectors but also relatively low LQs in the other sectors. The LADs of Oldham, Tameside and Kirklees have low LQs in nearly all of the 22 sectors identified for potential land-use changes.

Table 8.2 22 Sectors identified as having potential for changes in sectoral composition due to the NPR scheme

2007 SIC Code: Sector	Sectoral Group
58 : Publishing	Manufacturing
59 : Motion picture/video/TV, sound recording music publishing	Manufacturing
60 : Programming and broadcasting	Consumer Services
61 : Telecommunications	Consumer Services
62 : Computer programming, consultancy and related	Producer Services
63 : Information service	Producer Services
64 : Financial services except insurance and pension funding	Producer Services
65 : Insurance/reinsurance/pension funding	Producer Services
66 : Activities auxiliary to financial services and insurance	Producer Services
68 : Real estate	Other
69 : Legal and accounting	Producer Services
70 : Activities of head offices; management consultancy	Producer Services
71 : Architectural/engineering; technical testing and analysis	Producer Services
72 : Scientific research and development	Producer Services
73 : Advertising and market research	Producer Services
74 : Other professional, scientific and technical	Producer Services
77 : Rental and leasing	Producer Services
78 : Employment	Producer Services
79 : Travel agency, tour operator and other reservation services	Consumer Services
80 : Security and investigation	Producer Services
81 : Services to buildings and landscape	Producer Services
82 : Office administrative, office support and other business support	Producer Services

The two largest cities in the study area are Manchester in Greater Manchester and Leeds in West Yorkshire. Figure 8.9 shows that there are similarities in the estimated LQs in the two cities but there are also some notable differences. Within the three different finance and insurance sectors Manchester is more specialised in insurance & pension funding (SIC 65) and auxiliary services (SIC 66) but Leeds has a higher LQ in financial services (SIC 64). Manchester has a significantly higher LQ in a number of the other sectors relative to Leeds including 2.2 in legal & accounting (SIC 69), 2.0 in travel agencies & tour operators (SIC 79), 1.4 in advertising & market research (SIC 73), 1.4 in services to buildings (SIC 81) and 1.3 in real estate (SIC 68). Leeds has a significantly higher LQ than Manchester of 2.0 in security & investigation (SIC 80), 1.3 in other professional, scientific and technical (SIC 74) and 1.2 in computer programming & consultancy (SIC 62). An NPR station is also proposed in Bradford which has a high LQs of 2.9 in publishing (SIC 58) and 1.8 in financial services (SIC 64) but the LQs of the other 20 sectors in Bradford are relatively low.

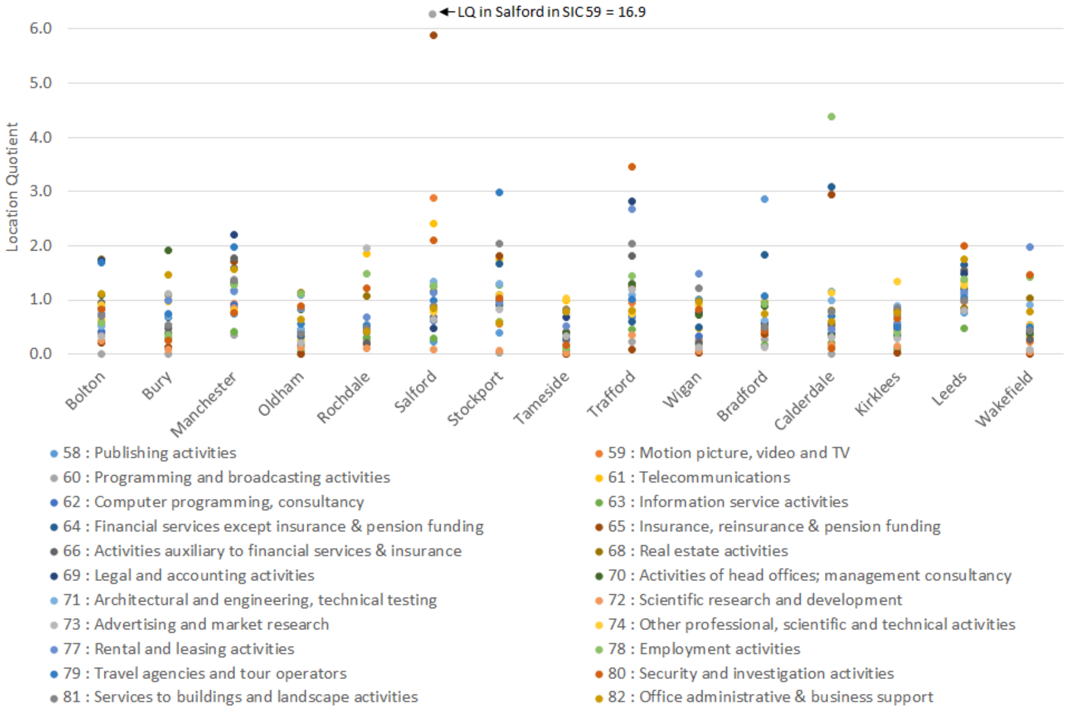

Figure 8.9 Location Quotients by Local Authority District for the 22 Sectors Selected for Land-use Changes due to the NPR scheme

The highest LQ across the study area is 16.9 for programming & broadcasting (SIC 60) in Salford. This is explained by the location of the MediaCityUK cluster in Salford which accounts for 74% of employment in programming & broadcasting in the study area. Salford also has a high LQ in motion picture & television production (2.9) and insurance & pension funding (5.9). Other examples of high LQs in the study area include employment services (4.4), financial services (3.1) and insurance & pensions (3.0) in Calderdale, security & investigation (3.5) and legal & accounting (2.8) in Trafford and travel agencies & tour operators (3.0) in Stockport.

8.3.2.2 Land-Use at Mid-level Super Output Area (MSOA) level

In the analysis undertaken in this chapter the land-use changes are implemented at Mid-Level Super Output Area (MSOA) level rather than at LAD level. This is a much finer level of detail than LAD and there are 645 MSOAs in the study area. The proportion of total employment in the 22 sectors identified for potential land-use changes due to the NPR scheme in each MSOA were estimated and are shown in Figure 8.10.

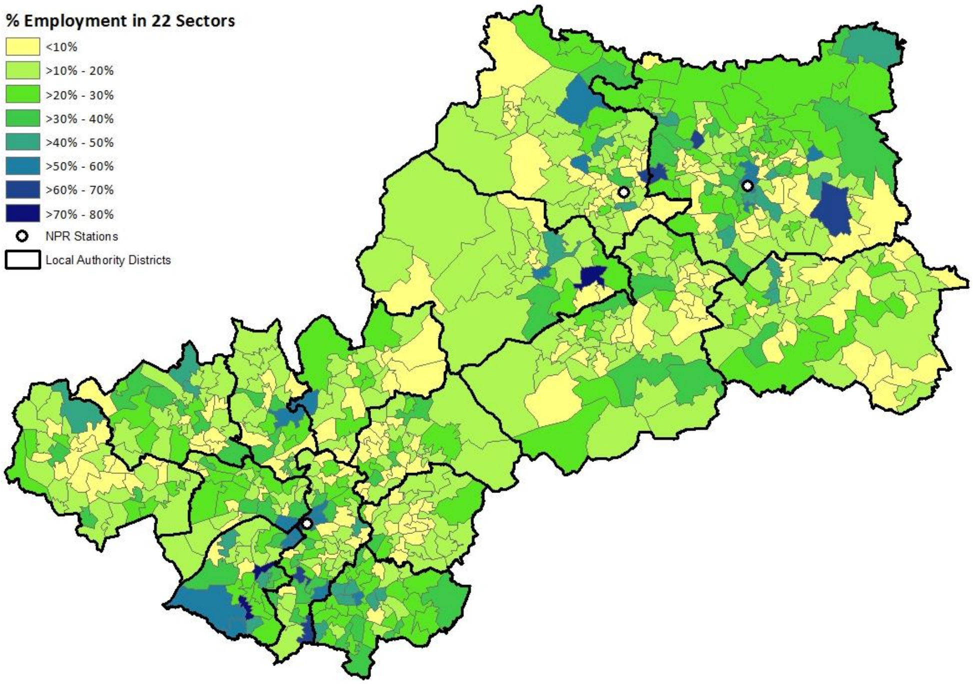

Figure 8.10 % Employment in the 22 Sectors selected for land-use changes due to the NPR scheme (2016)

Figure 8.10 shows that there is a wide variation in the proportion of employment in the 22 sectors across the study area ranging from 0.6% to 77.9%. In Greater Manchester the highest proportion of employment in the 22 sectors are in Manchester, Salford, Stockport and also Trafford which includes Manchester Airport. In West Yorkshire the highest proportion of jobs in the sectors are in the centre and to the east of Leeds, the east of Bradford and the market town of Halifax in Calderdale.

A frequency distribution of LQs for the 22 sectors in the 645 MSOAs is shown in Figure 8.11. As expected there is a much wider range of LQs for the 22 sectors across the MSOAs than for the analysis by LAD outlined above. The highest LQ in the study area is 129 for publishing in an MSOA in Bradford but 52% of LQs at MSOA level are zero and 86% are less than 1.

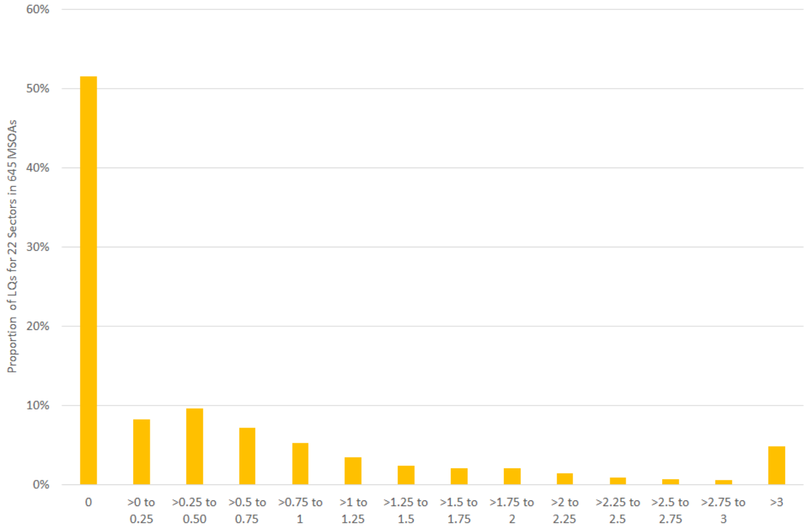

Figure 8.11 % Frequency Distribution of Location Quotients for MSOAs for the 22 Sectors Selected for Land-Use Changes due to the NPR scheme (2016)

A comparison was made of the estimated LQs for the 22 sectors at MSOA and LAD level to determine if using a more or less disaggregate geography would affect the scale of land-use changes implemented in the case study. Some of the results of this analysis are shown in Table 8.3. The first column of the table shows the SIC code of the 22 sectors which have been selected for land-use change due to the NPR scheme. In the second column the maximum LQ estimated for each of the 22 sectors at MSOA level is shown and the MSOA in which it was estimated for is shown in the third column. The fourth column shows the LAD in which the MSOA with the maximum LQ in the sector is located and the final column shows the LQ estimated for this LAD.

Table 8.3 shows that the maximum LQ estimated at MSOA level ranges from 6.95 in SIC 62 (computer programming & consultancy) to 128.74 in SIC 58 (publishing). The maximum LQs of all 22 sectors are of significant magnitude which shows that MSOAs can be highly specialised in particular sectors. The estimated LQs for the corresponding LAD shown in the final column of Table 8.3 show that the large LQs estimated at MSOA level do not always correspond with high values at LAD level. Of the 22 sectors 7 (32%) of them have LQs at LAD level which are less than one which indicates the LAD has a lower proportion of jobs in the sector compared to the national average. One of the most extreme examples of this is SIC 65 (insurance &

pension funding) which has a maximum LQ of 53.35 in an MSOA in the centre of Leeds but the LQ across the whole of the Leeds LAD is only 0.82.

Table 8.3 Comparison of the Maximum LQ in the Study Area for the 22 Sectors at MSOA level Compared to the LQ in the corresponding LAD

2007 SIC Code	Maximum LQ across all MSOAs	MSOA	LAD of MSOA	LQ in LAD
58	128.74	E02002212	Bradford	2.87
59	15.86	E02002383	Leeds	0.96
60	90.97	E02001184	Salford	16.92
61	26.17	E02001096	Manchester	1.36
62	6.95	E02001053	Manchester	0.92
63	16.23	E02000984	Bolton	0.54
64	29.07	E02002259	Calderdale	3.10
65	53.35	E02002357	Leeds	0.82
66	23.82	E02002192	Bradford	0.52
68	15.73	E02000988	Bolton	1.75
69	18.47	E02001282	Trafford	2.82
70	19.96	E02002220	Bradford	0.89
71	28.73	E02002370	Leeds	1.12
72	24.78	E02002419	Leeds	0.99
73	31.68	E02001152	Rochdale	1.96
74	30.50	E02001252	Tameside	1.02
77	33.54	E02001272	Trafford	2.68
78	20.62	E02002262	Calderdale	4.39
79	23.99	E02001011	Bolton	1.70
80	28.74	E02002445	Wakefield	1.46
81	16.87	E02001259	Trafford	2.04
82	12.96	E02002395	Leeds	1.75

This analysis has shown that specialisation in sectors can be highly localised and a high level of specialisation in a sector within MSOA may not be apparent at LAD level. This suggests that determining levels of specialisation based on LQs at LAD level could miss high levels of specialisation at MSOA level. In this case study the LQs by sector and location in the base year are used to identify which locations will realise land-use changes due to the NPR scheme. The differences between the estimated LQs at MSOA and LAD level suggests that the level of geographical disaggregation selected is important as it will affect the land-use changes implemented and therefore the estimated benefits. In addition, as in the abstract modelling undertaken in Chapter 7 one of the types of land-use changes implemented in the case study is the movement of jobs between locations. If these changes were implemented at LAD level this would not allow the movement of jobs between MSOAs within a LAD or between MSOAs in different LADs which would also affect the scale of the estimated benefits. These differences between undertaking analysis at LAD and MSOA level suggest that for the accurate modelling of changes in land-use the analysis should be undertaken at a detailed geographic level such as MSOA rather than a more aggregate level such as LAD.

8.3.3 Gross Value Added (GVA) per Worker

To estimate the urbanisation and localisation benefits resulting from the NPR scheme data is required on GVA per worker by sector and location. Ideally, the GVA per worker data would have been obtainable by sector at MSOA level but this data is not available in the UK[73]. For the purpose of the analysis GVA per worker therefore had to be estimated at LAD level using the data which is available.

The UK's Office for National Statistics (ONS) provides estimates of total GVA by LAD for 33 sector groups. These sector groups are based on a combination of the 88 sectors in the 2-digit (2007) SIC level classification which was discussed above. The GVA per worker by LAD for each of these sector groups was estimated by dividing the GVA by sector group sourced from ONS by the number of jobs in the sector groups which was sourced from BRES. The 33 sector groups which the data on GVA per worker by LAD is available were limiting for estimating changes in land-use due to the NPR scheme as the 22 sectors which were identified for potential land-use changes are combined together in 10 of the 33 sector groups. To improve the accuracy of the

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[73] Consideration was given to obtaining wage data from ASHE (Annual Survey of Hours and Earnings) at MSOA level to estimate GVA per worker. However, the sample sizes used in this survey mean the estimated values for the 88 sectors across the economy for individual MSOAs would not have been dependable.

estimation of benefits the GVA per worker for each of the 22 individual sectors by LAD was therefore approximated[74]. These were estimated by factoring the GVA data for the aggregated sectoral groups by LAD using ONS data on GVA by individual sector and metropolitan county (ONS, 2019) and the distribution of employment by individual sector within each metropolitan county from BRES[75]. The GVA per worker by LAD was then estimated by dividing the estimated GVA in each sector by the number of workers.

The localisation and urbanisation benefits in this case study are estimated through the application of elasticities and distance decay factors for manufacturing, construction, consumer services and producer services but the GVA per worker dataset included combinations of sectors with different categorisations. To take account of this two sectors (SIC 18 and SIC 26) were split out from their broader sector groups (SICs 18 to 23 and SICs 24 to 30 respectively) so the appropriate elasticities and distance decay factors could be applied to these sectors. The combination of these changes led to a total of 49 sector groups being used in the analysis which are listed in Table B.1 in Section B.1 of Appendix B.

The estimated GVA per worker by sector and LAD were normalised using the data on GDP per worker by broad industrial groups provided in WebTAG (DfT, 2018d). Each of the 49 sector groups was assigned to one of the broad industrial groups in based on their classification in the UK's WebTAG Guidance (DfT, 2018d) with 'Other' assigned to all remaining sectors. Finally, the GVA per worker values were growthed to the assumed scheme opening year of 2030 using forecast real growth in UK GDP per capita and to 2020 prices using the UK GDP Deflator (DfT, 2017b). The finalised GVA per worker by LAD dataset for the 49 sector groups used in the analysis is shown in Table B.2 in Section B.2 of Appendix B.

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[74] The following combined groups of SICs in the GVA data were split out into their individual sectors: 58-63, 64-66, 72-75 and 78-80.

[75] For example, the GVA per worker for SIC 78 in Bolton was estimated in the following process. In Greater Manchester SIC 78 accounts for 54% of total GVA for sectoral group SIC 78-80 with 37% and 9% in SICs 79 and 80 respectively. Within Greater Manchester Bolton accounts for 4.7%, 9.0% and 5.6% of employment in SICs 78, 79 and 80. These values were multiplied together and similarly for the other nine LADs in Greater Manchester to give an estimate of the proportion of GVA for the sectoral group SICs 78-80 in each of the three individual sectors by LAD. For Bolton these proportions were 2.6% (SIC 78), 3.3% (SIC 79) and 0.5% (SIC 80) which were used to estimate how the total GVA in Bolton (£112mn) for sectoral group SICs 78-80 were divided between the three individual sectors. For example, for SIC 78 this was estimated as (2.6%/(2.6% + 3.3% + 0.5%))*£112mn=£45mn.

8.3.4 Wage Rates

Data on wages by sector in the study area at regional were obtained from the UK Annual Survey of Household Earnings (ASHE). This data was analysed to understand the scale of wage differentials between sectors by location which could impact on the likelihood of workers moving sector which is how inter-sectoral migration in the system dynamics model was modelled. This dataset was not used directly in the case study but the analysis is presented in Section B.3 of Appendix B.

8.4 Methodology and Scenario Test Definitions

In this section the methodology which was used in the case study is outlined. The assumptions on the changes in generalised journey times due to the NPR scheme are presented first in Section 8.4.1. This is followed in Section 8.4.2 by the methodology which was used for the fixed land-use (static clustering) scenarios and in Section 8.4.3 by the methodology which was used for the variable land-use (dynamic clustering) scenarios.

8.4.1 Changes in Generalised Journey Times due to NPR Scheme

In the analysis the impact of the proposed Northern Powerhouse Rail (NPR) line between Manchester and Leeds is tested[76]. The NPR scheme will lead to a significant journey time reduction for rail trips between the two cities of approximately 20 minutes from the current journey time of 52 minutes. The final specification of NPR is still to be determined but it is expected that NPR services will also stop at the city of Bradford[77] which is located between Manchester and Leeds. The current journey time by rail between Bradford and Manchester is approximately 60 minutes and following the opening of the NPR scheme this is expected to fall significantly to 22 minutes (Bradford Council, 2019).

There are also planned to be significant reductions in the rail journey time between Bradford and Leeds due to the NPR scheme. The current rail journey time is 22 minutes and it is expected that this will fall by approximately 13 minutes based on the

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[76] As highlighted in Section 8.2 the scope of this case study is only the impact of the NPR scheme between Manchester and Leeds. NPR services may also serve areas outside the study area such as Liverpool, Hull and Newcastle but these are not considered in this case study.

[77] Bradford Interchange station or a new parkway station are the most likely options for NPR services stopping in Bradford (Bradford Council, 2019). For the purposes of the analysis it is assumed that NPR services will stop at Bradford Interchange station.

latest proposals[78] (Bradford Council, 2019). In the case study this reduction was not applied for all trips between Bradford and Leeds as there is an existing railway line[79] running between northern parts of the Bradford LAD and Leeds which is likely to remain quicker than using the NPR line. To take account of this the Bradford LAD was divided into Bradford (North) (MSOAs E02002183 to E02002204) and Bradford (South) (MSOAs E02002205 to E02002243) and the GJT reduction due to NPR was only applied for trips between MSOAs in the south of the Bradford LAD and Leeds.

The list of the assumed changes in GJTs for public transport trips by LAD in the do-something situation are shown in Table 8.4. These changes are applied to the MSOAs within each LAD to give a do-something PT GJT matrix at MSOA level.

Table 8.4 Changes in GJT (minutes) for Public Transport trips in the Do-Something

LAD Pairs	PT GJT Change (mins)
Greater Manchester LADs <-> Leeds	-20
Greater Manchester LADs <-> Wakefield	-20
Greater Manchester LADs <-> Bradford (South)	-38
Greater Manchester LADs <-> Bradford (North)	-38
Greater Manchester LADs <-> Calderdale	0
Greater Manchester LADs <-> Kirklees	0
Bradford (South) <-> Leeds	-13
Bradford (South) <-> Wakefield	-13
Bradford (North) <-> Leeds	0
Bradford (North) <-> Wakefield	0

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[78] A 13 minute reduction was applied based on the proposed future journey time of 7 minutes compared to the current journey time between Leeds and Bradford Interchange of approximately 20 minutes.

[79] This is the railway line which runs between Leeds and Bradford Forster Square via Shipley and is shown in Figure 8.3.

8.4.2 Static Clustering

The urbanisation and localisation benefits of the NPR scheme were estimated first with static clustering in which land-use is assumed to be fixed. As in the abstract modelling presented in Chapter 7 the assumptions on localisation effects were varied to test their impact on the scale of the benefits. The benefits were estimated with low, medium, and high impacts for localisation effects using the same elasticities and distance decay factors by sector as used in the abstract modelling which are shown again in Table 8.5. As in Chapter 7 the assumptions on urbanisation effects were held constant across all three scenarios and are similar to those used in the UK's WebTAG guidelines (DfT, 2018c) so the impact of varying the localisation assumptions could be tested.

Table 8.5 Definitions of Low, Medium and High Impacts for Localisation Effects

	Impact on Localisation Benefits		
Variable	Low	Medium	High
Manufacturing Urb Elasticity	0.02	0.02	0.02
Manufacturing Loc Elasticity	0.04	0.07	0.10
Producer Services Urb Elasticity	0.12	0.12	0.12
Producer Services Loc Elasticity	0.02	0.05	0.08
Consumer Services, Construction & Other Urb Elasticity†	0.04	0.04	0.04
Consumer Services, Construction & Other Loc Elasticity†	0.01	0.02	0.03
Manufacturing Urb DDF†	1.0	1.0	1.0
Manufacturing Loc DDF†	1.8	1.5	1.2
Producer Services Urb DDF	1.7	1.7	1.7
Producer Services Loc DDF	2.0	1.9	1.8
Consumer Services, Construction & Other Urb DDF	1.7	1.7	1.7
Consumer Services, Construction & Other Loc DDF	2.0	1.9	1.8

† Some light manufacturing sectors are particularly reliant on access to urban markets (SICs 18, 26, 58 & 59) and are assumed to have the same elasticities as applied for consumer services, construction & other but the distance decay factor for manufacturing.

8.4.3 Dynamic Clustering

The urbanisation and localisation benefits of the NPR scheme were also estimated with dynamic clustering in which land-use is variable. It was assumed that the land-use changes due to the NPR scheme would take place in the 22 sectors which were identified in Section 8.3.2 above. The types of land-use implemented are similar to those undertaken in the abstract modelling in Chapter 7 and are:

- Changes in sectoral composition (based on changes in sectoral employment within MSOAs); and,
- Changes in sectoral concentration (based on movement of sectoral employment between MSOAs).

For both types of land-use change it was assumed that an MSOA would gain jobs in the sectors in which it was initially specialised. These were defined as the comparative advantage sectors of an MSOA and were assumed to be the sectors in MSOA had an LQ of greater than one[80]. The estimated increases in these sectors in each MSOA were based on applying an elasticity of changes in land-use with respect to changes in GJT. The change in GJT used for each MSOA was calculated as the change in average inter-city GJTs[81] to and from all other MSOAs weighted by employment in those MSOAs to reflect that trips are more likely to and from locations with a higher number of jobs.

The increase in employment in zone *i* in the sectors in which it has a comparative advantage CA, $\Delta Employment_i^{CA}$, was estimated using the following formula[82]:

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[80] The value of 1.00 was chosen but consideration was given to using a higher value such as 1.25 which is given as the threshold for a sector which exports significant volumes from its location (McLean and Voytek, 1992). The LQs in many producer service sectors in the MSOAs in the study area, however, are dampened by the presence of London in the Great Britain data which is highly specialised in many of these sectors. This means that there are lower LQs in the study area even though relative to other MSOAs some have much higher LQs than others which may indicate they are exporting to other MSOAs within the study area.

[81] This is defined as trips between Greater Manchester and West Yorkshire. The impacts of the reduction in GJTs due to NPR between the Bradford and Leeds on land-use were not considered as the centre of the two cities are only 13km apart and the primary focus of this thesis is inter-city impacts.

[82] For expediency in the case study the changes in sectoral concentration land-use changes were estimated slightly differently to how they were implemented in the abstract modelling in Chapter

$$\Delta Employment_i^{CA} = \left(\frac{\overline{ICGJT}_{ij}^{DS}}{\overline{ICGJT}_{ij}^{DM}}\right)^{-\sigma} \times \left(\frac{20}{\overline{ICDIST}_{ij}}\right)^{\varphi} \qquad (8.2)$$

where $\overline{ICGJT}_{ij}^{DM}$ and $\overline{ICGJT}_{ij}^{DS}$ are the average inter-city journey time in the do-minimum and do-something situations respectively between zone *i* and destination zone *j*, $\overline{ICDIST}_{ij}$ is the average inter-city distance between zone *i* and destination zone *j*, σ is an elasticity for the change in land-use with respect to GJT and φ is an elasticity for the decline in trade impacts over distance. The latter is to take into account the consistent finding from the empirical literature that the level of trade declines as the distance between locations increases (Disdier and Head, 2008). As in Chapter 7 this was applied based on the distance between the cities relative to 20km as it was assumed that below this distance cities would be effectively adjacent and no decline in inter-city trade impacts over distance would take place.

The values for the two elasticities in equation 8.1 were based on those used in the abstract modelling in Chapter 7 which were informed by the empirical literature discussed in Section 2.4 of Chapter 2. A value of -0.5 was used for the elasticity for changes in land-use with respect to GJT (Gibbons et al., 2019) and an elasticity of -0.9 was used for the decline in trade impacts to distance (Disdier and Head, 2008). The estimated increase in employment in the sectors in which each MSOA is initially specialised in for both types of land-use change is shown in Figure 8.12.

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7. In Chapter 7 the movement of jobs was applied for all tradable service sectors and not just those in which a zone had a comparative advantage as in the case study. In addition, as shown in equation (8.3) it is assumed these increases in jobs are compensated by all other zones in the study area rather just within each city as in Chapter 7. These differences are not expected to have a significant impact on the scale of the estimated benefits.

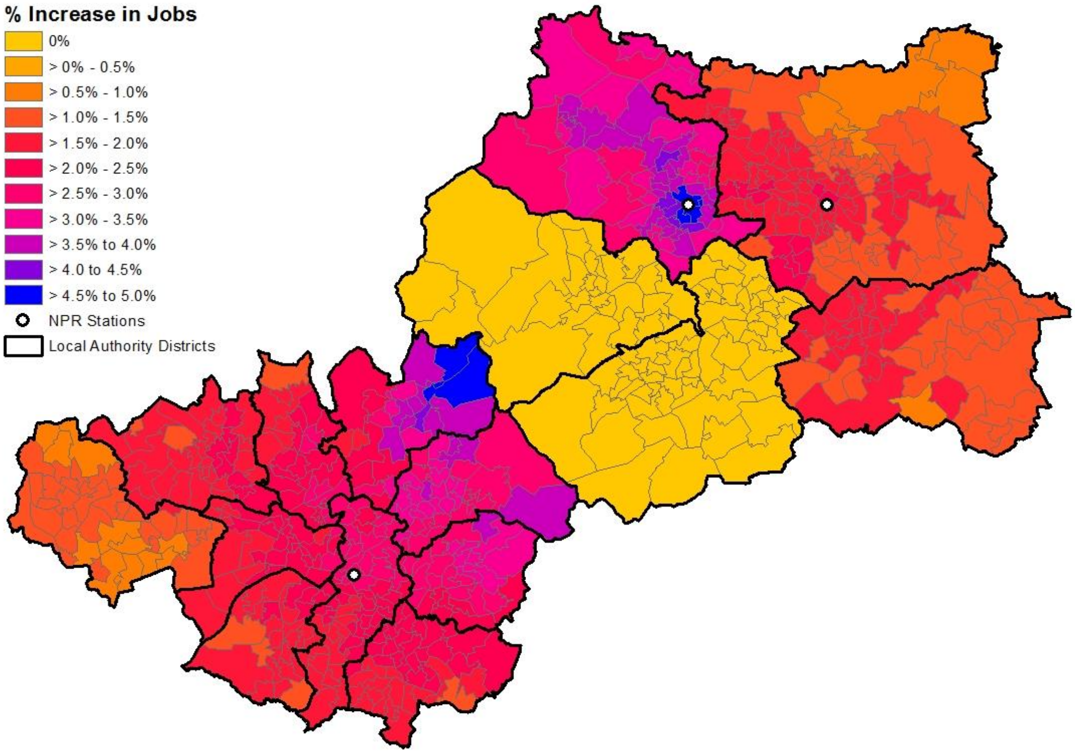

Figure 8.12 % Increase in jobs in sectors MSOAs are initially specialised in

Figure 8.12 shows that there are no estimated increases in jobs in Calderdale and Kirklees in the centre of the study area. This is because there are no changes in GJTs in these locations as they are assumed to be bypassed by the NPR scheme. In the other MSOAs across the study area the increases in jobs in their specialisms range from 0.8% to 4.8% and the mean increase is 2.2%. The highest increases are in the locations with the greatest proportional reductions in average inter-city GJT such as in the MSOAs which are either side of the centre of the study area. The increases in specialisation are generally higher across the MSOAs in Greater Manchester than in Leeds and Wakefield in the east of the study area. This is because the MSOAs in Greater Manchester gain from the 40 minute reduction in PT GJTs to and from Braford whereas the MSOAs in Leeds and Wakefield only gain a reduction of 20 minutes in PT GJTs to and from Greater Manchester

In the development of the do-something land-use matrices it was assumed that the total number of jobs in the study area remained constant. This meant that the increases in jobs in sectors which MSOAs were specialised in had to be balanced by reductions elsewhere. For the changes in sectoral composition type of land-use change the increases in jobs were assumed to be balanced by reductions in other sectors within the same MSOA. For the changes in concentration type of land-use change the increases in jobs were assumed to be balanced by reductions in the same sector in other MSOAs. It was assumed that the reductions in jobs for both types of land-use change would only take place in the 22 sectors identified for land-use changes due to the NPR scheme and no changes were made to employment in any of the other sectors.

For the changes in sectoral composition type of land-use change it was assumed that increases in jobs in a sector in an MSOA would be balanced by reductions in jobs in which the MSOA was not specialised. These were defined as sectors in which the MSOA has an LQ of less than one. The reductions in employment in zone *i* in the sectors the zone does not have a comparative advantage (NCA) in, ΔEmp_i^{NCA}, are given by:

$$\Delta Emp_i^{NCA} = -\sum_{CA} \Delta Emp_i^{CA} \times \left(\frac{Emp_i^{NCA}}{\sum_{NCA} Emp_i^{NCA}} \right) \tag{8.3}$$

where $\sum_{CA} \Delta Emp_i^{CA}$ is the sum of increases in employment across all comparative advantage sectors *CA* in zone *i*, Emp_i^{NCA} is the initial employment in non-comparative advantage sector *NCA* in zone *i* and $\sum_{NCA} Emp_i^{NCA}$ is the sum of employment across all non-comparative advantage sectors *NCA* in zone *i*.

For the changes in sectoral concentration type of land-use change it was assumed that increases in jobs in a location would be compensated by reductions in other MSOAs which had an LQ of less than one in the sector. The formula for the change in employment in non-comparative sector *NCA* in zone *i*, ΔEmp_i^{NCA}, is given by:

$$\Delta Emp_i^{NCA} = -\sum_{i} \Delta Emp_i^{CA} \times \left(\frac{Emp_i^{NCA}}{\sum_{i} Emp_i^{NCA}} \right) \tag{8.4}$$

where $\sum_{i} \Delta Emp_i^{CA}$ is the sum of employment in comparative advantage sector *CA* across all zones *i*, Emp_i^{NCA} is the initial employment in zone *i* in non-comparative advantage sector *NCA* and $\sum_{i} Emp_i^{NCA}$ is the sum across all zones *i* of employment in non-comparative sector NCA.

Minor adjustments were made to the estimated land-use changes in the few instances where there were very high levels of specialisation in the base year. For the changes in sectoral composition type of land-use change there were five MSOAs which this applied and there were two types of adjustment. Firstly, there were two MSOAs which did not have an LQ of less than one in any of the 22 sectors identified for land-use changes. In these MSOAs no changes in sectoral composition were applied. Secondly, there were three MSOAs in which the estimated increase in employment in the sectors they were specialised in was greater than the total number of jobs in the sectors it was not specialised. These MSOAs were in Bradford (E02002212 and

E02002236) and Manchester (E02006916). In these MSOAs the increase in jobs were applied up to the point where there were no more jobs in the sectors the MSOA was not specialised in.

There were also an adjustment made for the changes in sectoral concentration type of land-use change as it was found that programming and broadcasting (SIC 60) was highly concentrated in the study area. In this sector there were no jobs in 628 of the 645 MSOAs in the study area and 74% of all jobs in the sector were in one MSOA in Salford. This MSOA is the location of the MediaCityUK cluster which contains offices and studios for major media companies such as the BBC and ITV. For this sector no changes in sectoral concentration were applied as it was assumed that this sector was already so highly concentrated that no further increases would be likely to result from the NPR scheme.

A variable land-use scenario was also undertaken with the two types of land-use change combined. In total six scenarios were undertaken which are summarised in Table 8.6.

Table 8.6 Scenario Definitions

	Scenario					
	Static Clustering			Dynamic Clustering		
Assumptions	S1	S2	S3	D1	D2	D3
Low Localisation Impacts	✓					
Medium Localisation Impacts		✓		✓	✓	✓
High Localisation Impacts			✓			
Changes in Sectoral Composition				✓		✓
Changes in Sectoral Concentration					✓	✓

8.5 Results and Discussion

The urbanisation and localisation benefits were estimated for the static and dynamic clustering scenarios and are outlined in turn below. This is followed by an estimate of the impact of the inclusion of localisation effects and land-use changes on the total present value of benefits (PVB) of the NPR scheme.

8.5.1 Static Clustering Scenarios

The estimated benefits per annum for the low (S1), medium (S2) and high impact assumptions (S3) for localisation effects are shown in Table 8.7. The results show that varying the assumptions on localisation effects has a significant impact on the scale of the benefits. With medium impact assumptions localisation benefits were estimated at £69.0mn per annum compared to £28.0mn per annum with low impacts and £117.7mn per annum with high impacts. The assumptions used for urbanisation effects were the same across the three scenarios and urbanisation benefits were therefore consistent at £149.2mn per annum.

The results shows that a high proportion of localisation and urbanisation benefits are in the three local authorities of Manchester, Bradford and Leeds in which the three NPR stations are located. In the medium impacts scenario (S2) the total benefits in these three local authorities summed to £151.6mn p.a. (69%) which is significantly higher than their share of total jobs in the study area of 44%. Bradford realises a disproportionately high proportion of total benefits across the study area (27%) relative to employment (8%). This is because Bradford realises the most significant journey time reductions due to the NPR scheme as it currently has no station on the TransPennine line which is the present main railway link between West Yorkshire and Greater Manchester. In addition, Bradford realises significant journey time reductions to Leeds and Wakefield within West Yorkshire as a result of the NPR scheme. There are no benefits in the two local authorities in the centre of the study area (Calderdale and Kirklees) as these locations do not realise any reductions in GJT due to the NPR scheme.

One of the objectives of the case study was to test how the relative benefits from localisation and urbanisation compare to those estimated in the abstract modelling in Chapter 7. In the case study Manchester and Leeds are 57km apart and the relative benefits would therefore be expected to lie within the range of the abstract modelling results for the distances between cities of 20km and 150km. For the low impact localisation assumptions the localisation benefits were 24% (20km) and 18% (150km), for the medium impact assumptions they were 54% (20km) and 50% (150km) and for the high impact assumptions they were 90% (20km) and 97% (150km)[83]. The estimates from the case study can be calculated using the results in Table 8.7. Localisation benefits as a proportion of urbanisation benefits are 19% with

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[83] These percentages were estimates using the estimated localisation and urbanisation benefits in Table 7.11 in Chapter 7.

low impact assumptions (S1), 46% with medium impact assumptions (S2) and 79% with high impact assumptions (S3).

These estimates lie within or just below the expected ranges suggested by the abstract modelling for each of the three types of impacts. The lower estimates in the case study are explained by the low relative benefits from localisation effects in Leeds and Manchester compared to the average for the study area. In Scenario S2 localisation benefits as a proportion of urbanisation benefits are 38% in Leeds and 40% in Manchester compared to 46% for the study area as a whole. Leeds and Manchester account for a high proportion of total benefits which reduces the proportion of benefits due to localisation effects across the study area overall.

The lower estimates for Leeds and Manchester arise from the more disaggregate analysis in the case study in which the most significant increases in GJTs are in the areas in close proximity to the NPR stations. The MSOAs around the Manchester and Leeds NPR stations have a high proportion of jobs in consumer and producer services (as shown in Figure 8.10) which are assumed to have larger urbanisation elasticities than in other sectors. These assumptions mean that the generalised journey time reductions leads to higher benefits from urbanisation effects in these areas. The discrepancy between the relative benefits from localisation in the case study and abstract model for Leeds and Manchester is greatest for the high localisation impact scenarios. This is because localisation impacts are assumed to decay more rapidly over distance than urbanisation effects. This means that the increase in localisation benefits due to applying the higher impact assumptions for localisation effects is lower in the case study compared to the abstract model as the increases around the Leeds and Manchester NPR stations are more limited than other areas.

The benefits from urbanisation and localisation with the medium impact assumptions are plotted in Figures 8.13 and 8.14 respectively. In Figure 8.13 it can be seen that urbanisation benefits are concentrated in the LADs around the three NPR stations of Leeds, Bradford and Manchester. The urbanisation benefits in these LADs represent 29%, 26% and 15% of the total urbanisation benefits across the study area. Within many of the other LADS there are several MSOAs which benefit significantly more than others. These include Wakefield in West Yorkshire and Rochdale in Greater Manchester and several market towns in the north of the Bradford LAD such as Ilkley, Keighley and Shipley. These reflect the good accessibility from these places to NPR stations which means they realise a high proportional increase in GJTs than others areas and also the relatively high proportion of service sector jobs in those locations. The MSOAs within Calderdale and Kirklees do not realise any urbanisation benefits as they are not directly served by the NPR scheme.

Table 8.7 Urbanisation and Localisation Benefits (£mn p.a., 2030 Values & 2020 Prices) by LAD with static clustering

	Localisation Impact Assumptions								
	Low (S1)			Medium (S2)			High (S3)		
LAD	Urb	Loc	Total	Urb	Loc	Total	Urb	Loc	Total
Bolton	3.5	0.8	4.3	3.5	2.0	5.4	3.5	3.4	6.9
Bury	2.2	0.5	2.6	2.2	1.2	3.3	2.2	2.0	4.2
Manchester	22.2	3.2	25.4	22.2	8.4	30.5	22.2	14.7	36.9
Oldham	4.1	1.1	5.2	4.1	2.5	6.6	4.1	4.1	8.3
Rochdale	3.8	1.2	5.0	3.8	2.7	6.5	3.8	4.2	8.1
Salford	4.9	0.8	5.7	4.9	2.0	6.9	4.9	3.5	8.4
Stockport	6.0	1.1	7.2	6.0	2.8	8.9	6.0	4.9	10.9
Tameside	3.0	0.8	3.8	3.0	1.9	5.0	3.0	3.2	6.3
Trafford	6.0	0.9	6.9	6.0	2.4	8.4	6.0	4.2	10.2
Wigan	1.9	0.4	2.2	1.9	1.0	2.8	1.9	1.7	3.6
Bradford	39.3	8.5	47.8	39.3	20.3	59.7	39.3	33.7	73.1
Calderdale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kirklees	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Leeds	43.9	6.9	50.9	43.9	17.5	61.4	43.9	30.2	74.1
Wakefield	8.4	1.9	10.2	8.4	4.5	12.9	8.4	7.7	16.0
Total	149.2	28.0	177.3	149.2	69.0	218.2	149.2	117.7	267.0
% Split	84%	16%	100%	68%	32%	100%	56%	44%	100%

Figure 8.14 shows that significant benefits from localisation are concentrated in fewer MSOAs than urbanisation. This is because of the higher distance decay parameters used for localisation effects which means that journey time reductions between Greater Manchester and West Yorkshire have less impact on the scale of

the benefits. Similarly to urbanisation benefits the largest localisation benefits are in Leeds, Bradford and Manchester which account for 29%, 26% and 15% of total localisation benefits respectively which is 67% of the total. The localisation benefits in most other MSOAs are relatively small and concentrated in the smaller urban areas which have good connections to the NPR stations and therefore realise a greater proportional reduction in journey times.

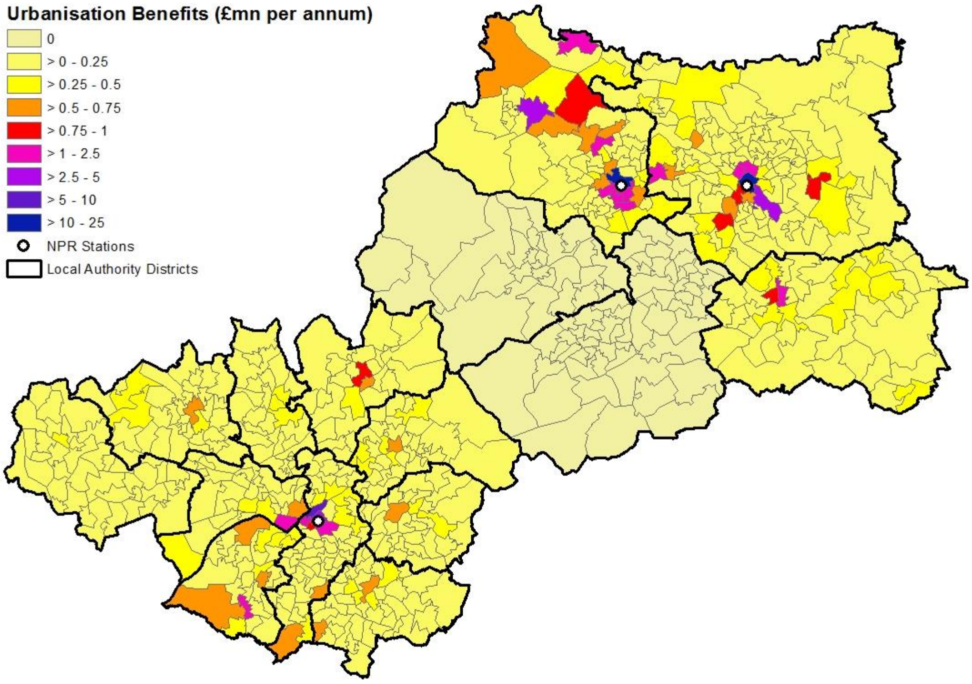

Figure 8.13 Urbanisation Benefits (£mn p.a., 2030 Values & 2020 Prices) with static clustering and medium impacts (S2)

The higher urbanisation and localisation benefits in Leeds and Bradford relative to Manchester is also reflected in the total benefit estimates for the two metropolitan counties. West Yorkshire realises 61% of both urbanisation and localisation benefits in the study area despite only 45% of total employment being located in the metropolitan county. This is explained by two effects. Firstly, as shown in Chapter 3 to 6 reductions in journey times between locations leads to a greater proportional increase in effective density in locations with fewer jobs. Secondly, there are significant journey time improvements within West Yorkshire due to the NPR scheme in addition to the reduced journey times to and from Greater Manchester. The difference in the scale of the estimated benefits between Greater Manchester and West Yorkshire has important implications for the funding and marketing of inter-city projects. If policymakers and residents know that their region will gain less than others as a result of an inter-city scheme they might be less willing to fund such projects and they may prefer to fund intra-city projects where benefits to their local area may be more certain.

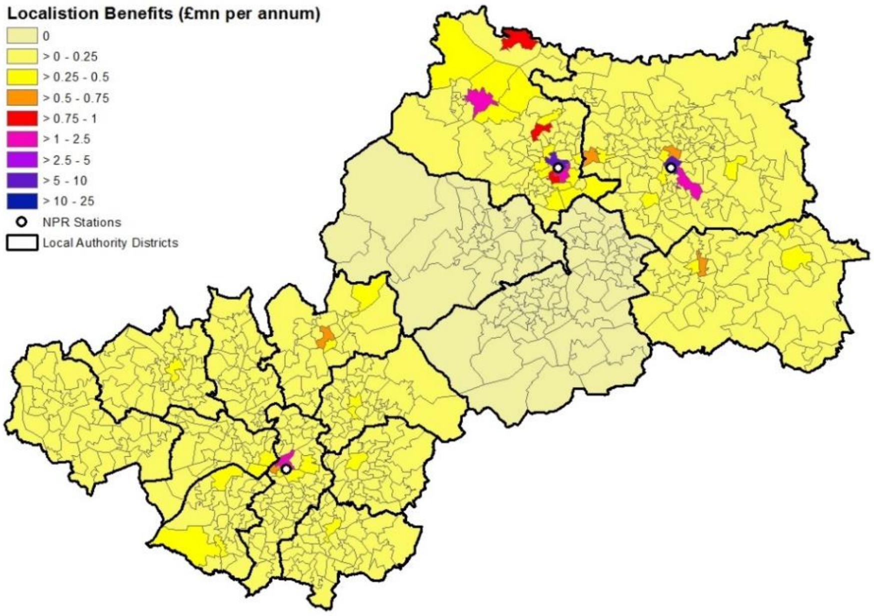

Figure 8.14 Localisation Benefits (£mn p.a., 2030 Values & 2020 Prices) with static clustering and medium impacts (S2)

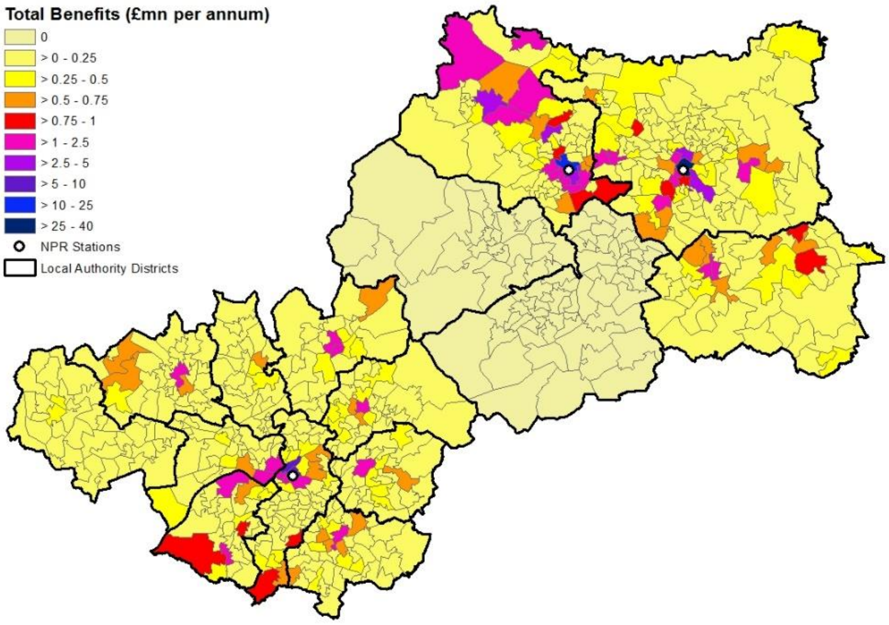

Figure 8.15 Total Benefits (£mn p.a., 2030 Values & 2020 Prices) with static clustering and medium impacts (S2)

Figure 8.15 shows a plot of the total benefits the medium impact localisation assumptions. This highlights that the estimated benefits are concentrated in the areas close to the NPR stations and other locations which realise a significant proportion reduction in journey times such as market towns and urban town centres. Many of the rural areas and other peripheral MSOAs in the study area realise only relatively small urbanisation and localisation benefits.

Plots of the estimated localisation benefits with the low and high impact assumptions are shown in Figures 8.16 and 8.17 respectively. These shows that varying the assumptions on localisation effects has a significant impact on the scale of the benefits. With the low impact assumptions only the MSOAs in the vicinity of the NPR stations realise significant benefits. With the high impact assumptions these areas achieve even larger benefits but there are also significant benefits in many other locations. While the magnitude of the localisation benefits varies significantly between the low, medium and high impact scenarios the distribution of localisation benefits between LADs does not vary as much. For example, Leeds, Bradford and Manchester account for 66% or 67% of total localisation benefits in all three static clustering scenarios.

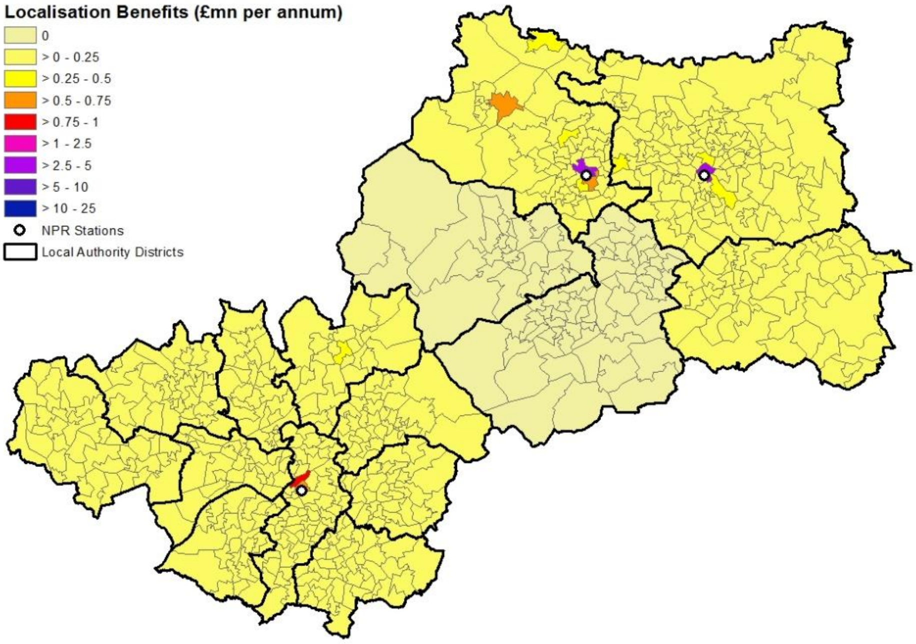

Figure 8.16 Localisation Benefits (£mn p.a., 2030 Values & 2020 Prices) with static clustering and low impacts (S1)

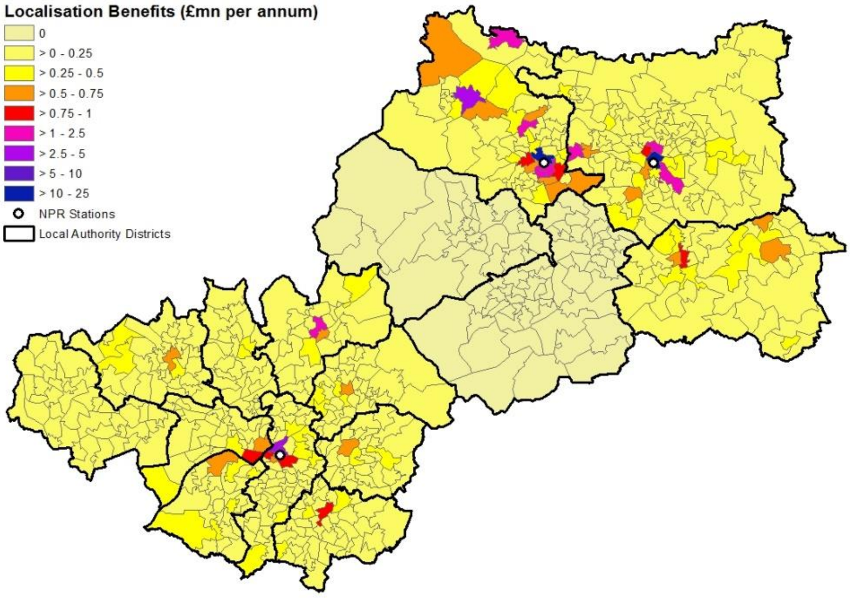

Figure 8.17 Localisation Benefits (£mn p.a., 2030 Values & 2020 Prices) with static clustering and high impacts (S3)

8.5.2 Dynamic Clustering Scenarios

The estimated urbanisation and localisation benefits per annum for the dynamic clustering scenarios for the two separate types of land-use change (Scenarios D1 and D2) are shown in Table 8.8. The percentage change from the benefits estimates for the static clustering scenario with medium localisation impact assumptions (Scenario S2) are also shown so the impact of the introduction of the land-use changes can be identified.

For the changes in sectoral composition within MSOAs scenario (D1) the benefits from urbanisation and localisation effects are estimated at £149.7mn and £79.6mn per annum respectively. In this scenario total employment in each zone is fixed and urbanisation benefits are therefore similar to those in the static clustering scenario which were £149.2mn per annum. Localisation benefits are significantly higher (15%) than the static clustering scenario as MSOAs have become more specialised in specific sectors leading to higher density at sector level. Some of the largest increases in localisation benefits due to the inclusion of land-use changes are in the three local authorities with the NPR stations of Manchester (27%), Leeds (29%) and Bradford (8%). There are also significant gains in the local authorities of Salford (21%) and Trafford (20%) which are located in close proximity to the NPR station in central Manchester.

Table 8.8 Urbanisation and Localisation Benefits (£mn p.a., 2030 Values & 2020 Prices) with land-use changes

	D1			% Change from S2			D2			% Change from S2		
LAD	Urb	Loc	Total	Urb	Loc	Total	Urb	Loc	Total	Urb	Loc	Total
Bolton	3.5	2.1	5.6	0%	7%	2%	3.3	1.8	5.1	-5%	-9%	-6%
Bury	2.2	1.1	3.3	0%	-5%	-2%	2.2	1.2	3.4	2%	4%	3%
Manchester	22.2	10.7	32.9	0%	27%	8%	28.3	14.2	42.5	28%	70%	39%
Oldham	4.1	2.4	6.5	0%	-4%	-2%	4.2	2.5	6.7	1%	1%	1%
Rochdale	3.8	2.8	6.6	0%	5%	2%	3.8	2.7	6.5	-1%	2%	0%
Salford	4.9	2.5	7.3	0%	21%	6%	5.8	2.7	8.5	18%	34%	23%
Stockport	6.0	3.0	9.0	0%	5%	2%	6.4	3.1	9.5	6%	10%	7%
Tameside	3.0	1.9	4.9	0%	-3%	-1%	3.1	1.9	5.0	1%	-1%	0%
Trafford	6.0	2.8	8.9	0%	20%	6%	6.8	3.5	10.2	12%	48%	22%
Wigan	1.9	0.9	2.8	0%	-3%	-1%	1.5	0.5	2.1	-18%	-43%	-27%
Bradford	39.6	22.0	61.6	1%	8%	3%	40.0	21.9	61.9	2%	8%	4%
Calderdale	0.0	0.4	0.4	N/A	N/A	N/A	-0.8	-0.4	-1.2	N/A	N/A	N/A
Kirklees	0.0	0.0	0.0	N/A	N/A	N/A	-0.5	-0.7	-1.2	N/A	N/A	N/A
Leeds	44.2	22.5	66.6	1%	29%	9%	46.9	22.4	69.4	7%	28%	13%
Wakefield	8.3	4.7	13.1	0%	5%	2%	8.1	4.3	12.4	-3%	-4%	-3%

Metro Counties	Urb	Loc	Total	Urb	Loc	Total	Urb	Loc	Total	Urb	Loc	Total
Greater Manchester	57.6	30.1	87.7	0%	13%	4%	65.3	34.1	99.5	13%	28%	18%
West Yorkshire	92.1	49.5	141.6	1%	17%	6%	93.7	47.6	141.3	2%	13%	6%
Total	149.7	79.6	229.4	0%	15%	5%	159.1	81.7	240.8	7%	18%	10%

The estimated urbanisation and localisation benefits for the movement of jobs between MSOAs scenario (D2) are £159.1mn and £81.7mn per annum respectively. In contrast to the changes in sectoral composition scenario (D1) urbanisation benefits are higher (7%) than with static clustering (S2). This is because the movement of jobs between MSOAs has led to employment becoming more concentrated leading to higher overall economic density. As in Scenario D1 the increase in both urbanisation and localisation benefits are highest in Bradford, Leeds, Manchester, Salford and Trafford.

While most LADs realise an increase in benefits due to the introduction of movements of jobs between MSOAs in Scenario D2 some do not. In Wigan, Bolton and Wakefield total benefits are 27%, 6% and 3% lower respectively in D2 than in the static clustering scenario (S2). This is due to the loss of jobs from these locations to MSOAs which gain a greater increase in accessibility due to the NPR scheme. In addition, there are also some disbenefits due to the scheme estimated in Calderdale (-£1.2mn per annum) and Kirklees (-£1.2mn per annum). These LADs are located in centre of the study area and the disbenefits in these locations result from the combination of zero journey time improvements due to the NPR scheme and the loss of jobs to other locations. The estimated disbenefits in some MSOAs is in contrast to the abstract modelling scenarios in Chapter 7 in which all zones realised positive benefits. This was because it was assumed in the abstract modelling that all zone realise inter-city journey time improvements. These results from the case study highlight that in the detailed case when detailed GJT and land-use changes are implemented there may be losers as well as winners with respect to urbanisation and localisation benefits.

The benefits estimates for the scenario with the combination of the two types of land-use change (D3) including a comparison to the central case static clustering scenario (S2) are shown in Table 8.9. As expected the benefits for Scenario D3 are the highest of all scenarios with urbanisation benefits of £159.9mn per annum and localisation benefits of £93.0mn per annum. Total benefits are £252.9mn per annum which is 16% higher than in Scenario S2.

The combination of the two types of land-use changes in Scenario D3 leads to a higher concentration of total benefits than in S2. The LADs of Bradford, Leeds and Manchester in which the three NPR stations are located realise 73% of total benefits compared to 71% in S2. The results in Table 8.9 can also be used to estimate the relative benefits from localisation and urbanisation effects. Localisation benefits are 58% of urbanisation benefits which is similar to the results for the comparable scenario in the abstract modelling in Chapter 7 (Scenario D4) when localisation benefits were estimated to account for 54% of benefits for a 20km distance between two cities and 62% for a 150km distance[84]. The case study estimate supports the finding from the abstract modelling that the incorporation of the land-use changes increases the proportion of benefits due to localisation effects.

Table 8.9 Urbanisation and Localisation Benefits (£mn p.a., 2030 Values & 2020 Prices) with combined land-use changes (D3)

	D3			% Changes from S2		
LAD	Urb	Loc	Total	Urb	Loc	Total
Bolton	3.3	1.9	5.2	-5%	-2%	-4%
Bury	2.2	1.2	3.4	2%	0%	1%
Manchester	28.6	16.7	45.3	29%	100%	48%
Oldham	4.2	2.4	6.6	1%	-3%	-1%
Rochdale	3.8	2.8	6.6	-1%	7%	2%
Salford	5.7	3.2	8.9	17%	55%	28%
Stockport	6.4	3.2	9.7	6%	15%	9%
Tameside	3.0	1.8	4.9	0%	-5%	-2%
Trafford	6.8	4.0	10.8	12%	70%	29%
Wigan	1.5	0.5	2.0	-19%	-44%	-27%
Bradford	40.3	23.7	64.0	3%	17%	7%
Calderdale	-0.8	0.0	-0.7	N/A	N/A	N/A
Kirklees	-0.5	-0.7	-1.2	N/A	N/A	N/A
Leeds	47.3	27.6	74.9	8%	58%	22%
Wakefield	8.0	4.5	12.6	-4%	1%	-2%
Metro Counties	Urb	Loc	Total	Urb	Loc	Total
Greater Manchester	65.5	37.8	103.3	14%	42%	22%
West Yorkshire	94.4	55.2	149.6	3%	31%	12%
Total	159.9	93.0	252.9	7%	35%	16%

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[84] These percentages are calculated from the benefits estimates in Table 7.15 in Chapter 7.

The estimated urbanisation benefits for Scenario D3 are plotted in Figure 8.18[85]. This shows that the areas around the centre of Leeds and Manchester gain significant increases in urbanisation benefits compared to the central case static clustering scenario (S2) which was shown in Figure 8.13. There are also higher benefits in Bradford (7%) but the increases from the static clustering are significantly less than in Manchester (48%) and Leeds (22%). The significantly lower increases in urbanisation benefits in Bradford are because it has a lower proportion of jobs in the 22 sectors for which land-use changes were implemented (21%) than in Leeds (34%) and Manchester (36%). Some of the increases in benefits relative to the static clustering scenario are counterbalanced by falls in some peripheral MSOAs as jobs move away from these locations to those which realise the greatest increases in accessibility due to the NPR scheme. As highlighted above the MSOAs in Calderdale and Kirklees realise disbenefits due to the NPR scheme. The disbenefits are small and reflect that these areas both realise no journey time improvements due to the NPR scheme and lose jobs to the locations which realise the greatest increases in accessibility.

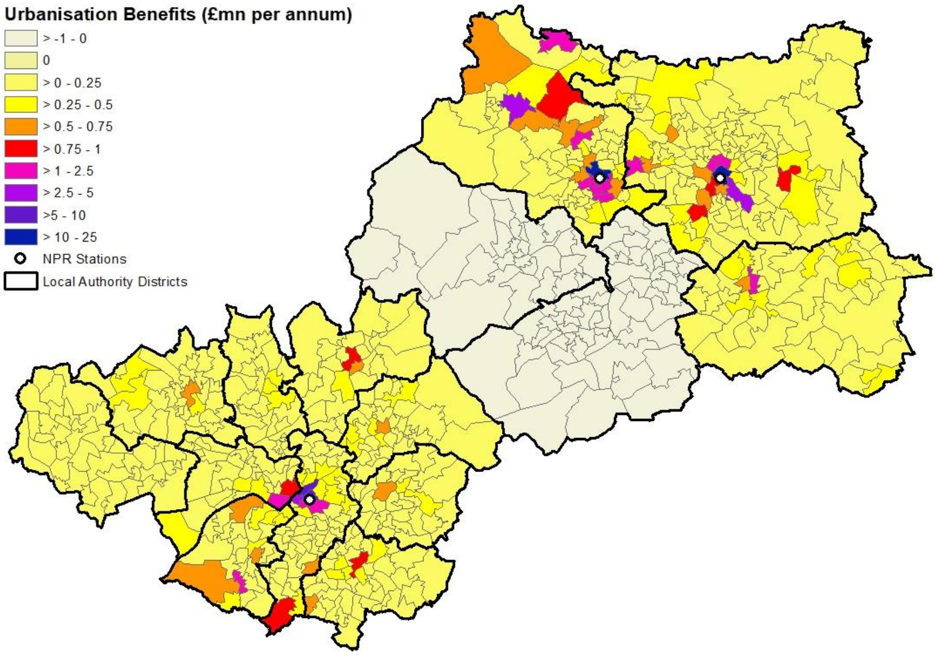

Figure 8.18 Urbanisation Benefits (£mn p.a., 2030 Values & 2020 Prices) with Changes in Sectoral Composition & Concentration (D3)

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[85] Plots of the estimated urbanisation and localisation benefits for Scenarios D1 and D2 are shown in Figures B.5 to B.8 in Section B.4 of Appendix B.

The estimated benefits from localisation effects for Scenario D3 are shown in Figure 8.19. This shows that the inclusion of the assumed land-use changes leads to further localisation benefits in the locations which gained the greatest journey time improvements due to the NPR scheme such as in the areas around the three NPR stations. In addition to the disbenefits in Calderdale and Kirklees there are also disbenefits in some of the peripheral MSOAs particularly in northern and western areas of Greater Manchester. These disbenefits are explained by the movement of employment from these areas to those which realise more significant increases in accessibility. Figures 8.18 and 8.19 highlight that with the assumed land-use changes not all locations would necessarily realise positive urbanisation and localisation benefits from the NPR scheme and there may be losers as well as winners.

The total benefits for Scenario D3 are shown in Figure 8.20. This shows that the areas which benefitted the most in the central case static clustering scenario (S2) which was shown in Figure 8.15 realise the greatest increase in benefits due to the inclusion of the land-use changes. The benefits in the other MSOAs do not change that much and there are small disbenefits in Calderdale and Kirklees and a few other peripheral MSOAs due to the loss of jobs from these areas.

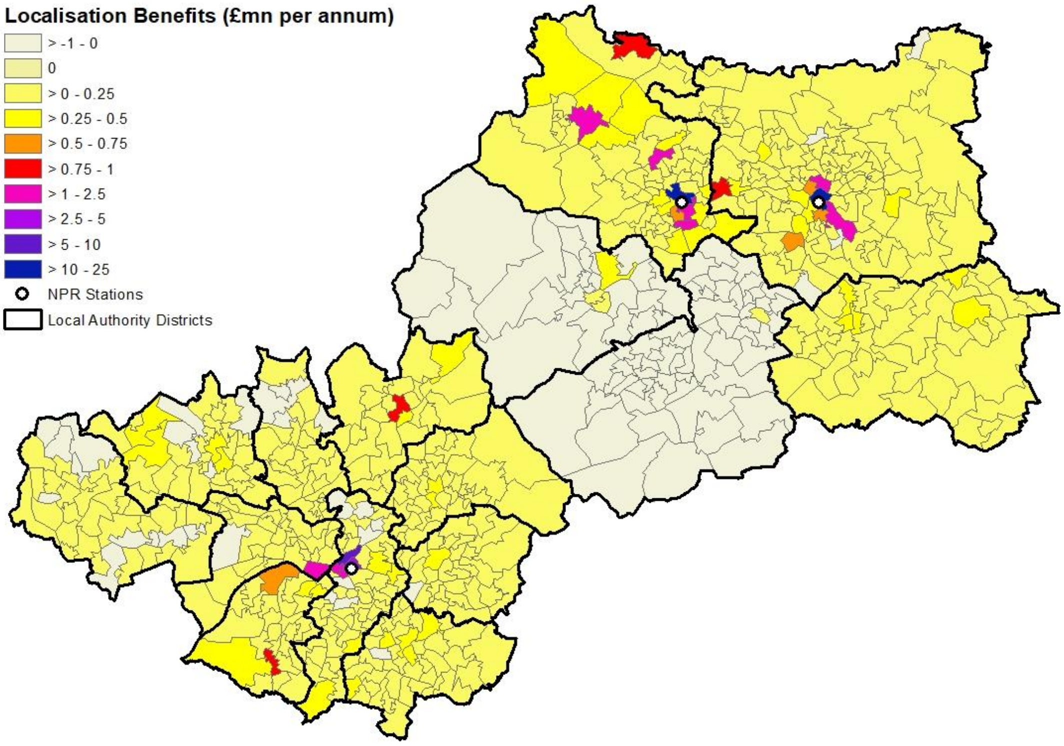

Figure 8.19 Localisation Benefits (£mn p.a., 2030 Values & 2020 Prices) with Changes in Sectoral Composition & Concentration (D3)

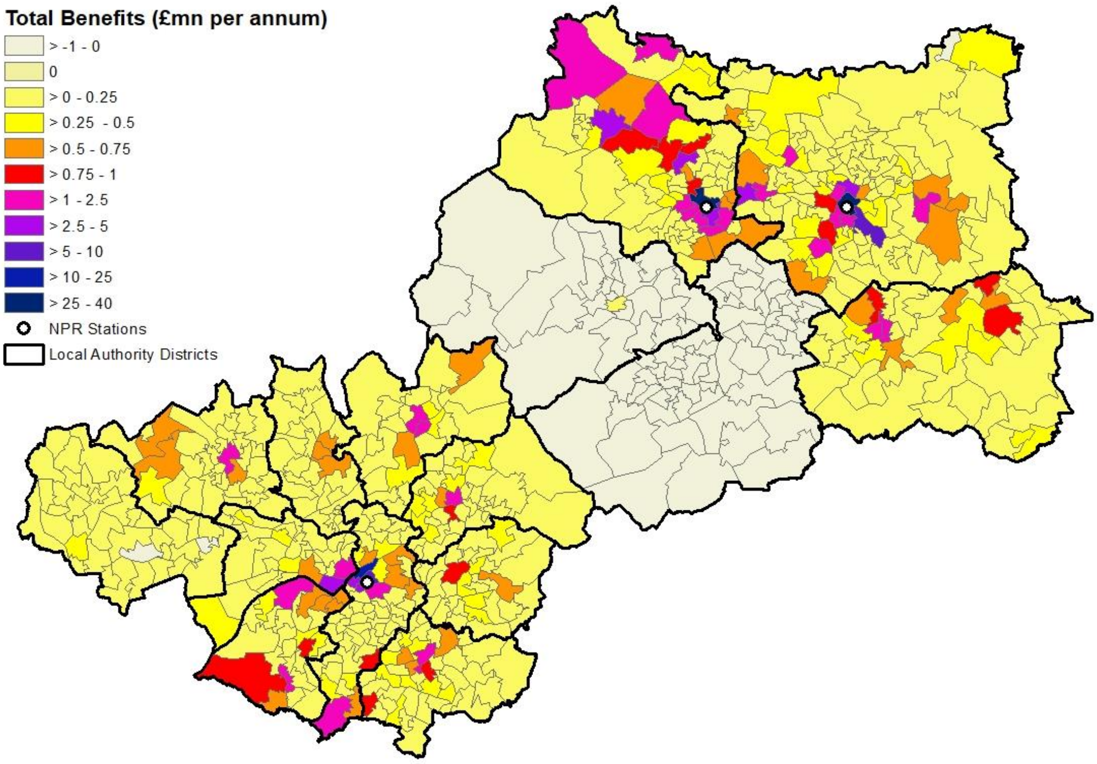

Figure 8.20 Total Benefits (£mn p.a., 2030 Values & 2020 Prices) with Changes in Sectoral Composition & Concentration (D3)

8.5.3 Estimated Increase in the Present Value of Benefits Due to Inclusion of Localisation Effects and Land-Use Changes

The estimated impact on the total present value of benefits (PVB) resulting from the inclusion of localisation benefits and land-use changes was estimated using the same method as in Chapter 7. This is calculated on the basis that if urbanisation benefits with fixed land-use typically account for 10 to 15% of the total PVB for an inter-city scheme (Eddington, 2006, DfT, 2017a) then the increase in PVB can be estimated by comparing the estimated benefits to those with static clustering for urbanisation benefits only. Based on the mid-point of the 10 to 15% range for urbanisation benefits the estimated increase in PVB with localisation benefits and land-use changes are shown in Table 8.10.

So that a comparison could be made to the abstract modelling results from Chapter 7 the increase in PVB was also estimated using the abstract model used in that chapter. In the abstract model a reduction in in-vehicle times for inter-city public transport trips was implemented so that an equivalent percentage reduction was made to those in the NPR case study[86]. As in the case study no reduction in GJTs was applied for highway trips. The benefits in the abstract model were estimated for a 57km distance between the cities which is the distance between the centre of Manchester and Leeds and the estimated increases in PVB are shown in Table 8.11.

Table 8.10 Estimated % Increase in Total PVB in an Economic Appraisal by Scenario for NPR

Scenario	Loc	Urb	Total
Static Clustering			
Low Impacts	2.3%	0.0%	2.3%
Medium Impacts	5.8%	0.0%	5.8%
High Impacts	9.9%	0.0%	9.9%
Dynamic Clustering (with Medium Impacts)			
Combined Land-Use Changes	7.8%	0.9%	8.7%

Table 8.11 Estimated % Increase in Total PVB in an Economic Appraisal by Scenario using Abstract Model for 57km distance between cities

Distance Between Cities	57km		
Scenario	Loc	Urb	Total
Static Clustering			
Low Impacts	2.8%	0.0%	2.8%
Medium Impacts	6.6%	0.0%	6.6%
High Impacts	11.5%	0.0%	11.5%
Dynamic Clustering (with Medium Impacts)			
Combined Land-Use Changes	7.6%	0.7%	8.4%

Table 8.10 shows that with static clustering the inclusion of localisation benefits is estimated to increase the Total PVB of the NPR scheme by 2.3%, 5.8% and 9.9% for low, medium and high impact assumptions respectively. These estimates are similar

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[86] These were estimated based on the proposed 20 minute reduction in average rail in-vehicle times between Leeds and Manchester of 52 minutes: -20/52=-38%.

but slightly lower than the equivalent estimated increases in PVB using the abstract model shown in Table 8.11 of 2.8%, 6.6% and 11.5%. The reason for these differences is that the increases in PVB are calculated relative to the scale of urbanisation benefits with fixed land-use and the proportion of total benefits due to localisation effects are slightly lower in the case study. As highlighted in Section 8.5.2 the reason for this is the lower proportion of total benefits due to localisation effects in Manchester and Leeds which account for significant proportion of total benefits across the study area. The lower proportion of benefits due to localisation in these places is due to more disaggregate zoning system used in the case study which means the greatest increases in GJTs are in the areas around the NPR stations in Leeds and Manchester which have a high proportion of jobs in consumer and producer services. These sectors have higher assumed urbanisation elasticities than other sectors which reduces the proportion of benefits due to localisation effects in these areas and leads to a lower proportion of total benefits due to localisation across the study area as a whole.

The results for the dynamic clustering scenarios shows that the scale of the estimated proportional increases in PVB for the two models are similar. The estimated increases in PVB are 8.7% in the case study compared to 8.4% in the abstract model. The estimated increase in the PVB in the case study is sizeable and suggests that the inclusion of localisation effects and land-use in the economic appraisal of the NPR scheme could have a material impact on the overall value for money assessment if they were included.

8.6 Conclusion

In this chapter a case study was undertaken of the proposed Northern Powerhouse Rail (NPR) scheme which would significantly reduce rail journey times between Greater Manchester and West Yorkshire in the north of England. With static clustering localisation benefits were estimated at 46% of urbanisation benefits using the central case assumptions for localisation effects. This is similar but slightly lower than the proportion estimated in the static clustering scenarios using the abstract model in Chapter 7. The reason for the lower estimate in the case study is the high proportion of benefits due to urbanisation effects in Manchester and Leeds which account for 42% of total benefits across the study area. The higher proportion of benefits due to urbanisation in these areas is due to their high proportion of jobs in producer and consumer services in the MSOAs close to the NPR stations. These sectors have higher assumed elasticities for urbanisation effects than localisation leading to a lower proportion of benefits due to localisation effects.

The estimated urbanisation and localisation benefits of the NPR scheme were found to be unevenly distributed across the study area. In the central case static clustering scenario 70% of the total benefits were realised in Bradford, Leeds and Manchester in which the three proposed NPR stations are located. Bradford was estimated to realise a disproportionately high percentage of total benefits (27%) compared to its share of total jobs in the study area (8%). This is because Bradford realises the most significant journey time improvements due to the NPR scheme as it is not served by the TransPennine line which is the current main railway line between Greater Manchester and West Yorkshire. Significant benefits were also realised in market towns and urban town centres with existing good links to the NPR stations but many of the other MSOAs in the study area realised only relatively small benefits.

The impact of dynamic clustering was tested through the implementation of changes in sectoral composition within MSOAs and the movement of jobs between MSOAs to those which realised the greatest improvements in accessibility. In the scenario test with both of these types of land-use change the estimated total benefits were 16% higher than in the central case static clustering scenario. Localisation benefits were estimated as 58% of urbanisation benefits which is in line with the estimates from the abstract modelling in Chapter 7. The estimated proportion is significantly higher than in the static clustering case (46%) which supports the finding from the abstract modelling that the assumed land-use changes have more impact on the scale of benefits from localisation than urbanisation.

With the introduction of land-use changes the estimated benefits were found to be more uneven. Benefits were lower than with static clustering in peripheral areas due to the assumed movement of jobs away from these areas to those which realised the greatest increases in accessibility. There were also disbenefits for urbanisation and localisation effects estimated for the Calderdale and Kirklees LADs which are located in the centre of the study area. The disbenefits in these LADs arise as they are bypassed by the NPR scheme and assumed to lose jobs due to places which realise increases in accessibility. These results were not realised in the abstract modelling in Chapter 7 where all locations were assumed to gain increased accessibility due to the inter-city journey time improvements. This result shows that with detailed GJT and land-use changes there may be losers as well as winners with respect to urbanisation and localisation benefits.

The estimated benefits were unevenly split between the two metropolitan counties connected by the NPR scheme. In the central case static clustering scenario West Yorkshire realised 61% of total benefits and in the dynamic clustering scenario with both types of land-use change the proportion was 59%. The higher benefits in West

Yorkshire arise even though only 45% of employment in the study area is located in this metropolitan county. This result derives from two effects. Firstly, as shown in Chapters 3 to 6 locations with fewer jobs realise greater proportional increases in economic density due to inter-city journey time improvements than areas with more jobs. Secondly, the NPR scheme will significantly reduce journey times between Bradford and Leeds and Wakefield within West Yorkshire. The uneven split of the estimated benefits between the regions connected by the NPR scheme has implications for the marketing and funding of such projects. If residents and policymakers know their region will gain less from an inter-city scheme they may be less willing to fund inter-city projects and may prefer to invest in intra-urban schemes in which benefits within the local area are more certain.

The estimated benefits were used to estimate the impact on the present value of benefits (PVB) of the inclusion of localisation benefits and land-use changes. With static clustering it was estimated that if urbanisation benefits typically account for 10 to 15% of the total PVB of an inter-city scheme then the inclusion of localisation benefits would increase the total PVB by 5.8% with the central case localisation assumptions. With the two types of land-use the inclusion of localisation benefits and the different types of land-use were estimated to increase the total PVB of the scheme by 8.7%. This is sizeable and suggests that the inclusion of localisation benefits and land-use changes in the economic appraisal of the NPR scheme could affect the overall value for money assessment of the project.

The analysis of land-use data in the base year showed that the level of geographical disaggregation used for modelling changes in specialisation is important. Levels of specialisation were found to be highly localised which suggests that identifying specialisation levels at a high level of geographical aggregation such as LADs could lead to high levels of specialisation in local areas being missed. This means if a more aggregate geographical level of detail was used the estimated land-use changes and therefore benefits would be less accurate. In addition, a more disaggregate zoning system allows the more detailed modelling of the movement of jobs between locations further increasing the accuracy of the analysis. The undertaking of the case study has highlighted that to undertake analysis at such a level there is a need for better quality data. In the UK there isn’t currently data available for GVA per worker by individual sector at a fine level of geographic disaggregation such as MSOA level.

9 Conclusion

9.1 Introduction

This research was motivated by the interest around the world in investing in inter-city transport infrastructure. One of the bases for these schemes is improved economic performance through increased productivity, jobs and output. Current economic appraisal guidelines focus on direct cost savings and over the last 10 to 15 years methods have also been developed to evaluate urbanisation effects within city regions but there has been much less focus on the effects of linking urban areas. These effects include the potential for fostering increased trade and specialisation leading to localisation benefits. The lack of focus on these impacts in economic appraisals is due to the complexity of the processes and the small evidence base which this thesis aims to contribute to. Many inter-city transport schemes require significant capital investment and without dependable methods to assess all of their impacts it raises policy questions about whether it is beneficial to invest in improving links between places.

This research has investigated these effects using two different methods. Dynamic models of trade and specialisation were developed based on the system dynamics approach (Chapters 4 to 6). These were used to understand the dynamic processes and to determine the final endpoint and the conditions required for an inter-city transport scheme to generate changes in specialisation with mobility costs. A case study approach was used to estimate the impact of including localisation effects and changes in specialisation in the appraisal of inter-city connectivity schemes under different scenarios regarding land-use (Chapters 7 and 8). Abstract modelling (Chapter 7) was undertaken using the empirical evidence from the literature to determine under what conditions localisation benefits will be more or less important. A case study (Chapter 8) was then carried out to determine if the results from the real world case support from the findings from the abstract modelling and to identify if there are any differences between the detailed and abstract cases.

The remainder of this chapter is organised as follows. In Section 9.2 an overview of the research findings is provided by chapter and in Section 9.3 the original research contributions are outlined. In Section 9.4 the caveats around the research findings are discussed and the modelling and policy recommendations are presented in Section 9.5. Finally, the recommendations for future research are outlined in Section 9.6.

9.2 Overview of Research Findings

The research objectives were outlined in Section 1.2 in Chapter 1. In Table 9.1 the five objectives are listed again along with the chapters in this thesis in which they were met.

Table 9.1 Meeting of Research Objectives

Objective	Thesis Chapter
1. To expand the economic framework for improved inter-city connectivity to include trade and specialisation and localisation effects	4, 5 and 6
2. To understand the dynamic processes of how inter-city connectivity impacts on economic activity	4, 5 and 6
3. To understand how different transition elements within the system interact with one another	4, 5 and 6
4. To identify the level of additionality to transport user benefits in a cost benefit analysis that increased productivity through specialisation will have	7 and 8
5. To identify differences between the abstract and detailed real world cases	8

To meet Objective 1 a dynamic model was developed to model changes in specialisation resulting from inter-city connectivity improvements. A dynamic specification was chosen to reflect the theory of neo-classical economic growth and the evidence on land-use changes in response to transport improvements which suggest that time lags are important. The model was developed using the system dynamics approach and it incorporated elements of new economic geography models through allowing labour and capital to choose between different combinations of zones and sectors based on the relative monetary returns. The initial economic inputs were set up to reflect Ricardo’s Theory of Comparative Advantage in which each city had a higher share of employment and productivity in one of the sectors. The model included labour, capital, wages, rents and total factor productivity and inter-city transport impacts on the system through business user benefits, urbanisation effects and localisation effects.

The dynamic model was used to meet Objective 2. In the model transport impacts on productivity through business user benefits and changes in effective density which feed through into changes in wage rates and capital rents. Labour and capital are able to respond to the changes by moving between sectors and zones to realise a higher return. As labour moves between different options this further impacts on the effective density for urbanisation and localisation effects leading to further changes in the wage rates and capital rents. Over time these effects can lead to a process of cumulative causation in which labour and capital can become concentrated in specific sectors and zones.

The system dynamics model was also used to meet Objective 3. The model included an innovative structure with a target-based/goal-seeking approach for determining equilibrium in the labour and capital markets. In this archetype the discrepancy between the target and current level of a variable is used to move the system towards equilibrium. In the model the labour and capital markets are interdependent and movements within one market affect the target level in the other. There are delays on how changes in productivity impact on wages and capital rents which affects the targets in both markets and slows down the transition to the steady state.

Objective 4 was investigated in Chapters 7 and 8. In Chapter 7 an abstract model was developed to test the impact of the inclusion of localisation benefits and changes in specialisation in the economic appraisal of inter-city transport schemes. Scenario testing was undertaken with both fixed and variable land-use and the distance between the cities was varied to determine under what conditions localisation benefits will be more important. There is some uncertainty around the localisation parameters and the scale of land-use changes due to changes in GJT and sensitivity tests were undertaken to test the impact on the scale of the benefits of varying each of the assumption. The impact of the inclusion of localisation effects and changes in specialisation on the total present value of benefits in an economic appraisal of an inter-city scheme was also estimated.

In Chapter 8 a case study was undertaken on the proposed Northern Powerhouse Rail (NPR) scheme in the north of England. Fixed and variable land-use scenarios were undertaken to test if the real world case gives similar relative benefits to the abstract case and if they confirm the other findings from Chapter 7. The case study was also used to meet Objective 5. A detailed zoning system and real world data were used and the model results were analysed to determine the extent to which these affected the estimated benefits. The base land-use data was also analysed to determine if the level of geographical disaggregation used in analysis of changes in specialisation is important.

In the remainder of this section the key conclusions from the thesis are summarised.

1) When labour is mobile between zones but capital is fixed the inter-city transport scheme has only a marginal impact on movement between sectors. This model simulations showed that capital being fixed had a greater impact than the transport scheme and therefore when capital was free to move between sectors at no cost there was an equilibrium with full specialisation. This is unrealistic which led to the extension of the model to include mobility costs.

2) With both mobile labour and capital between sectors significant potential benefits are unlocked and it is found that the model tends towards the corner solution with full specialisation. When capital is fixed changes in specialisation are limited by diminishing returns but this restriction does not hold when both labour and capital are mobile between sectors. As workers move into the sector with the highest returns this further increases the effective density of the sector. This leads to higher productivity which feeds through into higher wage rates and capital rents and more workers and capital choose to switch to the sector. This process continues in the same direction until each zone becomes fully specialised in one sector.

3) Mobility costs limit the potential for increased specialisation through investment in inter-city transport. For both labour and capital there are costs associated with moving between sectors which increase the barriers to changes in land-use resulting from an inter-city connectivity scheme. The modelling showed that in order for an inter-city transport scheme to overcome the mobility costs to generate changes in land-use the scheme needs to be significant. With even trip rates between sectors it was estimated that the business user benefits would need to be 140 times the base assumptions to generate changes in specialisation. With uneven trip rates to represent a city’s comparative advantage sectors gaining most from the inter-city transport scheme it was estimated that business user benefits would need to be 2.5 times the base assumptions. This result supports the finding from Venables (2017) who found that inter-urban transport is a necessary but not sufficient condition to generate changes in specialisation.

4) Land-use changes are more likely to occur when the scheme effects differ between sectors and between cities. As highlighted in Conclusion 2) above with even trip rates in each sector it was found that an unrealistic level of business user benefits were required to move the two cities towards further specialisation. When higher trip rates were assumed in the more productive sector in each location the scale of benefits required to change the level of specialisation is smaller but still significant. This suggests that investment in transport links between cities for which there is potential for significant time savings could generate changes in specialisation such as when there are existing good trade linkages between sectors in different cities and therefore a high number of business trips.

5) If changes in specialisation are large the scale of potential localisation benefits were shown to be significant. The dynamic model simulations showed that if a scheme leads to maximum specialisation then the potential localisation benefits were shown to be large and approximately four times the level of urbanisation benefits.

6) The scale of the estimated potential benefits from increased specialisation suggest that there is scope for other policies to promote clusters. The estimated additional benefits from changes in specialisation in Chapters 4 to 6 were estimated to be significant but as highlighted in Conclusion 2) it was found that the threshold for inter-city transport to generate these benefits is high. This suggests that other policies could be used to realise the potential benefits from increased specialisation. These include investment in local labour skills in specific sectors and direct policies to develop clusters such as the moving of several BBC departments to Salford in 2012 which promoted the media cluster located there. These policies could be implemented alongside inter-city connectivity improvements to increase the potential for generating changes in specialisation and localisation benefits.

7) The transition to a new steady state can take several decades. In the dynamic model there is a slow transition to the steady state due to the interaction of the labour and capital markets. As changes occur in one market this impacts on the target level in the other which then feeds back into the target level in the initial market. This process leads to a slow transition to the new steady state in both markets. There is also an assumed delay between changes in productivity and wages and capital rents which further slows down the movements.

8) The inclusion of zonal mobility leads to a different final endpoint in which each city becomes concentrated in the core zone only in the sector in which it has a comparative advantage of each city. With mobility between zones labour and capital can move to the locations with the highest wages and capital rents respectively which are in the core zones where density and therefore productivity are highest.

9) The speed of adjustment to the final endpoint is slower with zonal mobility. With no sectoral or zonal mobility costs it took over 100 years to reach a new steady state with zonal mobility compared to 44 years with mobility between zones. The movement away from the peripheral zone in the sector with the comparative advantage was estimated to take the longest. This is because as a sector becomes more highly concentrated in the core zone this has a spill over effect on the wage rate in the peripheral zone in the same sector. This limits the wage differential between the peripheral zone and the core zones which leads to only a few workers moving in each time step which leads to longer transition times.

10) The inclusion of zonal mobility generates higher urbanisation and localisation benefits. Zonal mobility allows labour and capital to become more concentrated in the core zones of each city where wage rates and capital rents are highest. With equal mobility costs between and within cities urbanisation benefits and localisation benefits were 37% and 27% higher respectively than in the simulation without zonal mobility. With lower intra-city mobility costs within cities than between cities there is a different endpoint with more workers concentrated in the core zone. This leads to even higher benefits and urbanisation and localisation benefits are 74% and 48% higher respectively than in the simulation without zonal mobility.

11) Localisation benefits are approximately 50% of urbanisation benefits with fixed land-use for an inter-city transport scheme. This estimate was based on applying parameters from the empirical literature on localisation and urbanisation effects to abstract data representing the north of England. The estimated proportion was higher for the shorter 20km distance between the cities (54%) than the longest of 400km (45%) as localisation effects diminish more rapidly over distance than urbanisation.

12) The absolute scale of the benefits from localisation and urbanisation are higher for shorter distances between cities. With the central case parameter assumptions for localisation effects the total benefits were £39.7mn per annum for the 20km distance between the cities and £36.3mn per annum and £15.7mn per annum for the 150km and 400km distances respectively. The lower scale of the benefits over the 400km distance is due to the decay of the effects over distance and the assumption that trade impacts decline over distance. These benefits estimates suggest that the inclusion of localisation effects and changes in specialisation will have more impact on the total benefits of inter-city schemes which link places which are closer together.

13) Variable land-use is more important for the scale of localisation benefits than urbanisation. The introduction of the assumed land-use changes increased localisation benefits significantly more than urbanisation benefits. The introduction of the central case land-use changes increased localisation benefits by 16% (150km distance) to 29% (20km distance) compared to 6% (150km distance) to 11% (20km distance) for urbanisation benefits. This suggests that to generate significant localisation benefits over longer distances between cities there needs to be a focus on improving links between cities with good trade linkages. As highlighted in Conclusion 5) there may also be a role for other policies to realise the full scale of the potential benefits.

14) The inclusion of localisation benefits effects and assumed land-use changes were estimated to have a sizeable impact on the total PVB of inter-city schemes. Based on the assumption that urbanisation benefits typically account for 10 to 15% of the total PVB of an inter-city scheme the inclusion of localisation benefits and land-use changes were estimated to increase the PVB by between 1.8% and 13.1% with static clustering. These estimates increase with the scale of the assumed localisation parameters. On the same basis with dynamic clustering the inclusion of localisation effects and changes in urbanisation benefits due to the land-use changes were estimated to increase the PVB by between 2.2% and 22.4%. These increase with the scale of the localisation impact parameters and the scale of land-use changes. These estimates suggest that the incorporation of land-use changes would be likely to affect the value for money outcome of a greater number of inter-urban schemes but the scale of the increase in benefits may still not be enough to transform an otherwise poor business case.

15) With the central case assumptions on localisation parameters and fixed land-use the relative benefits from localisation were estimated at 46% of urbanisation benefits in the NPR case study. This result is similar but slightly less than the estimate in the abstract modelling in Chapter 7 in which localisation benefits were estimated at approximately half of urbanisation benefits. The reason for this is the lower proportion of benefits due to localisation in Manchester and Leeds which account for 42% of the total benefits across the study area. The lower relative benefits from localisation in Leeds and Manchester is due to the high proportion of service sectors in the city centres of these cities for which elasticities are higher for urbanisation than localisation effects. With the central case assumptions on land-use change localisation benefits were estimated at 58% of urbanisation benefits which is similar to the proportion estimated in Chapter 7. This results supports the finding from the abstract modelling that localisation benefits will be more important the greater the changes in specialisation which take place.

16) The spatial distribution of benefits can be uneven and there can be both winners and losers from an inter-city transport improvement. In both the static and dynamic clustering scenarios of the NPR case study it was found that the benefits were concentrated in the areas which gained the highest proportional reductions in generalised journey times. The local authorities of Bradford, Leeds and Manchester accounted for only 44% of total jobs in the study area but with the central parameter assumptions were estimated to account for 69% of total benefits with fixed land-use and 73% with variable land-use. The results also showed that not every location would realise positive benefits from an inter-city transport scheme. Disbenefits arose in locations where there were small or no accessibility improvements and jobs moved away to other areas which realised the greatest accessibility improvements.

17) The inclusion of localisation effects and land-use changes may increase economic benefits significantly more in one region connected by an inter-city scheme than another. It was estimated in the central case scenario of the NPR case study that West Yorkshire would realise 61% of the total benefits from urbanisation and localisation effects compared to 39% in Greater Manchester. This is despite only 45% of total employment being located in West Yorkshire and occurs due to two effects. Firstly, reductions in journey times between locations leads to a greater proportional increase in effective density in the location with fewer jobs. Secondly, there are significant journey time improvements within West Yorkshire due to the NPR scheme in addition to the reduced journey times to and from Greater Manchester which leads to further increases in density. The difference in the scale of the estimated benefits between Greater Manchester and West Yorkshire has important implications for the funding and marketing of inter-city projects. If policymakers and residents know that their region will gain less than others as a result of an inter-city scheme they might be less willing to fund such projects and they may prefer to fund intra-city projects where benefits to their local area may be more certain.

18) The introduction of localisation benefits and changes in specialisation were estimated to have a significant impact on the total PVB in the NPR case study. Based on the evidence that urbanisation benefits account for 10 to 15% of the PVB of inter-city schemes the total benefits with the central case parameter assumptions were estimated to increase the total PVB by 5.8%. This is slightly lower than the estimate with the abstract model with similar assumptions on distances between the cities and journey time improvement due to the scheme. The reason for this is that the increases in PVB are calculated relative to the scale of urbanisation benefits with fixed land-use and the proportion of total benefits due to localisation effects are slightly lower in the case study. As highlighted in Conclusion 15) the reason for this is the lower proportion of total benefits due to localisation effects in

Manchester and Leeds which account for significant proportion of total benefits across the study area. With variable land-use the inclusion of localisation effects and the assumed land-use changes the estimated increase in PVB was 8.7%. This is sizeable and suggests that the inclusion of localisation effects and changes in specialisation could impact on the value for money outcome of the NPR scheme.

19) The level of geographic disaggregation chosen for modelling and appraising changes in specialisation is important. The analysis of the base employment data showed that sectoral employment can be highly localised. This suggests that identifying specialisation levels at a high level of geographical aggregation such as LADs could lead to high levels of specialisation in local areas being missed. This means if a more aggregate geographical level of detail was used the land-use changes and estimated benefits would be less accurate. In addition, a disaggregate zoning system allows more detailed modelling of the movement of jobs between locations further increasing the accuracy of the analysis.

9.3 Original Research Contributions

This research has made several original contributions to the literature. These are:

The development of a dynamic model to represent changes in effective density, productivity and wages resulting from inter-city connectivity improvements. The system dynamics approach was applied to a new area of investigating the impact of inter-city connectivity on trade and specialisation. The model included an innovative structure with a target-based/goal-seeking approach for determining equilibrium in the labour and capital markets which are interdependent. In the model labour and capital respond to changes in effective density through its impact on wages and capital rents.

Summarising the evidence on localisation parameters. Current appraisal guidelines focus on direct cost savings and wider economic impacts such as urbanisation benefits but there is much less focus on localisation benefits and there are no recommended parameters. In this research the evidence on elasticities and distance decay factors was summarised and suggested ranges for the parameters were determined. This work showed that elasticity estimates vary significantly by sector with localisation elasticities higher than urbanisation in manufacturing but higher urbanisation effects in services. The evidence also suggests that localisation effects may dissipate over distance more quickly than urbanisation effects.

Undertaking an abstract economic appraisal of an inter-city scheme and varying the inputs to show which changes have the most significant impact. It has been suggested that localisation benefits resulting from changes in specialisation due to inter-city connectivity could be significant (Rosewell and Venables, 2013, Venables, 2017). They are not, however, typically included in economic appraisals and there is uncertainty around the magnitude of the benefits. In this research an abstract model was developed to estimate the potential for such benefits and to determine under what conditions they are likely to be more or less important. It was found that localisation benefits are typically around 50% of urbanisation benefits and the level of localisation benefits are likely to be higher when there are greater changes in specialisation.

Estimating the magnitude of localisation benefits in a real world appraisal of an inter-city connectivity scheme. To the author's knowledge no economic appraisal of an inter-city transport scheme with localisation benefits and changes in specialisation has previously been undertaken. In this research a study was undertaken of the proposed Northern Powerhouse Rail (NPR) scheme will significantly reduce journey times between the cities of Manchester, Leeds and Bradford in the north of England which. The results supported the findings from the abstract modelling that localisation benefits are approximately 50% of urbanisation benefits. The study showed that in the real world case the distribution of benefits can be uneven and there may be disbenefits in some locations if they lose jobs to the places which realise the greatest increases in accessibility.

9.4 Caveats

There are some caveats around the results from the dynamic model simulations. In in Chapters 4 and 5 the simulations showed that inter-city transport can potentially generate significant changes in specialisation within zones. In reality, however, the extent of these changes in specialisation is unlikely to be fully realised. People may have preferences for working in particular sectors and capital owners may be tied to long-term contracts and there may be inertia about moving sectors. There is also the need for firms to serve local markets which means some sectors are unlikely to become fully specialised in particular locations.

In Chapter 6 the dynamic model was extended to allow labour and capital to move between zones. The model simulations showed that this can lead to further increases in benefits due to the increased concentration of employment in particular zones. These effects, however, are unlikely to be realised fully in reality due to increased competition for land and labour skills and other inputs which are likely to restrict the gains to capital and labour of moving to the core. In addition, workers and capital owners may have preferences for working and living in particular locations which would limit the scale of land-use changes and firms may also desire offices in more than one city.

There is uncertainty around the localisation and urbanisation parameters and land-use changes due to GJT changes which were applied in the modelling in Chapters 7 and 8. To get around this different scenarios were undertaken varying these assumptions to get a feel for the range of the potential benefits.

9.5 Implications of Research

The research has implications both for the modelling and appraisal of inter-urban transport schemes and policymaking. These are discussed in turn in the following sub-sections.

9.5.1 Implications for Modelling and Appraisal

The localisation benefits and changes in specialisation due to inter-city transport improvements have been shown to be significant under certain conditions. This suggests that current modelling and appraisal guidelines are not including some important effects and the economic benefits may be being underestimated.

The analysis of sectoral employment data in the case study showed that levels of specialisation can be highly localised and significant levels of specialisation in an MSOA may not be apparent at LAD level. As highlighted in Conclusion 19) this suggests that identifying levels of specialisation at a more aggregate level could lead to high levels of specialisation in local areas being missed. This means if a more disaggregate geographical level of detail was used the estimated land-use changes and therefore benefits would be more accurate. In addition, analysis at MSOA level would allow more precise modelling of movements of jobs between locations further increasing the accuracy of the analysis.

The results from the case study outlined in Conclusion 16) showed that the localisation and urbanisation benefits can be unevenly distributed and there can be winners as well as losers. This suggests that the distribution of benefits and not only the net effects would be important to consider in an economic appraisal of an inter-city scheme. Detailed modelling could be used to identify the locations which gain the most significant benefits which could be used to inform how projects are funded such as through land value uplift.

9.5.2 Implications for Policy

The results from the dynamic modelling showed that there are potentially significant benefits from generating increases in specialisation. The threshold on mobility costs has to be overcome for changes in specialisation to be realised which as outlined in Conclusion 3) means that an inter-city transport has to be significant. This suggests that to realise the potential for these benefits investment in inter-city transport needs to be focussed on instances where there are strong trade linkages between sectors in different cities and therefore a high number of business trips. In addition, specialisation changes may result from an inter-city transport improvement if the existing links are poor and transport is acting as a constraint on business trips.

As highlighted in Conclusion 6) the threshold for inter-city transport to realise changes in specialisation is high but the scale of the potential benefits suggests that there may be scope for other policies to generate them. These could as investment in local labour skills and direct policies to develop clusters such as incentivising sectors to locate together in a particular location. For example, a number of BBC departments were moved from London to Salford in 2012 which promoted the MediaCityUK cluster located there. These policies could be implemented in isolation or in conjunction with inter-city transport projects to maximise the potential benefits. As highlighted in Conclusion 7) the dynamic modelling also showed that it can take several years or even decades to realise the full development of clusters. This suggests that policy initiative to stimulate increases in specialisation are likely to represent medium- to long-term initiatives.

The modelling results outlined in Conclusions 14) and 18) showed that current economic appraisals are underestimating the benefits from inter-city connectivity schemes. These benefits derive from localisation benefits which are not normally included in economic appraisals and changes in specialisation which can lead to higher localisation and urbanisation benefits. The estimated increases in the present value of benefits were sizeable and suggest that the inclusion of localisation effects and changes in specialisation could impact on the value for money outcome of inter-city schemes but they are unlikely to be enough to transform an otherwise poor business case. The results also show that the benefits increase with the scale of land-use changes which suggests that improving links between cities with good trade linkages will be more likely to generate significant benefits.

As highlighted in Conclusion 16) the case study results showed that if a transport scheme generates changes in specialisation the benefits may be unevenly distributed and some places may realise disbenefits if they lose jobs to other areas.

This has implications for the marketing and funding of such projects. If projects are shown to generate disbenefits this may lead to local policymakers and the public being unwilling to support projects which are expected to have a negative effect on their area. To mitigate this there may be a case for more localised funding for such schemes to reflect the distribution of benefits through, for example, land value capture in which firms in the areas which benefit the most from the transport scheme pay for them. There could also be a case for additional measures to ensure that areas which lose jobs have good access to the high productivity clusters which are stimulated by transport improvements.

9.6 Recommendations for Future Research

The research has highlighted several opportunities for future work in this research field. The dynamic model which was developed in this thesis could be extended further to understand the impact on the end point and dynamics of the inclusion of other potentially important variables. These could include labour skills and vertical linkages between sectors to represent how impacts one sector can spill over into others. A stochastic choice model could also be incorporated into the location choices of labour and capital to get around the all or nothing nature of the model and to include taste heterogeneity.

In this research the analysis has focussed on the potential of inter-city connectivity to generate localisation benefits and changes in specialisation. It would be instructive to undertake similar analysis to establish the potential impact of intra-city connectivity schemes on fostering these effects. This analysis could determine under what conditions inter- and intra- schemes have the most significant impact on generating changes in specialisation. It would also be useful to investigate the extent to which inter- and intra- connectivity schemes could be used in conjunction to stimulate changes in specialisation.

In both the dynamic and abstract modelling undertaken in this thesis the cities were assumed to have a core-periphery structure. It would be useful to understand if the effects would be different in urban areas with different structures such as polycentric cities and urban sprawl. In addition, in both the dynamic and static modelling the study areas were analysed as a closed area and it would be instructive to expand the analysis to consider the effects of an inter-city scheme further afield. These effects would include the impacts of changes in the productivity of firms within the study area on firms through their demand and supply linkages. Changes in productivity due to a transport could also incentivise workers and capital to move between regions which may have further urbanisation and localisation impacts.

The modelling undertaken in this thesis has focussed on the impact of inter-city connectivity on changes in specialisation at the level of sectors but there may also be scope for land-use changes at task level. Modelling could be undertaken to determine the potential for changes in specialisation at task level and if the economic benefits at task level is similar to those for sectors.

The review of the literature highlighted that there has been only a limited number of empirical studies examining the extent of changes in specialisation due to inter-urban transport and the evidence is mixed. It would be informative to undertake empirical work to examine the impact of inter-city connectivity on changes in specialisation. This would provide more evidence on the magnitude of land-use changes due to inter-city connectivity and the length of time it takes for these changes to be realised. More evidence is also needed on localisation and urbanisation elasticities and distance decay factors by sector.

In this thesis a case study was undertaken on the proposed Northern Powerhouse Rail (NPR) scheme in the north of England. It would be useful to carry out case studies on other inter-city transport links between cities with different characteristics to Leeds and Manchester to understand the extent to which the economic impacts are context dependent. It would also be useful to undertake case studies on highway projects to determine how the impacts compare to rail schemes.

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List of Abbreviations

ASHE Annual Survey of Household Earnings (UK)

BCR Benefit Cost Ratio

BRES Business Register and Employment Survey (UK)

BUB Business User Benefits

CBA Cost Benefit Analysis

CBD Central Business District

CLD Causal Loop Diagram

CVL Calder Valley Line

DfT Department for Transport (UK)

DM Do-Minimum

DS Do-Something

GC Generalised Cost

GDP Gross Domestic Product

GJT Generalised Journey Time

GVA Gross Value Added

HSR High Speed Rail

LAD Local Authority District

LQ Location Quotient

LUTI Land-use and Transport Interaction

MPK Marginal Product of Capital

MPL Marginal Product of Labour

MSOA Mid-Level Super Output Area

NPR Northern Powerhouse Rail

NUTS Nomenclature of Territorial Units for Statistics

O-D Origin-Destination

ONS Office for National Statistics (UK)

PT Public Transport

PVB Present Value of Benefits

SCGE Spatial Computable General Equilibrium

SIC Standard Industrial Classification

TFP Total Factor Productivity

TPH Trains per Hour

TPL TransPennine Line

TTWA Travel to Work Area

WEIs Wider Economic Impacts

Appendix A
Sensitivity Testing and Data Input Tables for Chapter 7

A.1 Sensitivity Testing

Sensitivity tests were undertaken to test the impact of varying the parameter assumptions. Tests were undertaken with both fixed land-use and variable land-use which are outlined in the following sections in turn.

A.1.1 Fixed Land-Use Scenarios

The impact of varying each of the parameter assumptions in turn was tested in the most likely direction suggested by the evidence. The results from scenario S2 which is the medium localisation impact assumptions scenario from the main text is included in this section for comparison. The input assumptions for the baseline scenario and sensitivities (Tests S5 to S17) are shown in Table A.1 where changes from the assumptions used in the baseline scenario are shown as shaded.

The estimated benefits for the baseline scenario and sensitivity tests are presented in Table A.2. The second to tenth columns show the estimated annual benefits per annum for urbanisation, localisation the combined total for different distances between the city pairs of 20km, 150km and 400km. In the following three columns the localisation benefits as a proportion of the total are given for each of the three distances in turn. In the final two columns the benefits for the 400km distance between the cities as a proportion of the benefits for the 20km distance are given for localisation and total benefits.

In Tests S5 to S10 the impact of varying each of the elasticities by sector in turn is tested. The results show that as expected higher localisation elasticities and lower urbanisation elasticities lead to higher localisation benefits as a proportion of the total. The highest proportion of benefits due to localisation (39.2%) is in S8 for the 20km distance in which there is a higher localisation elasticity used for producer services. The highest proportion of benefits due to localisation for the 150km and 400km distances are 37.0% and 35.4% respectively in S6. This is due to the combination of higher localisation elasticities for heavy manufacturing industries specified in this scenario and the assumed slower decay of over distance of density effects for those sectors relative to services and construction.

Table A.1 Baseline (S2) & Sensitivity Test Assumptions (with changes from the baseline highlighted as shaded)

Variable	S2	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17
% Manufacturing employment	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%
% All Other Sectors employment	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%
Initial Specialisation Level	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	60%
Heavy Manufacturing Urb Elasticity	0.02	0.05	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Heavy Manufacturing Loc Elasticity	0.07	0.07	0.10	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Producer Services Urb Elasticity	0.12	0.12	0.12	0.16	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Producer Services Loc Elasticity	0.05	0.05	0.05	0.05	0.08	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
CS, CN & Other Urb Elasticity†	0.04	0.04	0.04	0.04	0.04	0.08	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
CS, CN & Other Loc Elasticity†	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Heavy Manufacturing Urb DDF†	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.0	1.0	1.0	1.0	1.0	1.0
Heavy Manufacturing Loc DDF†	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.2	1.5	1.5	1.5	1.5	1.5
Producer Services Urb DDF	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.8	1.7	1.7	1.7	1.7
Producer Services Loc DDF	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.0	1.9	1.9	1.9
CS, CN & Other Urb DDF	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.7	1.7
CS, CN & Other Loc DDF	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.0	1.9

† Urban Manufacturing is assumed to have the same elasticities as Consumer Services, Construction & Other and the same distance decay factors as Heavy Manufacturing.

Table A.2 Estimated Annual Benefits £mn p.a. (2021 Values & Prices)

	Distance Between Cities													
	20km			150km			400km			% Localisation			Loc Benefits 400km/20km	Total Benefits 400km/20km
Test	Loc	Urb	Total	Loc	Urb	Total	Loc	Urb	Total	20km	150km	400km		
S2	11.9	21.9	33.9	11.0	22.2	33.2	4.4	9.7	14.1	35%	33%	31%	37%	42%
S5	11.9	24.0	35.9	11.0	25.8	36.8	4.4	12.2	16.5	33%	30%	26%	37%	46%
S6	13.6	21.9	35.5	13.0	22.2	35.2	5.3	9.7	15.0	38%	37%	35%	39%	42%
S7	11.9	25.4	37.4	11.0	25.4	36.4	4.4	10.9	15.3	32%	30%	29%	37%	41%
S8	14.2	21.9	36.1	12.7	22.2	34.9	4.9	9.7	14.6	39%	36%	34%	35%	41%
S9	11.9	32.0	43.9	11.0	32.3	43.3	4.4	14.0	18.3	27%	25%	24%	37%	42%
S10	14.1	21.9	36.0	12.8	22.2	35.0	5.0	9.7	14.7	39%	37%	34%	35%	41%
S11	11.9	21.9	33.8	11.0	21.7	32.7	4.4	9.2	13.6	35%	34%	32%	37%	40%
S12	12.5	21.9	34.4	13.2	22.2	35.4	6.2	9.7	15.9	36%	37%	39%	50%	46%
S13	11.9	21.2	33.1	11.0	20.8	31.8	4.4	8.9	13.3	36%	35%	33%	37%	40%
S14	11.6	21.9	33.6	10.6	22.2	32.8	4.2	9.7	13.9	35%	32%	30%	36%	41%
S15	11.9	22.6	34.5	11.0	23.7	34.7	4.4	10.6	15.0	35%	32%	29%	37%	43%
S16	11.6	21.9	33.5	10.5	22.2	32.7	4.1	9.7	13.8	35%	32%	30%	36%	41%
S17	11.8	21.9	33.8	11.0	22.2	33.2	4.4	9.7	14.1	35%	33%	31%	37%	42%

Tests S11 to S16 show how the estimated benefits change when the distance decay factors by sector are varied. As expected lower decay factors for localisation effects and higher decay factors for urbanisation effects increase the proportion of total benefits due to localisation. The greatest impact on the scale of localisation benefits is in S12 in which a lower localisation decay factor is used for heavy manufacturing. The assumptions in this scenario also lead to the slowest rate of decline of localisation benefits with distance in all fixed land-use scenarios with the proportion of localisation benefits for 400km relative to 20km of 50% compared to 37% in S2.

Test S17 shows the impact of assuming an initial proportion of jobs in tradable sectors of 60% compared to 52% in the baseline scenario. Urbanisation benefits are unaffected by the change but there is a marginal reduction in localisation benefits compared to the baseline scenario ranging from -0.13% for the 400km distance to -0.83% for the 20km distance. These results suggest that the initial level of specialisation has only a limited effect on the scale of the benefits with fixed land-use.

A.1.2 Variable Land-Use Scenarios

Sensitivity tests were also undertaken to test the impact if varying the assumptions used in the variable land-use scenarios. Seven variable land-use sensitivity tests (D7 to D13) were undertaken and the input assumptions used in the tests are outlined in Table A.3 and the results are shown in Table A.4.

In Tests D7 and D8 the two type of land-use changes are applied separately as in Tests D1 and D2 respectively but using a land-use change to GJT elasticity of -0.3 rather than -0.5. The benefits estimates for D7 and D8 show that as expected the lower elasticities lead to lower benefits than in D1 and D2 respectively across all distances between the cities. The scale of the reductions relative to D1 and D2 increase with distance between the cities as the effect of the GJT changes only on density dissipates with distance and the land-use changes therefore become a greater proportion of the benefits. For the 400km distance total benefits are £1.7mn per annum (10%) lower in D7 compared to D1 and £10.1mn per annum (26%) lower in D8 relative to D2.

In Tests D9 and D10 both types of land-use change are implemented together but no decline in trade impacts over distance is applied. For the 400km distance total benefits are £29.5mn per annum for D9 and £41.4mn per annum for D10 which is significantly higher than any of the other scenario tests undertaken in this chapter. These results show that including an assumption that there is a decline in trade impacts over distance significantly affects the scale of the estimated benefits.

Table A.3 Baseline (BL) & Sensitivity Test Assumptions (with changes from the baseline highlighted as shaded)

Variable	S2	D7	D8	D9	D10	D11	D12	D13
Localisation Parameter Inputs	MED	MED	MED	MED	MED	MED	MED	MED
Change in Sectoral Composition Elasticity	0.0	0.3	0.0	0.3	0.5	0.5	0.5	0.5
Change in Concentration of Services in Core Elasticity	0.0	0.0	0.3	0.3	0.5	0.5	0.5	0.5
Elasticity of Trade w.r.t Distance	0	0	0	0	0	-0.5	-0.9	-1.2

Table A.4 Estimated Annual Benefits £mn p.a. (2021 Values & Prices)

Distance	20km			150km			400km			% Localisation			Loc Benefits 400km/20km	Total Benefits 400km/20km
Test	Loc	Urb	Total	Loc	Urb	Total	Loc	Urb	Total	20km	150km	400km		
S2	11.9	21.9	33.9	11.0	22.2	33.2	4.4	9.7	14.1	35%	33%	31%	37%	42%
D7	12.0	21.9	34.0	11.7	22.2	33.9	5.4	9.7	15.1	35%	34%	36%	45%	44%
D8	13.7	23.4	37.2	17.2	27.1	44.3	12.4	16.0	28.5	37%	39%	44%	90%	77%
D9	13.9	23.4	37.3	17.9	27.1	44.9	13.4	16.0	29.5	37%	40%	46%	97%	79%
D10	15.3	24.4	39.7	23.3	30.4	53.7	21.0	20.4	41.4	38%	43%	51%	137%	104%
D11	15.3	24.4	39.7	15.1	25.2	40.2	7.5	12.1	19.6	38%	37%	38%	49%	49%
D12	15.3	24.4	39.7	12.8	23.5	36.3	5.3	10.4	15.7	38%	35%	34%	35%	40%
D13	15.3	24.4	39.7	12.0	22.9	34.9	4.7	10.0	14.7	38%	34%	32%	31%	37%

% Benefits Due to Changes in Land-Use									
D7	1%	0%	0%	6%	0%	2%	19%	0%	7%
D8	13%	6%	9%	36%	18%	25%	65%	40%	51%
D9	14%	6%	9%	38%	18%	26%	68%	40%	52%
D10	22%	10%	15%	53%	27%	38%	79%	53%	66%
D11	22%	10%	15%	27%	12%	17%	42%	20%	28%
D12	22%	10%	15%	14%	6%	8%	17%	7%	10%
D13	22%	10%	15%	8%	3%	5%	8%	3%	4%

In Tests D11 to D13 the impact of combining both types of land-use change but varying the elasticity for trade impacts with respect to distance between the cities was tested. In Test D11 an elasticity of -0.5 is used and localisation benefits are £15.1mn per annum for the 150km distance and £7.5mn per annum for 400km which represent a 35% and 64% decreases respectively from Test D10 which did not include any decline in the level of trade impacts with distance. Urbanisation benefits in D11 are also lower than in D10 but the falls are not as significant. They are £25.2mn per annum for 150km and £12.1mn per annum for 400km which are 17% and 41% lower than in Test D10 respectively.

As expected the decrease in the estimated benefits for the two longer distances is even greater for the 0.9 and -1.2 elasticities for the decline of trade impacts with distance used in Tests D12 and D13 respectively. In Test D13 the benefits from localisation and urbanisation for the 400km distance are £16.3mn per annum (78%) and £10.4mn per annum (51%) lower respectively than in D10. The results for Tests D11 to D13 show that the assumption on the degree to which the level of trade impacts decline over distance has a significant impact on the scale of the estimated benefits. The results also show that the greater the distance between the cities the more this elasticity will impact on the scale of the benefits.

A.2 Generalised Journey Times

Table A.5 Baseline Journey Times (minutes) for 20km distance between cities

Zone	1	2	3	4	5	6	7	8	9	10
1	10	15	15	15	15	45	53	53	53	53
2	15	10	15	25	15	53	60	60	60	60
3	15	15	10	15	25	53	60	60	60	60
4	15	25	15	10	15	53	60	60	60	60
5	15	15	25	15	10	53	60	60	60	60
6	45	53	53	53	53	10	15	15	15	15
7	53	60	60	60	60	15	10	15	25	15
8	53	60	60	60	60	15	15	10	15	25
9	53	60	60	60	60	15	25	15	10	15
10	53	60	60	60	60	15	15	25	15	10

Table A.6 Baseline Journey Times (minutes) for 150km distance between cities

Zone	1	2	3	4	5	6	7	8	9	10
1	10	15	15	15	15	110	118	118	118	118
2	15	10	15	25	15	118	125	125	125	125
3	15	15	10	15	25	118	125	125	125	125
4	15	25	15	10	15	118	125	125	125	125
5	15	15	25	15	10	118	125	125	125	125
6	110	118	118	118	118	10	15	15	15	15
7	118	125	125	125	125	15	10	15	25	15
8	118	125	125	125	125	15	15	10	15	25
9	118	125	125	125	125	15	25	15	10	15
10	118	125	125	125	125	15	15	25	15	10

A.3 GDP per Worker

Table A.7 Base GDP per Worker by Sector (£k, 2021 Values & Prices)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	81.7	80.2	73.5	77.6	77.4	81.7	80.2	73.5	77.6	77.4
HM (T-B)	81.7	80.2	73.5	77.6	77.4	81.7	80.2	73.5	77.6	77.4
HM (NT)	81.7	80.2	73.5	77.6	77.4	81.7	80.2	73.5	77.6	77.4
UM (T-A)	81.7	80.2	73.5	77.6	77.4	81.7	80.2	73.5	77.6	77.4
UM (T-B)	81.7	80.2	73.5	77.6	77.4	81.7	80.2	73.5	77.6	77.4
CN (T-A)	45.4	45.7	45.3	45.8	42.8	45.4	45.7	45.3	45.8	42.8
CN (T-B)	45.4	45.7	45.3	45.8	42.8	45.4	45.7	45.3	45.8	42.8
PS (T-A)	71.4	54.7	57.3	68.0	64.3	71.4	54.7	57.3	68.0	64.3
PS (T-B)	71.4	54.7	57.3	68.0	64.3	71.4	54.7	57.3	68.0	64.3
PS (NT)	71.4	54.7	57.3	68.0	64.3	71.4	54.7	57.3	68.0	64.3
CS (T-A)	71.4	54.7	57.3	68.0	64.3	71.4	54.7	57.3	68.0	64.3
CS (T-B)	71.4	54.7	57.3	68.0	64.3	71.4	54.7	57.3	68.0	64.3
CS (NT)	71.4	54.7	57.3	68.0	64.3	71.4	54.7	57.3	68.0	64.3
Other (T-A)	53.1	48.1	48.3	46.2	44.3	53.1	48.1	48.3	46.2	44.3
Other (T-B)	53.1	48.1	48.3	46.2	44.3	53.1	48.1	48.3	46.2	44.3
Other (NT)	53.1	48.1	48.3	46.2	44.3	53.1	48.1	48.3	46.2	44.3

A.4 Sectoral Employment by Zone used in Scenario Tests

Table A.8 Percentage of Jobs by sector in each zone: Scenarios S1 to S3 for 20km, 150km and 400km distances between the cities

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.3	5.8	7.6	6.4	7.4	3.1	5.3	7.0	5.9	6.8
HM (T-B)	3.1	5.3	7.0	5.9	6.8	3.3	5.8	7.6	6.4	7.4
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.0	1.4	1.2	0.9	1.2	1.0	1.3	1.2
UM (T-B)	0.9	1.2	1.0	1.3	1.2	1.0	1.3	1.0	1.4	1.2
CN (T-A)	3.6	3.6	4.3	3.3	5.1	3.3	3.3	4.0	3.0	4.7
CN (T-B)	3.3	3.3	4.0	3.0	4.7	3.6	3.6	4.3	3.3	5.1
PS (T-A)	10.1	3.9	4.2	6.2	3.9	9.3	3.6	3.9	5.7	3.6
PS (T-B)	9.3	3.6	3.9	5.7	3.6	10.1	3.9	4.2	6.2	3.9
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.3	0.8	0.4	0.4	0.2	0.2
CS (T-B)	0.8	0.4	0.4	0.2	0.2	0.9	0.5	0.4	0.2	0.3
CS (NT)	19.6	28.4	26.5	20.0	24.5	19.6	28.4	26.5	20.0	24.5
Other (T-A)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Other (NT)	37.4	36.7	36.4	31.9	38.2	37.4	36.7	36.4	31.9	38.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	429.3	147.3	151.2	95.3	77.0	429.3	147.3	151.2	95.3	77.0

Table A.9 Percentage of Jobs by sector in each zone: Scenario S4 for 20km, 150km and 400km distances between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	7.0	11.3	14.4	12.4	14.0	6.4	10.4	13.3	11.4	13.0
HM (T-B)	6.4	10.4	13.3	11.4	13.0	7.0	11.3	14.4	12.4	14.0
HM (NT)	0.4	0.5	0.4	0.5	0.8	0.4	0.5	0.4	0.5	0.8
UM (T-A)	2.1	2.5	2.0	2.6	2.4	1.9	2.3	1.8	2.4	2.2
UM (T-B)	1.9	2.3	1.8	2.4	2.2	2.1	2.5	2.0	2.6	2.4
CN (T-A)	3.2	3.1	3.5	2.7	4.2	2.9	2.8	3.2	2.5	3.8
CN (T-B)	2.9	2.8	3.2	2.5	3.8	3.2	3.1	3.5	2.7	4.2
PS (T-A)	9.1	3.3	3.5	5.2	3.2	8.4	3.0	3.2	4.8	2.9
PS (T-B)	8.4	3.0	3.2	4.8	2.9	9.1	3.3	3.5	5.2	3.2
PS (NT)	5.7	4.8	2.5	11.7	1.9	5.7	4.8	2.5	11.7	1.9
CS (T-A)	0.8	0.4	0.3	0.2	0.2	0.7	0.4	0.3	0.2	0.2
CS (T-B)	0.7	0.4	0.3	0.2	0.2	0.8	0.4	0.3	0.2	0.2
CS (NT)	17.6	24.0	21.7	16.7	20.0	17.6	24.0	21.7	16.7	20.0
Other (T-A)	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1
Other (T-B)	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (NT)	33.6	31.1	29.8	26.5	31.2	33.6	31.1	29.8	26.5	31.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	411.3	149.9	159.1	98.5	81.3	411.3	149.9	159.1	98.5	81.3

Table A.10 Percentage of Jobs by sector in each zone: Scenario D1 for 20km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.4	5.8	7.6	6.5	7.5	3.1	5.3	6.9	5.8	6.8
HM (T-B)	3.1	5.3	6.9	5.8	6.8	3.4	5.8	7.6	6.5	7.5
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.1	1.4	1.3	0.9	1.2	1.0	1.2	1.1
UM (T-B)	0.9	1.2	1.0	1.2	1.1	1.0	1.3	1.1	1.4	1.3
CN (T-A)	3.6	3.7	4.3	3.3	5.1	3.2	3.3	3.9	3.0	4.7
CN (T-B)	3.2	3.3	3.9	3.0	4.7	3.6	3.7	4.3	3.3	5.1
PS (T-A)	10.2	3.9	4.3	6.3	3.9	9.2	3.6	3.9	5.7	3.5
PS (T-B)	9.2	3.6	3.9	5.7	3.5	10.2	3.9	4.3	6.3	3.9
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.3	0.8	0.4	0.4	0.2	0.2
CS (T-B)	0.8	0.4	0.4	0.2	0.2	0.9	0.5	0.4	0.2	0.3
CS (NT)	19.6	28.4	26.5	20.0	24.5	19.6	28.4	26.5	20.0	24.5
Other (T-A)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Other (NT)	37.4	36.7	36.4	31.9	38.2	37.4	36.7	36.4	31.9	38.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	429.3	147.3	151.2	95.3	77.0	429.3	147.3	151.2	95.3	77.0

Table A.11 Percentage of Jobs by sector in each zone: Scenario D1 for 150km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.5	5.9	7.8	6.6	7.7	3.0	5.1	6.7	5.7	6.6
HM (T-B)	3.0	5.1	6.7	5.7	6.6	3.5	5.9	7.8	6.6	7.7
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.1	1.4	1.3	0.9	1.1	0.9	1.2	1.1
UM (T-B)	0.9	1.1	0.9	1.2	1.1	1.0	1.3	1.1	1.4	1.3
CN (T-A)	3.7	3.7	4.4	3.4	5.3	3.2	3.2	3.8	2.9	4.5
CN (T-B)	3.2	3.2	3.8	2.9	4.5	3.7	3.7	4.4	3.4	5.3
PS (T-A)	10.4	4.0	4.4	6.4	4.0	9.0	3.5	3.8	5.5	3.4
PS (T-B)	9.0	3.5	3.8	5.5	3.4	10.4	4.0	4.4	6.4	4.0
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.3	0.8	0.4	0.3	0.2	0.2
CS (T-B)	0.8	0.4	0.3	0.2	0.2	0.9	0.5	0.4	0.2	0.3
CS (NT)	19.6	28.4	26.5	20.0	24.5	19.6	28.4	26.5	20.0	24.5
Other (T-A)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Other (NT)	37.4	36.7	36.4	31.9	38.2	37.4	36.7	36.4	31.9	38.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	429.3	147.3	151.2	95.3	77.0	429.3	147.3	151.2	95.3	77.0

Table A.12 Percentage of Jobs by sector in each zone: Scenario D1 for 400km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.5	6.0	7.9	6.7	7.7	2.9	5.1	6.7	5.6	6.5
HM (T-B)	2.9	5.1	6.7	5.6	6.5	3.5	6.0	7.9	6.7	7.7
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.1	1.4	1.3	0.9	1.1	0.9	1.2	1.1
UM (T-B)	0.9	1.1	0.9	1.2	1.1	1.0	1.3	1.1	1.4	1.3
CN (T-A)	3.7	3.8	4.5	3.4	5.3	3.1	3.2	3.8	2.9	4.5
CN (T-B)	3.1	3.2	3.8	2.9	4.5	3.7	3.8	4.5	3.4	5.3
PS (T-A)	10.5	4.1	4.4	6.5	4.0	8.9	3.4	3.7	5.5	3.4
PS (T-B)	8.9	3.4	3.7	5.5	3.4	10.5	4.1	4.4	6.5	4.0
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.3	0.8	0.4	0.3	0.2	0.2
CS (T-B)	0.8	0.4	0.3	0.2	0.2	0.9	0.5	0.4	0.2	0.3
CS (NT)	19.6	28.4	26.5	20.0	24.5	19.6	28.4	26.5	20.0	24.5
Other (T-A)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Other (NT)	37.4	36.7	36.4	31.9	38.2	37.4	36.7	36.4	31.9	38.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	429.3	147.3	151.2	95.3	77.0	429.3	147.3	151.2	95.3	77.0

Table A.13 Percentage of Jobs by sector in each zone: Scenario D2 for 20km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.3	5.8	7.6	6.4	7.4	3.1	5.3	7.0	5.9	6.9
HM (T-B)	3.1	5.3	7.0	5.9	6.9	3.3	5.8	7.6	6.4	7.4
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.0	1.4	1.2	0.9	1.2	1.0	1.3	1.2
UM (T-B)	0.9	1.2	1.0	1.3	1.2	1.0	1.3	1.0	1.4	1.2
CN (T-A)	3.5	3.6	4.3	3.3	5.1	3.3	3.4	4.0	3.0	4.7
CN (T-B)	3.3	3.4	4.0	3.0	4.7	3.5	3.6	4.3	3.3	5.1
PS (T-A)	10.2	3.8	4.1	6.1	3.8	9.4	3.5	3.8	5.6	3.5
PS (T-B)	9.4	3.5	3.8	5.6	3.5	10.2	3.8	4.1	6.1	3.8
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.2	0.8	0.4	0.3	0.2	0.2
CS (T-B)	0.8	0.4	0.3	0.2	0.2	0.9	0.5	0.4	0.2	0.2
CS (NT)	19.5	28.4	26.5	20.1	24.5	19.5	28.4	26.5	20.1	24.5
Other (T-A)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (NT)	37.3	36.8	36.5	31.9	38.3	37.3	36.8	36.5	31.9	38.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	430.2	147.0	150.9	95.0	76.9	430.2	147.0	150.9	95.0	76.9

Table A.14 Percentage of Jobs by sector in each zone: Scenario D2 for 150km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.3	5.8	7.6	6.5	7.5	3.1	5.3	7.0	6.0	6.9
HM (T-B)	3.1	5.3	7.0	6.0	6.9	3.3	5.8	7.6	6.5	7.5
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.1	1.4	1.3	0.9	1.2	1.0	1.3	1.2
UM (T-B)	0.9	1.2	1.0	1.3	1.2	1.0	1.3	1.1	1.4	1.3
CN (T-A)	3.5	3.6	4.3	3.3	5.1	3.3	3.4	4.0	3.1	4.7
CN (T-B)	3.3	3.4	4.0	3.1	4.7	3.5	3.6	4.3	3.3	5.1
PS (T-A)	10.4	3.6	4.0	5.8	3.6	9.6	3.3	3.7	5.4	3.3
PS (T-B)	9.6	3.3	3.7	5.4	3.3	10.4	3.6	4.0	5.8	3.6
PS (NT)	6.3	5.7	3.0	14.1	2.3	6.3	5.7	3.0	14.1	2.3
CS (T-A)	0.9	0.4	0.4	0.2	0.2	0.8	0.4	0.3	0.2	0.2
CS (T-B)	0.8	0.4	0.3	0.2	0.2	0.9	0.4	0.4	0.2	0.2
CS (NT)	19.4	28.6	26.6	20.2	24.6	19.4	28.6	26.6	20.2	24.6
Other (T-A)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (NT)	37.1	36.9	36.7	32.1	38.5	37.1	36.9	36.7	32.1	38.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	432.4	146.4	150.2	94.4	76.6	432.4	146.4	150.2	94.4	76.6

Table A.15 Percentage of Jobs by sector in each zone: Scenario D2 for 400km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.3	5.8	7.6	6.5	7.5	3.1	5.4	7.1	6.0	6.9
HM (T-B)	3.1	5.4	7.1	6.0	6.9	3.3	5.8	7.6	6.5	7.5
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.1	1.4	1.3	0.9	1.2	1.0	1.3	1.2
UM (T-B)	0.9	1.2	1.0	1.3	1.2	1.0	1.3	1.1	1.4	1.3
CN (T-A)	3.5	3.7	4.3	3.3	5.1	3.2	3.4	4.0	3.1	4.7
CN (T-B)	3.2	3.4	4.0	3.1	4.7	3.5	3.7	4.3	3.3	5.1
PS (T-A)	10.4	3.6	3.9	5.7	3.5	9.6	3.3	3.6	5.3	3.3
PS (T-B)	9.6	3.3	3.6	5.3	3.3	10.4	3.6	3.9	5.7	3.5
PS (NT)	6.3	5.7	3.0	14.2	2.3	6.3	5.7	3.0	14.2	2.3
CS (T-A)	0.9	0.4	0.4	0.2	0.2	0.8	0.4	0.3	0.2	0.2
CS (T-B)	0.8	0.4	0.3	0.2	0.2	0.9	0.4	0.4	0.2	0.2
CS (NT)	19.4	28.6	26.7	20.3	24.7	19.4	28.6	26.7	20.3	24.7
Other (T-A)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (NT)	37.0	37.0	36.8	32.2	38.5	37.0	37.0	36.8	32.2	38.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	433.3	146.1	149.9	94.2	76.4	433.3	146.1	149.9	94.2	76.4

Table A.16 Percentage of Jobs by sector in each zone: Scenario D3 for 20km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.4	5.8	7.6	6.4	7.5	3.1	5.3	7.0	5.9	6.8
HM (T-B)	3.1	5.3	7.0	5.9	6.8	3.4	5.8	7.6	6.4	7.5
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.1	1.4	1.3	0.9	1.2	1.0	1.3	1.1
UM (T-B)	0.9	1.2	1.0	1.3	1.1	1.0	1.3	1.1	1.4	1.3
CN (T-A)	3.6	3.6	4.3	3.3	5.1	3.3	3.3	3.9	3.0	4.7
CN (T-B)	3.3	3.3	3.9	3.0	4.7	3.6	3.6	4.3	3.3	5.1
PS (T-A)	10.2	3.9	4.2	6.2	3.8	9.3	3.5	3.8	5.6	3.5
PS (T-B)	9.3	3.5	3.8	5.6	3.5	10.2	3.9	4.2	6.2	3.8
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.2	0.8	0.4	0.3	0.2	0.2
CS (T-B)	0.8	0.4	0.3	0.2	0.2	0.9	0.5	0.4	0.2	0.2
CS (NT)	19.5	28.4	26.5	20.1	24.5	19.5	28.4	26.5	20.1	24.5
Other (T-A)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Other (NT)	37.3	36.8	36.5	31.9	38.3	37.3	36.8	36.5	31.9	38.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	429.8	147.1	151.0	95.1	76.9	429.8	147.1	151.0	95.1	76.9

Table A.17 Percentage of Jobs by sector in each zone: Scenario D3 for 150km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.4	5.8	7.6	6.4	7.4	3.1	5.3	7.0	5.9	6.8
HM (T-B)	3.1	5.3	7.0	5.9	6.8	3.4	5.8	7.6	6.4	7.4
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.0	1.4	1.2	0.9	1.2	1.0	1.3	1.1
UM (T-B)	0.9	1.2	1.0	1.3	1.1	1.0	1.3	1.0	1.4	1.2
CN (T-A)	3.6	3.6	4.3	3.3	5.1	3.3	3.3	4.0	3.0	4.7
CN (T-B)	3.3	3.3	4.0	3.0	4.7	3.6	3.6	4.3	3.3	5.1
PS (T-A)	10.1	3.9	4.2	6.2	3.9	9.3	3.6	3.9	5.7	3.6
PS (T-B)	9.3	3.6	3.9	5.7	3.6	10.1	3.9	4.2	6.2	3.9
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.3	0.8	0.4	0.4	0.2	0.2
CS (T-B)	0.8	0.4	0.4	0.2	0.2	0.9	0.5	0.4	0.2	0.3
CS (NT)	19.6	28.4	26.5	20.1	24.5	19.6	28.4	26.5	20.1	24.5
Other (T-A)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Other (NT)	37.4	36.7	36.5	31.9	38.2	37.4	36.7	36.5	31.9	38.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	429.4	147.2	151.1	95.2	77.0	429.4	147.2	151.1	95.2	77.0

Table A.18 Percentage of Jobs by sector in each zone: Scenario D3 for 400km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.3	5.8	7.6	6.4	7.4	3.1	5.3	7.0	5.9	6.8
HM (T-B)	3.1	5.3	7.0	5.9	6.8	3.3	5.8	7.6	6.4	7.4
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.0	1.4	1.2	0.9	1.2	1.0	1.3	1.2
UM (T-B)	0.9	1.2	1.0	1.3	1.2	1.0	1.3	1.0	1.4	1.2
CN (T-A)	3.6	3.6	4.3	3.3	5.1	3.3	3.3	4.0	3.0	4.7
CN (T-B)	3.3	3.3	4.0	3.0	4.7	3.6	3.6	4.3	3.3	5.1
PS (T-A)	10.1	3.9	4.2	6.2	3.9	9.3	3.6	3.9	5.7	3.6
PS (T-B)	9.3	3.6	3.9	5.7	3.6	10.1	3.9	4.2	6.2	3.9
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.3	0.8	0.4	0.4	0.2	0.2
CS (T-B)	0.8	0.4	0.4	0.2	0.2	0.9	0.5	0.4	0.2	0.3
CS (NT)	19.6	28.4	26.5	20.1	24.5	19.6	28.4	26.5	20.1	24.5
Other (T-A)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Other (NT)	37.4	36.7	36.5	31.9	38.2	37.4	36.7	36.5	31.9	38.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	429.3	147.3	151.1	95.3	77.0	429.3	147.3	151.1	95.3	77.0

Table A.19 Percentage of Jobs by sector in each zone: Scenario D4 for 20km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.4	5.8	7.7	6.5	7.5	3.0	5.3	6.9	5.9	6.8
HM (T-B)	3.0	5.3	6.9	5.9	6.8	3.4	5.8	7.7	6.5	7.5
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.1	1.4	1.3	0.9	1.2	1.0	1.3	1.1
UM (T-B)	0.9	1.2	1.0	1.3	1.1	1.0	1.3	1.1	1.4	1.3
CN (T-A)	3.6	3.7	4.3	3.3	5.2	3.2	3.3	3.9	3.0	4.7
CN (T-B)	3.2	3.3	3.9	3.0	4.7	3.6	3.7	4.3	3.3	5.2
PS (T-A)	10.3	3.8	4.2	6.2	3.8	9.3	3.5	3.8	5.6	3.5
PS (T-B)	9.3	3.5	3.8	5.6	3.5	10.3	3.8	4.2	6.2	3.8
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.2	0.8	0.4	0.3	0.2	0.2
CS (T-B)	0.8	0.4	0.3	0.2	0.2	0.9	0.5	0.4	0.2	0.2
CS (NT)	19.5	28.4	26.5	20.1	24.5	19.5	28.4	26.5	20.1	24.5
Other (T-A)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Other (NT)	37.3	36.8	36.5	31.9	38.3	37.3	36.8	36.5	31.9	38.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	430.2	147.0	150.9	95.0	76.9	430.2	147.0	150.9	95.0	76.9

Table A.20 Percentage of Jobs by sector in each zone: Scenario D4 for 150km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.4	5.8	7.6	6.4	7.5	3.1	5.3	7.0	5.9	6.8
HM (T-B)	3.1	5.3	7.0	5.9	6.8	3.4	5.8	7.6	6.4	7.5
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.1	1.4	1.3	0.9	1.2	1.0	1.3	1.1
UM (T-B)	0.9	1.2	1.0	1.3	1.1	1.0	1.3	1.1	1.4	1.3
CN (T-A)	3.6	3.6	4.3	3.3	5.1	3.3	3.3	3.9	3.0	4.7
CN (T-B)	3.3	3.3	3.9	3.0	4.7	3.6	3.6	4.3	3.3	5.1
PS (T-A)	10.2	3.9	4.2	6.2	3.9	9.3	3.5	3.8	5.7	3.5
PS (T-B)	9.3	3.5	3.8	5.7	3.5	10.2	3.9	4.2	6.2	3.9
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.2	0.8	0.4	0.4	0.2	0.2
CS (T-B)	0.8	0.4	0.4	0.2	0.2	0.9	0.5	0.4	0.2	0.2
CS (NT)	19.5	28.4	26.5	20.1	24.5	19.5	28.4	26.5	20.1	24.5
Other (T-A)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Other (NT)	37.4	36.8	36.5	31.9	38.3	37.4	36.8	36.5	31.9	38.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	429.8	147.1	151.0	95.1	76.9	429.8	147.1	151.0	95.1	76.9

Table A.21 Percentage of Jobs by sector in each zone: Scenario D4 for 400km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.4	5.8	7.6	6.4	7.4	3.1	5.3	7.0	5.9	6.8
HM (T-B)	3.1	5.3	7.0	5.9	6.8	3.4	5.8	7.6	6.4	7.4
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.0	1.4	1.3	0.9	1.2	1.0	1.3	1.1
UM (T-B)	0.9	1.2	1.0	1.3	1.1	1.0	1.3	1.0	1.4	1.3
CN (T-A)	3.6	3.6	4.3	3.3	5.1	3.3	3.3	3.9	3.0	4.7
CN (T-B)	3.3	3.3	3.9	3.0	4.7	3.6	3.6	4.3	3.3	5.1
PS (T-A)	10.1	3.9	4.2	6.2	3.9	9.3	3.6	3.9	5.7	3.5
PS (T-B)	9.3	3.6	3.9	5.7	3.5	10.1	3.9	4.2	6.2	3.9
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.3	0.8	0.4	0.4	0.2	0.2
CS (T-B)	0.8	0.4	0.4	0.2	0.2	0.9	0.5	0.4	0.2	0.3
CS (NT)	19.6	28.4	26.5	20.1	24.5	19.6	28.4	26.5	20.1	24.5
Other (T-A)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Other (NT)	37.4	36.7	36.5	31.9	38.3	37.4	36.7	36.5	31.9	38.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	429.6	147.2	151.1	95.2	77.0	429.6	147.2	151.1	95.2	77.0

Table A.22 Percentage of Jobs by sector in each zone: Scenario D5 for 20km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.4	5.8	7.7	6.5	7.5	3.0	5.3	6.9	5.9	6.8
HM (T-B)	3.0	5.3	6.9	5.9	6.8	3.4	5.8	7.7	6.5	7.5
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.1	1.4	1.3	0.9	1.2	1.0	1.3	1.1
UM (T-B)	0.9	1.2	1.0	1.3	1.1	1.0	1.3	1.1	1.4	1.3
CN (T-A)	3.6	3.7	4.3	3.3	5.2	3.2	3.3	3.9	3.0	4.7
CN (T-B)	3.2	3.3	3.9	3.0	4.7	3.6	3.7	4.3	3.3	5.2
PS (T-A)	10.3	3.8	4.2	6.2	3.8	9.3	3.5	3.8	5.6	3.5
PS (T-B)	9.3	3.5	3.8	5.6	3.5	10.3	3.8	4.2	6.2	3.8
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.2	0.8	0.4	0.3	0.2	0.2
CS (T-B)	0.8	0.4	0.3	0.2	0.2	0.9	0.5	0.4	0.2	0.2
CS (NT)	19.5	28.4	26.5	20.1	24.5	19.5	28.4	26.5	20.1	24.5
Other (T-A)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Other (NT)	37.3	36.8	36.5	31.9	38.3	37.3	36.8	36.5	31.9	38.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	430.2	147.0	150.9	95.0	76.9	430.2	147.0	150.9	95.0	76.9

Table A.23 Percentage of Jobs by sector in each zone: Scenario D5 for 150km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.4	5.8	7.7	6.5	7.5	3.0	5.3	6.9	5.9	6.8
HM (T-B)	3.0	5.3	6.9	5.9	6.8	3.4	5.8	7.7	6.5	7.5
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.1	1.4	1.3	0.9	1.2	1.0	1.2	1.1
UM (T-B)	0.9	1.2	1.0	1.2	1.1	1.0	1.3	1.1	1.4	1.3
CN (T-A)	3.6	3.7	4.4	3.3	5.2	3.2	3.3	3.9	3.0	4.7
CN (T-B)	3.2	3.3	3.9	3.0	4.7	3.6	3.7	4.4	3.3	5.2
PS (T-A)	10.3	3.8	4.2	6.2	3.8	9.3	3.5	3.8	5.5	3.4
PS (T-B)	9.3	3.5	3.8	5.5	3.4	10.3	3.8	4.2	6.2	3.8
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.2	0.8	0.4	0.3	0.2	0.2
CS (T-B)	0.8	0.4	0.3	0.2	0.2	0.9	0.5	0.4	0.2	0.2
CS (NT)	19.5	28.5	26.5	20.1	24.5	19.5	28.5	26.5	20.1	24.5
Other (T-A)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Other (NT)	37.3	36.8	36.5	32.0	38.3	37.3	36.8	36.5	32.0	38.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	430.4	147.0	150.8	95.0	76.8	430.4	147.0	150.8	95.0	76.8

Table A.24 Percentage of Jobs by sector in each zone: Scenario D5 for 400km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	3.4	5.8	7.7	6.5	7.5	3.0	5.3	6.9	5.9	6.8
HM (T-B)	3.0	5.3	6.9	5.9	6.8	3.4	5.8	7.7	6.5	7.5
HM (NT)	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4
UM (T-A)	1.0	1.3	1.1	1.4	1.3	0.9	1.2	1.0	1.2	1.1
UM (T-B)	0.9	1.2	1.0	1.2	1.1	1.0	1.3	1.1	1.4	1.3
CN (T-A)	3.6	3.7	4.3	3.3	5.2	3.2	3.3	3.9	3.0	4.7
CN (T-B)	3.2	3.3	3.9	3.0	4.7	3.6	3.7	4.3	3.3	5.2
PS (T-A)	10.3	3.8	4.2	6.2	3.8	9.3	3.5	3.8	5.6	3.5
PS (T-B)	9.3	3.5	3.8	5.6	3.5	10.3	3.8	4.2	6.2	3.8
PS (NT)	6.3	5.7	3.0	14.0	2.3	6.3	5.7	3.0	14.0	2.3
CS (T-A)	0.9	0.5	0.4	0.2	0.2	0.8	0.4	0.3	0.2	0.2
CS (T-B)	0.8	0.4	0.3	0.2	0.2	0.9	0.5	0.4	0.2	0.2
CS (NT)	19.5	28.4	26.5	20.1	24.5	19.5	28.4	26.5	20.1	24.5
Other (T-A)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (T-B)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Other (NT)	37.3	36.8	36.5	31.9	38.3	37.3	36.8	36.5	31.9	38.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	430.2	147.0	150.9	95.0	76.9	430.2	147.0	150.9	95.0	76.9

Table A.25 Percentage of Jobs by sector in each zone: Scenario D6 for 20km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	7.0	11.4	14.6	12.5	14.2	6.4	10.4	13.2	11.3	12.9
HM (T-B)	6.4	10.4	13.2	11.3	12.9	7.0	11.4	14.6	12.5	14.2
HM (NT)	0.4	0.5	0.4	0.5	0.8	0.4	0.5	0.4	0.5	0.8
UM (T-A)	2.1	2.5	2.0	2.7	2.4	1.9	2.3	1.8	2.4	2.2
UM (T-B)	1.9	2.3	1.8	2.4	2.2	2.1	2.5	2.0	2.7	2.4
CN (T-A)	3.2	3.1	3.5	2.8	4.2	2.9	2.8	3.2	2.5	3.8
CN (T-B)	2.9	2.8	3.2	2.5	3.8	3.2	3.1	3.5	2.8	4.2
PS (T-A)	9.2	3.3	3.4	5.1	3.1	8.3	2.9	3.1	4.6	2.8
PS (T-B)	8.3	2.9	3.1	4.6	2.8	9.2	3.3	3.4	5.1	3.1
PS (NT)	5.7	4.8	2.5	11.7	1.9	5.7	4.8	2.5	11.7	1.9
CS (T-A)	0.8	0.4	0.3	0.2	0.2	0.7	0.4	0.3	0.2	0.2
CS (T-B)	0.7	0.4	0.3	0.2	0.2	0.8	0.4	0.3	0.2	0.2
CS (NT)	17.5	24.1	21.7	16.7	20.0	17.5	24.1	21.7	16.7	20.0
Other (T-A)	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.0
Other (T-B)	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1
Other (NT)	33.5	31.1	29.9	26.6	31.2	33.5	31.1	29.9	26.6	31.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	412.1	149.6	158.8	98.3	81.2	412.1	149.6	158.8	98.3	81.2

Table A.26 Percentage of Jobs by sector in each zone: Scenario D6 for 150km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	7.0	11.4	14.5	12.5	14.1	6.4	10.4	13.2	11.4	12.9
HM (T-B)	6.4	10.4	13.2	11.4	12.9	7.0	11.4	14.5	12.5	14.1
HM (NT)	0.4	0.5	0.4	0.5	0.8	0.4	0.5	0.4	0.5	0.8
UM (T-A)	2.1	2.5	2.0	2.7	2.4	1.9	2.3	1.8	2.4	2.2
UM (T-B)	1.9	2.3	1.8	2.4	2.2	2.1	2.5	2.0	2.7	2.4
CN (T-A)	3.2	3.1	3.5	2.8	4.2	2.9	2.8	3.2	2.5	3.8
CN (T-B)	2.9	2.8	3.2	2.5	3.8	3.2	3.1	3.5	2.8	4.2
PS (T-A)	9.1	3.3	3.4	5.2	3.1	8.3	3.0	3.1	4.7	2.9
PS (T-B)	8.3	3.0	3.1	4.7	2.9	9.1	3.3	3.4	5.2	3.1
PS (NT)	5.7	4.8	2.5	11.7	1.9	5.7	4.8	2.5	11.7	1.9
CS (T-A)	0.8	0.4	0.3	0.2	0.2	0.7	0.4	0.3	0.2	0.2
CS (T-B)	0.7	0.4	0.3	0.2	0.2	0.8	0.4	0.3	0.2	0.2
CS (NT)	17.6	24.0	21.7	16.7	20.0	17.6	24.0	21.7	16.7	20.0
Other (T-A)	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1
Other (T-B)	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (NT)	33.6	31.1	29.8	26.6	31.2	33.6	31.1	29.8	26.6	31.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	411.7	149.7	158.9	98.4	81.2	411.7	149.7	158.9	98.4	81.2

Table A.27 Percentage of Jobs by sector in each zone: Scenario D6 for 400km distance between the cities (changes from S1 to S3 shaded)

	City A Zones					City B Zones				
Sectors	1	2	3	4	5	6	7	8	9	10
HM (T-A)	7.0	11.4	14.4	12.4	14.1	6.4	10.4	13.3	11.4	12.9
HM (T-B)	6.4	10.4	13.3	11.4	12.9	7.0	11.4	14.4	12.4	14.1
HM (NT)	0.4	0.5	0.4	0.5	0.8	0.4	0.5	0.4	0.5	0.8
UM (T-A)	2.1	2.5	2.0	2.7	2.4	1.9	2.3	1.8	2.4	2.2
UM (T-B)	1.9	2.3	1.8	2.4	2.2	2.1	2.5	2.0	2.7	2.4
CN (T-A)	3.2	3.1	3.5	2.7	4.2	2.9	2.8	3.2	2.5	3.8
CN (T-B)	2.9	2.8	3.2	2.5	3.8	3.2	3.1	3.5	2.7	4.2
PS (T-A)	9.1	3.3	3.5	5.2	3.1	8.4	3.0	3.2	4.7	2.9
PS (T-B)	8.4	3.0	3.2	4.7	2.9	9.1	3.3	3.5	5.2	3.1
PS (NT)	5.7	4.8	2.5	11.7	1.9	5.7	4.8	2.5	11.7	1.9
CS (T-A)	0.8	0.4	0.3	0.2	0.2	0.7	0.4	0.3	0.2	0.2
CS (T-B)	0.7	0.4	0.3	0.2	0.2	0.8	0.4	0.3	0.2	0.2
CS (NT)	17.6	24.0	21.7	16.7	20.0	17.6	24.0	21.7	16.7	20.0
Other (T-A)	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1
Other (T-B)	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other (NT)	33.6	31.1	29.8	26.6	31.2	33.6	31.1	29.8	26.6	31.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total No. Jobs (k)	411.5	149.8	159.0	98.4	81.3	411.5	149.8	159.0	98.4	81.3

Appendix B
Data Input Tables & Plots for Chapter 8

B.1 Sector Definitions

Table B.1 List of the 49 sectors used in the analysis

SIC Code(s): Sector(s)	WebTAG Sectoral Group[†]
1 & 35: Agriculture, electricity, gas, water and waste	Manufacturing
2-9 & 36-39: Mining, Water & Waste Collection	Other
10-15: Manufacture of food, beverages, textiles and clothing	Manufacturing
16-23: Manufacture of wood, petroleum, chemicals and minerals	Manufacturing
24-30: Manufacture of metals, electrical products and machinery	Manufacturing
31-33: Other manufacturing, repair and installation	Manufacturing
41: Construction of buildings	Construction
42: Civil engineering	Construction
43: Specialised construction activities	Construction
45: Motor trades	Consumer Services
46: Wholesale trade	Consumer Services
47: Retail trade	Consumer Services
49 & 50: Land and water transport	Consumer Services
51: Air transport	Other
52 & 53: Warehousing, transport support, postal and courier activities	Consumer Services
55-56: Accommodation and food service activities	Consumer Services
58 : Publishing activities	Manufacturing
59 : Motion picture/video/TV, sound recording music publishing	Manufacturing

60 : Programming and broadcasting activities	Consumer Services
61 : Telecommunications	Consumer Services
62 : Computer programming, consultancy and related activities	Producer Services
63 : Information service activities	Producer Services
64 : Financial service activities, except insurance and pension funding	Producer Services
65 : Insurance/reinsurance/pension funding	Producer Services
66 : Activities auxiliary to financial services and insurance activities	Producer Services
68 : Real estate activities	Other
69 : Legal and accounting activities	Producer Services
70 : Activities of head offices; management consultancy activities	Producer Services
71 : Architectural/engineering activities; technical testing and analysis	Producer Services
72 : Scientific research and development	Producer Services
73 : Advertising and market research	Producer Services
74 : Other professional, scientific and technical activities	Producer Services
75: Veterinary activities	Other
77 : Rental and leasing activities	Producer Services
78 : Employment activities	Producer Services
79 : Travel agency, tour operator and other reservation services	Consumer Services
80 : Security and investigation activities	Producer Services
81 : Services to buildings and landscape activities	Producer Services
82 : Office administrative, office support and other business support	Producer Services
84: Public administration and defence	Other

85: Education	Consumer Services
86 & 87: Human health and residential care activities	Other
88: Social work activities	Other
90-93: Arts, entertainment and recreation	Other
94: Activities of membership organisations	Other
95: Repair of computers and goods	Consumer Services
96: Other personal service activities	Consumer Services

[†]: The sectors with no sectoral groups designation in WebTAG have been assigned as ‘Other’.

B.2 Baseline GVA per Worker

Table B.2 Baseline GVA per Worker (£k, 2030 Values & 2020 Prices)

SICs	Bolton	Bury	Manchester	Oldham	Rochdale	Salford	Stockport	Tameside	Trafford	Wigan	Bradford	Calderdale	Kirklees	Leeds	Wakefield
1 & 35	220.5	90.8	152.4	154.4	198.9	114.0	149.5	103.1	156.3	41.1	213.4	121.3	116.5	165.4	192.3
2-9; 36-39	137.4	93.1	113.6	99.4	128.5	66.3	121.3	70.6	133.8	36.9	156.5	113.2	135.0	146.0	171.1
10-15	60.5	138.2	93.4	73.4	116.2	73.0	82.8	92.8	126.5	124.4	89.2	143.4	99.0	100.7	95.8
16-17; 19-23	101.0	110.9	132.9	107.3	107.6	155.4	89.6	135.8	156.6	106.1	132.8	103.4	97.7	104.6	94.6
18	101.0	110.9	132.9	107.3	107.6	155.4	89.6	135.8	156.6	106.1	132.8	103.4	97.7	104.6	94.6
24-25; 27-30	112.5	75.8	78.1	92.6	85.5	110.2	92.6	76.2	58.5	87.2	89.0	77.9	96.6	95.3	97.7
26	112.5	75.8	78.1	92.6	85.5	110.2	92.6	76.2	58.5	87.2	89.0	77.9	96.6	95.3	97.7
31-33	77.5	48.7	132.5	123.8	120.1	126.1	91.7	88.1	84.1	74.7	84.9	71.7	63.7	78.3	70.5
41	79.5	58.8	55.4	82.3	94.2	70.9	63.9	88.0	86.3	72.9	60.0	56.2	78.6	63.8	82.3
42	65.6	75.2	93.4	52.0	56.5	104.9	90.8	64.6	56.3	76.7	117.4	48.7	22.4	78.6	64.0
43	44.9	55.8	51.2	47.3	51.7	32.8	50.1	46.2	36.7	45.9	52.1	64.1	61.3	52.4	45.8

45	126.8	148.8	127.2	79.6	78.6	89.3	128.3	87.5	104.3	71.7	88.0	70.9	73.9	70.9	96.4
46	51.1	104.4	107.1	86.4	59.7	56.3	72.7	60.1	56.5	61.9	48.5	57.4	34.3	71.3	63.9
47	55.2	43.4	41.8	45.1	43.9	54.8	45.7	53.8	47.7	48.7	57.3	52.7	66.9	41.6	61.4
49 & 50	58.8	67.5	83.8	47.4	79.9	78.9	78.6	103.7	92.9	72.7	84.8	102.7	118.1	121.0	104.8
51	36.9	63.2	64.9	28.9	56.2	64.2	64.3	65.0	60.3	55.6	58.8	89.0	98.2	94.8	72.3
52-53	66.2	19.7	48.2	97.2	109.2	106.5	47.6	44.6	63.5	105.2	49.4	44.6	60.3	49.2	43.8
55-56	29.2	30.9	33.5	25.1	31.9	30.0	29.3	34.7	37.4	32.6	32.7	31.0	35.3	28.3	45.3
58	83.9	122.5	67.0	52.7	46.2	79.3	55.5	39.5	35.8	55.7	86.9	78.9	69.1	64.9	67.5
59	144.0	210.3	115.0	90.5	79.4	136.2	95.2	67.9	61.4	95.7	54.6	49.6	43.4	40.7	42.4
60	101.1	101.1	114.6	101.1	75.5	100.7	101.1	101.1	83.9	116.6	180.3	146.8	146.8	143.4	170.9
61	293.8	471.8	227.4	196.1	149.8	199.9	194.0	152.2	166.4	231.4	364.1	336.5	381.3	289.5	345.1
62	165.3	226.9	140.6	154.5	130.4	105.5	117.4	57.2	113.3	165.7	95.2	114.9	87.3	83.1	76.6
63	127.8	175.5	108.8	119.5	100.8	81.6	90.8	103.4	87.6	128.2	89.1	107.6	81.7	77.8	71.7
64	266.3	254.6	278.7	277.5	302.3	206.9	223.2	262.7	147.6	251.6	173.8	293.3	87.1	250.9	273.7
65	459.1	438.8	480.5	412.7	521.1	356.7	384.8	412.7	254.5	433.7	282.3	476.3	141.5	407.4	423.8
66	78.9	75.4	82.6	82.2	89.5	61.3	66.1	77.8	43.7	74.5	58.9	99.4	29.5	85.0	92.8
68	118.0	194.0	190.0	150.0	132.9	197.6	134.3	162.7	208.1	142.7	194.5	228.0	174.7	223.0	229.4

69	102.6	65.2	103.3	114.0	102.5	73.4	73.5	59.1	102.6	92.9	210.2	152.8	180.9	143.3	118.6
70	22.5	79.9	67.8	73.4	54.4	16.3	26.1	14.2	30.8	20.4	23.9	45.7	49.3	41.6	31.6
71	107.0	107.9	60.6	116.8	129.1	80.9	103.6	52.4	93.4	124.1	202.7	45.8	44.9	33.3	63.6
72	125.0	40.4	170.4	168.3	74.4	119.8	124.7	155.1	92.0	215.1	17.4	26.8	22.2	23.5	20.9
73	132.7	42.9	181.1	178.8	79.0	127.3	132.4	88.2	97.7	228.5	117.1	180.3	149.1	158.1	140.4
74	93.5	30.3	127.6	126.0	55.7	89.7	93.3	62.2	68.9	161.0	52.5	80.8	66.8	70.8	62.9
75	35.2	19.9	54.0	33.0	15.2	46.7	42.6	35.0	22.2	58.0	68.4	100.7	119.4	95.0	96.1
77	196.4	235.1	191.0	264.5	288.0	83.9	145.8	411.1	333.7	277.9	165.7	667.1	427.4	366.5	215.5
78	45.0	34.2	27.2	32.8	31.9	56.1	32.3	19.4	55.5	35.3	24.1	29.3	40.6	29.6	18.8
79	177.3	157.8	97.6	92.4	81.4	235.9	118.4	114.4	180.9	109.5	120.1	112.0	231.6	134.6	110.4
80	31.0	23.6	18.8	22.6	22.0	38.7	22.3	13.4	38.3	24.4	31.1	37.8	52.4	38.2	24.3
81	28.1	11.9	22.9	38.9	51.1	33.2	20.3	25.7	23.1	20.2	15.2	39.4	30.2	37.9	32.4
82	53.8	59.4	35.0	85.9	72.3	50.5	170.4	185.1	253.7	82.3	22.0	43.1	58.7	63.9	75.5
84	54.0	81.3	76.4	60.3	66.5	69.5	66.3	62.0	56.8	67.4	70.0	78.4	84.8	76.7	70.0
85	54.6	62.7	61.0	63.4	57.9	58.1	50.7	59.3	59.0	58.5	65.6	56.1	62.5	60.0	63.5
86-87	45.7	43.2	58.2	48.0	45.7	55.2	46.7	44.1	38.4	56.2	42.5	39.7	47.2	51.5	38.9
88	51.3	41.4	26.3	20.5	28.4	39.1	27.1	50.1	36.6	22.8	17.9	17.7	34.8	29.7	24.9

90-93	42.1	46.0	73.8	30.8	50.5	59.3	32.3	27.8	48.1	36.5	38.5	36.9	45.1	35.8	50.3
94	72.0	35.8	51.3	53.3	34.3	127.4	209.3	22.6	93.5	56.6	20.9	40.2	44.4	106.3	39.4
95	114.8	38.2	66.2	87.4	48.7	156.6	256.0	36.0	144.3	74.1	30.1	46.4	53.4	135.7	57.1
96	174.1	139.9	93.5	179.4	152.6	123.3	91.2	92.0	132.7	105.2	99.7	173.2	80.6	58.2	101.4
Average	71.5	70.3	76.9	67.5	70.6	78.0	74.0	67.8	73.8	69.2	70.1	80.1	67.3	75.6	68.0

B.3 Wage Rates by Sector in Study Area

In this section the data on wage rates by sector in the study area is discussed.

B.3.1 Wages Rates by Region: 1999-2018

UK wage data was sourced from ASHE (ONS, 2019) from 1999 to 2018. The highest level of geographical disaggregation available over this time period is for the 12 regions of the UK. The wage rates over time for the North West and the Yorkshire & Humber regions in which Manchester and Leeds respectively are located are shown in Figure B.1.

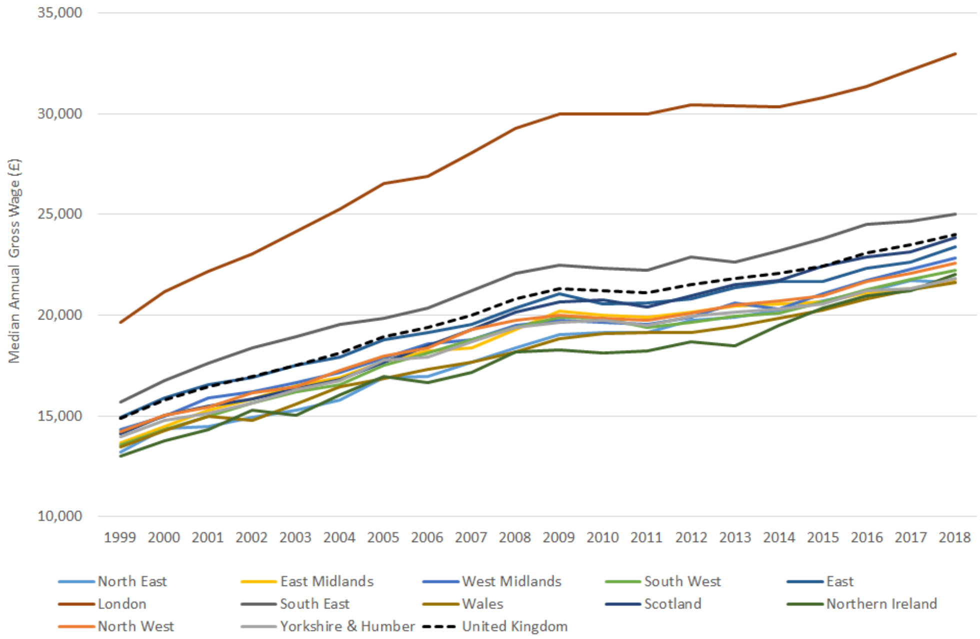

Figure B.1 Annual Median Wage (£) 1999-2018 for UK Regions[87]

Figure B.1 shows there are large differences in the wage rates across the UK. In 1999 the median wage was £14,888 with only London, South East and East regions having a higher wage than the average. Most of the other regions had similar median wage rates ranging from £13,022 in Northern Ireland to £14,326 in the West Midlands. The median average rates in the North West (£14,220) and Yorkshire & Humber (£13,969) were the fifth and seventh highest of the 12 UK regions respectively.

The wage rates in each region rise over time until the UK recession in 2008-2009 when median wage rates either declined or stabilised in all UK regions over the subsequent years. The relative positions of each region are relatively consistent over the analysis

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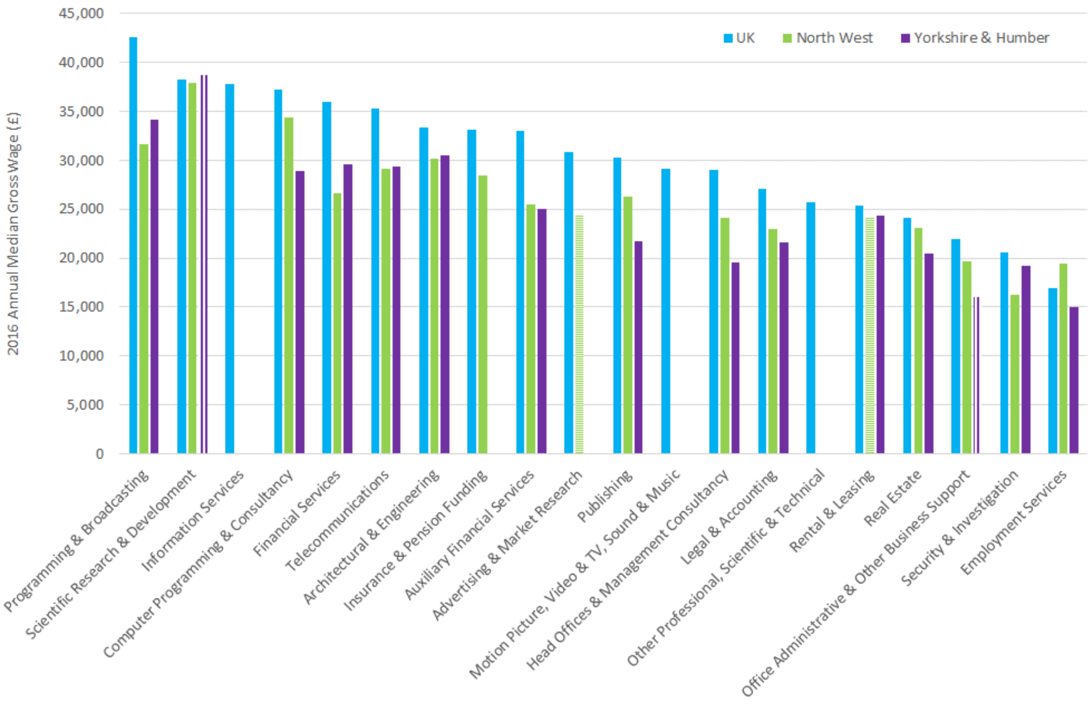
[87] The data for 2018 is provisional.

period with only Scotland rising significantly from sixth highest in 1999 to third highest in 2018. The average median wage increase in the UK over the period is 2.55% per annum. The wage rates in the North West increased by 2.44% per annum and Yorkshire & Humber had the lowest wage growth of all UK regions at 2.37% per annum.

B.3.2 Wages Rates by Region & Sector: 2016

The focus of the land-use changes in response to the inter-city rail journey time improvement is business services. The median wage data from ASHE for the 2016 base year for business service sectors for the UK, North West and Yorkshire & Humber is shown in Figure B.2. This shows that there are large differences between the wage rates by sector for the UK overall ranging from £16,985 for Employment Services to £42,583 for Programming & Broadcasting. The highest wage rates in North West and Yorkshire & Humber are in Scientific Research & Development and the wage rates in both regions are generally lower than the UK average.



Notes: Bars with horizontal stripes = 2015 data, bars with vertical stripes = 2017 data

Figure B.2 2016 Annual Mean Gross Wage by Business Service Sector

The wage rates are similar in both regions in many sectors but there are larger differences in some sectors. Wage rates are significantly higher in the North West for Computer Programming & Consultancy, Publishing, Head Offices & Management Consultancy, Real Estate and Employment Services and in Yorkshire & Humber for Programming & Broadcasting, Financial Services and Security & Investigation.

The data suggests that in specific locations there may be similar wages which would allow changes in specialisation to take place if the skills required in each sector are similar. In the North West there are eight sectors with a mean wage between £22,971 and £26,567 which are Financial Services, Publishing, Auxiliary Financial Services, Advertising & Market Research, Rental & Leasing, Head Offices & Management Consultancy, Real Estate and Legal & Accounting. There are also similar wages in higher paid sectors such as Programming & Broadcasting, Architectural & Engineering, Telecommunications and Insurance & Pension Funding which range from £28,387 to £31,620 although it might be expected that jobs in such sectors are likely to require to more specialist skills meaning mobility between them may be more limited. Outside of these groups there are two sectors with higher wage rates (Scientific R & D and Computer Programming & Consultancy) and three sectors with the lower wage rates (Office Administration & Business Support, Employment Services and Security & Investigation).

In Yorkshire & Humber there are again groupings of sectors with similar wage rates but they are slightly different to those in the North West. The highest wage rates are again in Scientific R & D but wages are also high in Programming & Broadcasting. The wage rates in Computer Programming & Consultancy are lower than in the North West and are within a group which comprises Architectural & Engineering, Financial Services, Computer Programming & Consultancy and Telecommunications which range from £28,872 to £30,487. There is then another smaller grouping of Auxiliary Financial Services and Rental & Leasing which range from £24,337 to £25,006 and then another group of five sectors (Publishing, Legal & Accounting, Real Estate, Head Offices & Management Consultancy, and Security & Investigation) with wage rates lying between £19,234 and £21,663. The three sectors with the lowest wage rates are the same as those in the North West (Security & Investigation, Office Administration & Business Support and Employment Services).

The ASHE data was sourced over time to determine whether the wage differentials between sectors were consistent over time in each region. The wages for the North West and Yorkshire & Humber are shown in Figures B.3 and B.4 respectively from 2009 to 2018 which is the period for which data at SIC 2007 level is available[88].

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[88] There is also data available at 2007 SIC level for 2008 but there is no median data by sector for business service sectors in the two regions.

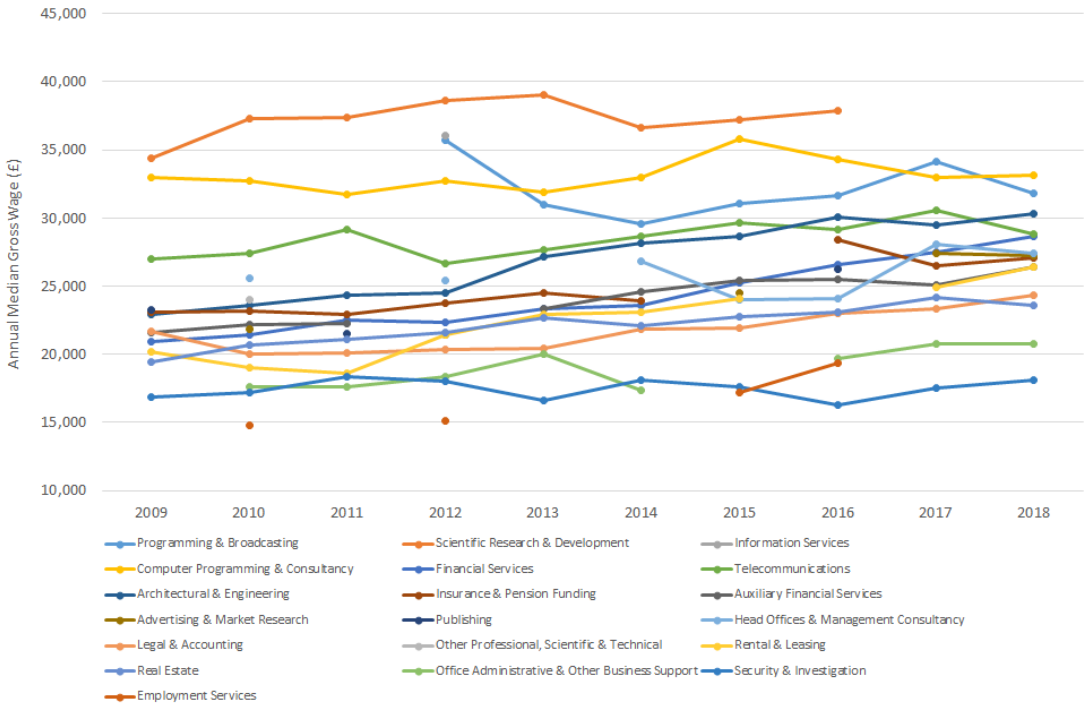

Figure B.3 Median Wage Rates by Business Service Sector 2009-2018: North West[89]

Figure B.3 shows that the three groupings of sectors with similar wage rates observed in the 2016 data outlined above are relatively consistent over time. The only exception to this is architectural & engineering in which the wage rate increases over time above the level of the other sector in the largest grouping. The wage rate in telecommunications also seems to decline from one of the highest towards the largest group of sectors but this is partly dependent on the 2018 data which is currently only provisional.

Figure B.4 shows that the groupings of sectors by wage rate over time also remain relatively consistent in Yorkshire & Humber although there are a few notable exceptions. Firstly, in Financial Services in which the wage rate increases over time from a similar level to the largest grouping of sectors in 2009 to the grouping with higher wages which also includes Architectural & Engineering, Computer Programming & Consultancy and Telecommunications by 2014. Secondly, over the early years of the analysis period the wage rate in Head Offices & Management Consultancy is similar to the wage in Architectural & Engineering and Scientific R & D but it then falls to be among the largest grouping of sectors. Finally, the wage rate in

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[89] The data used for 2018 in Figures B.3 and B.4 is provisional.

Scientific R & D increases significantly over time and is the highest for the sectors which data is available for in 2018.

The evidence from Figures B.3 and B.4 give support to the assumptions about the wage differentials used in the dynamic modelling. They show that the wage differentials in business service sectors are relatively consistent over time which can act as a barrier to labour moving sector and realising the benefits from increased specialisation.

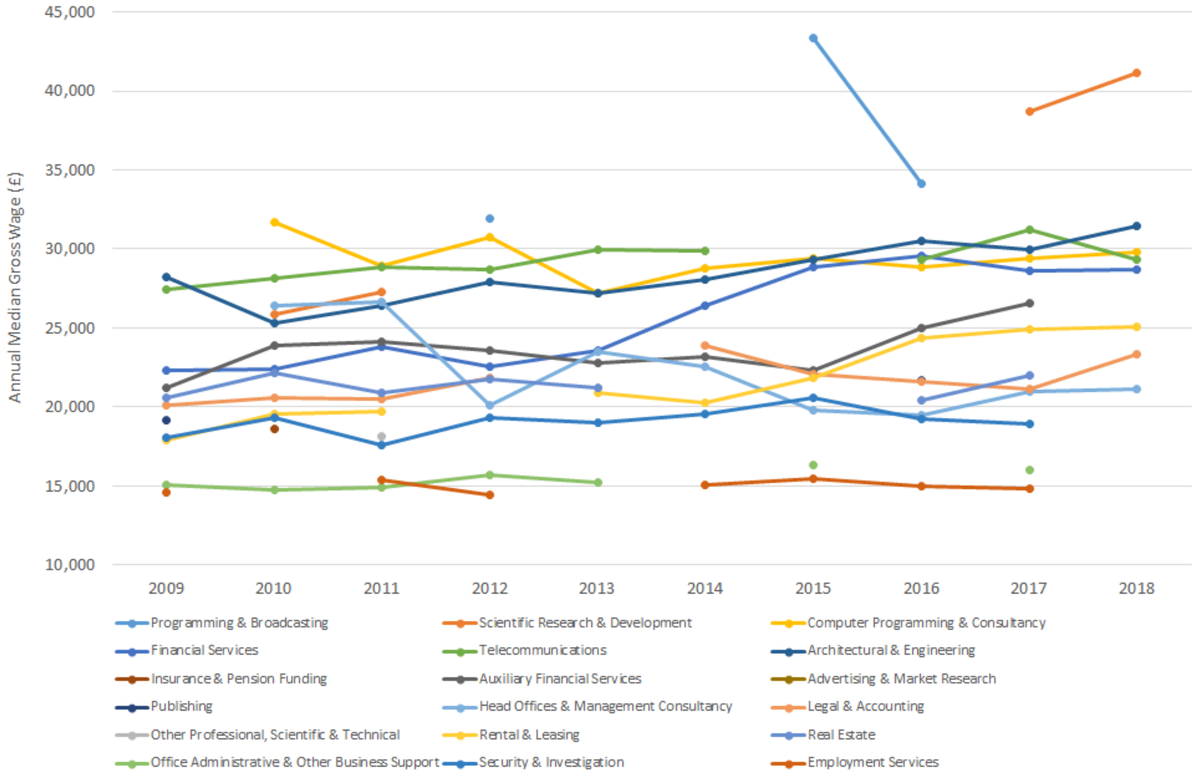

Figure B.4 Median Wage Rates by Business Service Sector 2009-2018: Yorkshire & Humber[90]

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[90] Ibid.

B.4 Plots of Estimated Benefits

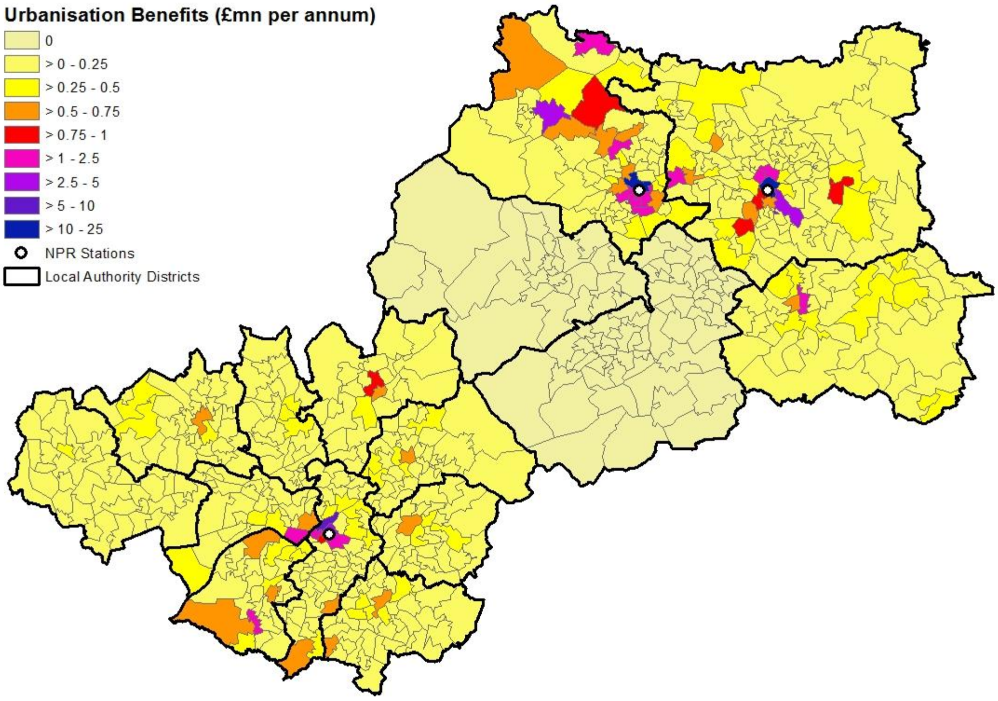

Figure B.5 Urbanisation Benefits (£mn p.a., 2030 Values & 2020 Prices) with Changes in Sectoral Composition (D1)

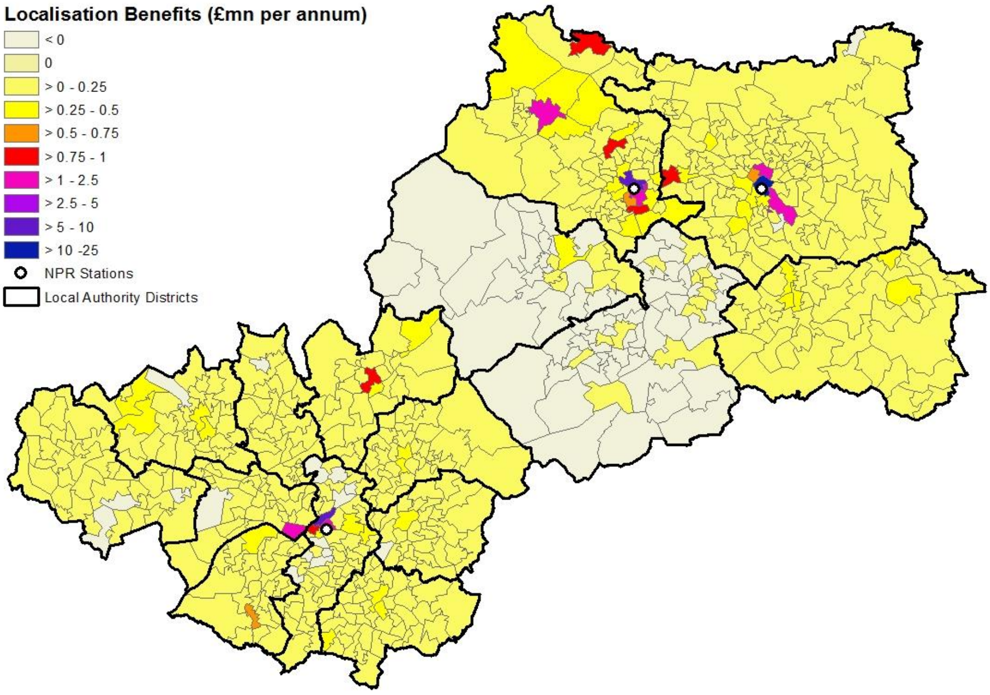

Figure B.6 Localisation Benefits (£mn p.a., 2030 Values & 2020 Prices) with Changes in Sectoral Composition (D1)

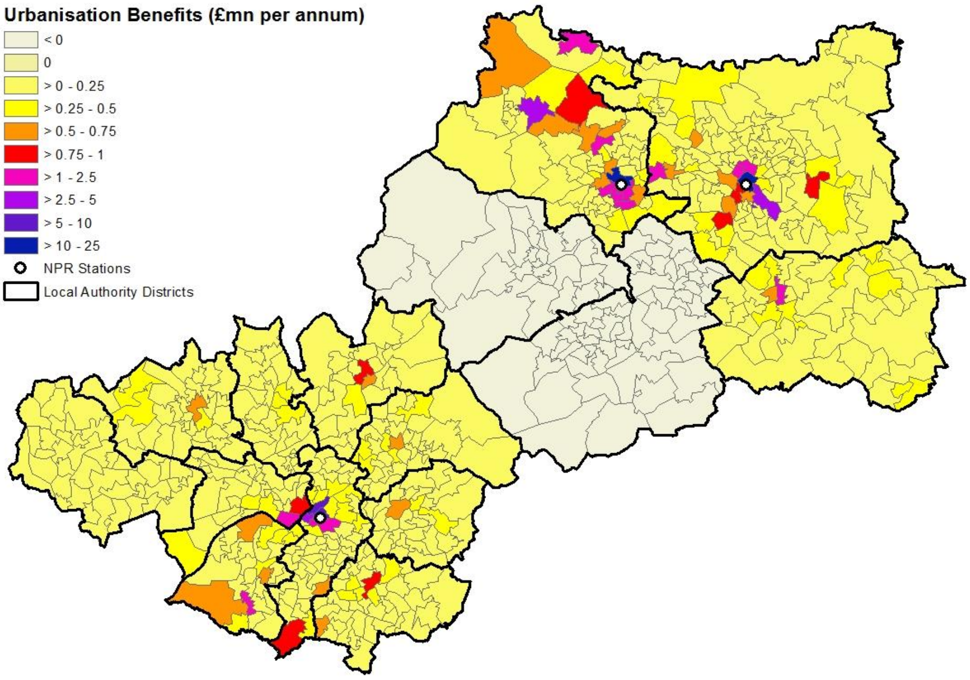

Figure B.7 Urbanisation Benefits (£mn p.a., 2030 Values & 2020 Prices) with Changes in Sectoral Concentration (D2)

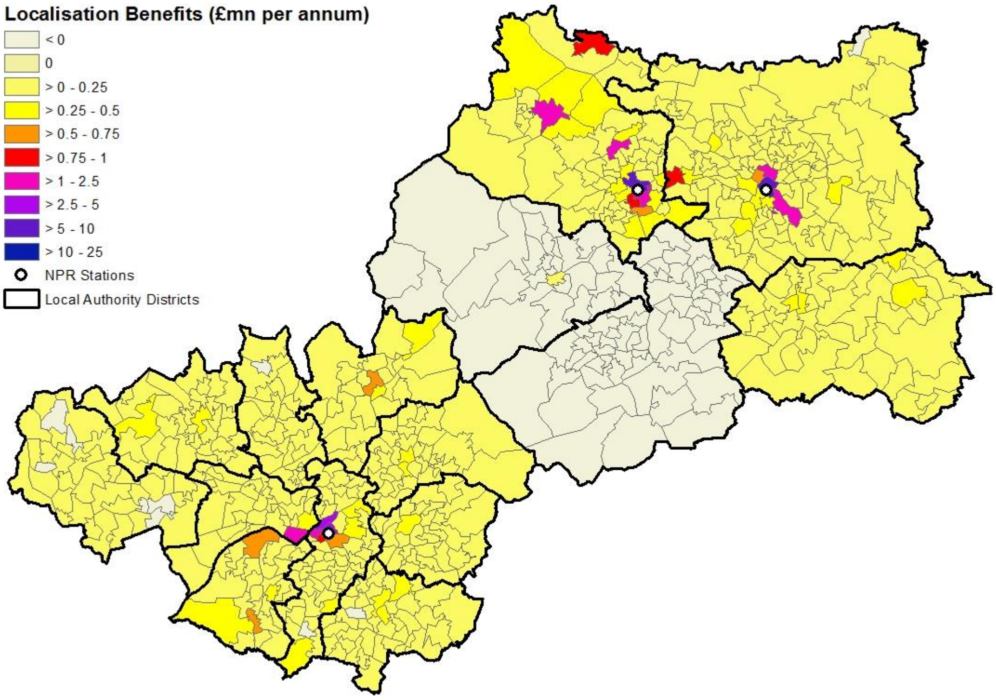

Figure B.8 Localisation Benefits (£mn p.a., 2030 Values & 2020 Prices) with Changes in Sectoral Concentration (D2)