Dynamic clustering and transport appraisal

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Abbreviations

ATM2	Auckland Transport Models
CAZ	Central Activity Zone
CBA	cost–benefit analysis
CBD	central business district
CGE	computable general equilibrium
GDP	gross domestic product
GVA	gross value added
LUTI	land use–transport interaction
NLE	Northern Line Extension
OA	Opportunity Area
S-CGE	spatial computable general equilibrium
TAG	Transport Analysis Guidance
VNEB	Vauxhall, Nine Elms, Battersea
VNEB OA	Vauxhall, Nine Elms, Battersea Opportunity Area
WEI	wider economic impact
WRR	Western Ring Route

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Executive summary

Why was this research needed?

It is increasingly important to be able to analyse and quantify how dynamic clustering (of businesses and people) can be caused by transport projects and investment, and to be able to incorporate this in the appraisal of transport projects. This is because transport projects are increasingly seen as a way to transform places, rather than solely to improve or increase transport links, and they need to be appraised as such. However, this is a relatively novel area, so guidance on and research about it is limited.

What was the purpose of the research?

The purpose of the research was to develop a framework for assessing:

- whether, the extent to which, and how transport interventions will trigger dynamic clustering
- how to analyse this in a way that allows us to assess the economic impact of dynamic clustering (ie, on welfare and potentially also on gross domestic product) – in other words, what is the value to society of the dynamic clustering, and to what extent is it additional to other impacts caused by the transport intervention?

At a more granular level, we wanted to develop answers to the following key questions.

1. What do we mean by terms such as agglomeration, dynamic clustering, and land-use change?
2. At a high level, how, when, and under what conditions do agglomeration externalities (positive and negative) occur?
3. What more fundamental micro-economic processes occur in the lead-up to (and after) the agglomeration externalities themselves (eg, location decisions), and what feedback loops exist within and between these processes?
4. How and to what extent do transport policies or investments affect the micro-economic processes from (3) and therefore agglomeration externalities?
5. How can different models or analytical tools be used to trace the cause and effect from transport intervention (4) to micro-processes (3) to agglomeration externalities (2)? These tools may be step-wise – that is, only effective at modelling the link between (4) and (3) or only (3) and (2).
6. Which approaches should be incorporated into guidance for transport CBA practitioners?
7. What would the recommended approach look like as shown in a case study?
8. What areas might be productively analysed through future research, given the considerable conceptual and empirical challenges in the area? The principal focus of our work has been to conceptualise dynamic clustering and to identify the issues involved in their analysis, rather than to provide comprehensive guidance on how to quantify their impacts.

How was the research conducted?

First, we carried out a review of literature from peer-reviewed academic journals, reports and guidance documents intended for appraisal practitioners, and some work that has been carried out by practitioners on the practical appraisal of transport schemes.

Second, we developed a flexible methodology for appraising the economic impacts of dynamic clustering brought about by a transport intervention. We did this by:

- summarising economic appraisal tools for transport interventions under static and dynamic land use. We started by developing an understanding of the various economic impacts that may result from a transport intervention and then how the approaches may change with land-use change. We also explored three key areas of dynamic clustering: timing, feedback loops, and additionality of benefits;

- exploring the different economic and land-use mechanisms in detail, with a focus on the interaction between economic impacts and dynamic land-use impacts. We use logic maps to show how economic narratives can be developed in a way that helps to capture dynamic clustering in transport appraisal;

- considering the analytical approaches that could be used. We combine complementary approaches into four potential frameworks that may be used to assess dynamic clustering and economic impacts. We also consider what conditions would need to be satisfied when analysing whether dynamic clustering is likely to result in impacts that are truly additional – that is, additional after accounting for displacement;

- exploring how land-use benefits or impacts fit into the appraisal of wider economic impacts of transport interventions.

Third, we developed two case studies to show how our framework might be applied in practice.

- The first case study is a road transport project in New Zealand called the Waterview Tunnel. This project is relevant because it significantly altered journey times and accessibility in and around Auckland. The change in accessibility could be expected to affect land use and alter the economic benefits of the scheme.

- The second case study is an Underground rail project in London, England, called the Northern Line Extension. This project is different and interesting because it involves a coordination of land-use and transport planning. In other words, facilitating dynamic clustering is one of the key objectives of the scheme.

What did the research find?

First, the area is not only important, it is also complex and challenging.

Second, practitioners should be guided by the literature, which is extensive and evolving. Key points to note include the need to understand the different reasons why businesses and individuals might relocate as a result of changes in connectivity, and the different reasons why agglomeration benefits are likely to materialise and over what timeframes.

Third, there is no 'one size fits all' approach to assessing dynamic clustering impacts. A great deal depends on the specific context. Practitioners would be well advised to inform their appraisals using a well-developed economic narrative that sets out what economic impacts are expected from the project and why, which could be usefully informed by the tools we have developed, particularly:

- **logic maps**, which set out the impacts that the transport project is expected to have, given the various contexts and market failures that are specifically relevant to the project

- **appraisal summary tables**, which summarise the various impacts that could be expected to materialise as a result of the project, depending on whether the analysis is static or dynamic in nature

- the **methodology funnel**, which helps to assess which specific types of analytical approach are likely to be most relevant and appropriate for any given project

- a **checklist** of the types of reasons why dynamic clustering might generate impacts that are truly additional rather than displacement

- a **brief summary** of the likely magnitudes of different impacts, although it is vital to recognise that this is intended to serve as a very high-level guide

- some **model selection criteria**, including:
  - the use of rigorous and context-specific narratives and evidence
  - ensuring that analysis is as soundly based on economics as possible
  - validation of results – for example, by showing the extent to which the model or quantitative technique is able to forecast impacts that have actually materialised in the past
  - the use of uncertainty quantification to avoid the considerable risk of spurious accuracy – uncertainty can arise for numerous reasons, including:
    - the quality of the data used
    - the economic principles and parameters that are applied
    - the inherent challenges in forecasting complex systems over long periods of time
  - the use of a 'trust-test' – it is important to be able to explain to a non-expert:
    - the approach that has been used
    - why this approach is the best approach to use given the specific context
    - the results that have been generated
    - why these results are likely to transpire.

Fourth, it is crucial to recognise that it is very challenging to quantify many of the impacts of dynamic clustering in a robust manner – whether individually or together. In our view, it is critically important that analysis is carried out – rather than simply sticking to static analysis – to ensure that sound decisions are made on specific projects. But it is equally vital that analysis is carried out robustly with the strengths and potential shortcomings of such analysis being clearly articulated and recognised. This can help to ensure that the area advances in a way that people are able to understand and trust.

Fifth, there is a great deal more work that could be done in the area.

1. Our framework could be applied on a 'live' project. This could be done at a high level and semi-illustrative basis or on a much more detailed and quantitative basis.

2. The use of spatial computable general equilibrium (S-CGE) models could be developed by, for example, using simple or 'stripped-down' versions alongside fuller models – in order to help users to test and explain their results. It could also be useful to ensure these models better analyse and capture location choice by individuals and businesses, and more granular analysis of land use.

3. Refinements could be made to existing approaches to land use–transport interaction (LUTI) modelling – in particular, to increase their transparency and the extent to which they are founded on sound economics and context-specific narratives and evidence.

4. The induced demand approach to benefits estimation could be further developed and evaluated alongside a robust wider economic impacts (WEI) framework approach.

5. A deeper understanding of the labour market is needed. The main areas here include a more thorough understanding of:
   a. situations where increased labour supply generates truly additional welfare
   b. the elasticity of labour supply, which affects the above point as well as how the benefits of transport projects might ultimately flow through to labour rather than the property market
   c. the impact of employment on wellbeing and life opportunities (over and above wages paid)

    d.   the value of leisure time or other time not in employment that may be valuable (eg, cleaning, caring, teaching, volunteering).

6. A fuller understanding of the magnitude of the relevant elasticities of land supply would be useful. This parameter was identified as a key determinant of land and property prices, and the extent to which dynamic clustering occurs depends on whether more intensive land use is possible.

7. Further research could be carried out into locational choice models. Further understanding of how location choices are made by both firms and individuals/households would improve how these decisions are analysed in LUTI or S-CGE models or in *ad-hoc* analysis.

8. There could be further analysis of consumption amenity benefits, which may provide welfare benefits that are additional to the welfare benefits generated from production externalities (which are generally the focus of this report and framework).

Abstract

It is increasingly important to be able to analyse and quantify how dynamic clustering (of businesses and people) can be caused by transport projects and investment, and to be able to incorporate this in the appraisal of transport projects. This is because transport projects are increasingly seen as a way to transform places, rather than solely to improve or increase transport links, and need to be appraised as such. We develop a framework for assessing (a) whether, the extent to which, and how transport interventions will trigger dynamic clustering, and (b) how to analyse this in a way that allows us to assess the economic impact of dynamic clustering (ie, on welfare and potentially also on GDP). We carry out a literature review, develop a methodology, and apply the methodology to two case studies. We have five main findings. First, the area is not only important, it is also complex and challenging. Second, practitioners should be guided by the literature, which is insightful, vast and evolving. We therefore develop high-level summaries as well as a detailed discussion of the literature. Third, there is no 'one size fits all' approach, and much depends on specific context. We therefore develop some practical tools that can be applied in a flexible but rigorous way. Fourth, it is critically important that analysis is carried out – rather than simply sticking to static analysis – to ensure that sound decisions are made on specific projects. But it is equally vital that analysis is carried out robustly with the strengths and potential shortcomings of such analysis being clearly articulated and recognised. This will help to advance the frontier of best practice. Fifth, there is much work in the area that still needs to be done, particularly in the quantitative analysis of key impacts. We therefore highlight potential areas for future research.

1   Introduction

NERA Economic Consulting was commissioned by Waka Kotahi NZ Transport Agency to carry out a research assignment into how to capture dynamic clustering in cost–benefit analysis (CBA). Our work was carried out under the terms of our contract with Waka Kotahi dated 21 July 2020. We received input from our independent peer reviewers (Professor Dan Graham and Professor Hans Koster), but the work in this report is our own.

1.1   Research questions

Our fundamental research question is how to analyse and quantify one of the most contentious areas in transport project appraisal today – dynamic clustering brought about by transport investment. This area of research is important because transport projects are increasingly seen as a way to transform places, rather than solely to improve or increase transport links.

At a high level, our task is to develop a framework for assessing:

- whether, the extent to which, and how transport interventions will trigger dynamic clustering

- how to analyse this in a way that allows us to assess the economic impact of dynamic clustering (ie, on welfare and potentially also on gross domestic product (GDP)) – in other words, what is the value to society of the dynamic clustering, and to what extent is it additional to other impacts caused by the transport intervention?

This fundamental research question can be broken down into smaller constituent questions. In order to evaluate dynamic clustering in transport appraisal, the questions we really want to answer are:

1. What do we mean by terms such as agglomeration, dynamic clustering, and land-use change?

2. At a high level, how, when, and under what conditions do agglomeration externalities (positive and negative) occur?

3. What more fundamental micro-economic processes occur in the lead-up to (and after) the agglomeration externalities themselves (eg, location decisions), and what feedback loops exist within and between these processes?

4. How and to what extent do transport policies or investments affect the micro-economic processes from (3) and therefore agglomeration externalities?

5. How can different models or analytical tools be used to trace the cause and effect from transport intervention (4) to micro-processes (3) to agglomeration externalities (2)? These tools may be step-wise – that is, only effective at modelling the link between (4) and (3) or only (3) and (2).

6. Which approaches should be incorporated into guidance for transport CBA practitioners?

7. What would the recommended approach look like as shown in a case study?

8. What areas might be productively analysed through future research, given the very considerable conceptual and empirical challenges in the area? The principal focus of our work has been to conceptualise dynamic clustering and to identify the issues involved in their analysis, rather than to provide comprehensive guidance on how to quantify their impacts. Much more work in this area still needs to be done.

1.2   Structure of report

The report is divided in four sections:

- section 2 – a literature review summary
- section 3 – a methodology report where analytical tools are developed and explained
- section 4 – a pair of case studies applying the methodology in practice
- section 5 – conclusions and recommendations.

There are also three appendices:

- the full literature review (Appendix A)
- a discussion of issues in relation to imperfect competition (Appendix B)
- a discussion of issues in relation to the labour market (Appendix C).

2 Literature review

This report draws on literature from peer-reviewed academic journals, reports and guidance documents intended for appraisal practitioners, and some work that has been carried out by practitioners on the practical appraisal of transport schemes. The relevant literature is vast, reflecting the broad scope of this research assignment.

We have therefore carried out as thorough a literature review as was feasible. This chapter contains a summary of those findings (with some direct references to the literature). The full review is included in Appendix A (which includes more comprehensive references to the literature).

Some readers may find it sufficient to review this chapter on its own. Others may prefer to review this chapter in conjunction with the detailed literature review included in Appendix A.

2.1 Introduction and context

When appraising a transport intervention, some aspects of the required approach are well established, particularly what we refer to as direct and wider impacts.

- Direct impacts include the value of journey time savings caused by how the transport intervention makes people able to travel between places quicker.

- Wider impacts include agglomeration economies, imperfect competition and labour market impacts. In contrast to direct impacts, these impacts are caused by market failure.

  - **Agglomeration effects** refers to externalities that are triggered when people and businesses are made closer to each other – either effectively (due to reductions in generalised journey costs) or actually (due to relocation or reconfiguration by businesses and individuals – see 'dynamic clustering' below).

  - **Imperfect competition effects** refers to how markets are not, in reality, perfectly competitive, and therefore how reducing travel costs has a disproportionate impact on the outputs generated and prices charged by firms.

  - **Labour market effects** reflect additional tax revenue resulting from individuals' greater access to work (due to reduced commuting times), leading to greater labour force participation. The main labour market impact (the so-called 'tax wedge') is considered to be an externality because individuals' work decisions are based on the impact of these decisions on their post-tax income levels – but these decisions have an impact on tax revenues, which are not 'internalised' to the individual.

It is becoming increasingly important to be able to incorporate into appraisals the way in which a transport project can prompt businesses and individuals to relocate or reconfigure and the impacts that this can have. This is referred to as **dynamic clustering**. This area of research is important because transport projects are increasingly seen as a way to transform places, rather than solely to improve or increase transport links.

Some aspects of dynamic clustering can be caused by how the transport intervention makes a place more attractive by lowering the cost of travelling to and from it – that is, individuals and businesses might move to or expand in an area simply because it is easier to travel to and from it (and around it when there). As with direct impacts, these aspects of dynamic clustering do not require market failure to occur.

However, dynamic clustering can also both cause, and be caused by, market failure. When individuals and businesses relocate to or expand in an area, this makes the area more attractive to other individuals and businesses (so clustering creates a positive externality) – which, in turn, can cause other similar decisions by

individuals and businesses. These decisions create more externalities and can therefore continue to make the place more attractive.

Importantly, however, there are also frictions associated with clustering – mainly in the form of congestion, environmental externalities and higher land prices. These frictions help to explain why transport interventions tend not to trigger endless rounds of location and relocation, with entire populations relocating to the most dense and well-connected places. This issue is covered well by Duranton (2011) through a graph that shows how the gains to agglomeration start to diminish with increasing costs.

Our challenge in this assignment is to formulate the best way of analysing the above. In other words, to develop a framework for assessing:

- whether, the extent to which, and how transport interventions will trigger dynamic clustering

- how to analyse this in a way that allows us to assess the economic impact of dynamic clustering (eg, on welfare and potentially also GDP) – in other words, what is the value to society of the dynamic clustering, and to what extent is it additional to other impacts caused by the transport intervention?

In order to do this, we begin with this literature review. The purpose of the literature review is to inform the development of a methodology, which is contained in section 3.

2.2   Key concepts

Terminology is important. Referring back to the research questions provided in the introduction, we start by summarising what the literature tells us about the definitions of some key concepts. We provide a summary in Table 2.1.

Dynamic clustering refers to the process of density increasing over time through increased development and the clustering of economic activity at a location (through relocation or reconfiguration decisions), which may also increase the attractiveness of a location. For dynamic clustering to occur, it is necessary for people and businesses to want to relocate to a place, and there also needs to be land available to them at the right price. In this report, we refer extensively to 'relocation' decisions, but this should be interpreted in a general sense in that it also includes decisions by businesses to reconfigure their activities (eg, to expand or contract in different places). Dynamic clustering involves changes to the intensity of land use.

It is therefore important to define what we mean by **land use**. We define land use as the intensity and type (eg, sector mix) of activities that occur in an area (eg, a change in the number of residents, businesses or employees constitutes a change in land use). This definition of land use is wide ranging and covers many different changes in the deployment of capital, labour or other resources. It is also in accordance with most guidance. The *Monetised Benefits and Costs Manual* (Waka Kotahi, 2020) states that land-use change is 'affecting the scale, sector mix and the density of a location by inducing a change in the level and/or location of economic activity' (p. 74). In the UK, Transport Analysis Guidance (TAG) unit 2.1 defines changes to land use as 'changes in the purpose or intensity of usage' (Department for Transport, 2016a, p. 5).

Land use is sometimes used to refer to the type of activity that is permitted to occur in a given area. To avoid confusion, we refer to this as 'land-use regulation' or 'zoning'.

Table 2.1   Summary of definitions of key concepts

Key concept	Summary definition	Consensus	Analysis of dynamic clustering needs to...
Dynamic clustering	• The change in density or concentration of activity that occurs over time	✓	• Correctly predict the increase in concentration that will occur
Land use	• The type and intensity of an activity at a location	✓	• Consider the scope for potential land-use changes
Static and dynamic appraisal	• Static approaches to appraisal exist that hold land use constant to estimate agglomeration economies • Dynamic approaches to appraisal exist but are beset with challenges, hence this piece of work	✗	• Account for the circular nature of dynamic processes • Develop understanding of timing of impacts • Consider both the positive and negative externalities
Agglomeration economies	• Productivity impacts due to increased effective density, which may be caused by lower generalised journey costs or dynamic clustering • Extensive analysis has been carried out of the size of potential elasticities • Some gaps in the literature about which impacts are static vs dynamic and the time it takes for dynamic impacts to occur	✓	• Ensure that the appropriate parameters are used for assessing agglomeration economies • Ensure that displacement of agglomeration economies is accounted for
Market failure	• Key market failures are those involved in: (a) matching sharing and learning; (b) coordination; (c) externalities; and (d) land-use regulations	✓	• Categorise the different types of market failure that are relevant and how they are addressed by different modelling approaches
Additionality	• Quantification of benefits that ensures no double counting of impacts and that benefits are not simply displacement of activity from other areas/sectors • Key issues include: (a) potential overlaps between transport user benefits and agglomeration; (b) links between agglomeration and land value; (c) the need to take account of reductions in agglomeration caused in place B as a result of clustering in place A; and (d) whether and when displacement could be treated as additional due to the use of a social welfare function	✓	• Categorise the circumstances where benefits are likely to be additional, and methods to determine the extent of additionality
Partial/General equilibrium	• Second-round effects and markets outside the main market of interest	✓	• Assess whether general equilibrium approaches may become appropriate when interventions are likely to have transformational impacts (eg, dynamic clustering)

In transport appraisal, fundamental economic parameters (eg, land use) may be held fixed. This can be appropriate when looking to estimate benefits at the margin. We use the terms **static and dynamic appraisal** or **static and dynamic land use** to refer to a situation where the appraisal allows land use to change (dynamic) or has fixed land use (static).[1]

Agglomeration economies refers to the economic effects caused by density, the most prominent being an increase in business productivity. A transport intervention can generate agglomeration economies by making people and businesses better connected simply through a reduction in generalised journey cost – that is, they are made effectively closer together even if their actual locations remain unchanged. Agglomeration economies may be either static or dynamic, where static agglomeration effects involve mechanisms that may occur instantaneously while dynamic agglomeration effects involve mechanisms that occur over time. However, we are not aware of empirical approaches that manage to separate the effects of agglomeration into static and dynamic elements.

There is a relatively high level of consensus in the literature about the definition of agglomeration economies. There is also a great deal of quantitative evidence on the relationship between concentration on the one hand and business productivity on the other.

Increased density can also bring about negative effects, the most notable of which are congestion and environmental externalities. There are many more potential negative effects, but for the purpose of this report we mention the most transport-relevant ones: congestion and vehicle emissions. We also cover the key links with land and land prices.

We also need to be clear about key concepts of **market failure**. The market failures that are most relevant to our discussion seem to be:

- the external benefits of matching, sharing and pooling that are generated when businesses and individuals are brought closer together. We discuss these effects in more detail below but note here that there is a consensus about the existence and underlying nature of these effects;

- coordination failures in relation to location decisions by people and businesses, and also in relation to the development of land. Some location and development decisions are essentially complex forms of the 'prisoner's dilemma', in that it might not be individually rational for individuals and businesses to relocate or for landowners to develop their land, but it is if they know that others will be relocating to a place or developing their land. It seems to us that issues of coordination are likely to be important to the analysis of dynamic clustering, but we have not yet identified much literature that specifically addresses this issue.

The concept of **additionality** is also crucial. Additionality is a concept in CBA related to whether a benefit is truly additional to the economy, rather than displaced from elsewhere or double counting of another benefit (whether one that has been monetised or one that has been considered qualitatively but still factored into the analysis).

As a general but fundamental point, when appraising multiple wider economic impacts, whether static or dynamic, it is important to ensure that there is additionality (ie, no double counting) between the different elements. For example, the extent to which dynamic clustering or agglomeration economies are truly additional to travel time savings is discussed in the literature. If we take agglomeration economies as productivity impacts, then Venables (2007) shows a theoretical modelled example of why agglomeration

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[1] This is in contrast to the often-used terms 'static agglomeration' and 'dynamic agglomeration', which we avoid using unless referring to the timing with which agglomeration economies occur.

economies are additional to travel time savings. Graham and Gibbons (2019) elaborate on this to explain that in the UK context, user benefits are calculated using the pre-intervention and spatially constant value of time, which ensures that the wage/productivity impact of agglomeration economies is additional. An approach that uses variable values of travel time, which increase when wages increase (as a result of agglomeration economies), could, in theory, capture agglomeration impacts, but we are not aware of any user-benefit models that do this. Graham and Gibbons (2019) also note that there are gaps in our knowledge and recognise that there may be ways that agglomeration economies flow to user benefits.

We also highlight three other points in relation to additionality:

1. **Dynamic clustering brought about by relocation**
    If a transport intervention causes dynamic clustering in an area, this will increase the density of this area. It is, however, also likely to reduce density in another area. If agglomeration elasticities are considered to be constant, this means that many such impacts will net-out. If, however, agglomeration elasticities increase with the level of concentration in an area (which might well be the case in service sectors), or indeed if clustering involves people or businesses switching between sectors with different agglomeration elasticities, then there is more scope for genuinely additional impacts.

2. **Whether land value uplift is additional to changes in travel time savings**
    The *Monetised Benefits and Costs Manual* (Waka Kotahi, 2020) considers land value impacts to be *not* additional, but rather a capitalisation of travel time savings, which the literature supports. Productivity increases due to agglomeration economies may also flow into land values. If that occurs, it is also unlikely to be additional since the land value uplift simply reflects all or some of the productivity gain and can be viewed as an increase in factor prices.

3. **Use of a social welfare function**
    If society places a greater weight on the additional wealth or utility accruing to certain individuals or groups, then a transport intervention that simply displaces economic activity from one area or sector to another can have an impact that has additional value. This is an important issue given the extent to which policymakers in many countries are considering the potential impact of policies that will have distributional impacts – that is, policies to help the relatively badly off. The economic rationale for this type of additionality (and the use of a social welfare function) is that there is diminishing marginal utility of income as individuals increase in wealth – that is, a wealthy individual may value an additional £1 earned/saved less than individuals in lower-income brackets. A project that effectively moves £1 of economic activity from a wealthy area to a poor area could therefore have a net positive welfare impact.

Finally, we consider the difference between **partial equilibrium** and **general equilibrium** frameworks. Transport appraisal is often based on the assumption that prices and demand in non-transport markets are held constant. Any changes to the price or demand of transport are reflected in the market for transport, but not in any other markets. And if there are any such changes, then these will simply reflect and be equal to impacts in the primary (transport) market. In economics, this is defined as a partial equilibrium framework.

Indeed, economic theory has shown that when markets are perfectly competitive and prices in secondary (in this case, non-transport) markets do not change as a result of interventions in the primary (in this case, transport) market, then an assessment of the benefits and costs in solely the primary market will capture all of the relevant social benefits and costs – see, for example, Boardman et al. (2017) and Just et al. (1982).

However, when we begin to analyse agglomeration economies or dynamic clustering impacts, there is an inconsistency with the partial equilibrium framework. Introducing changes to productivity, levels of competition, employment levels etc involves recognising that (a) other markets are not working perfectly (ie, there is some market failure), and (b) that prices and demand/supply in other markets may change as a

result of changes in the transport market (and in a way that does not simply reflect and is equal to the change in the transport market).

This is where a general equilibrium approach, which allows for changes to prices in other markets, can become relevant. General equilibrium models 'simulate the function of entire economies with micro-economic behavioural functions. These represent the actions of households, firms and others, solved simultaneously to trace non-linear relationships throughout an economy' (Robson & Dixit, 2017, p. 990).

While most CBAs are carried out within a partial equilibrium framework, there is an increasing amount of use of general equilibrium approaches – particularly for interventions that could have transformational impacts (such as dynamic clustering). This is recognised in the UK where spatial computable general equilibrium (S-CGE) models are used and explicitly described as being acceptable in guidance on supplementary economy modelling (Department for Transport, 2019), and we are aware of a number of appraisals having been carried out using various forms of general equilibrium approach.

2.2.1   Key mechanisms

We now consider the mechanisms that are at work and provide a summary in Table 2.2.

At the outset, however, it is important to note the difficulty in separating and quantifying the impacts of the different mechanisms. In particular, the theoretical evidence for the different mechanisms in Table 2.2 is not matched by empirical estimates of their different impacts. For example, empirical estimates of agglomeration economies include the impacts of sharing, matching, and learning – but little progress has been made in isolating their individual impacts, and the challenges in doing so are great.

Table 2.2   Summary of key mechanisms

Mechanisms	Summary of literature review	Consensus	Analysis of dynamic clustering needs to...
Sharing	• Sharing of indivisible amenities provides increasing returns to scale and allows additional productivity gains from specialisation.	✓	Be able to analyse the magnitude and timing of these different effects
Matching	• Labour market matching results in higher productivity and wages. • Potential evidence for spatial sorting as a result of better matching in cities.	✓	
Learning	• Evidence that learning occurs via agglomeration, for both individual workers and at the firm level.	✓	
Crowding	• Generally agreed that crowding impacts exist and land costs are often modelled. • Crowding impacts are less well studied than positive impacts. Still fewer studies review the positive and negative impacts together.	✓	Ensure that models include negative as well as positive impacts of increases in density
Firm location choice	• Firm characteristics are the main reason that firms relocate. • Natural locational advantages are a significant and large reason for choosing a specific location. • Evidence both urbanisation and localisation agglomeration affect location choice.	✓	Incorporate the recursive nature of firm location decisions, which are affected by other firms' locations
Household location choice	• Two specific modelling approaches are the main options for modelling location choice: choice models and spatial equilibrium models (urban economics models like bid-rent). It is not clear to what extent these two approaches are/can be made consistent with one another.	✓	Understand whether modelling approaches rely on spatial equilibrium and/or choice models and whether they are consistent
Labour market decisions	• Appraisal guidance tends to have travel time reductions result in increased labour supply. In the literature, the evidence for this is mixed. • There is a literature that incorporates job choice with other location/commute decisions, but these models do not deal well with heterogenous agents.	✗	Revisit the evidence on labour supply impacts of changes in travel time
Land supply	• Literature on costs of land-use regulation is well established, and estimates exist for the New Zealand context. • Interaction between land-use restrictions and dynamic clustering exist in the academic literature but are not very well understood (via negative agglomeration).	?	Incorporate either land capacity or elasticity of supply for development into analysis
Accessibility	• Relationship between accessibility and other mechanisms such as location choice is fairly well established. • Specific metrics for measuring accessibility may vary.	✓	Consider the issue carefully

Referring back to research question 2 (from the introduction), we explore the processes of agglomeration economies. There is consensus that the driving forces of agglomeration economies are **sharing, matching and learning**. Some work has been carried out on the timings of these effects: sharing and matching effects appear to manifest themselves relatively quickly, but learning effects take longer to materialise. However, this work is relatively nascent. There is also little, if any, evidence on the relative magnitude of these effects.

We think that obtaining a better understanding of timings will be important because an analysis of dynamic clustering needs to reflect:

- the time over which clustering might actually occur. How quickly might businesses and individuals actually relocate?
- the time over which the economic impacts of clustering will then occur. How long might sharing and matching benefits actually take to materialise, and how much longer before learning effects kick in?
- how each of the above are inter-related. Businesses and individuals are more likely to relocate (and to do so quickly) if matching, sharing and learning effects materialise quickly.

There is consensus that there are also frictions involved with dynamic clustering. The main negative transport-related externalities include congestion and environmental impacts. Evidence on the magnitude of these frictions exists, although they tend to be analysed separately from the relationship between concentration and business productivity. We are not aware of any 'all-in' measure of agglomeration economies that includes both positive and negative impacts. The negative impacts therefore should be analysed properly because dynamic clustering will likely have both positive and negative impacts.

Research questions 3 and 4 are investigated by looking at micro-processes and how transport plays a role. On **location choice**, there seems to be consensus that:

- firm location choice can be analysed and that agglomeration economies can be important in these decisions, but these choices are complex and will vary by sector, age of firm, and also the 'natural features' of an area
- individual or household location can be analysed and that agglomeration economies matter, but so do many other factors
- local economic factors, including the level of concentration, can also influence the formation of new firms and the expansion of, or investment by, existing firms in new areas.

It seems to us that a thorough understanding of location choice will be essential to any analysis of dynamic clustering because this is the only way that it will be possible to know whether it will, in fact, occur – and if it does occur, whether this is due to the transport intervention (rather than any other reason).

Land supply is essential for dynamic clustering: unless there is unused or under-used building stock, development must occur to accommodate increased economic density. Land-use regulations may reduce the elasticity of supply of development and affect the extent to which additional population density can be accommodated (Glaeser et al., 2006), and may impact the price of land/development. Importantly, transport links can raise land values, and there is an extensive literature on this. If transport links induce dynamic clustering, then the second-order effect on land values could be very significant in determining (eg, constraining) the benefits that ultimately emerge.

We did not find much in the literature about the importance of strategic interaction – in relation to location choice by businesses and individuals, and indeed in relation to the development of land. **Strategic interaction** in this context means the ways in which decisions depend on the decisions/actions of other firms/individuals/policymakers and is typically analysed in economics using game theory. This may be a fruitful area for potential future research.

2.2.2 Models

We now deal briefly with models and summarise our findings in Table 2.3. Research questions 4 and 5 are addressed here. We divide models into two categories: those that forecast changes in supply and demand in transport and property markets, and those that assess the economic and welfare impacts of those changes.

Table 2.3   Summary of models

	Model	Description	Consensus	Analysis of dynamic clustering needs to...
Forecasting supply and demand	Traffic demand	Four-stage traffic models are commonly applied to projects of all types and scales.	✓	• Note
	Land use–transport interaction (LUTI)	Wide set of model approaches that forecasts land-use changes that result from transport intervention.	?	• Ensure validation of models • Ensure that displacement/additionality can be measured • Ensure models are transparent and use reliable data • Ensure it is based on sound economics
	Supply analysis	Approaches to assess the extent and type of land-use changes that may occur.	?	• Account for the effect of demand on supply (ie, whether development is viable due to price implied by level of demand)
	Game theory	Approaches to assess strategic interaction between landowners, developers, firms or households when their decisions (investment, location) depend on the actions of other agents.	?	• Predict outcomes for different strategic actors • Model decisions under asymmetric or imperfect information
Analysing the economic and welfare impacts	Wider economic impacts (WEIs)	Quantifies the change in effective density by industry and multiplies this by the elasticity of agglomeration for that industry to determine productivity impacts. Other changes in labour supply and price changes in markets with imperfect competition are also assessed.	✓	• Ensure timing of impacts is consistent with theory • Assess the change in density/demand due to transport intervention • Assess distribution of impacts (eg, extent to which impacts flow to landowners, workers, etc)
	Spatial computable general equilibrium (S-CGE)	General equilibrium model that accounts for changes in labour supply and other non-transport markets using transport cost changes and agglomeration productivity impacts as inputs.	?	• Ensure correct granularity of analysis • Ensure models are transparent • Ensure that location decisions by businesses and individuals, and the availability of land, are captured in the analysis
	Induced demand	Approaches that identify the total impacts of a transport intervention, including transport user benefits, wider benefits and benefits from changes in 'place attractiveness' through assessing changes in demand and supply in the transport market only.	✗	• Determine preferred approach to assessing these impacts • Understand underlying assumptions, whether these are realistic or under what conditions they hold • Determine whether there are impacts of transport intervention that may not be captured • Assess whether the dynamic nature of impacts can be captured using this method
	Land value uplift	Using the projected increase in property values as a proxy for welfare impacts of a scheme.	?	• Determine extent to which land value impacts capture the welfare impacts of dynamic clustering

Models that forecast supply and demand in transport and property markets are important when assessing what impacts a transport intervention might have. The models we assessed include:

- **Traffic demand models**
  These typically flow in four stages to assess (1) trip generation, (2) trip distribution, (3) mode choice, and (4) route assignment. These models are constantly being refined and improved, but there is consensus on the general approach. A known weakness of these models is that they do not deal well with the heterogeneity in value of travel time (eg, between sectors or individuals), which may lead to distortions in some of the impacts that we are looking for.

- **Land use–transport interaction (LUTI) models**
  This class of models includes a wide range of models that analyse the inter-relationships between transport networks and land use. Some include traffic modelling within them, others use accessibility indicators generated by traffic models external to the LUTI model. Behaviours of representative agents such as households and firms are modelled using choice models – the transport or accessibility element features in a function that predicts location choice. The fundamental land-use and transport markets are the key components of LUTI models, but other relationships are often included as well. The additional relationships may include labour market decisions, changing demographics and migration, among others. LUTI models have developed to a high degree of sophistication and granularity. Drawbacks of LUTI models include what some consider to be a lack of grounding in rigorous economic theory; difficulty in validating against real-world data and interrogating the workings of the models due to their high complexity; and the very granular (and potentially spuriously accurate) data they use. LUTI models operate in a partial equilibrium framework, so when assessing wider economic impacts, it may be difficult to prove additionality. Considering LUTI models as a single category is difficult because there are so many types of them – individual models should be assessed on their own merits.

- **Supply analysis**
  This approach to estimating capacity for development is often used by planning authorities to understand the development pipeline in a region and how land-use regulation may impact the supply of development. Basic supply analysis may not account for the effect of demand on supply (ie, the capacity may be assumed to be equal to predicted supply rather than assessing whether development is viable due to price implied by level of demand). Approaches to calibrating supply using historical data such as build rates may improve forecasts.

- **Game theory**
  Strategic interaction may feature in dynamic clustering where decisions to locate or decisions to develop land may depend on actions of other agents. If that is the case, we believe that game theory may help to show how a strategic interaction is likely to play out. A key challenge is how to assign payoffs that closely reflect reality and to deal with situations with imperfect or asymmetric information, but we think these models could be worth further exploration. Part of the reason they are not used often may be how game theory models generally involve a very small number of players but clustering situations in the real world tend to involve many more players than this.

Models that analyse the economic and welfare impacts of changes include:

- **Wider economic impact (WEI) analysis**
  WEI analysis is really a family of models in their own right and involve the quantification of specific impacts such as price changes under imperfect competition, labour supply impacts, and agglomeration economies. These impacts are grounded in economic theory, and quantifying benefits this way is recommended in guidance in New Zealand and the UK. New Zealand and the UK differ in their approach to dynamic clustering, where New Zealand does not incorporate the agglomeration economies that could

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result from changing land use (yet), but the UK does. This leads us to one of the primary difficulties with this approach for dynamic clustering: determining the extent to which land-use changes occur as a result of a transport scheme. For example, even when using UK guidance, it is unclear whether the timing of impacts is properly accounted for and whether there may be a risk of double counting of travel-time benefits and agglomeration economies.

- **Spatial computable general equilibrium (S-CGE)**
  S-CGE models apply a general equilibrium model with a spatial component that includes transportation costs. Changes to transportation costs can have knock-on effects in other markets, which makes a GE approach conceptually appealing. The main benefits of an S-CGE approach include how it is firmly grounded in economic theory and how it allows the user to understand whether and how impacts are truly additional rather than displacement. The main drawbacks are that S-CGE models tend not be very spatially granular and, like LUTI models, can be complex and difficult to understand, which can undermine the extent to which they are trusted. Potentially fruitful areas for progress with these models include:

  – using simple or 'toy' models alongside for sophisticated and detailed models to help users to test and understand the results being generated

  – improving the way these models analyse location decisions by individuals and businesses and in how they capture changes in the supply of land.

- **Induced demand**
  This approach assumes that the welfare impacts of dynamic clustering can be approximated using the consumer surplus of the transport demand function alone. There is some exploratory academic literature that defines and develops this approach, but there is not enough to consider the use of this approach to be anything like 'settled'. We believe there are several strong assumptions needed to make this approach work, which need to be properly interrogated to see if the approach makes economic sense. Practically it may not be as simple as the theory assumes, though an interesting approach using 'log-sums' (a mathematical concept in choice modelling) may provide a useful analytical shortcut.

- **Land value uplift**
  This technique, which often draws on the principles of hedonic pricing, assesses the extent to which property values may increase. Models that predict land value increases may provide reasonable estimates of the increase in land values. However, the extent to which land value uplift approximates the welfare effects of dynamic clustering is not settled.

Our research and experience suggest that some potential criteria for success in the use of these models should be developed and used. These might include:

- the use of rigorous and context-specific narratives and evidence;

- ensuring that analysis is as soundly based on economics as possible;

- validation of results – for example, by showing the extent to which the model or quantitative technique is able to forecast impacts that have actually materialised in the past;

- the use of uncertainty quantification to avoid the considerable risk of spurious accuracy. Uncertainty can arise for numerous reasons including the quality of the data used, the economic principles and parameters that are applied, and the inherent challenges in forecasting complex systems over long periods of time;

- what we call the 'trust-test'. In view and experience, it important to be able to explain to a relative non-expert: the approach that has been used, why this approach is the best approach to use given the specific context, the results that have been generated, and why these results are likely to transpire.

Models and quantitative techniques that pass this trust-test are, in our view, considerably more useful than those which do not.

3   Methodology

This section sets out methodologies for appraising the economic impacts of dynamic clustering brought about by a transport intervention. The section is structured as follows.

- Section 3.1 summarises economic appraisal tools for transport interventions under static and dynamic land use. Our starting point is to develop an understanding of the various economic impacts that may result from a transport intervention and then explore how the approaches may change with land-use change. The economic impacts that are typically assessed have particular data requirements and models that are used to assess impacts under static land-use conditions. Some, but not all, of these approaches change when land use is allowed to vary. This section analyses how elements of economic appraisal must be adapted to incorporate dynamic land use. We then explore three key areas of dynamic clustering: timing, feedback loops, and additionality of benefits.

- Section 3.2 shows the different economic and land-use mechanisms in detail with a focus on the interaction between economic impacts and dynamic land-use impacts. This section is developed around each of the economic impacts defined in section 2. The discussion is based around the use of logic maps, which serve as an example of how economic narratives can be developed in a way that helps to capture dynamic clustering in transport appraisal.

- Section 3.3 takes the perspective of the project proponent who is deciding which analytical approach to use for a given scheme. This section discusses how characteristics of the scheme influence the type of approach that could be used. There is no 'one size fits all' approach. Rather, we suggest that different models are complementary in their ability to assess different impacts. We combine complementary approaches into four potential frameworks that may be used to assess dynamic clustering and economic impacts. We also consider what conditions would need to be satisfied when analysing whether dynamic clustering is likely to result in impacts that are truly additional (ie, additional after accounting for displacement).

- Section 3.4 explores the four frameworks set out in the previous section in more detail. We consider how the approaches may be developed to assess dynamic clustering in greater detail and define the links between predicting land-use change and economic impacts. We provide some ideas on how to adapt approaches to consider dynamic clustering benefits, and we evaluate the appropriateness of each approach.

- Section 3.5 explores how land-use benefits or impacts fit into the appraisal of wider economic impacts of transport interventions.

3.1   Economic appraisal of transport under static and dynamic conditions

In this section we summarise the most relevant economic impacts to be considered when assessing a transport intervention. We first consider economic impacts in a 'static' environment where land use is held constant and agents are assumed not to be able to relocate. Location decisions are typically 'sticky' in the sense that changes in location are difficult to make at short notice, but rather (in general) change only after the passage of some time. Accordingly, this initial analysis can be interpreted as a short-run assessment of the wider economic impacts. It is also an approach that is traditionally used in appraisal because it minimises the risk of double counting impacts that start off in the transport market but then work their way into other parts of the economy. This approach is also sometimes referred to as focusing on 'first-round' impacts. We report these results in Table 3.1.

We then describe how these impacts could vary with dynamic clustering (ie, when land use is allowed to vary). Table 3.2 describes how the benefits presented in a static environment flex as a result of a change in land use and dynamic clustering. The discussion shows that dynamic clustering affects the various impacts positively and negatively. Finally, we explore further aspects of dynamic clustering: timing, feedback loops, and additionality. A summary of our findings in these areas are reported in Table 3.3.

3.1.1 First-round impacts

Table 3.1 reports the full list of first-round economic impacts that we consider in our analysis and whether they affect welfare or output (GDP), or both.[2]

The first column in Table 3.1 groups different economic impacts in broader categories, depending on the economic mechanisms on which they rely. For example, we define **market structure effects** as those impacts that arise because of the presence of imperfect competition or following a change in the market structure of the economy. We refer to **labour market effects** as those impacts that result from mechanisms within the labour market.

Table 3.1 also classifies impacts based on the economic impacts considered in appraisal guidance. Those impacts that may be assessed within the context of static land use are shaded light blue. Impacts that require dynamic land use are shaded light orange. We also identify a number of impacts that are not currently or generally included in guidance but could be – these are shaded in white, and while some could be included under static land use, others require dynamic land use.

The main economic impacts considered under static land use are:

- direct user benefits
- agglomeration economies
- imperfect competition
- tax wedge on labour earnings
- externality impacts (eg, carbon emissions).

The main economic impact considered under dynamic land use is 'move to more productive jobs'.

The main economic impacts that we have added for consideration that are not currently or generally included in guidance are set out below. (Whether they occur under static or dynamic land use is indicated in parentheses.) The impacts are:

- increase in competition (static, dynamic)
- increase in labour supply (dynamic)
- move to more productive jobs – private benefits (dynamic)
- increase in labour market competition (static, dynamic)
- consumption amenities (dynamic).

Finally, Table 3.1 also includes reference to how these impacts can be measured. For example, direct user benefits can be measured in terms of travel time savings.

Before we deal with these impacts in more detail, it is important to note that the relevance and likely magnitude of the various impacts are difficult to establish on an *a priori* basis. This is partly because different

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[2] When considering the welfare and GDP effects of impacts, we effectively follow the approach set out in the PwC report *Squaring the Circle* (PwC, 2019).

projects will have different effects and partly because there is not as much evidence on the *ex-post* impacts of projects as would ideally be the case. It is therefore important to consider carefully what impacts are expected in the case of any specific project rather than assume that each and every impact will occur with each and every project.

Moving onto the detail, the first-round effects included in our analysis are described below.

3.1.1.1 Direct user benefits

Direct user benefits consist both of monetary impacts (eg, a reduction in transport costs) and non-monetary benefits (eg, time savings, which have a value). These benefits result in (a) higher welfare, as people value shorter and/or cheaper trips, and (b) higher output, as some time/cost savings will accrue to people travelling for work and will increase the time they spend working. These benefits are estimated by means of a traffic model and are then monetised using standard formulas for costs and time savings.

It is worth noting that for most transport projects, even those where wider impacts play a significant role, direct user benefits account for the majority of monetised impacts. For many standard projects, it may be possible to assess the wider impacts using some 'back of the envelope' assessment based on the direct user benefits. This is an imperfect approach and not a substitute for a detailed assessment. Nevertheless, if two projects have qualitatively similar dynamic clustering impacts (ie, they involve the same network, mode, locations, etc) but one is estimated to have higher user benefits, then assessing wider benefits is unlikely to change the relative benefits of the two projects.

3.1.1.2 Agglomeration economies

'Agglomeration economies' refers to increases in both welfare and output brought about by how individuals and firms are made more productive when they are better connected. Lower travel costs and shorter travel times allow individuals and businesses to improve their interactions and be more efficient and innovative. An improvement in productivity delivers greater levels of output and, consequently, higher profits. Welfare benefits accrue to the providers of labour and capital to whom a share of increased profits flow. These benefits are estimated by means of a traffic model to find changes in effective density, and then productivity impacts are estimated using agglomeration elasticities and a measure of output per worker.

We note that Waka Kotahi guidance on agglomeration economies quantifies the urbanisation (total economic mass) economies of agglomeration but does not quantify the localisation (within industry or sector economic mass) economies of agglomeration. It may at some point be useful to explore this in more detail – drawing on, for example, the approach that is used in the UK, which analyses impacts on a sector-by-sector basis. If this were explored in more detail, it would be useful to thoroughly review what, if anything, the literature says about different urbanisation and localisation mechanisms to help distinguish between these two types of agglomeration economies (considering the timing of impacts, feedback loops, additionality etc).

3.1.1.3 Imperfect competition

'Imperfect competition impacts' refers to benefits that occur in the presence of market power.

A transport intervention reduces firm costs and, in turn, reduces prices and increases output. Standard practice assumes that lower costs and higher output also unlock positive welfare benefits in the presence of imperfect competition: as output increases, the value of the additional output will capture firms' positive price-

cost margin and will lead to an increase in welfare.[3] Imperfect competition benefits are typically estimated using a kind of 'rule of thumb' approach where the uplift is applied to time/cost savings for 'in work' travel.

It is worth noting, however, that standard practice seems to exclude other positive and negative welfare implications of transport-induced increases in output in imperfectly competitive markets. A first positive welfare effect consists of a shift in surplus from producers to consumers. This shift corresponds to a decrease in producer surplus of an amount that is identical to the increase in consumer surplus. A second effect on welfare consists of an increase in deadweight loss as a result of higher output produced under imperfect competition. These two additional welfare effects are considered in greater detail in Appendix A.

3.1.1.4   Increase in competition (product)

A reduction in transport costs may increase competition between firms by creating market access. Higher competition can manifest in the product market or in the labour market. Here we consider an increase in competition in the product market. We return later to impacts in the labour market.

An increase in competition causes firms to reduce their price-cost mark-ups and to increase output. Greater competition would also result in higher welfare as the deadweight loss associated to market power is reduced (see Appendix B).

The benefits of an increase in competition are not typically quantified in a standard appraisal of transport infrastructure projects – likely because the impacts will generally not be large and are also difficult to quantify. There are also other responses to changes in competition such as product differentiation that may be hard to predict but could be considered a consumption amenity.

3.1.1.5   Tax wedge on labour earnings

Tax wedge impacts refer to the benefits that occur when labour income tax increases as a result of a transport intervention.

A transport intervention decreases travel times and costs, benefitting people who travel for work reasons and thus affecting their labour supplied. Individual decisions about their labour supply are made by comparing the utility derived from their labour income, net of taxes and transport costs with the disutility of lower leisure time. If transport costs decrease, some individuals find themselves with the potential for their net labour income to be higher than their reservation wage and decide to work more.

The increase in labour supply causes both a welfare improvement as well as an increase in output. Typically, the only welfare benefit that is quantified is the increase in tax that is generated as a result of people working more. This is because standard practice is to assume that the increased pay (net of tax) to the individual is equal to the marginal utility of time they give up in working more. We consider the potential to relax this assumption below where we argue that much depends on firms' ability to engage in what amounts to 'third-degree price discrimination' by paying them exactly their reservation wage. Labour supply elasticities are also important. The increase in tax that is generated (ie, the 'tax wedge') is considered to be an increase in

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3   The level of mark-up varies, but an average is typically applied. As stated in the *Monetised Benefits and Costs Manual*:

> *The average price-cost margin in the New Zealand economy is 20%. Together, with evidence on how the economy responds to a reduction in transport costs at an aggregate demand elasticity of -0.6, this gives an estimated wider economic benefit from increased competition of 10.7% of business user benefits.* (Waka Kotahi, 2020, p. 82)

We note that this quote refers to 'increased competition', though we believe it actually means to refer to 'imperfect competition'.

welfare because it allows the government to spend more in the interest of its citizens. Note also that there is a significant 'wedge' between the welfare and GDP impacts of this impact because the latter does not value the leisure time foregone by working more.

3.1.1.6   Increase in labour supply – private benefit

As explained above, a reduction in travel times and costs can increase the labour supply of individuals because it allows them to benefit from higher net labour income and/or a reduction in their disutility from working. Standard practice is to assume that there is no private benefit from this increased work because people are perfectly compensated for their foregone leisure time. However, as explained above, this hangs on whether firms pay workers their exact reservation wage rather than a more general 'market clearing' wage. Labour supply elasticities are also important.

We can see from Figure 3.1 that if a transport project increases the demand for labour and if we assume that labour supply is elastic rather than fixed, then the increase in market wage does result in an increase in private benefits – provided that the wages paid are at the market level rather than individual-specific reservation wages (ie, the wages on the labour supply curve).

An increase in the market wage can therefore increase individual private benefits of those individuals who are already employed in the labour market (the intensive margin) who simply get paid more, as well as of those individuals who were previously either unemployed or outside the labour force (extensive margin). These people get paid more than the value of the leisure time foregone. The only individuals for whom the increased wage is roughly equal to the value of time foregone are those at the very margin. Much also depends on labour supply elasticities.[4]

Figure 3.1 shows the effect of an increase in market wages on individual private benefits. It considers a transport intervention that increases the demand for labour, which increases real wages from w to w' and labour supply from L to L'. Assuming that workers are paid a market clearing wage rather than their individual reservation wages, the higher labour supply leads to an increase in welfare because people are paid more to work the same amount as before (areas D+E) and because the new labour supply is remunerated at wages higher than individuals' reservation wages (areas A+B). The size of these benefits depends on the elasticity of labour supply. In the presence of higher elasticity of labour supply, the increase in labour supply is larger and equal to L'', while the private benefits amount to the size of areas E+B+C.

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[4]   An increase in the labour supply following an increase in real wages depends on income effect (people feel richer and want to work less) and on the substitution effect (leisure becomes more expensive and individuals want to work more).

Figure 3.1   Labour markets – the impact of increased work on private welfare benefits
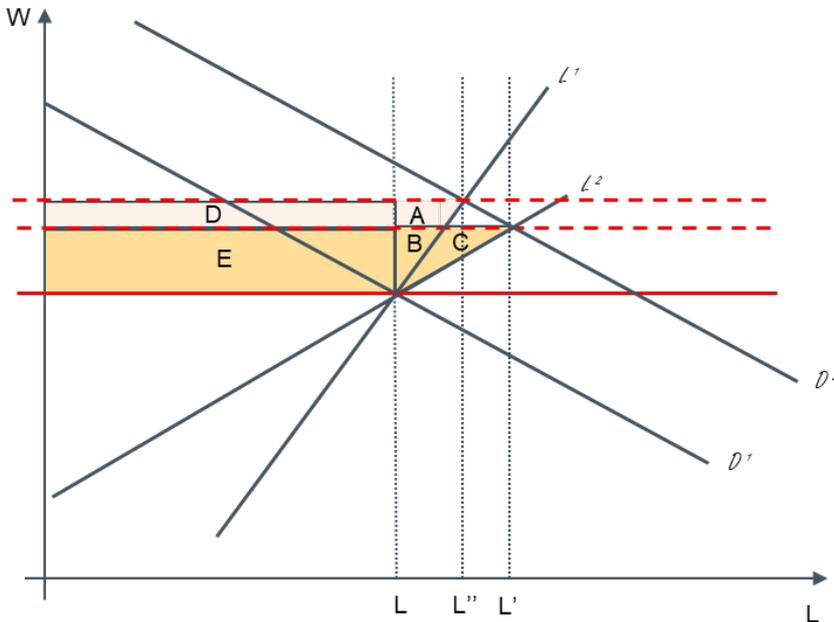
3.1.1.7   Move to more productive jobs

'Move to more productive jobs' describes the benefit that can result from a transport project that makes it possible for individuals to be able to access more productive and better paid jobs. In other words, it is the benefit from how the transport project overcomes a key labour market friction that impedes the matching process between individuals and the skills required for particular jobs.

A transport intervention can reduce these matching inefficiencies by increasing the catchment areas of firms and individuals, improving the likelihood of a 'good' match between skills required and individual abilities.

These impacts are normally analysed in a similar way to an increase in labour supply in that the only increase in welfare that is analysed is a tax wedge – that is, while an individual might be paid more, they are assumed to lose an equivalent level of utility through, for example, longer travel-to-work times.

3.1.1.8   Increase in competition (labour)

Higher competition in the labour market could affect the labour market discussions above by reducing any potential monopsony power that is held by firms in the labour market and/or by reducing any monopoly power held by individuals.

For example, if wages are held down due to monopsony power, then a transport project that opens up the labour market in a way that gives people more choice over where to work could increase wages. This would result in a welfare benefit for workers that would be partly offset by a loss in economic rent to firms. This type of impact is not typically quantified in transport appraisal – again, possibly because the impacts are unlikely to be large and may be difficult to quantify.

3.1.1.9   Consumption amenities

Most of the impacts described so far relate to the production of goods and services. People also enjoy cities because they provide opportunities to consume. It is uncontroversial to suggest that people prefer to live or work in places that have good amenities (eg, access to more restaurants, theatres, parks etc). But it is not common to value these benefits in transport CBA.

Some academics (eg, Venables, 2016) refer to this as a love of variety. Love of variety is a concept from the trade literature in economics. It shows that individuals place value on access to different types of goods and services (variety). The benefits are typically shown in terms of utility (ie, welfare). In the case of dynamic clustering, it is possible, or even likely, that access to variety will increase following relocation of households or firms. The welfare impact of this is not usually quantified, and we are not aware of robust methods that would be able to readily quantify the benefits from increased variety due to a transport intervention.

Consumption amenities also include public goods and non-tradeable goods. People enjoy visiting local parks but generally do not pay for access. People have preferences for certain types of places due to a variety of factors such as climate or architecture, but again, they generally do not pay for access. We posit in section 3.5 that the 'payment' for these goods may take the form of rents or land prices. The link between property prices and access to amenities could be and has been shown using hedonic analysis.

Despite not being included in appraisal, consumption benefits could be a potentially important factor in the location choices of households and firms, so we include it in our framework. It could be a useful area of future research.

3.1.1.10 Environmental effects

Environmental impacts of transport interventions include carbon emissions, air quality, and noise. These externalities are typically valued using estimates of the marginal external costs or abatement costs under some circumstances.

Table 3.1   Impact assessment

Impacts		Measured through	Welfare	Output
Direct user benefits	Business trips	Savings in travel time, together with the value of time.	✓	✓
	Leisure trips		✓	–
	Commuters		✓	✓
Agglomeration effects	Agglomeration	Changes in access to economic mass caused by changes in travel time, together with agglomeration elasticities.	✓	✓
Market structure effects	Imperfect competition	Mark-ups on the direct user benefits referred to above that accrue to business. Rationalised by how the price-cost margin in imperfectly competitive markets magnifies the impact of reductions in cost on price and output.	✓	✓
	Increase in competition	Increase in competition reduces deadweight losses.	✓	✓
Labour market effects	Tax wedge	The tax on increased income/output caused by people working more as a result of lower commuting costs. Value depends on elasticity of labour supply and assumes that people are perfectly compensated for working instead of taking more leisure.	✓	✓
	Increase in labour supply	The private value to people from working more as a result of lower commuting costs. Value depends on elasticity of labour supply and assumes that people earn more than they forego in lost utility.	✓	✓ (*)
	Move to more/less productive jobs	The tax on increased income/output caused by people being able to access more productive jobs. Like the tax wedge effect, the analysis assumes no private benefit (ie, benefits from better jobs are offset by increased cost of travel).	✓	✓
	Move to more productive jobs	The above but when private benefits do accrue (eg, when labour markets do not price labour perfectly and/or when there is structural unemployment).	✓	✓ (*)
	Increase in competition	Firms' monopsony power (as buyers of labour) decreases. Workers' monopoly power (as suppliers of labour) decreases.	✓	✓
Consumption	Amenity benefits	No proposed method, may be possible using hedonic analysis.	–	–
Environmental effects	Marginal external cost	Carbon, congestion, health, air quality.	✓	–

Effects always considered in project appraisal   Effects not generally considered in project appraisal

Effects considered in dynamic project appraisal   (*) Output effects are larger than welfare effects

3.1.2 Relative importance of impacts

It is worth noting the relative magnitude and importance of the different impacts that we are discussing. The observations below are based on views from appraisal practitioners and guidance documents. We note that the severe lack of *ex-post* analysis of benefits from transport infrastructure makes claims about the magnitude of benefits less robust. Most of the observations are based on *ex ante* impact assessments, meaning they were conducted prior to the opening of the scheme. More work on the evaluation of transport interventions – for example, by comparing the benefits that are achieved with the benefits that were expected – would be very useful.

At the outset it is important to note that each project is unique and may have different objectives. We are referring to larger transport infrastructure projects whose primary objectives typically involve increasing accessibility and reducing journey times. Other types of projects may focus specifically on certain impacts (eg, environmental benefits), and we are not referring to those.

In general, transport user benefits are the largest category of benefits. Business trips, though they make up a smaller proportion of trips, account for an outsized share of benefits due to much higher values of travel time.

Agglomeration impacts vary widely depending on the scheme type and location, but there is a general consensus that static agglomeration economies have an elasticity of about 0.04, albeit with a relatively wide range around this. Schemes that impact more rural areas with lower densities and agglomeration elasticities may not generate agglomeration economies. Urban rail projects in dense city centres may produce large agglomeration benefits. For example, the Crossrail project in London was estimated to generate agglomeration benefits equal to roughly 64% of user benefits in terms of welfare and 98% of user benefits in terms of GDP (Colin Buchanan & Volterra, 2007).

Market structure effects in the form of increased output under imperfect competition are typically assumed to be equal to approximately 10% of business user benefits.

Labour market benefits can be quite large but depend greatly on the underlying assumptions and the extent to which jobs created are additional. The case study we present in section 4.3 gives an example of a project where labour market impacts were estimated to be multiples of the transport user benefits. This is not common, and typically the labour market benefits will be a fraction of user benefits.

Environmental (dis)benefits for most transport infrastructure projects are highly variable. The direction of benefits often depends on the type of project. Projects that involve shifts to more sustainable modes of travel may generate benefits, while projects that increase usage of less sustainable modes may impose costs. Environmental costs may not be estimated to have a large economic value, but stakeholders are increasingly mindful of these impacts.

On average, the combined total of the wider economic impacts of transport infrastructure (ie, the above impacts excluding user benefits and environmental benefits) are often estimated to be around one-third of user impacts or around one-quarter of total benefits. However, this average masks a high degree of variation for individual projects, and it is possible for the total impacts to be higher.

3.1.3 Dynamic benefits

The size of the economic benefits described in the previous section changes with dynamic clustering. These changes follow from firms' and individuals' changes to their location choices as the result of a transport intervention. Table 3.2 describes how the benefits outlined in Table 3.1 are expected to change when land use changes.

3.1.3.1 Direct user benefits

Relocation or dynamic clustering could lead to an increase or decrease of direct user benefits. Direct user benefits could increase because relocation towards an area could shorten people's trips and increase the amount of their time savings. However, relocation towards specific areas could also erode benefits by considerably increasing congestion.

One important consideration for user benefits under dynamic clustering is the treatment of additional trips on the network caused by in-migration. Additional new trips on the network are generally valued using the rule of half, which is an estimate of consumer surplus from new journeys. However, if the population of the model area increases due to the scheme, then using the rule of half will attribute consumer surplus without accounting for the lost surplus of the trips that were previously made outside the model area (ie, displacement effects need to be considered).

3.1.3.2 Agglomeration economies

The benefits from higher productivity due to agglomeration economies are likely to increase when land use is assumed to change. The attractiveness of agglomerated areas causes individuals and firms to relocate closer to each other, benefitting from higher productivity and causing productivity to increase even more. As a partial brake on dynamic clustering, agglomeration economies push up the value of land, which reduces relocation benefits.

As mentioned in the previous point, one important consideration is that not all of the change in agglomeration economies will be additional. Some are the results of displacement caused by firms relocating from areas that suffer from a decrease in agglomeration economies. Identifying whether, when and how these impacts will be net-additional is likely to be important.

This highlights a crucial issue which is the need to define the spatial extent of the appraisal. Relocation of firms and individuals from outside the spatial boundary would not be considered as displacement, but relocation from within the spatial boundary would be. A second important point to consider is the extent to which agglomeration elasticity varies across different regions. Existing research on agglomeration elasticities shows that these can vary depending on factors such as sector and the level of concentration. A transfer of resources from an area with a lower agglomeration elasticity towards an area with a high elasticity could therefore be welfare improving. We discuss this in more detail later in the report.

3.1.3.3 Imperfect competition

In the previous section we explained that a transport intervention generates positive welfare benefits to consumers if markets are not perfectly competitive. The increase in efficiency due to quicker and cheaper transport services reduces costs for firms and increases output. As output is valued at prices that include a positive price-cost margin, an increase in output leads to uplift in business user benefits. These results are based on the assumption of imperfect competition not varying as a result of a transport intervention.

In the presence of dynamic clustering, firms' and workers' relocation decisions can change the level of this reduction in cost – probably by increasing it but potentially by reducing it. The imperfect competition impact will also increase or decrease in line with this.

We would generally expect dynamic clustering to increase the direct user benefits (and therefore the impact of imperfect competition), but this might not always be the case. Greater density will ultimately trigger negative effects such as an increase in the demand for and inflation of the price of inputs. This could reduce the price-cost margin, which would reduce this benefit.

3.1.3.4   Increase in competition (product and labour markets)

Relocation of firms as a result of agglomeration economies could also raise positive welfare benefits stemming from an increase in competition. Firms compete more as new markets become available at lower costs. Higher competition erodes the monopoly power of incumbent firms, lowering firms' mark-ups and eliminating the deadweight loss (see Appendix B for more detail). Higher competition will have beneficial effects, as firms lose their monopsony power in the input markets (eg, resulting in higher wages) as well as to output markets, resulting in lower goods prices. As mentioned previously, this impact is not generally assessed – likely because the impacts will generally be small or difficult to quantify.

3.1.3.5   Tax wedge on labour earnings

The benefits from an increase in labour supply are expected to be larger when dynamic clustering is considered. All else being equal, individuals' travel costs decrease as they strategically locate closer to their employers. This increases labour force participation even further, raising aggregate wages and labour income taxes.

3.1.3.6   Increase in labour supply

The benefits of increased labour supply may also accrue to private individuals, as discussed in the previous section.

The increase in labour supply can result in both an increase of the number of hours worked (intensive margin) and more people joining the active labour force (extensive margin). This translates into higher private benefits for individuals, who are paid a market wage that is higher than their reservation wage.

As for the case of direct effects, the size of workers' private benefits will depend on the elasticity of labour supply.

3.1.3.7   Structural unemployment and move to more productive jobs

The labour market benefits are higher if we consider areas characterised by high unemployment rates, where relocation could bring individuals out of unemployment towards more productive jobs.

An increase in net wages will generate even more private labour supply benefits of individuals who are already active in the labour market, but even more so for those who are currently unemployed.

Moreover, dynamic clustering could reduce the labour market frictions, assuring a better match in terms of skills/productivity between firms and employees.

3.1.3.8   Consumption amenities

To the extent that access to amenities or a variety of goods and services is important to households, this may influence their locational decisions. Similarly, firms may prefer to locate in places near where complementary amenities, goods, or services are consumed (eg, a greengrocer opening beside a butcher shop, an ice-cream truck at a park).

3.1.3.9   Environmental impacts

The environmental impacts that result from dynamic clustering could increase or decrease, depending on journey times, mode choices, etc. The point about displacement is also relevant here. The environmental impacts of new journeys made by people that move into the model area should be counted, but their previous journeys outside the model area should be subtracted to quantify the net impact (unless they are outside the spatial perimeter of the analysis).

Table 3.2   Dynamic clustering impact assessment

Impacts		Dynamic Clustering	Description
Direct user benefits	Business trips	↕	• Travel time savings could increase or decrease as a result of people having moved and therefore travelling between different places. • Congestion could also go up or down as a result of people relocating and internalising the impact of their actions on others.
	Leisure trips		
	Commuters		
Agglomeration effects	Agglomeration	↕	• Agglomeration impacts will increase when individuals relocate from areas with low access to economic mass to areas with high access to economic mass. There will also be offsetting effects in areas where people have moved from. • Net impact will also depend on whether people switch between sectors with different agglomeration elasticities and if elasticities are variable (ie, depend on the level of agglomeration).
Market structure effects	Imperfect competition	↕	• Effect will follow the impact on travel time savings (as per the above). • Relocation could also change demand for inputs and, thus, input prices.
	Increase in competition	↕	• Relocation could reinforce or detract from increases in competition.
Labour market effects	Tax wedge	↑	• Relocation will increase labour income tax collected by the government as the result of an increase in labour supply. • Value depends on elasticity of labour supply and assumes that people are perfectly compensated for working instead of taking more leisure.
	Increase in labour supply	↕	• Firms' relocation will raise the demand for labour. This will trigger a rise in wages even greater than in the static case. • Dynamic effects will also increase individuals' disutility of work.
	Move to more/less productive jobs	↑	• Relocation of firms and individuals will raise the benefits from moving to more productive jobs. • Value depends on the increase in productivity brought about by agglomeration and by the extent to which labour markets become more efficient.
	Move to more productive jobs	↑	• The above, but when relocation also increases private benefits and/or there is structural unemployment
	Increase in competition	↕	• Relocation would decrease firms' monopsony power even further. • It would also decrease workers' monopoly power as suppliers of labour.
Consumption	Amenity benefits	↑	• Relocation decisions consider amenity benefits and result in a net welfare increase.
Environmental effects	Marginal external cost	↕	• Firms' relocation would increase time efficiency savings brought about by individuals and firms relocating. • However, it would also result in higher congestion as a result of people relocating in few concentrated productive areas.

☐ Effects always considered in project appraisal   ☐ Effects not generally considered in project appraisal

▨ Effects considered in dynamic project appraisal

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3.1.4   Dynamic clustering – timing, feedback loops, and additionality

In this section we explore some of the dynamic clustering impacts in more detail. For each impact we focus on the timing of impacts, whether and how they are likely to be recursive, and the ways in which additionality or displacement should be considered. These are areas that are particularly important when dynamic clustering is expected to occur.

For many of these dynamic benefits there will be an issue of displacement caused by the loss of benefits in the places that people and firms leave behind when they relocate. For a proper economic evaluation of benefits, additionality and displacement must be properly accounted for to avoid double counting. If people and firms relocate from areas within the spatial extent of the model (traffic, and others) then the displacement should be accounted for. However, for those that move from outside the spatial boundary, displacement is arguably less of a challenge – that is, it can be more simply assumed to be additional.

So, to reiterate, one solution to the issue of displacement is to ensure that all activity that originates in the appraisal study area is captured within the spatial extent of the model – that is, if the appraisal is concerned with the welfare and output of all of New Zealand, then the displacement of activity within New Zealand is important, but any migration into New Zealand could be assumed to be additional. It may not be possible to model such a large area in all circumstances, and different simplifying assumptions may be applied, recognising that the robustness of the analysis with respect to displacement and additionality is reduced.

3.1.4.1   Anticipatory effects and land-use change

Before we dive into the main impacts, it is important to point out that timing does not solely refer to the time lag between the project and the expected benefits. Anticipatory effects are also possible, as individuals and firms alter their expectations about travel costs in advance of the scheme being approved/built/opened.

Land-use changes in particular are likely to be anticipatory, because acting early represents a potential opportunity for investors/developers. Anticipatory effects may speed up the time in which dynamic clustering impacts are realised by beginning the process of land-use change before the scheme actually opens. This can give a 'head start' to dynamic impacts.

Ultimately, however, the magnitude of benefits is unlikely to be increased due to anticipatory effects (although there might be some differences in present value terms to account for differences in timing).

Anticipatory effects also come with a degree of risk. All projects involve some risk that they will not be completed, may be altered in some meaningful way, or that the expected change in travel time savings is not achieved. Anticipatory effects are therefore likely to be slightly hedged and depend to some degree on the confidence that the project will be delivered as planned.

3.1.4.2   Direct user benefits

The spatial distribution of user benefits is likely to be concentrated in areas closer to or better connected to the transport intervention. The magnitude and spatial concentration of benefits may influence a place enough to increase its relative attractiveness as a place for businesses or residents to locate.

- **Timing**
  The increase in place attractiveness may come about relatively quickly, assuming that it becomes apparent which places benefit from the shorter travel times of the intervention. Indeed, sometimes this increased attractiveness can occur before a project is even complete as people and businesses anticipate the future changes in accessibility. The time it takes for land-use changes to reflect the higher attractiveness depends on the elasticity of supply of land and property and the elasticity of demand of households and firms relocating.

- **Positive feedback loops**
  Individuals and firms may relocate to further reduce travel times. However, with increased intensity of land use often comes additional trips and congestion. There is therefore also a negative feedback mechanism.

- **Additionality**
  The rule of half will appropriately value the benefits of changing travel patterns if, and only if, all individuals are modelled in both the do-nothing and do-something scenarios. For example, if a household moves to a new location because it is made more accessible by a transport scheme, then the appraisal should capture both the benefits the household gains from the new location and the benefits the household lost due to leaving the old location. It would be the difference in these two benefits that represents the marginal gain in welfare. A simplifying approach may be to exclude the benefits for these movers and assume they are at least as well off in the new location (or else they would not have moved).

3.1.4.3 Agglomeration economies

The productivity increase due to agglomeration under static land use may have second-round impacts that occur because a more productive place becomes still more attractive for firms and workers. In other words, as firms relocate and agglomeration economies cause higher productivity, the incentive for firms to relocate becomes even stronger due to even higher potential gains in productivity (because productivity is a function of the increasing economic mass).

- **Timing**
  Agglomeration economies could be viewed as occurring immediately, due to the transport intervention impacting effective density as soon as it is operational. However, evidence on the timing of agglomeration economies suggests that the benefits may not materialise right away. Studies suggest that the sharing and matching mechanism of agglomeration economies may generate benefits more quickly than learning. Empirically estimated elasticities of agglomeration do not, however, separate out these impacts. Moreover, some studies have suggested there is a lag between change in density and productivity of around 10 years.[5] The timing of dynamic clustering would have a longer lag between intervention and benefits realisation than agglomeration economies, because changing land use takes additional time.

- **Positive feedback loops**
  The change in attractiveness of locations due to higher productivity may result in yet more businesses and individuals relocating to the area, which in turn could prompt additional dynamic clustering and productivity benefits – and so on until and unless the costs of relocation offset the benefits (eg, through land prices or congestion).

- **Additionality**
  Like user benefits, agglomeration economies will need to be assessed for regions that lose population or employment when people and firms move due to dynamic clustering – as well as for those regions which gain. In order for agglomeration economies to be a net benefit, it must be the case that the benefit gained in the region that people and firms move to is not fully offset by the loss in the region they leave (unless migration or investment originates outside the appraisal perimeter – eg, from outside the country). Additionality due to agglomeration economies from internal migration/relocation may occur when activity moves from:

  – a place with lower average productivity to a place with higher average productivity

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[5] If true, the term 'static agglomeration' may be an oxymoron.

– a region with lower effective density to a region with higher effective density

– a region with lower agglomeration elasticity to a region with higher agglomeration elasticity.

It is important to mention that the functional form of the estimation matters[6] and that there are several factors and parameters involved, so it is difficult to precisely predict the impact of a change in agglomeration economies without fully estimating it.

Agglomeration under static and dynamic land use are not separate impacts but quantifications of the same impact under different assumptions, and appraisals should reflect this.

3.1.4.4   Imperfect competition

- **Timing**
  Impacts are likely to be slightly lagged, as time is required for businesses to adjust. Nonetheless, this lag is unlikely to be material, with impacts expected relatively soon after the transport scheme opens.

- **Positive feedback loops**
  It seems unlikely that substantial dynamic clustering or second-round impacts would be caused by this impact.

- **Additionality**
  Imperfect competition impacts are likely to be additional unless they are offset by increases in competition (next point).

3.1.4.5   Increase in competition (product and labour markets)

- **Timing**
  The timing of these first-round impacts (output increase, labour supply or move to more productive jobs) could be assumed to occur with 'immediate' effect. The second-round impacts may therefore also be assumed to occur immediately, though the impact of increased place attractiveness is something that would build over time, as people and firms make location decisions, and the elasticity of land supply affects the rate at which this can be accommodated.

- **Positive feedback loops**
  Positive feedback loops are possible if increased place attractiveness for consumers/workers further increases competition through land-use change.

- **Additionality**
  Impacts such as changes to employer monopsony power could be appraised in conjunction with other labour market impacts, because they are inter-related. An approach that deals properly with both increases and decreases in competition would be required to properly account for additionality and displacement.

3.1.4.6   Increased labour supply and moves to more productive jobs with income tax wedge

- **Timing**
  The move to more productive jobs is not likely to occur immediately. It takes time for individuals to switch jobs, and analysis of these impacts should account for that.

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[6] We note that the Waka Kotahi guidance applies agglomeration economies to aggregate measures of effective density, per capita productivity, and total employment, with an industry-weighted-average agglomeration elasticity. This is in contrast to the UK TAG approach, which sums the productivity impact for each sector using sectoral measures of effective density, per capita productivity, and employment, with industry-specific agglomeration elasticities. These functional forms would result in different estimates of agglomeration economies.

- **Positive feedback loops**
  The change in attractiveness of locations may result in additional land-use changes, which may further increase the number of workers in more productive jobs.

- **Additionality**
  This analysis needs to account for displacement (from previous work or leisure).

3.1.4.7   Additional labour supply and move to more productive jobs benefits

- **Timing**
  Transport interventions may draw people into the labour market over time, but this is unlikely to be immediate due to labour market frictions.

- **Positive feedback loops**
  For this impact to result in feedback loops the affected population would have to be quite large in a specific region.

- **Additionality**
  Labour supply increase presents as highly additional because the activity displaced (being out of the labour force) is often portrayed as having no economic value (it does not contribute to GDP). However, the displacement of leisure time should be accounted for. Moreover, it is possible that other productive activities such as cleaning, caring, and teaching are being displaced, and these have inherent value that is not monetised. This area may be worth further research.

  The 'move to more productive jobs' framework typically already accounts for displacement by measuring the change in value of jobs. What it may not capture is whether there are additional (dis)benefits at the end of the chain when a less productive job goes unfilled. Analysis also tends only to focus on the directly monetised value of working rather than factors such as the value of esteem and better life opportunities caused by working (and of doing so in good jobs).

3.1.4.8   Consumption amenities

- **Timing**
  The timing of benefits due to consumption amenities is likely to be relatively rapid.

- **Positive feedback loops**
  Positive feedback loops exist on the production side as in agglomeration economies. On the consumptions side it seems likely that both positive and negative feedback loops exist. Positive feedback could occur as households relocate and the density of the market increases, and this could increase investment in public goods and the probability that firms choose to relocate there – it is not clear that it is separate from agglomeration economies, except it is the density of customers rather than workers that matters. The negative feedback loop would be due to congestion caused by more households being located in a given location.

- **Additionality**
  The benefits from consumption amenities are likely to be additional but should account for displacement. We note that the benefit may take the form of a welfare externality to the household or consumer, or the benefit could be captured by firms if they are able to charge higher prices as a result. As discussed previously, we are not proposing any methods for quantifying this benefit. It could, however, be a fruitful area for future research.

3.1.4.9   Environmental and health externalities

- **Timing**
  Depends on the scheme, but some impacts (eg, changes in carbon emissions caused by switches between different travel modes) would be expected to occur soon after scheme opening.

- **Positive feedback loops**
  To the extent that additional land-use changes occur due to place attractiveness, more residents/workers may benefit from the health impacts of the scheme.

- **Additionality**
  We are not aware of evidence on whether land value uplift due to health externalities reflects a capitalisation of health benefits in land prices, but it seems reasonable to assume and expect this would occur.

Table 3.3   Timing, feedback loops and additionality

Impacts		Timing	Feedback Loops	Additionality
Direct user benefits	Business trips	Direct user benefits may arise relatively quickly, together with costs and time reductions.	Negative feedback loop arising from greater congestion and higher intensity in land use.	Rule of half applies to new trips due to transport intervention. Understanding the reason behind new benefits would be crucial to avoid double counting.
	Leisure trips	Time for higher attractiveness of land use depends on the supply of land.		
	Commuters			
Agglomeration effects	Agglomeration	Sharing and matching mechanisms of agglomeration may generate quicker benefits than learning (after 10 years). Dynamic agglomeration benefits may take even longer to materialise.	Positive feedback. The change in attractiveness of locations due to higher productivity may result in yet more agglomeration.	Productivity increases have historically proven to be additional with respect to direct user benefits.
Market structure effects	Imperfect competition	The timing of first order impacts is assumed to occur contextually to a reduction in costs. The timing of place attractiveness evolves more gradually over time and depends on the elasticity of labour supply.	Further increase in competition due to an increased attractiveness of a location is plausible, although not expected to be large.	Impacts can be additional but magnitudes are unlikely to be large.
	Increase in competition			
Labour market effects	Tax wedge	Changes in labour supply (and related tax and private benefits) are not immediate because of labour market frictions. Dynamic labour market benefits may take even longer to materialise.	Positive feedback. The change in attractiveness of locations due to higher productivity may result in a further increase in labour supply.	The move to more productive jobs in a different location implies a change to travel behaviour, which should be reflected in modelling of direct benefits to avoid mis-counting.
	Increase in labour supply			
	Move to more productive jobs			
	Structural unemployment	Reduction in structural unemployment and monopsony power following a transport intervention will not be immediate. Dynamic labour market benefits may take even longer to materialise.	Unlikely positive feedback. Structural unemployment benefits would need to affect a large proportion of the population to trigger feedback loops.	Benefits from this type of impact would be additional and would also include health benefits resulting from people brought into the labour force.
	Increase in competition			
Love of variety	Benefits from access to variety	Impacts likely to materialise immediately.	Both positive and negative feedback loops may occur.	Impacts likely to be additional but challenging to quantify.
Environmental effects	Marginal external cost	Environmental benefits from mode switch would be quickly implemented, while other health benefits triggered by lower congestion and emissions would take more time to implement.	Positive or negative feedback loops possible. Congestion may reduce place attractiveness, or perhaps increased investment in amenities drives positive feedback loops.	Benefits from this type of impact would be additional as long as they are modelled to reflect the same state of the world implied by other wider economic impact models.

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3.2 Mapping economic impact mechanisms and potential dynamic implications

In this section we provide examples of logic maps showing how economic impacts occur as a result of a transport intervention that increases accessibility. We explore each impact as defined in the previous section and show the context or market failures that lead to these impacts if relevant. We also show second-round impacts as they are relevant for dynamic clustering and may influence or be influenced by these mechanisms.

Appraisal practitioners could find it useful to carry out a logic mapping exercise at an early stage to clarify how and when the scheme would generate economic impacts. The exercise of developing an economic narrative is useful for both improving analysis and presenting results. Developing a clear narrative is crucial because it makes selecting the right analytical tools easier. It makes explaining the objectives and expected results of the project more intuitive to non-economists. And, crucially, it should help to ensure that sound investment decisions are made by ensuring that analysis is properly focused and avoids arbitrary rules of thumb about the absolute or relative sizes of various potential impacts.

The impact pathways shown in Figures 3.2 to 3.4 are examples and are not intended to be exhaustive. Projects often have unique context and objectives, and each appraisal is also unique.

3.2.1 Logic maps

The following pages contain three logic maps of increasing complexity. We describe them briefly in this section.

- Figure 3.2 is the basic logic map that includes the market imperfections that are most widely accepted in transport appraisal. The core impacts assessed here include direct user benefits, imperfect competition benefits, agglomeration economies, and a tax wedge on labour earnings. In this formulation we consider first-round impacts and dynamic impacts, but exclude recursive elements (ie, feedback loops). In practice, if dynamic impacts are included, then the recursive elements should be incorporated, but this may not always be possible.

- Figure 3.3 includes the recursive impacts of dynamic clustering. This diagram shows how land-use changes will result in further changes to place attractiveness (positive feedback loops) and how these also result in transport demand changes that ought to be modelled. The transport demand changes may be both positive and negative, but on net it is likely that increasing density will also increase congestion and reduce some benefits (negative feedback loops).

- Figure 3.4 includes additional wider economic impacts of transport interventions that are not typically included in appraisal. These are driven by market imperfections or context that we have identified and are in bold boxes in the diagram.

It is worth re-iterating that these logic maps are intended as examples and that they may not apply to every situation. Due to the potential complexity of impacts when assessing dynamic clustering, it is especially important to be clear about how and why each benefit is expected to occur and the dependencies of each impact.

3.2.2 Developing narratives through logic mapping

Practitioners should be encouraged to use logic mapping to develop narratives about a scheme. The use of logic maps as shown in the examples below clarifies the reasoning involved in a specific narrative. Two important principles for developing narratives through logic mapping are as follows.

- Mechanisms that are described should be evidence-based and relevant to the specific context. The evidence for mechanisms likely comes from academic literature, guidance, or case studies.

- The existence of a market failure or particular spatial context should be shown using data, where possible. Transport, demographic, and economic data should be used to set the scene and show – rather than tell – that the circumstances that exist may lead to economic impacts from the transport project.

Figure 3.2   Basic approach with accepted market imperfections, with a focus on social welfare
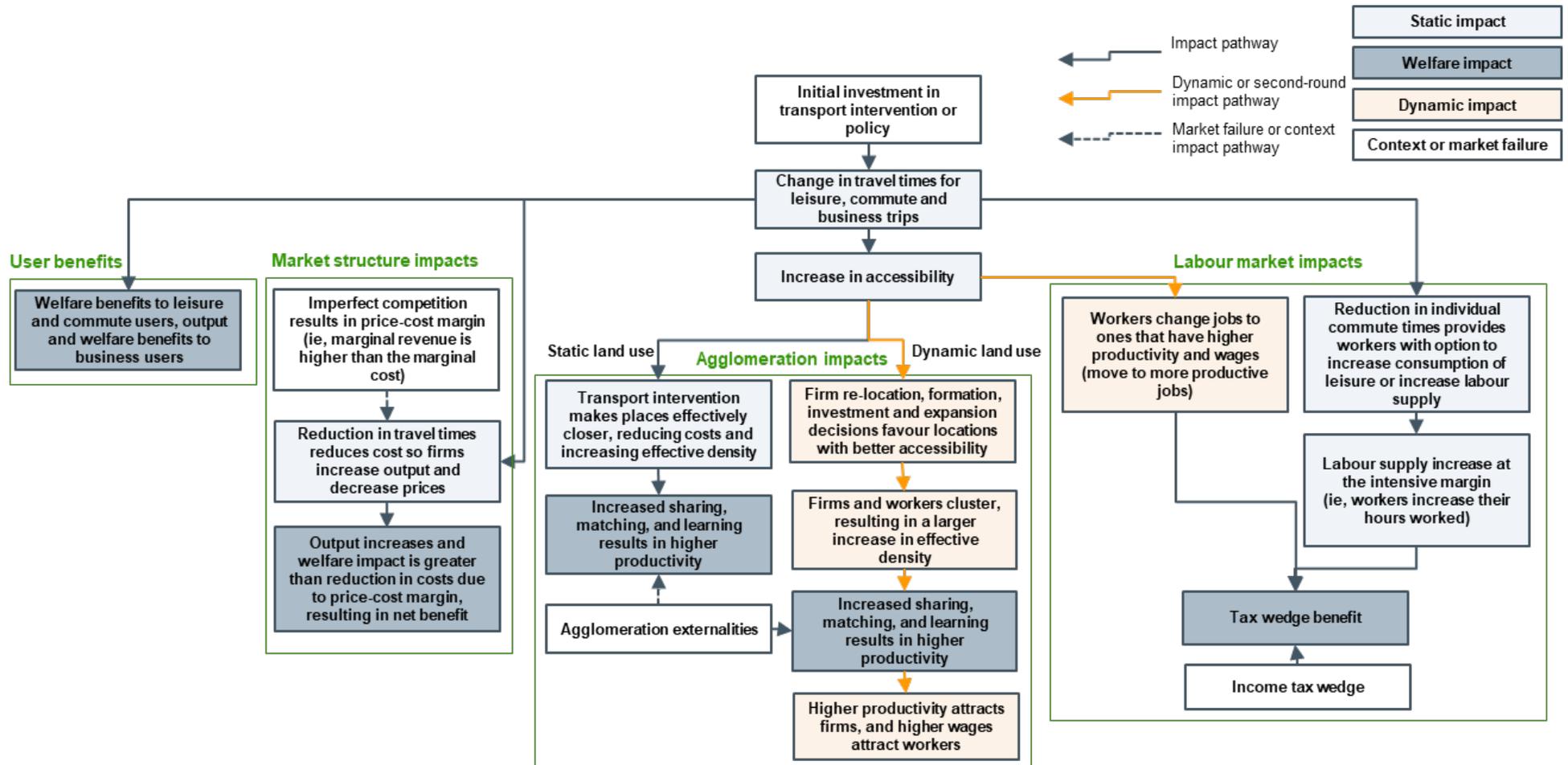
Figure 3.3   Basic approach with accepted market imperfections and recursive impacts of dynamic land use, with a focus on social welfare
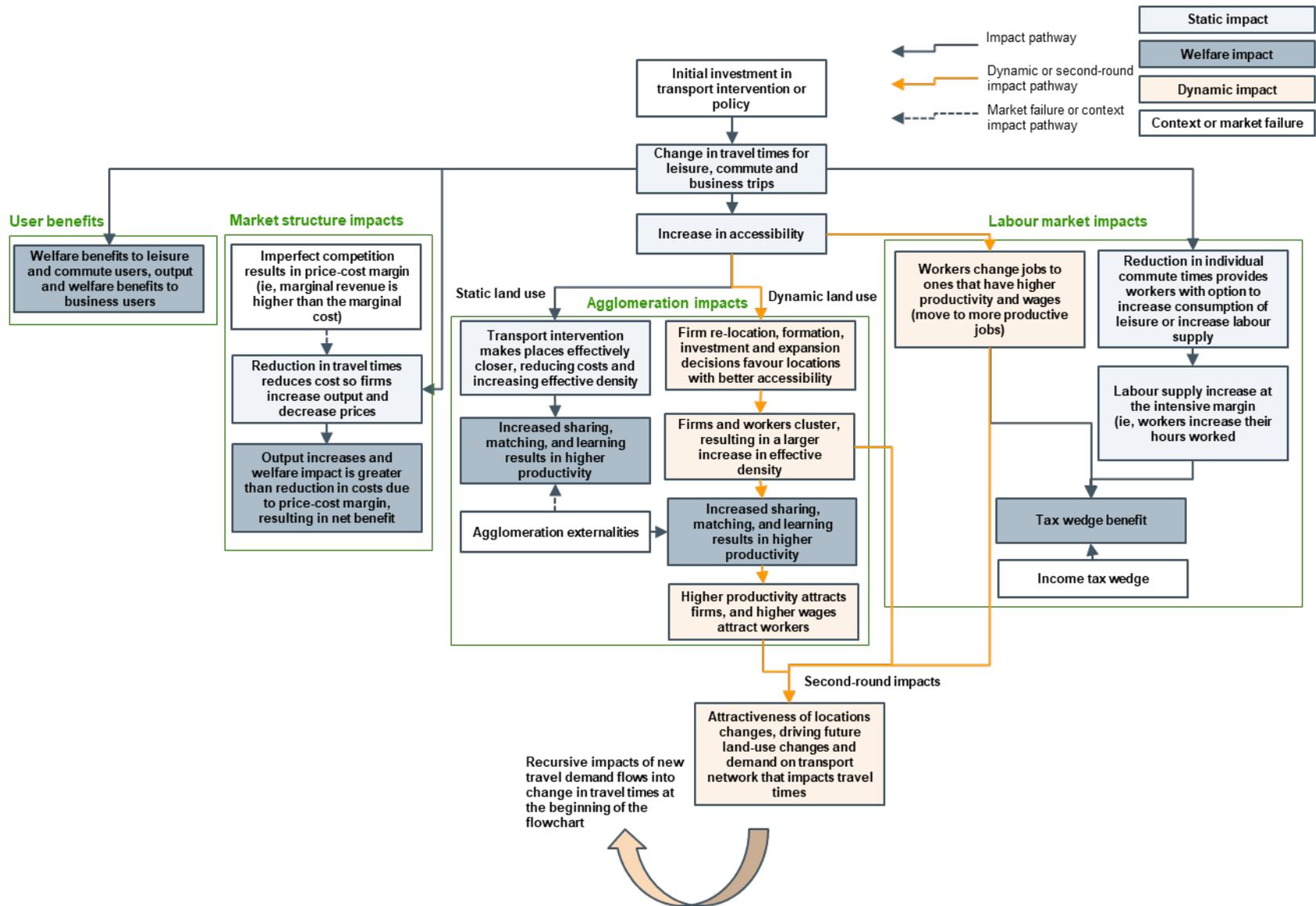
Figure 3.4   More complex approach with some potential market imperfections, with a focus on social welfare
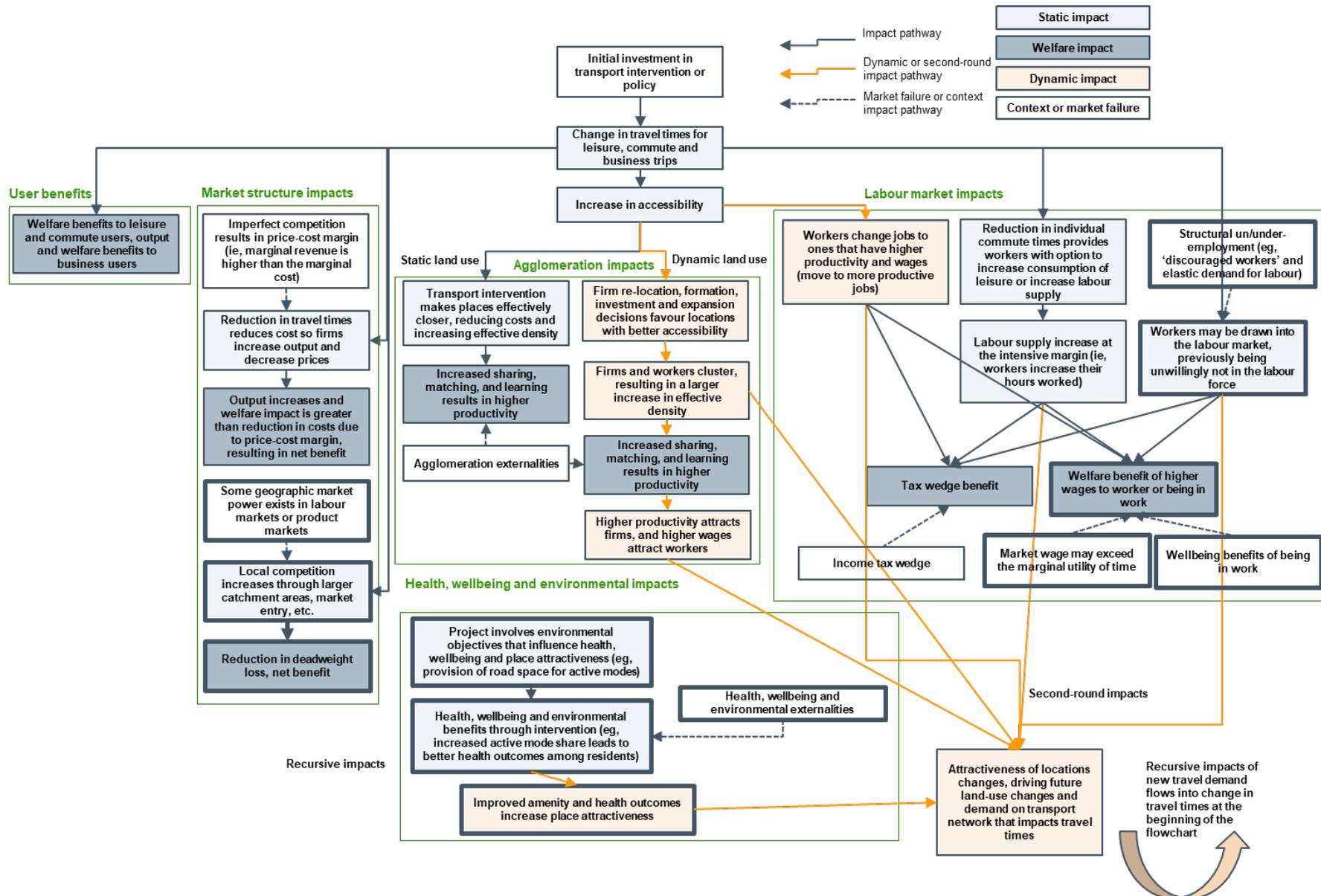
3.3   Developing methodological approaches

In this section we explore how a project proponent should determine whether additional modelling is needed to assess dynamic clustering, and if so, what type of modelling is most appropriate. Each project is unique, with its own distinct characteristics and impacts. The remainder of this section explores how different characteristics of the project and the impacts being measured influence the type of analysis that should be undertaken. We also include a potentially important checklist of the factors that could cause dynamic clustering to be genuinely additional.

3.3.1   The methodology funnel

The approach described here involves assessing characteristics of the project and expected impacts along several dimensions, eventually leading to a preferred approach. Figure 3.5 illustrates the process through a series of questions:

1.   Should dynamic clustering be considered?

2.   Which mechanisms of dynamic clustering will be important?

3.   Which market failures are at play?

4.   What data and modelling capabilities are appropriate?

Figure 3.5   Methodology 'Funnel'

Proposed approach
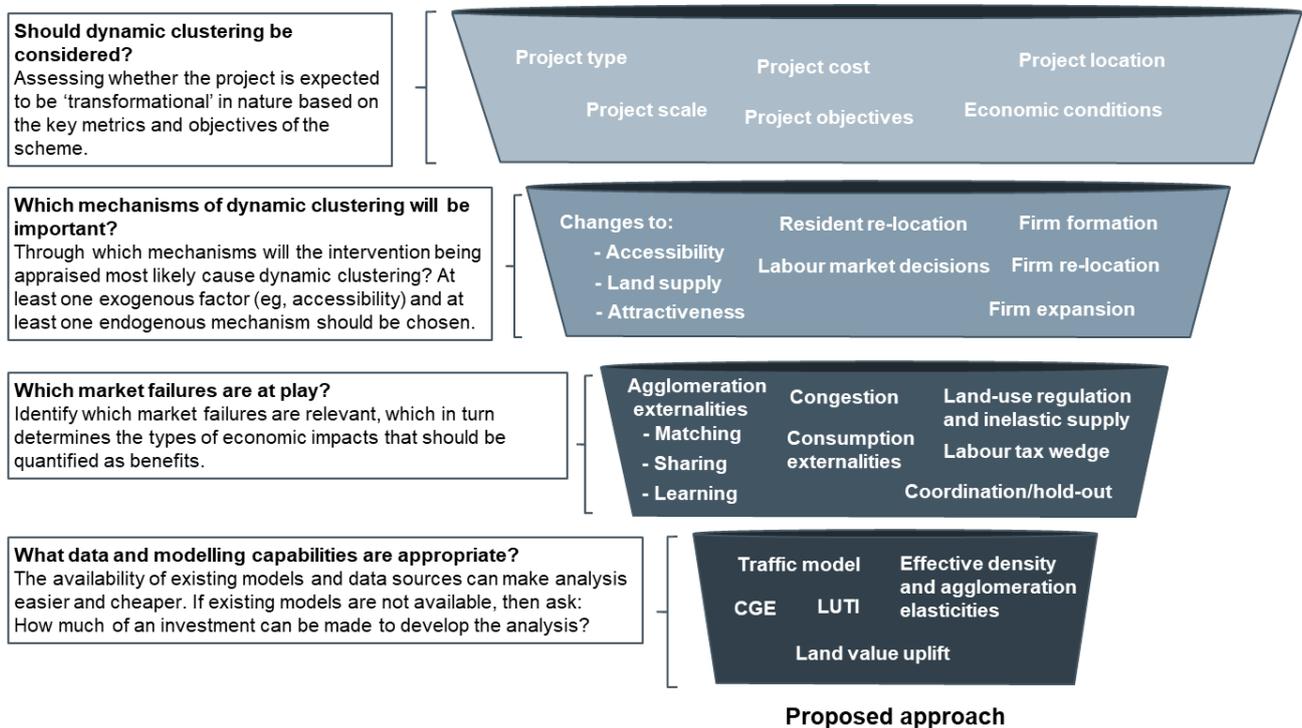
1.   Should dynamic clustering be considered?

It is very important at the outset to consider whether dynamic clustering should be considered, given the project and local context. To state the obvious: it is not necessary to analyse dynamic clustering in the appraisal of each and every project.

Larger projects are more likely to cause dynamic clustering. There is, however, no specific threshold for what constitutes a 'large' project; rather, this assessment is best made based on the experience of transport practitioners and applying good judgement. Typically projects that cause dynamic clustering are ones that are likely to have 'transformational' impacts and will involve one or more of the following:

- a significant improvement in travel times that impacts a large number of transport users

- a new mode of transportation (eg, a new rail line) where previously that mode was not present

- a link between places that previously had none (eg, a new bridge)

- a scale of impact that is at the corridor, city or region level, rather than the neighbourhood level

- a significant project budget – this is not a standalone requirement but tends to go along with the types of schemes that meet the above criteria.

In addition to being associated with larger-scale projects, dynamic clustering is associated with projects that include land-use change as a stated objective. Some transport schemes may be designed to unlock land for development, or to help support geographic growth of a region. If that is the case, then it is more likely that dynamic clustering impacts should be considered.

Transport alone does not drive growth unless economic fundamentals support it. It is therefore worth considering if the economic conditions in the region are conducive to development and land-use change. If not, then dynamic clustering is unlikely to occur.

2. Which mechanisms of dynamic clustering will be important?

Dynamic clustering brought about by a transport intervention is likely to occur when the transport intervention triggers an exogenous change in accessibility. Depending on the scheme, it may also change the supply of land or the perceived attractiveness of a place. This in turn is likely to cause changes in endogenous mechanisms such as location decisions, investment decisions, and/or labour market decisions.

It is plausible that a large-scale project will involve all of the above. However, smaller-scale projects may only involve some of these elements (eg, projects focusing only on unlocking residential development).

3. Which market failures are at play?

The degree to which benefits should be quantified as additional to the economy depends heavily on the existence of market failures or externalities. Otherwise, analysis typically considers that the location of activity is unimportant for net benefits to society (eg, because the activity might have occurred otherwise, just somewhere else). However, in the case of market failures or externalities, the impacts are more likely to be additional and increase the net benefit to society.

4. What data and modelling capabilities are appropriate?

An obvious point, but important nonetheless, is the extent to which models for analysis are already available. Developing the models described in later sections can require significant investment of time and money. If models have already been developed, then the bar for using them is lower than if they need to be built from scratch. The availability of data that is required may also be a barrier in some instances. In other cases, parameters that can be used in modelling are needed, which may require empirical research.

According to New Zealand Treasury (2015, p. 39) guidance: 'The effort that is put into a CBA is likely to be proportional to the size of the project and to the scope for reducing uncertainty around the estimates.' To state the potentially obvious, the larger and more potentially transformational the scheme is, the more likely it will be appropriate to invest in a full analysis of wider impacts (including dynamic clustering).

3.3.2   When and how is dynamic clustering truly additional?

Another important way to think about dynamic clustering impacts is through the lens of additionality. If we consider all the various impacts that could result but limit the circumstances so we only consider the situations where benefits are additional, we find a set of situations where we think quantifying dynamic clustering could be particularly important. These situations include the following.

1. **Potential increases in user benefits** (although this will depend on congestion, and there may be offsets elsewhere).

2. **Increases in agglomeration economies that are not fully offset elsewhere** (eg, due to varying productivity, effective density, or agglomeration elasticities).

3. **Increased employment**
    Unless the labour market somehow functions with third-degree price discrimination, it seems plausible there will generally be a net private benefit (contrary to the approach in much existing guidance).

4. **Moves to more productive jobs and businesses** (which again are not fully offset elsewhere).
    This will be particularly additional if we see the clustering of businesses that might not otherwise have existed at all or if the businesses might otherwise have developed in another country.

5. **Imperfect/increases in competition**
    As we have discussed above, increases in competition could act as a brake on additionality because of how it reduces the price-cost margin in output markets. However, if it boosts wages in the labour market (by reducing monopsony power of employers), then it could magnify the employment impacts set out in 3 and 4 above.

6. **Increased land supply**
    An increase in effective supply of land can be considered as an increase in productivity in much the same way as an increase in agglomeration economies. Whether it is net positive to GDP or welfare is, however, unclear. One could argue that the reduction in land prices that go with an increase in land supply will reduce GDP and welfare (depending on who owns the land). This is one of the issues we explore in more detail in section 3.5.

7. **Distributional impacts**
    If clustering has the impact of displacing economic activity from relatively affluent to relatively disadvantaged areas, then this could have a positive welfare impact even if the impact on national gross value added (GVA) is neutral.

3.3.3   Complementarity of models

It seems to us that a set of complementary models is likely to be the approach that best captures dynamic clustering and the various different market failures, mechanisms and impacts that are involved in this. Figure 3.6 shows the flow of static and dynamic impacts that may result from a transport intervention, including the potential for recursive dynamic impacts. It also identifies some of the different types of models available, and the impacts that are captured by them.

Figure 3.6   Dynamic clustering impacts and the models that capture them
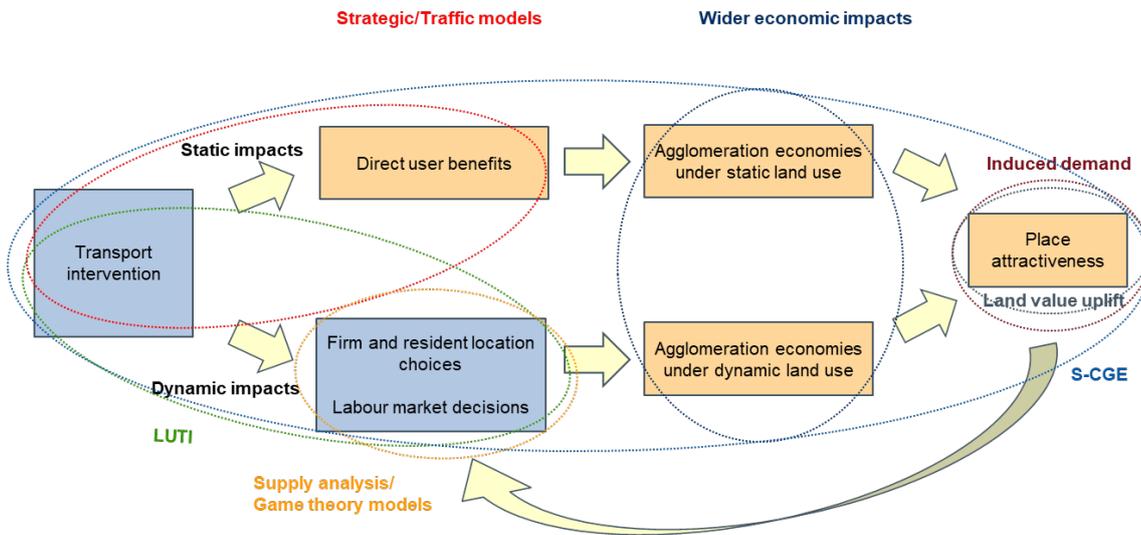
Table 3.4 shows something similar but in tabular format. Each model is able to address some areas that are important for dynamic clustering, but not others. The approach that is selected will therefore depend on what is important (given the nature of the project and of the appraisal) and what is feasible (given, for example, the feasibility and cost of the different approaches).

Some of the assessments in Table 3.4 may also be open to interpretation, as there are different variants of each approach, some of which we discuss in more detail in section 3.4. This table is intended as an initial guide that informs our selection of proposed approaches in the following section.

Table 3.4   Key impacts assessed by each approach

Technique	User benefits	Agglomeration	Labour market impacts	Location choice	Labour market decisions	Land supply	Aggregate consumer surplus
Traffic models	✓	✗	✗	✗	✗	✗	✗
LUTI	Taken as input	May be modelled separately	May be modelled separately	✓	✓	May be included	✗
WEI	✗	✓	✓	Taken as input	Taken as input	✗	✗
S-CGE	Taken as input	May be modelled separately or incorporated	✓	May be incorporated	✓	Not explicitly but could be incorporated	✓
Induced demand	Taken as input	✗	✗	Taken as input	Taken as input	✗	✓
Supply analysis	✗	✗	✗	✗	✗	✓	✗
Game theory	Taken as input	✗	✗	✓	✗	✓	✗

3.3.4 Proposed approaches

Building on the above, in this section we frame the various modelling techniques as sets of options. We discuss three main complementary approaches (Options 1–3) that may be used to assess dynamic clustering impacts. In addition to these three main approaches, in Option 4 we discuss a number of other techniques that may be used depending on the magnitude and type of clustering that is expected. They can be used to provide a sense check on the results generated from Options 1–3 – or indeed as standalone techniques.

3.3.4.1 Option 1 – Spatial computable general equilibrium (S-CGE)

The first proposed approach uses S-CGE modelling in conjunction with a transport model. This approach highlights inter-regional economic interaction and includes a complete view of different markets: product market, labour market, land market, and transport market to name a few. When an S-CGE model is applied to transport project appraisal, improvements in regional productivity or direct reductions of generalised transport cost caused by transport infrastructure investment flow through the entire economy so that the total net effect can be measured.

We describe all the options in more detail in the following section. At a high level, the S-CGE approach incorporates land-use impacts and agglomeration economies either through extensions within the model framework or by using 'overlays' that alter the inputs and outputs. The primary advantages of this approach are:

- confidence that there is no double counting occurring
- the analysis is based on sound economic theory
- the mechanisms that capture land-use changes may be relatively simple and therefore not 'black box-like' in nature.

The main downsides are:

- the approach tends to operate at a relatively high level of spatial granularity
- it is better at predicting where a system will end up rather than precisely how it gets there
- the models do tend to be quite complex – models that are sufficiently rich to capture the nuances of how complex economies function can also be difficult to explain.

3.3.4.2 Option 2 – Land use–transport interaction and wider economic impacts (LUTI + WEI)

The second proposed approach involves using a transport model and LUTI model to identify the location and extent of land-use changes and then WEI analyses (ie, quantification of each impact using economic models with external parameters) to quantify the benefits to society. The advantage of this approach is that the analysis using LUTI is likely to be more granular than S-CGE, but there are questions about whether this granularity provides spurious precision. The approach can also be very 'black-box' in nature and therefore difficult to explain, understand and trust. It can also be more prone to double counting because the architecture of LUTI models is considered by some to be less soundly based on economics (or, more specifically, economics that are general equilibrium in nature). Problems can also arise if some regions that are impacted fall outside the spatial extent of the LUTI model.

3.3.4.3 Option 3 – LUTI + induced demand

Similar to Option 2, this approach first assesses land-use changes using LUTI and a transport model, but then uses induced demand analysis to quantify benefits. Our literature review highlighted a number of issues and challenges with the induced demand approach, but it is conceptually appealing – if the challenges with

LUTI modelling are overcome. It is worth noting that this approach effectively produces a similar type of output to an S-CGE model, albeit in a different way. This is because while most people think of the outputs of an S-CGE model as being focused on GDP and other 'real' economic variables, the architecture of an S-CGE model is based on utility functions, so it can also produce outputs in terms of changes in overall utility (eg, compensating and equivalent variations).

3.3.4.4   Option 4 – Ad-hoc analysis of dynamic clustering

Alternative approaches to analysing dynamic clustering should also be considered. These may be methods to predict the extent of land-use change through micro-surveys with firms and econometric analysis (eg, analysis of whether/when/why people and businesses will relocate, production functions, partial equilibrium models) or by looking at case studies. Land-use benefit approaches, which we discuss in section 3.5, may also fit in this category.

3.3.5   Other factors to account for in appraisal framework

The appraisal framework must consider all the other factors that are important when conducting an appraisal. This includes factors such as developing a robust counterfactual or do-minimum scenario, and discounting future benefits to present values. These factors are covered in more detail in the relevant guidance documents, and their omission in this document does not indicate they are not important to consider.

The question of additionality/displacement of impacts is also crucial. It is covered to some degree in this document, but the uniqueness of each appraisal warrants a fresh analysis of additionality in each case. If multiple methods or models are being used, then the framework must clearly distinguish between the impacts and provide justification that there is no double counting of impacts.

3.4   Evaluating methodology options for dynamic clustering

This section builds on the proposed approaches to appraising dynamic clustering by explaining the mechanics of the models in more detail and evaluating how well each approach captures the key benefits. The four options were set out in section 3.3.4 based on our assessment of how different models are able to capture the process of dynamic clustering and the ensuing economic impacts. Three of the four approaches involve modification of a complex system (either S-CGE or LUTI) and each approach may be suitable under different circumstances. Each approach has the potential to be modified in different ways (so we sometimes include different permutations within an option). It is important to be clear that the suggestions that we make in the following sections are not the only possible approaches to take.

We also note that the proposed options involving S-CGE and LUTI are not models that are typically available 'off the shelf'. The development of these models is time consuming, costly, and not without risk.

Before we evaluate the options in detail, it is worth emphasising that our research and experience suggests that some potential criteria for success in the use of these models would be useful. These might include:

- the use of rigorous and context-specific narratives and evidence
- ensuring that analysis is as soundly based on economics as possible
- validation of results (eg, by showing the extent to which the model or quantitative technique is able to forecast impacts that have actually materialised in the past)
- the use of uncertainty quantification to avoid the considerable risk of spurious accuracy – uncertainty can arise for numerous reasons, including:
  - the quality of the data used

– the economic principles and parameters that are applied

– the inherent challenges in forecasting complex systems over long periods of time

• the 'trust-test' – in view and experience, it important to be able to explain to a non-expert:

– the approach that has been used

– why this approach is the best approach to use given the specific context

– the results that have been generated

– why these results are likely to transpire.

Models and quantitative techniques that pass this trust-test are, in our view, considerably more useful than those that do not.

Whether and the extent to which particular models meet these criteria will, of course, depend crucially on the specific model used and how it is actually applied in practice. In our experience, however, Options 1 and 4 – if done well – are most likely to best meet these criteria.

3.4.1 Option 1 – S-CGE

The first option for appraising dynamic clustering impacts of a transport intervention involves using an S-CGE model. We explore two ways that S-CGE may be used to deal with dynamic clustering. The first is a fully integrated approach that we think is theoretically possible, but potentially difficult in practice. The second is an approach that uses a more typical S-CGE model with transport and land-use model overlays to generate the types of productivity shocks and land-use outputs we are interested in.

The integrated S-CGE approach:

• uses a transport model to generate travel times/costs and accessibility metrics. Some of these welfare impacts will be standalone, but others will flow through the economy and have knock-on impacts that are measured in the S-CGE model;

• includes a production model for firms. Firms in different sectors choose where and how much to produce, using a technology that involves inputs such as labour, land and capital, and productivity spillovers – which depends on the travel cost/time and economics mass (eg, the travel time or generalised transport cost weighted sum of workplace employment density). The change in travel times generated by the scheme enters the production function of firms as a reduction in costs, which flows through to productivity. This allows agglomeration economies to be estimated at a firm level through changes in accessibility. An increase in accessibility (ie, lower travel cost/time) will increase productivity of firms either via a pre-determined parameter of agglomeration economies (ie, agglomeration elasticity) or may be estimated within the S-CGE model using historical data;[7]

• has a consumption model for households. Households choose working hours, where to live, where to work, what sort of housing to occupy, and what to consume depending on rents, access to jobs, commuting costs and the prices of goods and services;

• includes a labour market sub-model. Labour market decisions are incorporated through modelling labour demand, derived from firms' production functions, and labour supply from households' consumption decisions. Labour market decisions that are affected by changes in commute costs will be reflected here;

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[7] The productivity impact of agglomeration economies is implemented as a total factor productivity shifter – the elasticity of output with respect to total labour supply – using changes in commuting trips and/or the effective (employment) density in the S-CGE model.

- captures changes in land use through the land-use sub-model. Land developers choose the quantity of residential and commercial land based on consumption of land of firms and households. Land prices also vary by location and change in response to changes in transport costs and accessibility.

Figure 3.7 shows how an integrated S-CGE model delivers most of the outputs required with only transport user impacts as an input.

Figure 3.7   Integrated S-CGE approach
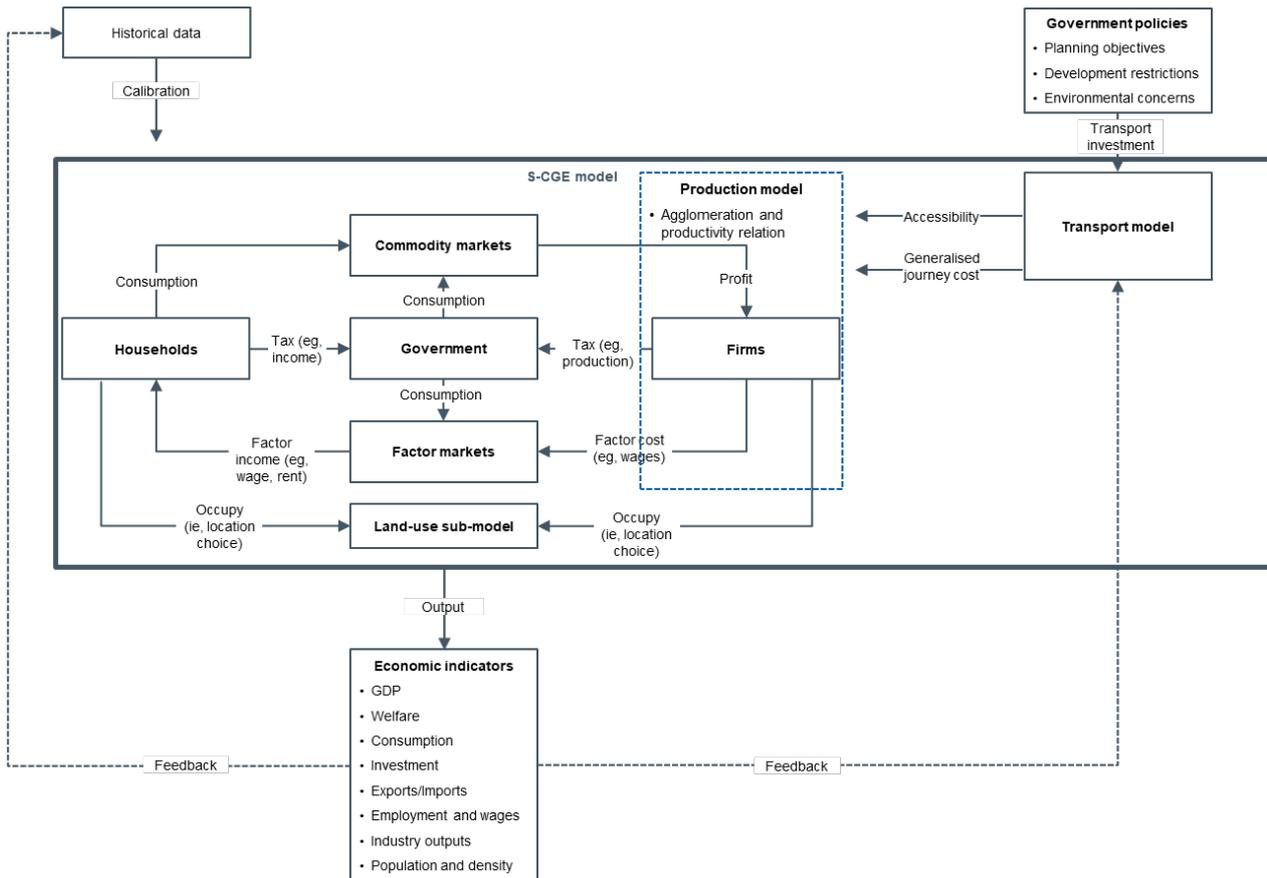
The method of using overlays with a more typical S-CGE model is one that we have first-hand experience with, and we therefore consider it to be feasible.[8] The method involves the use of an S-CGE model in conjunction with:

- a transport model that both quantifies journey cost savings and informs estimates of changes in access to economic mass:

  – The journey cost savings can be fed directly into firms' costs as a 'productivity shock'.

  – The change in access to economic mass can be used to estimate the aggregate productivity benefits of agglomeration economies, which are also fed into the firm production function as a 'productivity shock'.

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8   This approach is based on the 'complementary wider economic impact appraisals' of the Lower Thames Crossing and A303, which were, are far as we are aware, the first generally accepted applications of the S-CGE modelling on transport projects in the UK and which also included an approach to predicting very local impacts ('attractiveness mapping') within a wider growth envelope assessed using S-CGE modelling.

- an attractiveness mapping process to estimate changes in land use that result from the economic impacts of the transport intervention, as estimated by the S-CGE model. In this case the relationship between output and land use may be used to predict the magnitude of land-use change (rather than in LUTI where the relationship is usually between accessibility and land use).

Figure 3.8 shows this approach.

Figure 3.8   S-CGE approach with overlays
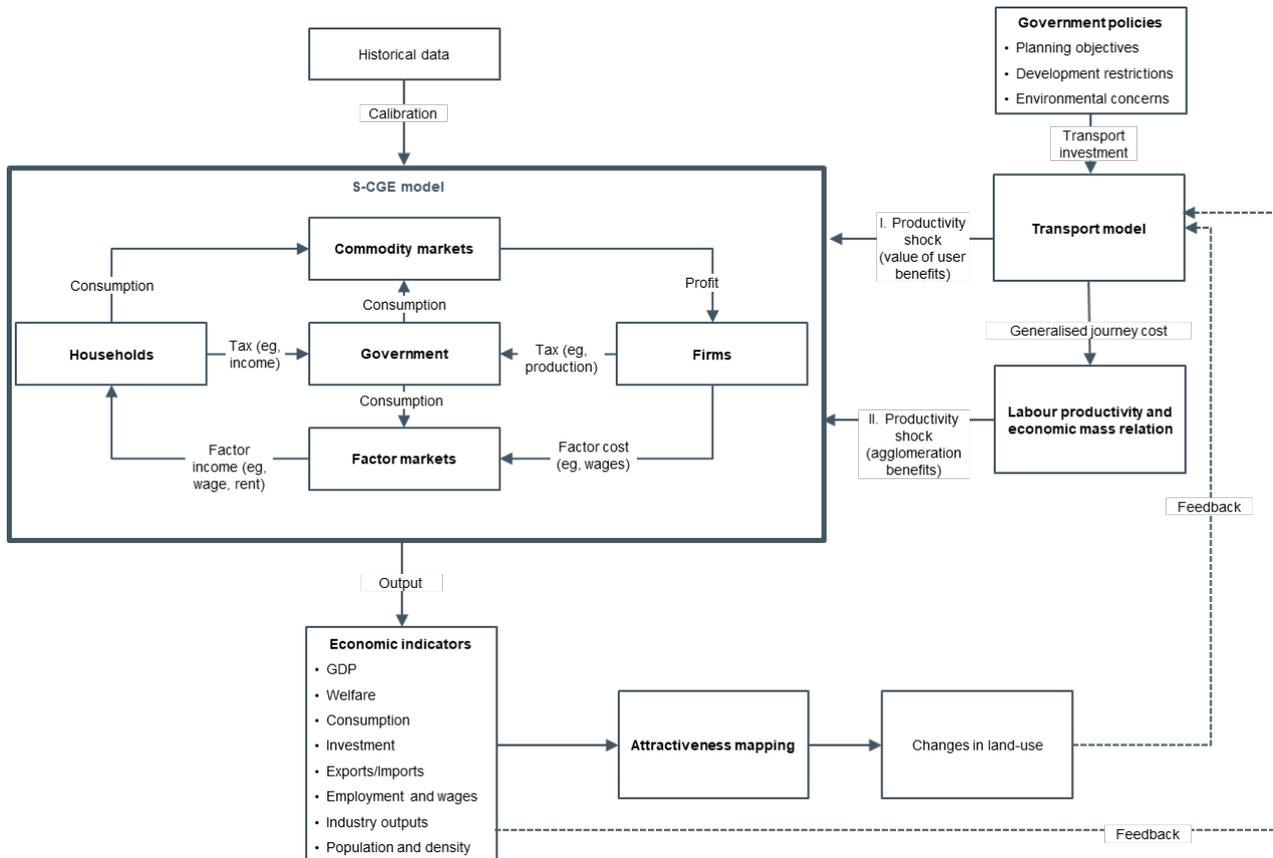
In both cases, the main benefits of using the S-CGE approach include:

- theoretically strong foundation throughout but including price decisions (eg, imperfect competition through a Dixit-Stiglitz model of monopolistic competition among producers) and (dis)economies of scale

- avoiding double counting of impacts – the nature of general equilibrium modelling requires supply to equal demand in all markets, and the ensuing prices reflect this

- an explicit modelling of market imperfections (in particular, through imperfect competition, agglomeration economies, and related effects) to calculate indirect generative effects.

A few open questions, as a relatively young research area, are:

- how best to capture location choices by individuals and businesses, particularly how the models tend to assume 'representative' firms and individuals, but these groups will actually be very heterogenous in nature

- how best to capture and ensure that the use of different types of land is done at an appropriate level (ie, level of granularity in land)

- how to carry out effective, efficient iterations between the transport and S-CGE models.

The main drawbacks involved are:

- **The low level of spatial granularity of results**
  However, land-use impacts from the higher-level regional basis that exists in the S-CGE model can be translated to more granular analysis. Options include using a measure of accessibility which is linked to changes in land use or 'attractiveness mapping'.

- **Complexity**
  The models are complex. This could be best overcome by running a simple 'toy model' alongside a more sophisticated one to help users to test and understand the results of the analysis.

- **Data requirement**
  The models also require a lot of data. For example, the estimation of agglomeration elasticities requires detailed firm-level data (micro-data) providing sectoral location patterns and firm characteristics (eg, factors affecting their location choices as well as production), and the number of workers in each region, including their residential and workplace details.

- **Parameter consistency**
  Statistical estimation of parameters is challenging because large and spatially detailed data samples are required. The validation of the selected or estimated parameters is important but can be challenging.

3.4.2   Option 2 – LUTI + WEI

The second option for appraising dynamic clustering impacts of a transport intervention involves using a LUTI model to develop land-use scenarios and then WEI analysis to appraise the different benefits.

This approach provides a consistent basis for quantifying policy impacts and has the advantage of quantifying wider impacts using rigorous and auditable models. The quantification of agglomeration economies and employment impacts can be done using techniques that are currently recognised in New Zealand and fall under standard guidance in the UK.

The transport model runs iteratively with the land-use model, and the outcome of the transport model (ie, accessibility) is fed into the land-use model, which assigns firms and households that are relocating within or across regions to land. This approach consists of:

- the land-use model, which uses accessibility measures obtained from generalised transport costs, congestion, travel times and trip length to develop land-use scenarios such as residential and commercial space ratio, land values, land-use mix, dwelling and occupancy types, demolition and redevelopment

- WEI analysis, which combines the LUTI model with exogenous models for socio-demographic transitions that capture the dynamics of clustering, employment, population, and household transformation.

LUTI models are typically made up of four interrelated sub-models:

- a residential location sub-model for households

- an economic activity location sub-model for industry

- a real estate price predicting sub-model

- a transport sub-model.

The four sub-models interact through various information flows, mainly the indicators of accessibility and journey times between areas, to simulate the equilibrium of the area being studied. Figure 3.9 shows the main elements of a LUTI model composed of households, industry/firms, land use and transport infrastructure. The set of relationships in the diagram can be summarised as follows.

- A range of land use such as residential and commercial distributed over the land determines the location of households' activities such as living, working, shopping, education or leisure.

- The distribution of households' activities in land requires trips in the transport system between origins and destinations of activities.

- The transport infrastructure provides accessibility, affecting location decisions and land development, which are restricted by policies such as planning objectives and development restrictions.

- The output of the LUTI model in terms of land use serves as an input to the economic appraisal.

The appraisal approach relies on iterative transport and LUTI modelling to assess the extent to which transport infrastructure causes land use to change in different scenarios.

The main benefits of this approach are as follows.

- The analysis tends to be very spatially disaggregated.

- The models can cater for various hypothetical combinations of spatial structure and their mobility implications, starting from a monocentric structure to a highly decentralised structure in which all jobs and population are dispersed.

- The feedback loops between the land-use model and the transport model can help in understanding the long-term land-use consequences of transport interventions.

- LUTI models can account to a considerable extent for relocation and new growth of businesses and the population in response to a transport project.

Figure 3.9   LUTI + WEI approach
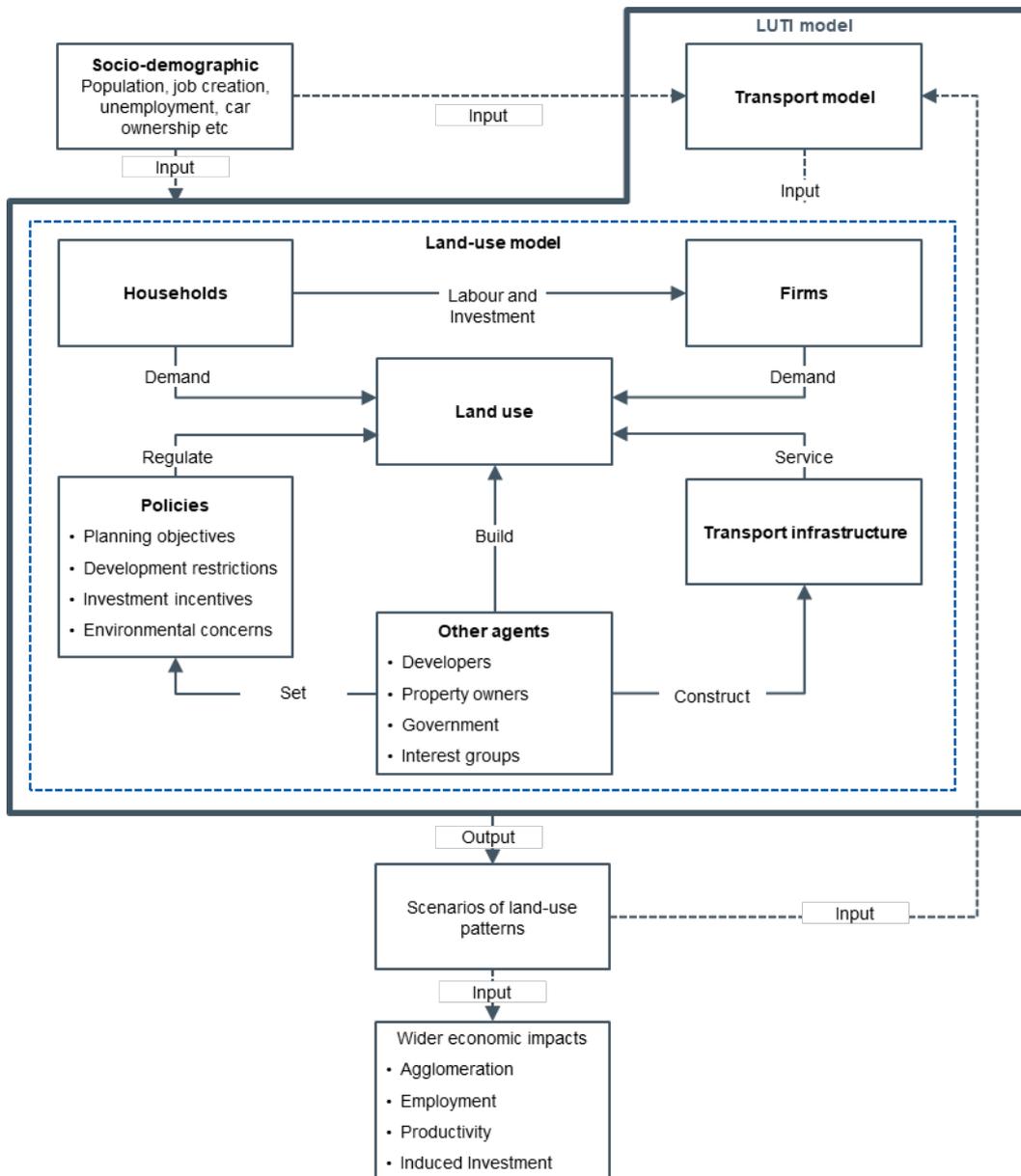
The main drawbacks to LUTI models are as follows.

- Not many people really understand how they work.

- Spatial granularity could come at the expense of spurious precision (particularly given how the quality of data deteriorates with granularity).

- They are not as soundly based on economics as CGE models.

- They are considered to be more prone to double counting than CGE models.

- They do not model production decisions of firms (cost and/or production functions are not included in the model).

- They are difficult and costly to build, and therefore typically only done for relatively large projects.

- They typically assume constant returns to scale and constant product range, and therefore will not capture many of the productivity effects that arise from increasing returns to scale, product varieties, and enhanced learning and communication related to transport investment.

- If parameters are adopted from other models and/or studies, it is difficult to validate them for the context in which they are applied.

While we realise that others might take a different view, and much will crucially depend on the specific model used and how it is actually applied, in our experience many LUTI models would not fare well against the criteria set out at the start of this section.

3.4.3 Option 3 – LUTI + induced demand

The third option for appraising dynamic clustering impacts of a transport intervention involves using a LUTI model to develop land-use scenarios and then induced demand analysis to appraise the different benefits. This approach is potentially able to capture several impacts under a single metric. However, the approach is relatively untested. If Option 2 is used as a primary approach, then it may not be too much additional work to carry out induced demand analysis as well (eg, as a robustness check).

Figure 3.10 shows the high-level interaction between LUTI and transport models and how it would link to the induced demand analysis. This approach can be roughly split up in three parts corresponding to traditional modelling concepts:

- A transport model simulates the transport behaviour of groups of households/individuals for different areas, different travel purposes, using different transport modes, at different times.

- A land-use model describes the settlement pattern as associated with economic activities and, in particular, the behaviour of firms and households.

- An induced demand analysis using the outputs of the LUTI model allows for assessing the effects of changes in the transport system and land use on the economic performance of different groups in different areas.

The impact of induced land-use changes is derived from the utility functions that model the transport behaviour of agents in the economy by:

- **The rule-of-half approximation**
  Assuming demand curves are approximately linear, the rule of half can be used to assess the wider economic impacts.

- **The log-sum measure**
  The rule of half may be considered as only a rough approximation of impacts that can be estimated more precisely from discrete choice models.

The concept of deriving social surplus using probabilistic discrete choice models has existed for quite some time and provides a conceptually appealing approach.

The advantages of using discrete choice models to determine the total impact are that:

- the log-sum is easily computed from choice models – choice models are based on micro-economic utility theory (ie, random utility framework), which enables the derivation of utility-based accessibility measures

- the log-sum measure may account for changes in (generalised) journey costs, destination utility and trip production, all at the same time – it is thus capable of providing the accessibility benefits due to changes in both transport and land use

- the log-sum measure is based on actual demand curves – it therefore provides accurate measures of surpluses (ie, no linear approximation required).

Some of the disadvantages are that:

- this approach may be sensitive to accessibility and attractiveness measures – the ability to capture benefits and losses from changes in attractiveness and accessibility depends on whether the utility functions of land use and transport include a measure or proxy of these changes

- there is a risk of double counting – similar to Option 2, this option raises concerns about double counting when the market failures are not completely modelled

- there are various other issues that arise with induced demand analysis, as summarised in the literature review.

Figure 3.10 LUTI + induced demand approach
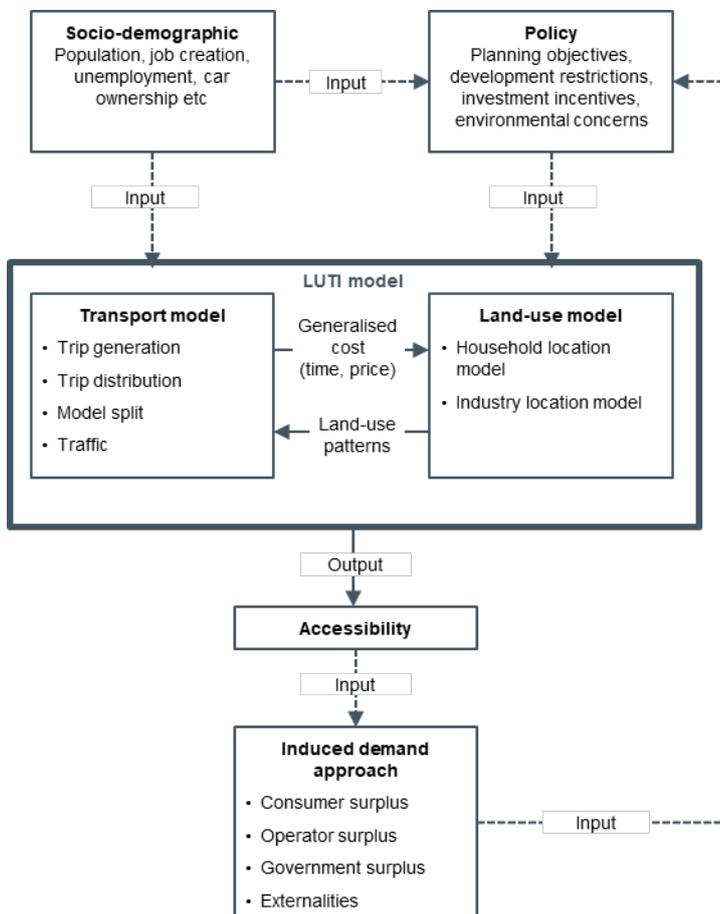
3.4.4 Comparison of options

Table 3.5 draws together how each modelling option addresses each impact when dynamic clustering is expected to occur (ie, land-use changes are modelled).

The key points to consider (summarised in Table 3.5) are as follows.

- User benefits can be captured under all three approaches, but S-CGE has an advantage in dealing with displacement because the model extent is likely to cover the complete study area and because the models, almost by construction, avoid the risks of double counting impacts. LUTI models have limited

information about what occurs outside the extent of the model, which is important to quantify displacement. They are also more prone to the risks of double counting because they are less grounded in general equilibrium economics.

- Agglomeration economies can be assessed using all three approaches. S-CGE likely requires a higher level of spatial aggregation, which will affect the quantification of agglomeration economies. On the other hand, LUTI models are likely to be inherently more spatially granular, but, as with user benefits, the concerns about displacement of activity remain.

- The extent to which in- or out-migration is expected to occur may influence which model is appropriate. If the migration patterns are expected to occur across large regions, then S-CGE with transport and land use is better able to capture impacts over a larger spatial extent. If the migration changes are expected to occur only within a region or at a local level, then LUTI can provide more granular analysis.

- S-CGE has an advantage dealing with market structure effects because it explicitly models production decisions with a cost/production function.

- Labour market tax wedge impacts and moves to more productive jobs can be assessed using all three options. Once again, the issue of displacement may be a challenge for LUTI models due to the smaller spatial extent of the model.

- Environmental impacts could be assessed in all three frameworks.

- Aggregate (total) changes in utility can be assessed using either Option 1 or Option 3. Option 2 is less able to assess utility.

In general, we find that:

- S-CGE models are more rigorously based on economics and in a way that best avoids the risk of double counting (at least being fused with other modelling techniques);

- the strength of LUTI models compared to S-CGE lies in their segmentation and detail. However, some people consider this to be at the cost of 'spurious precision'. LUTI models also tend to be less rigorous in their grounding in economics. Both approaches (S-CGE and LUTI) can be viewed as being complex and difficult to understand/trust.

Table 3.5   Evaluation of model approach to benefits under dynamic clustering

Impact category	Impact	S-CGE	LUTI + WEI	LUTI + Induced demand
User benefits		✓	May require a demographic/transport model overlay for regions outside the LUTI model.	May require a demographic/transport model overlay for regions outside the LUTI model.
Agglomeration effects	Agglomeration	Yes, but with potentially less granularity than LUTI	Depends on spatial extent of LUTI model. More granular approach in study area but areas outside the LUTI model may have limited data.	Depends on spatial extent of LUTI model. More granular approach in study area but areas outside the LUTI model may have limited data.
Market structure effects	Imperfect competition	✓	Requires modelling producer (re-)location decisions	Requires modelling producer (re-)location decisions
	Increase in competition	Potential to assess this	–	–
Labour market effects	Tax wedge	✓	May require a demographic/transport model overlay for regions outside the LUTI model.	May require a demographic/transport model overlay for regions outside the LUTI model.
	Increase in labour supply	Potential to assess this	–	–
	Move to more productive jobs	✓	Depends on spatial extent of LUTI model. More granular approach in study area but areas outside the LUTI model may have limited data.	Depends on spatial extent of LUTI model. More granular approach in study area but areas outside the LUTI model may have limited data.
	Increase in competition	Potential to assess this	–	–
Environmental effects	Marginal external cost	May require additional overlays	May require additional overlays.	May require additional overlays.

3.4.5   Ad-hoc analysis

Ad-hoc analysis is a term we use to refer to other methods of assessing the extent of land use or other changes that result from dynamic clustering. These are likely to be less robust than the above modelling frameworks but could provide useful and relatively simple insight into the magnitude and direction of impacts. As this is something of a catch-all for alternative approaches, the list below of tools and techniques is not exhaustive but provides a few examples of approaches that could be used. We also want to emphasise that these approaches may be used to supplement the main options – for example, to generate parameters or extend the outputs.

- **Surveys**
  Surveys combined with choice modelling could shed light on the location choice decisions that firms or residents make. This information could be used to assess the ways in which land use may change as a result of a scheme.

- **What-if analysis**
  An approach to developing scenarios that involve different levels of dynamic clustering may help to gauge what degree of land-use change is likely due to a scheme.

- ***Ex-post* analysis of similar projects**
  Using comparable projects that have been previously built as case studies may provide evidence for dynamic clustering. The extent of land-use change or change in demand for land that was caused by a similar scheme could help assess the expected level of dynamic clustering for a comparable project. *Ex-post* evaluation of projects more generally could be a very useful way of learning about whether appraisals are generating robust results.

- **Econometric approaches**
  These may investigate any number of relationships that matter for dynamic clustering, such as location choice, property market impacts, productivity impacts, and labour market impacts.

- **Land-use benefit approaches**
  We discuss these in detail below.

3.5   Land-use benefits

This section explores additional mechanisms that are relevant when land-use changes occur. We have kept this discussion somewhat separate from the other methodologies because the benefits appraised here are only additional under certain circumstances. If these circumstances do not apply, then appraising land-use benefits would lead to double counting of first- and second-order transport benefits.

'Land-use benefits' is a term sometimes used to refer to the economic benefits derived from changes in land use or land value. In our view, land-use benefits fall into two categories:

1. **Benefits derived from increasing the supply of land** (also called 'unlocking' land).
   This increase in land supply allows people and firms to use more land at a lower price and increases productivity or output much in the same way that a reduction in travel costs does. The increase in land supply occurs in discrete amounts (ie, a specific plot of land is unlocked) rather than as a widespread distribution of benefits, as with journey time savings. The change in land supply caused by a transport intervention may result in welfare and economic benefits.

2. **Increases in land value (prices, rents) that reflect the location of the land** (eg, access to jobs, markets, amenities).
   Some economists argue for the use of market prices of land values as a proxy for benefits of a transport scheme (ie, land value uplift). Locational benefits that are capitalised in land prices represent production and consumption benefits of that location, and therefore could be double counting of the other wider impacts discussed in the previous sections of this report. The method used to deal with this is commonly known as 'hedonic pricing'.

There is a significant amount of discussion and debate about the extent to which these benefits could be assessed in conjunction with transport appraisal. It seems to us that a transport intervention that induces (1) above could represent additional benefits, while a transport intervention that induces (2) above is likely to represent the capitalisation of other benefits we have discussed previously in this report – with one notable exception being the consumption benefits of a location (because it is not clear that this benefit is included in the options presented in the report). We discuss the consumption benefit theory in more detail later in this section.

In this section we set out the mechanisms that result in land-use benefits and some methods for assessing the impacts, and we discuss whether these benefits are additional. In our view, the approaches to assessing wider economic impacts set out in the previous section (if done correctly) will likely capture land-use benefits related to (2) above, to the extent that they are additional. The use of land-use benefit approaches is

therefore relevant when (1) above applies. Under (2), it is best viewed as supplementary analysis best used to assess or cross-check other analysis of the economic impacts of transport interventions.

3.5.1 Market failures and context that lead to land-use benefits

We highlight two areas where market failures lead to land-use benefits per (1) above. It is important to show that such market failures exist in order to claim that the land-use benefits may be additional. These failures, which result in benefits from unlocking land, are:

- **Coordination failure and holdout or underdevelopment**
  This is a supply constraint that is due to developer actions.

- **Inelastic land supply and land-use regulation**
  Inelastic land supply is to some extent a feature of land that is inherent, but some markets may have more or less elastic supply, and this should be considered. The main factor impacting elasticity is likely to be regulation, but other factors that affect the cost or risk of development such as geography or geology of a region impact elasticity as well. In addition, land-use regulation is often a major constraint on land supply that is imposed by local government.

3.5.1.1 Coordination and holdout problems

Coordination between infrastructure providers and property developers is a typical challenge when 'unlocking' land for development is an objective of a transport investment. In terms of dynamic clustering impacts, the new development may induce additional trips on the transport network and may increase the place attractiveness or density, resulting in agglomeration economies.

'Holdout' typically refers to a situation when a landowner can extract additional value from a developer by refusing to sell their land. The landowner uses their monopoly control of the essential input to seek a price well in excess of their true reservation price. This results in projects that require land assembly having high bargaining costs.

A similar but different type of holdout may be referred to as land speculation, where landowners have a truly high reservation price, believing that the value of the land will appreciate in the future and therefore waiting to sell or develop the land.

Transport interventions may not deal with either type of holdout directly (ie, by reducing bargaining costs or speculation), but it may act as a catalyst by increasing the land value significantly to allow reservation prices of landowners to be met. It does this by shifting out the demand curve for property at that location. In terms of dynamic clustering impacts, the new development will induce additional trips on the transport network, and may increase the place attractiveness or density resulting in agglomeration economies.

For both dependent and induced development, the issues around timing, positive feedback loops and double counting are largely the same.

- **Timing**
  Land-use change and property development will take some time, and developers will typically use phasing for large schemes, so that should be accounted for.

- **Positive feedback loops**
  Depending on the scale and location of the scheme, there may be knock-on effects inducing additional land-use changes.

- **Double counting of benefits**
  If land value uplift is being used as a proxy for the benefits of the development, then it must be done in a way that accounts for displacement of other activity (ie, accounting for a proper counterfactual) and so

that it avoids double counting of direct user benefits and wider economic impacts (to the extent that user benefits are capitalised in land values).

3.5.1.2 Inelastic land supply and land-use regulation

Inelastic land supply and land-use regulation are separate but related concepts. Land supply is inelastic because the quantity in any place is fixed. Land use (referring to the intensity of activity) is somewhat elastic because it can be intensified through, for example, building construction. Land use is sticky due to the time, investment, and inherent risk to modify the use (ie, constructing a building). All of these reasons result in relatively inelastic supply of property. There may be local market conditions that cause the elasticity to be higher or lower (eg, building regulations, policies, physical or geological constraints).

Land-use regulations such as zoning exist to manage externalities but also limit the use of land, so it is not always possible to commit to its highest value or most efficient use. Land-use regulations impose additional regulatory costs on any changes that are allowed to occur, and thus they further decrease the elasticity of supply. Almost every place is subject to land-use restriction, so any discussion of inelastic supply must take land-use regulations into account. Land-use regulations are also a policy constraint rather than a law of nature or economics, and as such can be modified or changed, usually at the local government level.

There may be a case to be made for changes to land-use regulation as a result of a transport scheme, when the transport scheme is responsible for unlocking land, reducing congestion, or when transit-oriented development is involved. These are all cases where land-use regulation is dependent on a transport intervention.

The critical links between dynamic clustering and elasticity of land supply (including regulation) are as follows.

- The ability for land-use change to occur depends on elasticity of supply.

- The price of land and the extent to which location-based externalities are capitalised in land prices depend on elasticity of supply.

- The price also acts as a second-round 'brake' on dynamic clustering by pushing investment to other, cheaper locations.

The first-round impact may result in a location becoming more attractive due to a transport intervention. Second-round impacts such as increased productivity/agglomeration economies may also influence attractiveness. A proportion of the increased attractiveness will be capitalised into land values and rents whether land-use change occurs or not. The extent to which prices increase depends in part on the elasticity of supply.

When changes to land-use regulation occur in conjunction with a transport scheme, then that should be included in the appraisal. To the extent that dynamic clustering is an objective of a scheme, it is very important to consider whether land-use regulation permits the type of development that is expected/desired.

Some of the key considerations for appraisal are as follows.

- **Timing**
  Elasticities are typically different along different time horizons, with lower elasticity over shorter timeframes and much higher elasticities over the long run. The changes in price in the property market will reflect the current level of supply and demand, and these factors may take some time to evolve in response to a transport intervention.

- **Positive feedback loops**
  As discussed above, the price mechanism is one of the main 'brakes' on positive feedback loops that

may occur during dynamic clustering. In the absence of land-use regulation, price acts as a signal that higher-density development (ie, taller buildings) could be built there.

- **Double counting of benefits**
  The ways in which elasticity of supply impacts price show why using land value uplift may be a particularly challenging way to capture benefits. This is because the price reflects (potentially artificial) scarcity as well as the value that consumers place on property. Other factors, such as interest rates and the potential returns from property speculation, mean that prices may be decoupled from the benefits.

3.5.2   Logic map

The impact pathways for land-use benefits described above are shown diagrammatically in Figure 3.11 on the following page.

Figure 3.11   Logic map of land-use impacts
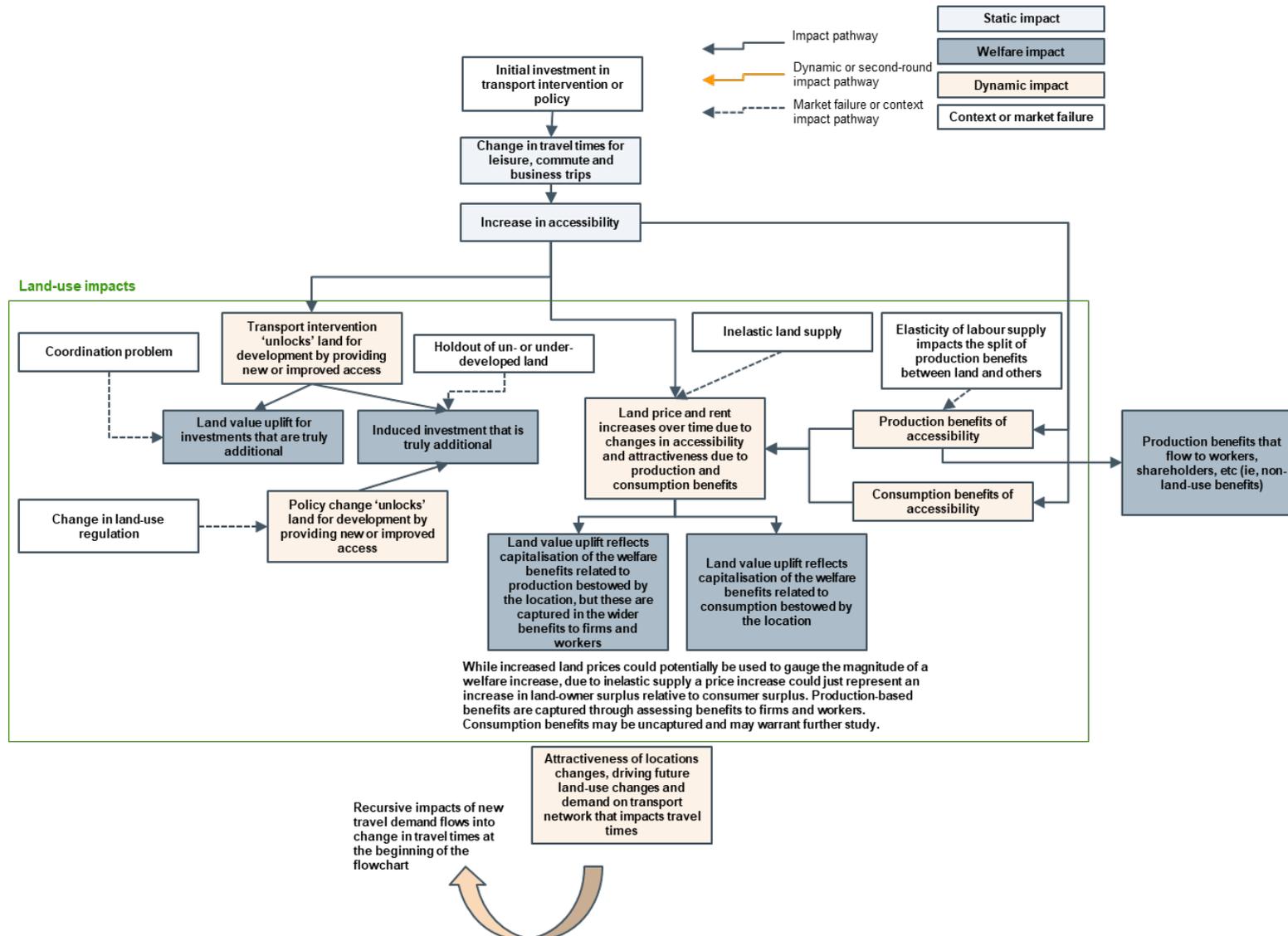
3.5.3 Methods for assessing land-use benefits

In this section we explore methods that have been proposed by others for assessing land-use benefits. As we previously described, the quantification of land-use benefits using these methods may be double counting of other benefits that are capitalised in land values. Under some circumstances, such as unlocking land, these approaches could be used to quantify impacts that are additional. We note that the burden of proof is on the project proponent to show that the transport intervention is necessary to unlock land for development. In the UK, the test for showing this is relatively difficult to satisfy and involves modelling the traffic impacts with and without the development, and with and without the transport scheme, in order to show that the transport network is necessary to develop the land.[9]

3.5.3.1 Supply analysis (including higher value land use)[10]

Supply analysis involves assessing the pipeline of development that may occur under different scenarios. Under circumstances where a transport intervention unlocks development potential, there may be a case for claiming additional benefits.

Supply analysis in its rudimentary form involves assessing the pipeline of development opportunities in a region and quantifying the floorspace or number of dwellings that are planned to be developed. This approach does not involve quantifying economic benefits, but it may be useful as a robustness check of other land-use change predictions (ie, from a LUTI or S-CGE model).

In cases where the land supplied is additional, supply analysis can place an economic value on the additional development. In this case it would be possible to place a value on the increase in planned floorspace that is equal to the market value of that floorspace, less the cost of development. Often, the value used is the market price multiplied by the floorspace. This approach implicitly assumes that demand for land (or floorspace) increases at least the same as the supply of land and that the unit price of land remains the same or increases. In other words, it assumes the increase in supply does not reduce prices.

If, more realistically, land prices reduce due to the unlocking of supply, this represents a productivity shock similar to the reduction of costs brought about by transport user benefits. The reduction in land costs could have knock-on effects through the economy. It would be important to measure this as well as quantifying the potential loss in value to landowners.

On the other hand, the assumption of constant prices could be sound at the margin, and/or one could conduct analysis to show that there is sufficient demand to absorb the increase in supply. The timing of benefits assessed by supply analysis should be assessed in a realistic way that accounts for the ways in which developers are likely to phase development. The costs of development should be assessed as well, including the cost of additional infrastructure and the externalities associated with the development.

A challenge when using this approach is properly accounting for displacement. If the perimeter of the appraisal is national, rather than local or regional, then it may be the case that the increased supply is not additional to the economy as a whole. It may be possible to show that development is unlocked due to a market failure, but it is less clear that the investment would not be made somewhere else instead, in the absence of this unlocking. One way to deal with this could be to consider the benefits with respect to the next likely location that demand could be met. If this is the case, then the additional benefits are derived from the locational externalities at play, not the increase in supply (because the supply could be increased elsewhere,

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9 See section 3.2 in TAG unit A2.2 (Department for Transport, 2020).

10 This approach borrows from the Australian Transport Assessment and Planning report *Land Use Benefits of Transport Initiatives*, where this approach is called 'Higher value land use' (Transport and Infrastructure Council, 2021).

at a place that is potentially less valuable). Another approach may be to consider only the value of foreign investment as a benefit, assuming that within the national economy, displacement is likely to be 100%.

Another element to consider if this type of analysis is to be accepted in CBA is the extent to which transport and land-use policy are coordinated. It may be the case that incorporating the benefits of this approach would favour schemes that involve a coordinated approach to transport investment and land-use regulation, because the approach relies on knowledge about the quantum of development that will occur.

3.5.3.2 Land value uplift – hedonic pricing

Land value uplift approaches differ from supply analysis in that they involve the change in value to all land and property impacted by the transport scheme, rather than just the additional development enabled by the scheme. We think land value uplift is best viewed as a complementary way of analysing benefits – for example, as a cross-check on more standard approaches where impacts are analysed directly.

There are numerous approaches to hedonic valuation. In general, these all involve econometric analysis to assess the impact of a variable of interest on property values. The study design should account for several control variables in order to isolate the impact of the variable in question.

3.5.3.3 Game theory

Game theory deals well with interaction between actors, whether that is in terms of location choice (ie, where to develop) or investment decisions (ie, whether to develop). There are some cases where development is dependent on strategic or competitive decision-making between a few actors. In such cases, game theory may be helpful to show what the outcome is likely to be. We assessed some examples in the literature review. In our view, game theory may be useful for determining the expected quantum of development as a result of an intervention or policy. It is not likely to be used in appraisal frequently, but could serve as an additional tool in the practitioner's toolbelt.

Game theory approaches are designed to deal with decision-making under strategic interaction. Game theory approaches can aid our understanding of complex collective decision-making in which the stakeholders (ie, decision makers) involved have potentially conflicting and interdependent payoffs. This approach is useful to conceptualise relations between stakeholders (eg, cooperative or non-cooperative behaviour of stakeholders) and provides the best possible strategy for every stakeholder by taking into account stakeholders' responses to each other's strategy. This process may feature either in the logic mapping stage or modelling stage to predict outcomes. However, the real world is generally more complex than the model abstraction in game theory. How well game theory predicts outcomes will depend on the assumptions and information of the model.

Alternatives to game theory may produce results easier and more directly. For example, rather than modelling the behaviour of developers, it may be possible to speak with developers and ask them how many units they plan to develop under different scenarios. This may yield realistic results, but it is also possible that they would game the process by responding strategically.

In particular, this method may be useful to assess:

- whether an intervention acts as a 'catalysing event', where investment is increased as a response to a transport intervention
- location choices when strategic interaction or competition are relevant – for example, the hotelling model of location choice is a common theoretical example to show how strategic interaction affects location
- the extent to which planning policies would affect the best possible strategy for stakeholders (eg, location choices, investment decision).

3.5.4 Overlap between land-use benefits and economic impacts of transport

In this section we explore a few issues that are important to reconcile the land-use impacts and economic impacts explored in previous sections of this report. We consider consumption benefits and how key elasticities affect how land values capitalise economic impacts due to transport interventions.

3.5.4.1 Consumption and production externalities as drivers of value

Cities are places for both consumption and production. The framework that has been used in this research paper and in most of the literature is to focus on production benefits. In the impacts that we set out in section 3.1, we include one consumption benefit among the production benefits. 'Love of variety' is a term used in economics to reflect the additional utility that individuals get from having different goods (or the option of different goods). Love of variety could play an important role in dynamic clustering to the extent that households make location decisions based on this factor. However, it is difficult to say exactly how important it is and whether welfare benefits are derived from it.

If, as some research suggests, job availability is more important in location decisions for households than consumption amenities, then the focus on production benefits in this framework may be justified. Nevertheless, we recognise that consumption amenities are likely to affect location decisions, and if that is the case, there are possibly welfare benefits from these amenities, as well. However, we are not aware of guidance or appraisal frameworks that explicitly model consumption amenities to generate an economic/welfare impact. This could be an area for further research.

As for production benefits of a location, if the wider economic impacts set out in this paper are exhaustive, then the production benefits of location should be fully captured using the methodologies set out in section 3.4.

We do, though, recognise that there is a gap in understanding about the potential for consumption externalities and how they fit in this framework. If we are open to the possibility that locational externalities of consumption exist, but that we don't know how to measure them, then there may be benefits additional to the production benefits assessed in section 3.4. One way to estimate these consumption benefits could be through land values, if the benefits are capitalised in land prices – that is, if we know the production benefits and the land value uplift, at least part of the residual of land value uplift minus production benefits may be due to consumption benefits. This is an area that may warrant further research.

3.5.4.2 Elasticities of land and labour

We consider two theoretical arguments for how different parameters impact land prices. These are not exhaustive in terms of determinants of land prices but reflect important factors with respect to dynamic clustering. The two arguments are as follows.

1. **The elasticity of labour supply affects the extent to which wider productivity impacts flow to workers or land.**
   In the case that there is a productivity increase due to agglomeration economies, workers can command higher wages, reflecting their productivity. If dynamic clustering occurs (ie, land use intensifies), then demand for land from both firms and workers will increase. More workers will move to the region to avail themselves of more productive and higher wage work. However, the increase in demand for land from workers will bid up prices. If there is an infinitely elastic supply of homogeneous labour, then landowners would take 100% of the urban 'surplus' (Collier & Venables, 2017). Heterogeneity in labour reduces the elasticity of labour supply and increases the proportion of productivity that rests with workers.

2. **The elasticity of land supply affects the extent to which higher demand for land caused by a transport intervention results in higher land prices.**
As the elasticity of land supply increases, the price impact of an outward shift in demand decreases. Figure 3.12 shows this using a stylised example with a demand shift under completely inelastic demand (S i) and roughly unit elastic supply (S e). The outward shift of demand from D to D' results in a price increase from P0 to P1 if supply is inelastic and to P2 if supply is elastic. There is also a welfare benefit – – labelled CS for 'consumer surplus' – to the individuals who are able to relocate.

Figure 3.12   Consumer surplus loss due to inelastic land supply
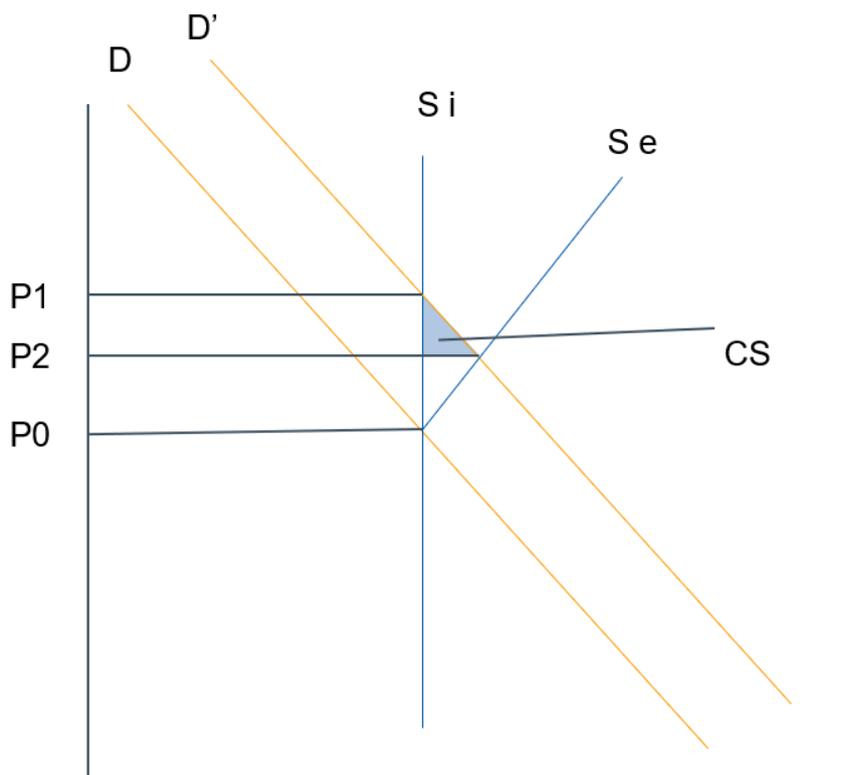
3.5.5   Distributional considerations and land prices

As has been discussed throughout the report, the capitalisation of benefits – time savings/accessibility and productivity impacts – into land values/rents is something that tends to occur over time. One may reasonably ask, how does dynamic land use and changing land prices affect households of different incomes?

In social CBA, the magnitude of benefits is key, but the distribution of those benefits is increasingly viewed as important. With respect to transport and dynamic clustering, the distribution of benefits across some categories may be quantifiable. Transport models will typically separate direct user benefits among commuters, business users, and leisure travellers. Alternatively, the split may be shown by zone of trip origin; in other words, showing the quantity of benefits to people who live in different areas that benefit differently from the scheme.

Interestingly, if these benefits get bid into property values, then they are likely to become highly dissipated – that is, benefits could ultimately flow to property owners even if they do not use transport. A map of initial beneficiaries of a project (eg, that shows where travel time savings accrue and which businesses benefit

from agglomeration economies) could therefore be very different to a map of the ultimate beneficiaries of the project (eg, property owners if benefits flow through the property market). There is also a potentially important owner/renter angle that could be worth analysing, in that renters may end up paying higher rents to have access to more productive jobs and may not end up better off if landowners capture all the surplus.

4 Case studies

4.1 Introduction

In this section, we develop two case studies to show how our framework might be applied in practice.

The first case study is a road transport project in New Zealand called the Waterview Tunnel. This project is relevant because it significantly altered journey times and accessibility in and around Auckland. The change in accessibility could be expected to affect land use and alter the economic benefits of the scheme. We explore how this may occur and be quantified.

The second case study is an Underground rail project in London, England, called the Northern Line Extension. This project is different and interesting because it involves a coordination of land-use and transport planning. In other words, facilitating dynamic clustering is one of the key objectives of the scheme.

In both cases we refer back to the original economic analysis that was done for the project. It is important to note that we do not re-do the analysis but rather we frame the analysis that was carried out at the time using the methodology and language developed in our methodology section and literature review. In the future it might also be useful to carry out analysis on live projects or semi-hypothetical examples using illustrative numbers.

In the rest of this section, we develop case studies of two transport projects. For each, we:

- describe the project and the economic context
- produce logic maps and explain the expected impacts (including dynamic clustering)
- explain the selection of a methodology for appraisal
- assess the impacts, relying primarily on work that was previously done by project proponents.

4.2 Waterview Tunnel, Western Ring Route – Auckland, New Zealand

4.2.1 Description of the project

The Waterview Tunnel is a key component of the Western Ring Route (WRR), a broader transport investment project in Auckland. The WRR is a 48 km stretch of motorway linking Manukau, Auckland, Waitakere and North Shore. It was intended to provide an alternative motorway route through the Auckland region, reducing the dependence on State Highway 1 (SH1), particularly for traffic utilising the Auckland central business district (CBD) and Auckland Harbour Bridge (Linzey et al., 2010, p. 1.1) – as can be seen in Figure 4.1. A further key objective of the route was to 'provide for economic growth, unlocking potential for development along its length' (Linzey et al., 2010, p. 1.1), suggesting that dynamic clustering impacts are a key consideration.

Figure 4.1   Map of the WRR

Source: https://www.nzta.govt.nz/projects/the-western-ring-route/gallery
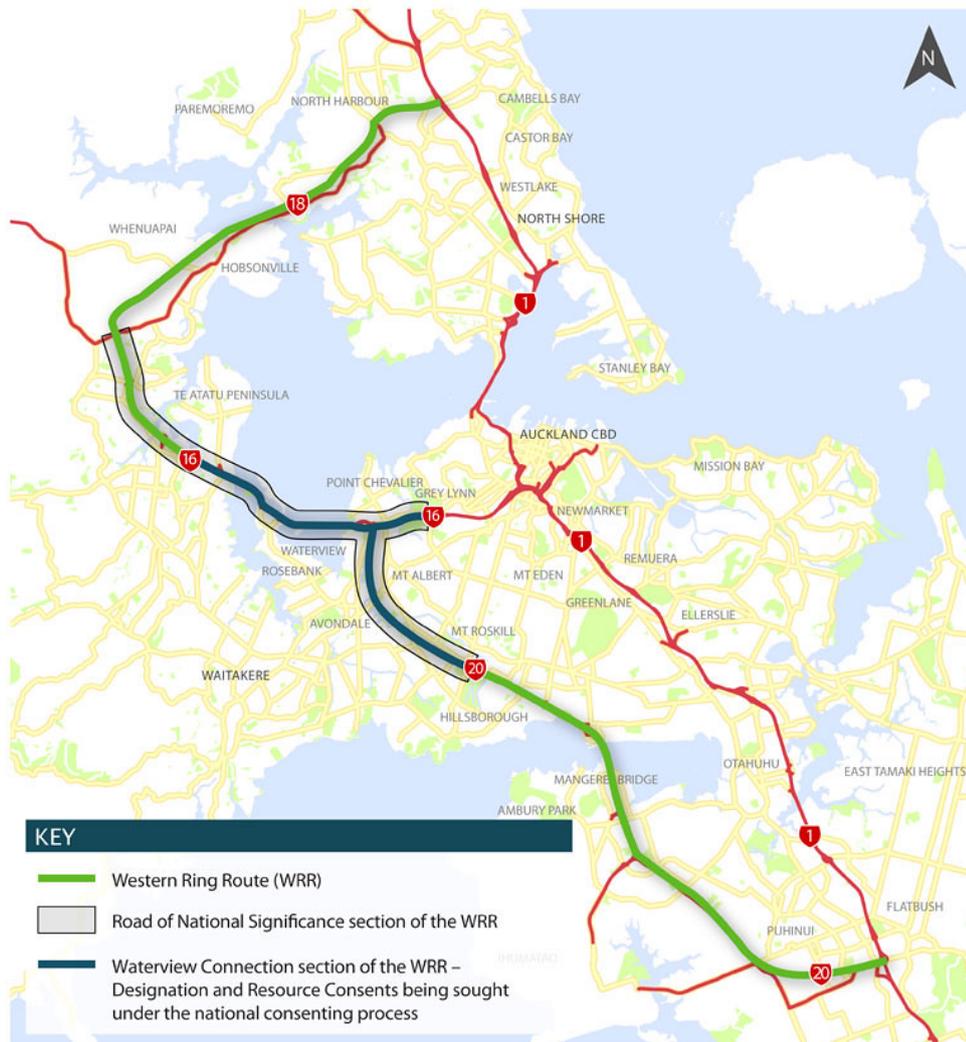
The WRR was constructed on a staged basis, with construction spanning many years. The first sections opened around 2006, with some remaining sections (particularly the Auckland Northern Corridor) expected to be completed in 2022. In order to concentrate the focus of our case study, we consider only one particular component of the WRR: the Waterview Tunnel (although we note that the broader context of the tunnel as a section of the WRR remains important). The Waterview Tunnel was the most significant (in terms of investment cost) component of the WRR and was considered to be the key aspect to 'complete the missing link' of the WRR (Linzey et al., 2010, p. 1.2).

The Waterview Tunnel was opened in 2017 and provides a connection between SH20 and SH16 (see Figure 4.2). This provides a link between the fast-growing areas of Manukau (utilising SH20) and Waitakere (utilising SH16), as well as with the WRR linking the North Shore. The tunnel also improved the motorway links to and from Auckland Airport (located in Manukau) and the CBD, which was a route that previously relied on the use of local roads through residential areas. The Waterview Tunnel involves twin two-lane tunnels (northbound traffic in one tunnel, southbound in the other), with interchanges at either end.

Figure 4.2   Map of the Waterview Tunnel
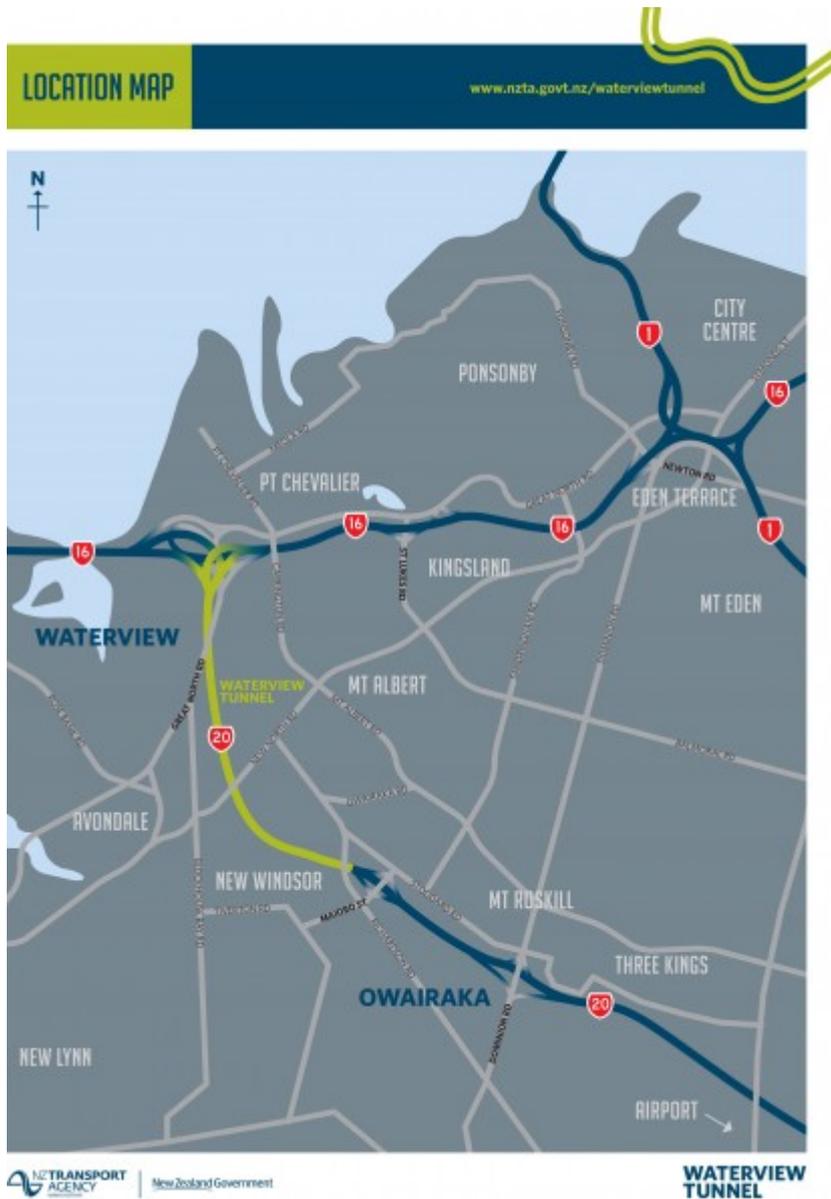
Like the WRR more broadly, a key objective of the Waterview Tunnel was 'to improve accessibility for individuals and businesses and support regional growth and productivity by improving access to and between centres of future economic development' (Linzey et al., 2010, p. 3.2). Similar to the WRR more generally, the implication is that dynamic clustering effects are likely to be relevant to the Waterview Tunnel. Other objectives of the Waterview Tunnel were to:

- contribute to the Auckland region's critical transport infrastructure

- improve resilience and reliability of the state highway network

- support mobility and modal choices

- improve connectivity and efficiency of the transport network (Linzey et al., 2010, pp. 3.2–3.3).

4.2.2 Economic and transport context

Key elements of the economic and transport context are as follows.

- At the time of planning the Waterview Tunnel, significant population growth was predicted for the Auckland region. The population in 2006 was around 1.4 million, while estimates in 2010 were that Auckland would have a population of over 2 million by 2031 (Linzey et al., 2010, pp. 3.3). More updated projections (from the time of our report) from Stats NZ's medium population projections from 2018 to 2048 are for Auckland's population to grow at an average rate of 1.1% per annum over this period, the highest rate across all regions in the country.

- Strong population growth is expected in particular for areas linked by the Waterview Tunnel. The *Auckland Plan 2050* (Auckland Council, 2018) expects that key nodes for future growth in Auckland are the CBD, Albany, Westgate, and Manukau. Each of these areas are strongly linked to the Waterview Tunnel and the WRR more generally, via SH18 (Albany), SH16 (Westgate and the CBD) and SH20 (Manukau). Expected population growth in these areas from 2018 to 2048 is as follows:

  - Auckland CBD: 58,430

  - Albany: 16,080

  - Westgate: 81,760

  - Manukau: 13,920.

- These areas also feature a number of significant business and industrial locations, including:

  - Rosedale and Apollo Drive business and industrial areas in Albany

  - the Manukau business area, which is estimated to produce 14% of Auckland's GDP (Auckland Council, 2018) – Manukau also includes Auckland Airport and Port of Onehunga on the Manukau Harbour

  - the CBD, which is the 'largest and fastest growing employment centre in New Zealand' (Auckland Council, 2018, p. 249).

- With these business and industrial locations, employment growth is expected to be strong in these areas. The *Auckland Plan 2050* notes that:

  - in the CBD there were 114,264 filled jobs in 2016, and there are expected to be an additional 75,850 jobs by 2048

  - by 2048, employment growth is expected to be 6,740 in Albany, 20,260 in Westgate, and 22,620 in Manukau.

- At a more localised level, the tunnel is expected to improve accessibility to and between local centres of future economic growth in the Auckland region. In particular, the Rosebank Road Industrial Area (located off SH16 to the west of the tunnel) and Stoddard Road area (located to the south of the tunnel, off SH20) are future employment growth areas, with improved accessibility leading to projections of up to 18,000–18,500 jobs generated in these areas in the 10 years following project completion (Linzey & Franks, p. 96). While some of these may have been relocated from less productive Auckland areas, it was expected that there would be a net job creation.

The above context shows that the Waterview Tunnel is, and in the context of it being a crucial link in the WRR, a key piece of transport infrastructure linking some of the key areas of Auckland where both population growth is expected and where there are existing strong business developments.

4.2.3   Selecting the analytical framework

In this section we follow the methodology funnel presented in section 3 to determine whether additional modelling is needed to assess dynamic clustering, and if so, what type of modelling is most appropriate.

1.   Should dynamic clustering be considered?

The project seems likely to influence the location choices of firms and households because:

- the scale of the project is large, with large gains in accessibility for certain places
- the project provides a new link where previously none existed
- the context of growth in population and employment in Auckland means large changes in land use are expected.

We therefore propose that dynamic clustering should be explored in the economic analysis of the project.

2.   Which mechanisms of dynamic clustering will be important?

The Waterview Tunnel will increase the accessibility and therefore the attractiveness of certain locations, including Manukau, Waitakere and North Shore. The change in accessibility and attractiveness will influence businesses and residents when they are making location decisions. It is also possible that investment decisions by firms will be influenced, resulting in a higher level of business formation or expansion at these locations.

To the extent that new business formation or expansion leads to higher productivity (eg, due to the sector of the new entrants, or due to agglomeration economies) then we may expect some workers to move to more productive jobs. Assumptions about the labour market will influence the extent to which these benefits are additional. If the labour market is assumed to operate at full employment, then all increases in employment would be offset by decreases elsewhere. If the economic activity that is 'crowded in' comes from foreign direct investment and the labour market is assumed to have some slack, then there may be fully additional new employment.

To the extent that travel time savings influence labour market decisions, we may also expect a change in labour supply through increased hours worked or entry into the labour force. Including this impact depends in part on the local labour market context (ie, un- and under-employment, labour force participation, etc) and assumptions about the labour market (ie, whether the labour market is operating at 'full employment').

3.   Which market failures are at play?

The key market failure involved in assessing the Waterview Tunnel project is that of **congestion**. Congestion occurs when the demand for road usage exceeds capacity, and journeys become longer and more costly. The Waterview Tunnel project reduces congestion by creating a new link, increasing capacity, and spreading demand. The effect of the capacity increase is more notable for certain origin–destination pairs, which leads to a change in accessibility and attractiveness of certain locations. For example, Beca's traffic modelling report (Rochford, 2010, p. 91) estimated that vehicle kilometres travelled on local and arterial roads would fall 2% across the wider Auckland region and by 6% in the localised area of the tunnel. While there was expected to be additional traffic attracted to the tunnel, overall it was estimated that congestion would be reduced because of the project.

Other market failures include:

- **Resilience and reliability**
  The additional link between SH20 and SH16 provides road users with more options for traversing the city. This is particularly valuable when accidents, congestion, or other causes of delay affect SH1.

- **Agglomeration economies**
  These occur via increased sharing, matching, and learning, and are another important externality. The Waterview Tunnel will facilitate more connection between businesses, which over time would result in more sharing of resources, specialisation, knowledge spillovers, and lower job market frictions, all of which contribute to raising productivity.

- **Labour income tax wedge**
  This would provide a welfare benefit to society when people move into the labour force, increase quantity of labour supplied, or move to more productive jobs.

- **Private marginal benefit from work**
  This would lead to greater utility for workers who increase their earnings (ie, the assumption that marginal disutility of work equals wages does not necessarily hold).

- **Environmental externalities**
  These are caused by increased road usage and the associated emissions and noise.

4.   What data and modelling capabilities are appropriate?

A transport model is essential for appraising a road scheme such as this. We understand that a 4-stage multi-modal demand model was used to generate trip matrices and traffic flows, with the associated costs to users.

This 4-stage model used a land-use scenario to inform the first stage of demand modelling. We understand that for the year 2016, census data was used to inform the land-use scenario, and that for future years a LUTI model was used to generate the land-use scenario. The use of the LUTI model seems to have involved some additional inputs and modifications to generate the scenarios.

For the purpose of this project, it was not necessary to analyse the LUTI model or its modifications in any detail, nor to assess the justification for these modifications. If, for example, the LUTI model outputs were modified to fit with the existing zoning or land-use regulation, then that could be an important consideration for the analysis of dynamic clustering. It would suggest that land-use restrictions would be a market failure to consider, and increasing the elasticity of supply of land/development could be an outcome of the Waterview Tunnel project. However, without further evidence or analysis of the LUTI model, we do not consider this to be an angle that is worth pursuing in this case study.

As noted, we have not found it necessary to access the LUTI model for this case study, and running the model would likely have been costly. However, for a project of this scale it may be proportionate to use the model to inform multiple land-use scenarios, rather than just one. This would avoid potentially circular logic. Using a single land-use scenario assumes that the level of development at each location would not be affected by the construction of the Waterview Tunnel, which is unlikely to be the case.

There are a few different analytical approaches that could have been used to estimate impacts of dynamic clustering. Each of these makes different underlying assumptions and uses different techniques or models for estimating benefits. Section 3 has suggested a number of potential approaches, including:

- **Option 1 – single land-use scenario**
  This was the LUTI approach used to assess the Waterview Tunnel, which assumes that land-use change is exogenous to transport benefits (ie, it uses only a single land-use scenario but multiple

transport scenarios – with and without the Waterview Tunnel). This approach focuses on user benefits and takes land use as being constant. This approach only correctly estimates the benefits of dynamic clustering if they are equivalent to the time savings estimated in the traffic model (ie, if the dynamic clustering benefits simply involve the capitalisation of travel time savings, and the time savings are perfectly offset by induced demand). This assumption is unlikely to hold because of the externalities involved (described under question 3 above).

- **Option 2 – multiple land-use scenarios**
  A fully modelled land-use scenario approach would involve developing projections of land use with and without the Waterview Tunnel, and estimating the full suite of benefits under each scenario. The changes in land use and benefits could be assessed using a LUTI model or S-CGE.

- **Option 3 – ad-hoc analysis**
  An ad-hoc approach could involve different analyses that assess benefits of accessibility. For example, an econometric approach could use regression analysis to estimate the impact of accessibility on demand for commercial or residential real estate. A scenarios-based approach could use different land-use scenarios (as in (2) above), but instead of using models to predict land use, one may use assumptions and treat the scenarios as 'what-if' analysis.

4.2.4 Impacts and logic maps (economic narrative)

In this section we assess what the expected impacts of the Waterview Tunnel project would be. To do this we apply versions of the impact matrix and logic maps that were developed in section 3.

4.2.4.1 Expected impacts

We begin by thinking through which economic impacts could be expected from the scheme. These are shown in Table 4.1

The third column of the table sets out the rationale for why we expect each impact to occur.

The fourth column sets out whether a welfare impact is expected. In the impact matrix in section 3, a fifth column shows whether an output (or GDP) impact is expected. To simplify the exposition, for this case study we have not included the expected GDP impacts.

The fifth column in this table sets out whether the impact was assessed in the original analysis. To test this, we looked at both the Business Case for the Waterview Connection (New Zealand Treasury & Ministry of Transport, 2009) and the Assessment of Social Effects (Linzey & Franks, 2010).

The sixth column sets out any comments or details we wish to add with respect to the assessment of each impact.

The labour market effects in particular warrant more explanation. The Assessment of Social Effects found that:

> *Projections for the SH20 section of the Project for the 10 years following the completion of construction estimate the Project would generate up to 18,000–18,500 jobs in those areas benefitted by improved accessibility (it is acknowledged that while many of these jobs will be relocated from comparatively less productive areas in Auckland, there is likely to be a net job creation).*

> *The EIA also projected that the SH20 section of the Project would generate a (one-off) potential increase in GDP worth between $1.4 and $2.4 billion, including welfare gains of between $0.8 and $1.3 billion as a result of the productivity, labour market and competition impacts of improved accessibility* (Linzey & Franks, 2010, pp. 96–97).

The above quote could be interpreted as involving labour market impacts of increased labour supply and/or moves to more productive jobs. It could also be interpreted as involving welfare impacts via the income tax wedge, or due to private benefits. Lastly, the quote also suggests a case for additionality with respect to some of the jobs, and these may be treated differently than the jobs that are displaced from elsewhere. Overall, it is clear that labour market impacts are a portion of the economic benefits, but further exploration would be required to fully understand the mechanisms and market failures involved in this analysis.

Table 4.1   Expected impacts caused by the Waterview Tunnel scheme

Impact category	Impact sub-category	Rationale: The Waterview Tunnel will...	Welfare impact	Quantified in business case?	Comments
Direct user benefits	Business trips	Reduce journey times for each type of road user	✓	✓	✓
	Leisure trips		✓	✓	✓
	Commuters		✓	✓	✓
Agglomeration effects	Agglomeration	Increase agglomeration by increasing effective density and could result in dynamic clustering, which would increase density further	✓	✓	✓
Market structure effects	Imperfect competition	Provide journey time (and cost) savings to companies operating in imperfectly competitive markets	✓	✓	Included in Social Impact Assessment
	Increase in competition	Increase accessibility for businesses that rely on the road network to provide goods and services, widening their market reach and increasing competition	✓	✗	A framework for assessing this does not exist
Labour market effects	Labour supply – tax wedge	Reduce journey times, which may increase labour supply and the taxes collected on income	✓	?	Welfare and GDP impacts from labour market effects are included in the Social Impact Assessment, but it is not clear which framework was applied to assess these
	Labour supply – private benefit	Reduce journey times, which may increase labour supply and the private benefit from wages earned	✓	?	
	Move to more productive jobs – tax wedge	Increase access to higher productivity jobs, resulting in more taxes collected on income	✓	?	
	Move to more productive jobs – private benefit	Increase access to higher productivity jobs, resulting in private benefit from wages earned	✓	?	
	Increase in competition	Increase labour market catchments, causing firms to compete with more firms for workers, potentially resulting in higher wages	✓	✗	A framework for assessing this does not exist
Environmental effects	Marginal external cost	Increase vehicle kilometres travelled, resulting in more emissions and noise	✓	✓	✓

4.2.4.2   Logic maps

The logic map in Figure 4.3 (overleaf) shows the contexts, market failures, and processes involved in the economic narrative of the scheme.

In section 3 we set out three logic maps of increasing complexity. The first logic map included only widely accepted impacts, the second included the recursive nature of LUTI, and the third showed more types of impacts, including those that are less commonly assessed.

This logic map essentially replicates the third logic map from section 3 (Figure 3.4). Most of the impacts that one would expect from dynamic clustering we could expect from the Waterview Tunnel project.

Figure 4.3   Waterview Tunnel economic impacts logic map
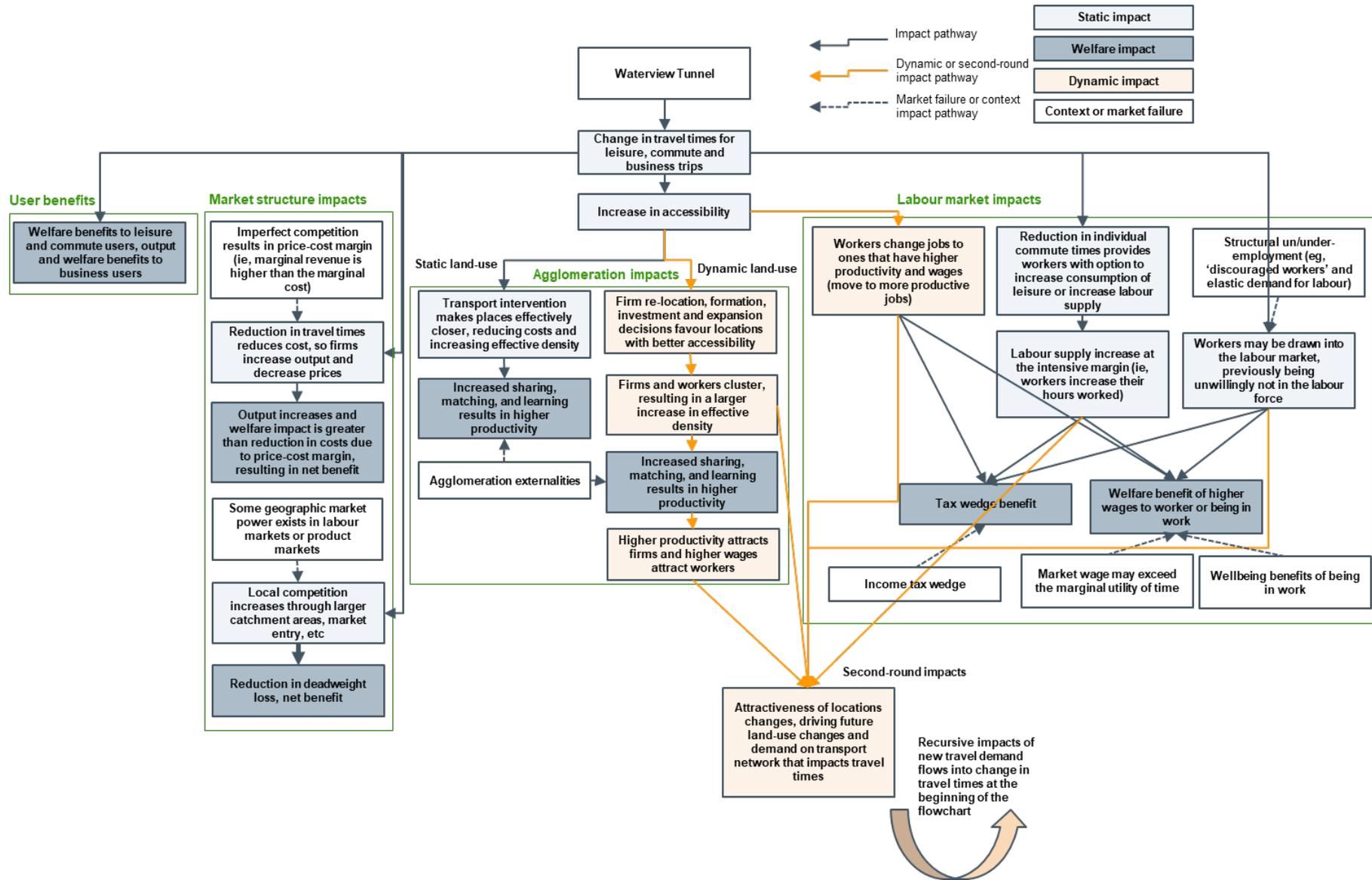
4.2.5   Assessing the impacts

In this case study we do not quantify economic impacts. Instead, we build on the three modelling approaches set out in section 4.2.3. In this section we explain in more detail what each approach could look like if it were to be applied to the Waterview Tunnel scheme.

4.2.5.1   Option 1 – single land-use scenario

This was the approach used in the assessment that was conducted for the Waterview Tunnel. One of the benefits of this approach is that it avoids the potential for double counting of transport benefits. This is because the recursive impacts of land use on transport are baked into the transport model (see the curved arrow at the bottom of Figure 4.3).

If a single view or scenario of future land use is what is being fed into the transport models, then it is important to explain how this view was arrived at. If the land-use scenario was developed using one or more of the techniques we described in section 3 (ie, a LUTI or S-CGE model, or supply analysis, or another approach), then it should be possible to explain how land use is expected to change due to the scheme being proposed. In other words, the land-use scenario includes the Waterview Tunnel being constructed, so it may be possible to examine what land-use impacts result from it.

As we describe in Option 2, a counterfactual scenario using the same technique as the with-scheme scenario is preferable. But in Option 1 we propose that a shortcut may be used instead of developing a full counterfactual. Land-use scenarios are complex and involve many different inputs. It may not be proportionate to conduct the full analysis for a counterfactual scenario. Nevertheless, this shortcut approach could be used to discover what the impact of the Waterview Tunnel would be on land use.

This shortcut approach involves interrogating the approach to develop the with-scheme land-use scenario and deconstructing it. Depending on the data that is used to develop the with-scheme land-use scenario, it may involve showing the qualitative and quantitative analysis and making an educated guess, or inference, as to what quantum of development would occur due to the project. It may also involve making assumptions about where development would be displaced from. From here it is a simple step to understanding the counterfactual scenario because the counterfactual is equivalent to the with-scheme land-use scenario but without that project-specific development.

In summary, using a single land-use scenario is not the most robust approach to assessing dynamic clustering impacts. But some more detailed discussion of how the land-use scenario was generated might shed light on how the scheme in question affects dynamic clustering. Using this approach, the dynamic clustering benefits could be assessed. In a sense these would be backed out by reverse engineering the counterfactual in a short-hand way.

4.2.5.2   Option 2 – multiple land-use scenarios

If the modelling or analytical framework allows, then developing multiple land-use scenarios helps to assess economic impacts in a much more rigorous way using a counterfactual. This involves having a land-use scenario with the scheme being assessed and one without the scheme. The development of the two land-use scenarios should follow the exact same approach, with the only difference being the inclusion of the scheme in question.

Any of the methodologies we describe in section 3 can be applied in this fashion. For LUTI and supply analysis approaches, the economic impacts must be (at least in part) assessed using separate economic models. For the S-CGE approach, the economic impacts are integrated alongside the land-use model. The

economic benefits of each type can be compared between the with-scheme and without-scheme scenarios. The difference between the two scenarios is the benefit brought about by the scheme.

It may be, for example, that this form of analysis could assess capacity and demand for residential development (with and without the project) in areas directly affected by the Waterview Tunnel, such as Manukau, Waitakere and North Shore, or in the more localised areas such as Waterview and Ōwairaka. Similarly, this may be assessed for business development around some of the key business districts that were expected to be impacted by the tunnel (and WRR more generally), such as in Manukau and Albany.

This approach should also include a comparison of transport benefits under both scenarios. Land-use changes that generate benefits may be partially offset by transport disbenefits if they cause congestion, for example.

For the Waterview Tunnel project, this option would likely involve using the LUTI model for Auckland to develop each scenario and then assessing the economic impacts. A comparison of benefits with and without the tunnel would produce the dynamic clustering benefits due to the scheme.

4.2.5.3   Option 3 – ad-hoc analysis

The use of ad-hoc approaches are varied and will depend on the context. For example, in some cases there may be a specific land-use change that could be predicted and which could be seen as dependent on the scheme (see the second case study). Or perhaps there is neither a LUTI nor S-CGE model available and instead an econometric approach would be used, which is the type of analysis that we consider for this option as it applies to the Waterview Tunnel.

An econometric approach would involve identifying and defining at least one key impact and mechanism to assess. Then an econometric model would be developed to understand the relationship between a variable that is affected by the scheme and a variable that represents the impact being investigated.

For example, using the Waterview Tunnel scheme and context, we could pursue an econometric approach to assessing the land value uplift due to the scheme. This type of econometric model is known as hedonic analysis. The analysis would involve gathering data on an appropriate accessibility metric (eg, travel time or proximity to business/shopping districts) and estimating the relationship between accessibility and land value, controlling for several other factors that may also influence land value. Having estimated this relationship between accessibility and land value in general, it is possible to estimate the expected change in land value given the expected change in accessibility due to the scheme in particular.

We note, however, that this approach risks double counting travel time benefits, which may be capitalised into land values. It also does not deal with the issue of land-use scenarios directly. Both of these concerns would need to be dealt with.

4.2.6   Conclusion

In this section we have explored the mechanisms and impacts of dynamic clustering that we would expect to see in an appraisal of the Waterview Tunnel. Given the scale of the scheme, along with other features such as the population and employment context and the nature of the tunnel as a 'missing link', it is likely to be important to explore dynamic clustering impacts in an economic appraisal of this project. Indeed, we note that after the tunnel had been completed, the key identified nodes for future growth in the Auckland region are all linked via the tunnel and the WRR. This might suggest some dynamic clustering effects are expected from the project (although it does not preclude a more detailed analysis of these effects, based on the framework we set out in this report).

We explored three high-level options for assessing the benefits of the scheme in a way that deals with land-use change. The approach we understand that was used to assess the scheme (single land-use scenario) is unlikely to be the most robust way of assessing dynamic clustering, but may shed some light on these impacts. A more robust approach would assess multiple land-use scenarios using, for example, an S-CGE or a LUTI model, and from here derive the welfare impacts of these scenarios. The third approach is more ad-hoc and could involve econometric specification of the relationship between accessibility and land values, which may be appropriate if a LUTI or S-CGE model is not available. Overall, the three options each could be applied under different circumstances. The appropriate option depends on the available data and models, and the proportionality of conducting analysis for the appraisal. If the analysis were to be carried out from afresh, it could be particularly useful to apply our model selection criteria – that is:

- using rigorous and context-specific narratives and evidence

- ensuring that analysis is as soundly based on economics as possible

- validating results (eg, by showing the extent to which the model or quantitative technique is able to forecast impacts that have actually materialised in the past)

- using uncertainty quantification to avoid the considerable risk of spurious accuracy – uncertainty can arise for numerous reasons, including:
  - the quality of the data used
  - the economic principles and parameters that are applied
  - the inherent challenges in forecasting complex systems over long periods of time

- the 'trust-test' – whatever approach is used, it should be possible to explain to a non-expert:
  - the approach that has been used
  - why this approach is the best approach to use given the specific context
  - the results that have been generated
  - why these results are likely to transpire.

4.3 Northern Line Extension – London, England

The second case study is for a (soon-to-be) completed project extending the Tube network in London. We draw on data and discussions provided by Transport for London. The Economic and Business Case written by Steer Davies Gleave and Volterra (2013) has been used to develop this section of the report.

The Northern Line Extension (NLE) project is an example of a project where the transport intervention and dynamic clustering occur simultaneously. The transport project and land-use change have been designed to work together, and each enables the other. The dependency goes in both directions – land-use change would not occur without the new rail link, but the rail link would not be needed or break-even financially without the new development.

The business case for the NLE project reflects this by drawing on a relatively detailed analysis of the planning pipeline for the development enabled by the scheme. In this case study we explore how the economic benefits of the unlocked development were quantified and justified.

We fit the analysis of economic impacts into the dynamic clustering framework using the impacts matrix and logic maps. We also pay particular attention to the unique risks that stem from coordination issues involved with a project of this type. Lastly, we set out the key assumptions that are of particular importance to quantifying benefits from dynamic clustering in this case.

4.3.1   Description of the project

The Vauxhall, Nine Elms, Battersea Opportunity Area (VNEB OA) is an area of 227 hectares located in Central London. It is on the South Bank of the Thames and within walking distance from Westminster (where parliament is located and the site of Big Ben). The VNEB area was specified as an Opportunity Area (OA) because much of the land is brownfield former industrial land, including the iconic Battersea Power Station building. The VNEB OA was subjected to a special planning framework for development.[11] The adopted plan allows for employment capacity of 25,000 jobs and at least 20,000 new homes – figures which are based on the construction of the NLE.

The NLE project involves extending the existing Underground rail alignment from Kennington Loop to two new stations within the VNEB OA: Nine Elms, and Battersea Power Station (Underground Station), where the line terminates. The alignment will be part of the Western branch of the Northern Line. The NLE will provide frequent high-capacity trains with direct access to the City of London and connections with the wider London Tube network. The Northern Line is one of the longest and busiest Underground lines and includes multiple branches through Central London and in North London.

The NLE project was brought about through the confluence of three unique factors:

1. The OA designation of the area, which helped the mayor of London and the two local borough councils focus on increasing development in this location to accommodate overall growth in London. This also had a critical impact on funding for the project. At the time, business rates (ie, a tax on commercial rather than residential property) were completely controlled by central government. The Enterprise Zone of the area meant that business rates were taken out of the national arrangements and allocations and allowed the mayor of London to have the increment over the very low initial rates base in the area. This aligned the mayor's interests strongly with those of the developer. By contrast, the low level of residential taxation, the use of what many consider to be an outdated valuation base, and the use of residential development as the main way of paying for affordable housing meant that the contribution from residential development was (a) smaller and (b) upfront capital only.

2. The development potential of the unique brownfield site – in particular, the massive size and visual prominence of the Battersea Power Station building, which as a listed building would need to be preserved. Developers were interested in investing in the site but were hesitant due in part to the poor accessibility of the location. There had been numerous previous attempts to develop the Power Station building, which strengthened the argument that transport improvement was necessary. There was also a feasible alternative of lower density housing, served by the existing stations and better buses. But this development would not fit well with the Power Station – itself unsuitable for a residential conversion (eg, because of a lack of windows).

3. The congested local transport network, which meant that development at the desired scale (see (1) and (2) above) could not be supported by the existing network. Other transport improvements had been considered in the past (eg, tram links to Waterloo, shuttle trains to Waterloo/Victoria, a Tube extension to Vauxhall) but these options all had serious drawbacks.

While the NLE is a transport project, we believe that a more holistic perspective helps to assess the benefits of the scheme, which arise mostly from enabling development. The interdependencies between transport and land use can be seen clearly and are the focus of the approach taken.

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[11] We use various configurations of the acronym VNEB OAPF, which stands for 'Vauxhall, Nine Elms, Battersea Opportunity Area Planning Framework'.

Figures 4.4 to 4.6 show the VNEB OA as it was prior to the NLE approval, and how it is envisaged to be developed with the NLE.

Figure 4.4   Aerial photograph with VNEB OA boundary marked

Source: Transport for London

Figure 4.5   Routing of the NLE with station locations
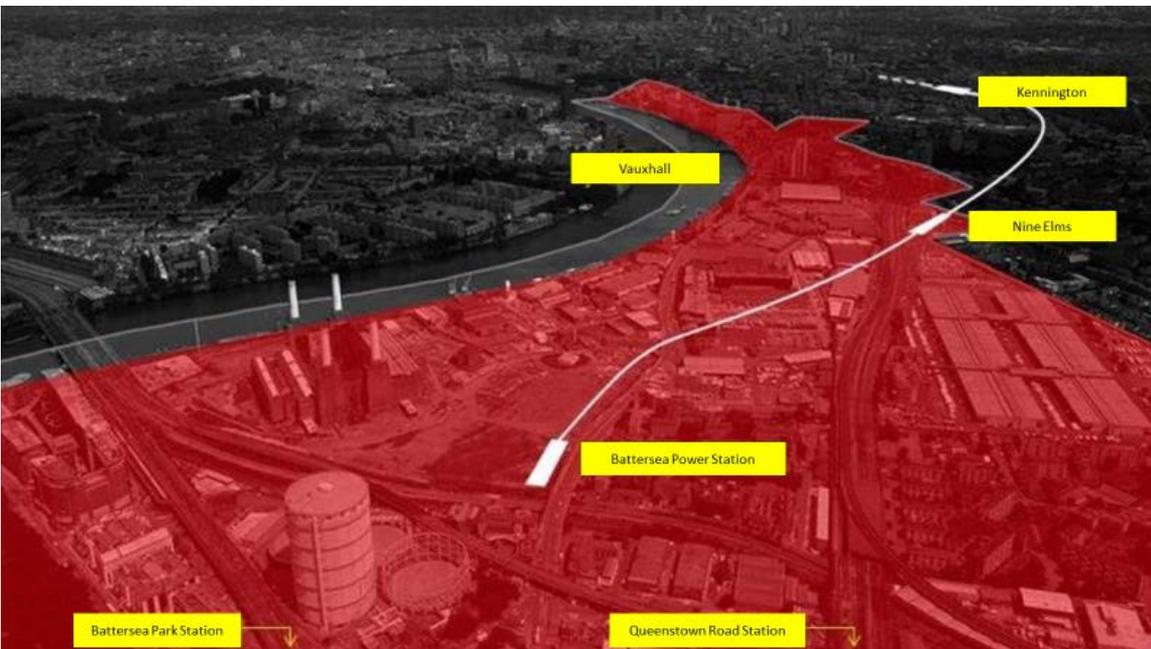
Source: Transport for London

Figure 4.6   Graphic envisioning the development that will occur in the VNEB OA (note the perspective of this image is slightly different from the previous two)

Source: Transport for London

4.3.2   Economic and transport context

There are a few key elements of the economic context that we want to highlight (and that are important to the Economic and Business Case). We group these elements around three themes below. The themes we selected are:

- growing London and the economy
- project risks and coordination
- transport accessibility and capacity.

These themes are correlated with the three unique factors leading to the NLE project being developed, which we set out in section 4.3.1.

4.3.3   Growing London and the economy

London is a growing city surrounded by a greenbelt to limit urban expansion. As a result, the continued growth of London must be accommodated within the built-up area. London's Central Activity Zone (CAZ) is an area made up of the City of London, Westminster, and parts of the surrounding boroughs. The CAZ contains most of the high-value clusters of businesses and institutions that drive the high productivity of the region. The VNEB OA is strategically located so that it can act as an expansion of the CAZ.

- London's population, economy, and workforce are growing. London's population aged between 16 and 64 (working age population) is projected to increase from 5.7 million in 2011 to over 6.6 million by 2036, and the number of jobs in London is projected to increase from 4,896,000 in 2011 to 5,757,000 in 2036. The type of employment expected is largely in services and office type activity.
- The 2004 London Plan extended the boundary of the capital's CAZ to embrace VNEB, recognising its strategic proximity to the heart of London. It also removed a large part of the Strategic Industrial Location allocation of the area (a planning restriction to safeguard industrial land), which had affected and

constrained its planning and development. However, VNEB remains much less densely developed than the other parts of the CAZ, likely due to poor transport connectivity.

• Productivity is higher in London than the UK average, and especially high in Central London. Different measures of productivity are average or median wages, or GVA per worker or per capita. UK transport analysis guidance uses an index of productivity per worker (Dargay et al., 2008), which can be applied to the national average GDP per worker for that year. Using this method, the productivity differential between Inner and Outer London[12] is shown in Table 4.2 below.

Table 4.2   Productivity differentials in London

Area	Index of productivity per worker	GVA per worker (2010)
National average	N/A	£54,313
Inner London	0.172	£63,660
Outer London	−0.025	£52,953

Source: NERA analysis of Department for Transport (2020) data

• At least part of the high productivity in London is due to agglomeration economies. Reducing travel times in and around Central London would increase productivity due to agglomeration economies, as would adding new jobs to the area.

• London's economy is extremely dynamic and includes many companies from around the world that choose to locate in London because of the unique environment. They value the access to talent, and the nearness to customers, competitors, and suppliers. Analysis from the Economic and Business Case found that foreign direct investment accounts for 13% of all jobs.

4.3.4   Project risk and coordination

The second theme is around the risks involved with the project and how these acted as a barrier. With the hindsight we have today looking back to the early stage of the project, it is possible to underestimate the risks. We should try to avoid survivorship bias in our assessment, which would lead us to think that because the project has nearly completed, it was always destined for such an outcome. The risks and the tools used to mitigate those risks are a very important part of the story.

The overarching risk of developing the VNEB OA and the Battersea Power Station building site in particular was demand risk. In other words, would there be enough demand for homes and office space to absorb the new development, at prices that covered the costs and earned developers a profit? The fact that the area remained undeveloped for many years may indicate that demand was not there. A different explanation may be that there would be demand if accessibility of the site were improved. London can be viewed as a monocentric city – the centre of the city is the most desirable due to accessibility, and the price of rent reflects this. As one goes further and further out on the Tube network, rent prices decrease. The demand risk of developing the VNEB OA could be reduced by making the site more accessible and therefore more desirable.

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[12] The statistical definition of Inner London consists of the boroughs of Camden, City of London, Hackney, Haringey, Hammersmith and Fulham, Islington, Kensington and Chelsea, Lambeth, Lewisham, Newham, Southwark, Tower Hamlets, Wandsworth, and Westminster.

The NLE was one project that would increase accessibility and attractiveness of the site. Transport for London, the authority responsible for the Underground network, was not in the business of building rail lines to nowhere. At the same time, there were many disparate landowners and developers in the VNEB OA, none of whom had the authority to build a new Underground rail link privately. This situation was a classic *coordination problem.*

Solving this problem was not easy. Negotiations between the different parties and political pressure from different levels of government helped to build trust. Eventually, Transport for London and the developers came to the table and agreed to work together. The development would fund most of the capital costs of the NLE through initial contributions and future business rates revenues.

Even once this had been agreed, there remained a further *credibility problem*. New risks existed in the early stages of planning that were viewed as potential dealbreakers. These included:

- potential issues with Section 106 funding[13] that made developer contributions difficult to guarantee
- the risk that developers could stop progress at a partial stage in order to extract profit and move on
- the risk that developers could switch the type of development to residential instead of commercial property
- the risks to the NLE project that it may not be finished on time, on budget, or may be stopped entirely
- economic risk that a downturn or change in the macro-environment would affect the investment climate.

The mitigation of these risks required a series of agreements between different parties to safeguard their interests. On the one hand, developers were seeking assurance that the NLE would be built, and on the other hand Transport for London wanted assurance the development would occur. An agreement was eventually reached that included a commitment on Transport for London's part to build the NLE once the work on the Battersea Power Station development had been committed and begun. This was viable because that one development site involved a large share of the additional employment, which drove the economic case for the NLE. In the absence of such a large anchor site, one may imagine that an agreement among all the many smaller developers and interests could have been more difficult to achieve.

4.3.5 Transport accessibility and capacity

The transport situation in the VNEB OA prior to the NLE was varied. The area around Vauxhall was already very well connected due to the Vauxhall rail, Underground, and bus stations. However, much of the site, and the Battersea Power Station development in particular, was not very easily accessible. In addition to accessibility, crowding was a concern on many of the rail links near the site, as was congestion on the roads.

Transport for London measures the Public Transport Accessibility Level of different zones based on the distance from and frequency of public transport. The map in Figure 4.7 shows that the Vauxhall area (the dark red section of the OA, which is outlined in black) is very well connected, but there is a gap between Vauxhall and Battersea Park station on the south-west edge of the OA, which scores quite poorly in terms of Public Transport Accessibility Level – this is where the Battersea Power Station building site is.

Crowding is an issue for both Tube passengers and National Rail passengers near the OA. This is due to the proximity of the OA to Central London, so the build-up of passengers reaches crowding conditions, causing passengers discomfort and delays. Along the main passenger rail lines through the OA that terminate at Waterloo and Victoria stations the crowding factors are between 1.25 and 1.5 during the morning peak. The

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[13] Section 106 of the Town and Country Planning Act 1990 covers developer contributions agreed through the planning framework.

Northern Line has a crowding factor of over 1.5 from Clapham Common Station during the morning peak. This high degree of crowding indicates that a large number of new trips originating or terminating in the OA would cause more delays and disbenefits to users (ie, missed trains and/or cramped compartments).

Figure 4.7   Public Transport Accessibility Level score prior to the NLE
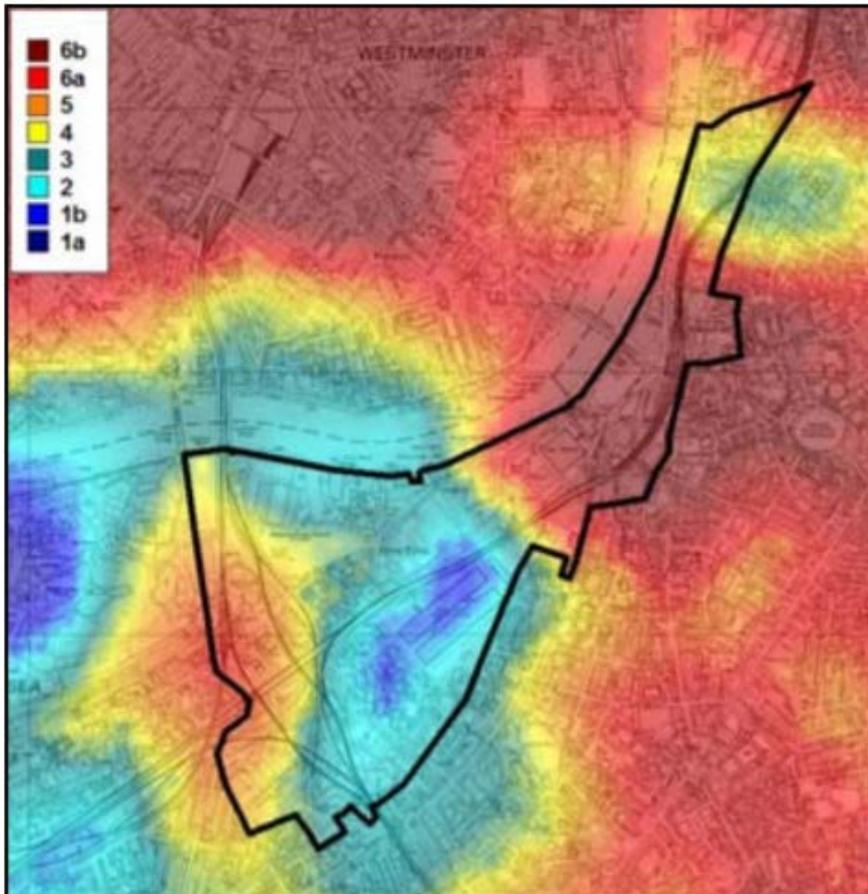
Source: Transport for London

4.3.6   Selecting the analytic framework

In this section we apply the methodology funnel to determine a framework that is appropriate for assessing economic impacts of this project.

1.   Should dynamic clustering be considered, given the project and local context?

The VNEB OA is explicitly about large-scale land-use change, and as such the NLE business case should consider it.

2.   Which mechanisms of dynamic clustering will cause it to occur and when?

The main mechanism by which the NLE facilitates dynamic clustering is by solving the coordination problem described in the previous section. The transport mechanism through which the NLE facilitates clustering is by improving accessibility and attractiveness, and by alleviating rail network capacity concerns if development were to happen without the NLE. The additional employment space unlocked by the NLE means we expect some business relocation and new business formation or expansion. Additional homes mean we may expect some residential relocation. Due to the proximity of the site to London's CAZ we expect that the employment

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here will be of relatively high value added, and that some of it may be truly additional due to foreign investment. The proximity of new employment opportunities to workers who are unemployed or out of the labour force may cause some individuals to enter the labour market or increase participation.

3. **Which market failures are at play, and therefore which economic impacts are quantifiable?**

There are several market failures involved that result in economic benefits that should be quantified and attributed to the NLE scheme, including:

- **coordination failure**, which caused the site to remain undeveloped. The tricky coordination problem was perhaps the primary reason that the development of the NLE transport infrastructure and Battersea Power Station building site had not occurred until commitments could be agreed (and enforced);

- **land-use regulations**, which safeguarded industrial uses in the VNEB OA until the 2004 London Plan revised this to allow for the types of uses (housing and offices) that allow better integration with the London CAZ;

- **congestion and the existing transport context**, which acted as a constraint on the types of transport solutions that could meet the transport demand generated by the development of the VNEB OA;

- **agglomeration economies**, which would be caused by the additional development in the VNEB OA. Agglomeration economies occur at higher densities, which the NLE enables. The additional jobs created in the VNEB OA would produce productivity spillovers to nearby workers (of which there are many, relative to a counterfactual where these jobs may be located elsewhere in the UK or not at all);

- **labour income tax wedge**, which would provide a welfare benefit to society when people move into the labour force, increase quantity of labour supplied, or move to more productive jobs;

- **private marginal benefit from work**, which would lead to greater utility to workers who increase their earnings (ie, assumption that marginal disutility of work equals wages does not necessarily hold);

- **wellbeing benefits of having a job**, which would reduce the cost of social programme spending and would provide better health and wellbeing outcomes for individuals.

4. **What data and modelling capabilities are available, and what is a proportionate amount of analysis?**

For this case study we do not have access to S-CGE or LUTI models, which could be used to predict development and economic impacts, but are not necessary. The Economic and Business Case points out that it:

> *does not include the results from a Land Use Transport Interaction model, as specified in the guidance for estimating M2MPJs [move to more productive jobs]. The reason is that this too rests on historical parameters, while the intention of this investment is substantially to change these and the perception of the area.* (Steer Davies Gleave & Volterra, 2013, p. 21)

A transport model should be a standard requirement for a transport project of this scale.

Other analysis to justify the additionality case can be done using economic data and inference; no detailed modelling is required.

We identify four types of analysis that should be undertaken to assess the economic benefits of the NLE (in addition to the obvious analysis of user benefits such as journey time savings):

1. Quantifying the development that is only possible with the NLE. In the UK a couple of different approaches exist to prove dependence.

   a. The first is the transport analysis guidance 'dependent development' framework (Department for Transport, 2020). This is a mix of supply analysis and traffic modelling. It is designed to show and quantify the exact amount of development that can be claimed as additional due to a transport intervention. It works by modelling traffic under different development assumptions until a 'reasonable level of service' cannot be provided by the network. This is intended to show that the land-use change could not occur without the transport link.

   b. The 'But-for' test by Her Majesty's Treasury (HMT).

   c. A third approach (which is the one taken here) is to show logically that development is dependent on the transport improvement. In our case we have explained the bi-directional dependency and couched it in terms of a coordination problem that was overcome through enforceable agreements.

2. Quantifying the proportion of economic activity (in this case measured in jobs) that is additional to the UK, rather than additional to the area, by considering how much inward investment is being generated.

3. Valuing the agglomeration benefits of locating jobs in the VNEB OA. There are few avenues through which this impact can be viewed:

   a. Some of the jobs are additional to the UK, per point (2) above, and therefore increase the economic mass of London with no particular jobs being displaced from elsewhere.

   b. The remainder of the jobs would be displaced from other places in the UK, and therefore the level of economic density and the agglomeration elasticity in the location of the displaced jobs matters. The density and agglomeration elasticity of the jobs located in the VNEB OA are likely to be high, and therefore the increase in agglomeration economies is likely to be greater than the loss elsewhere (but this should be tested).

   c. The types of jobs located in the VNEB OA are likely to have a higher productivity than jobs elsewhere in the UK, which would result in larger agglomeration benefits (because the elasticity of agglomeration would be applied to a higher base of GVA per worker).

4. Valuing the benefits as a result of moves to more productive jobs, increases in labour supply, and entry into the labour market. These include:

   a. income taxes on higher earnings

   b. private marginal benefits from higher earnings

   c. the wellbeing and greater life opportunities as a result of being in work.

4.3.7   Impacts and logic maps (economic narrative)

In this section we assess what the expected impacts of the NLE project would be. To do this we apply versions of the impact matrix and logic maps that were developed in section 3.

4.3.7.1   Expected impacts

We begin by considering which economic impacts could be expected from the scheme. Table 4.3 shows that we could expect nearly all of the impacts set out in section 3 to result from this scheme.

The third column of the table sets out the rationale for why we expect each impact to occur.

The fourth column sets out whether a welfare impact is expected. In the impact matrix in section 3, a fifth column shows whether an output (or GDP) impact is expected. For this case study we have not included the

expected GDP impacts or estimated these. This information was not included in the original Economic and Business Case and is not possible to replicate.

The fifth column in this table sets out whether we assess and quantify the value of the impact, and if not, why. Not all impacts should be quantified if it would not be proportionate or if it would not make a material difference to the economic case. In the Economic and Business Case it is stated that increased output in imperfectly competitive markets and improved labour force participation were potential wider economic impacts that were not quantified because 'Experience of other transport projects shows that the [move to more productive jobs and pure agglomeration] are the most significant. For this reason the focus of the analysis is on these impacts' (Steer Davies Gleave & Volterra, 2013, p. 21).

Table 4.3   Expected impacts caused by the NLE scheme

Impacts	Impact sub-category	Rationale	Welfare impact	Quantified in Economic and Business Case?
Direct user benefits	Business trips	NLE will reduce journey times for existing rail and road users, and welfare benefits of new trips can be estimated using the rule of half. NLE will reduce crowding on the wider network, and the benefits can be measured in terms of journey times savings and/or pounds.	✓	✓
	Leisure trips		✓	✓
	Commuters		✓	✓
Agglomeration effects	Agglomeration	NLE will make places effectively closer, resulting in higher effective density and agglomeration economies. Greater development in the VNEB OA will occur as a result of the NLE, and this also increases effective density and agglomeration economies.	✓	✓
Market structure effects	Imperfect competition	Some output increase due to business travel time saving in imperfectly competitive markets could be expected but likely small.	✓	No, this impact is likely to be small.
	Increase in competition	No strong reason to suspect increased competition in product markets.	✗	N/A
Labour market effects	Labour supply – tax wedge	Around 5,300 jobs created in the VNEB OA will be low skilled or entry level, and these could be filled by the unemployed people or economically inactive people in nearby wards.	✓	This impact is not assessed because it is difficult to predict with certainty.
	Labour supply – private benefit	If unemployed people or economically inactive people enter the labour force, they would increase their income and likely their wellbeing.	✓	This impact is assessed qualitatively.
	Move to more productive jobs – tax wedge	The new jobs created in the VNEB OA are likely to be similar in output per worker to the average output of jobs in Inner London (ie, above average). This implies a movement away from lower output jobs to fill these new roles – a move to more productive jobs.	✓	✓
	Move to more productive jobs – private benefit	If workers move to more productive jobs with commensurate higher salaries, they are likely to be better off.	✓	This impact is not widely accepted in transport analysis guidance.
	Increase in competition	The large increase in jobs in the London CAZ will likely have effects on the wider job market, increasing competition and potentially requiring firms to bid up wages.	✓	This impact is not assessed because it is difficult to predict with certainty.
Environmental effects	Marginal external cost	The reduction in road journeys would lower emissions.	✓	✓

4.3.7.2   Logic maps

The logic map in Figure 4.8 shows the contexts, market failures, and processes involved in the economic narrative of the scheme. While this logic map has been developed after the Economic and Business Case, in principle it should be possible to develop a logic map for a project at a relatively early stage. This logic map will guide our analysis in the later sections where we show why, how, and to what extent (in terms of £value) economic benefits materialise.

In section 3 we set out three logic maps of increasing complexity. The first logic map included only widely accepted impacts, the second included the recursive nature of LUTI, and the third showed more types of impacts, including those that are less commonly assessed.

The logic map in Figure 4.8 may, at first glance, most closely resemble the first logic map in the section 3 because it only includes a few key impacts, and it does not appear to show recursive impacts between transport and land use. However, the analysis here actually does account for the recursive impacts between transport and land use because the transport models used includes the additional trip demand from the new developments in the VNEB OA. With that in mind, the logic map presented here is probably closest in nature to the second logic map from section 3.

First, **transport user benefits** will result from the scheme in the form of journey time savings, and reductions in crowding.

Next, consider **land-use impacts**. The NLE project successfully navigated the coordination problem, which had left the VNEB OA under-developed. The construction of the NLE occurred simultaneously with development of the Battersea Power Station building site, resulting in higher intensity land use in the OA. While some development would have occurred under the VNEB OA alone, the NLE allowed for denser uses and more commercial floor area. A portion of the additional development due to NLE can then be attributed as additional to the UK economy, by virtue of it being inward investment, also known as foreign direct investment.

The additional development that is attributable to the NLE also results in a new spatial structure of the London economy – one that is denser with more jobs in the CAZ. Increased sharing, matching, and learning (ie, **agglomeration economies**) can be expected to take place, which will increase productivity in the CAZ.

Labour market impacts are also expected as a result of additional jobs, higher productivity jobs, and increased accessibility to jobs, which will increase labour supply and draw workers into the labour force.

First, we consider moves to more productive jobs. Some of the jobs that are due to induced investment are truly additional to the UK economy – however, we recognise that these jobs will abstract from other jobs if we assume a steady employment rate. We therefore quantify the additional value created by these jobs, compared to the jobs that are being replaced. These jobs are located in the CAZ, which features a much higher average level of productivity compared to the national average. The tax wedge on the increase in productivity from moves to more productive jobs can be quantified as a benefit.[14]

Next, we could consider a situation where people are drawn into the labour force as a result of the NLE. The NLE will reduce travel times for some workers, and the location of jobs in the VNEB OA will provide work close to areas with high unemployment. For workers whose commute times are reduced, some will increase their quantity of labour supplied with the time that has been freed up, resulting in tax-wedge benefits. For the

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[14] We note that in previous reports we entertained the possibility that individuals who move to more productive jobs could also benefit from higher wages. We have not pursued this line of reasoning in part because it was not done in the Economics and Business Case and also because the justification remains somewhat controversial.

people who live in the areas near the VNEB OA and are not in the labour force, the opportunity to work nearby in some of the many new entry-level jobs will draw them into work. This has not only a tax-wedge benefit but also wellbeing benefits from being in work. This benefit is not quantified in £value terms in the Economic and Business Case, but there is some qualitative evidence for it, so we have included it here.

Figure 4.8   NLE economic impacts logic map
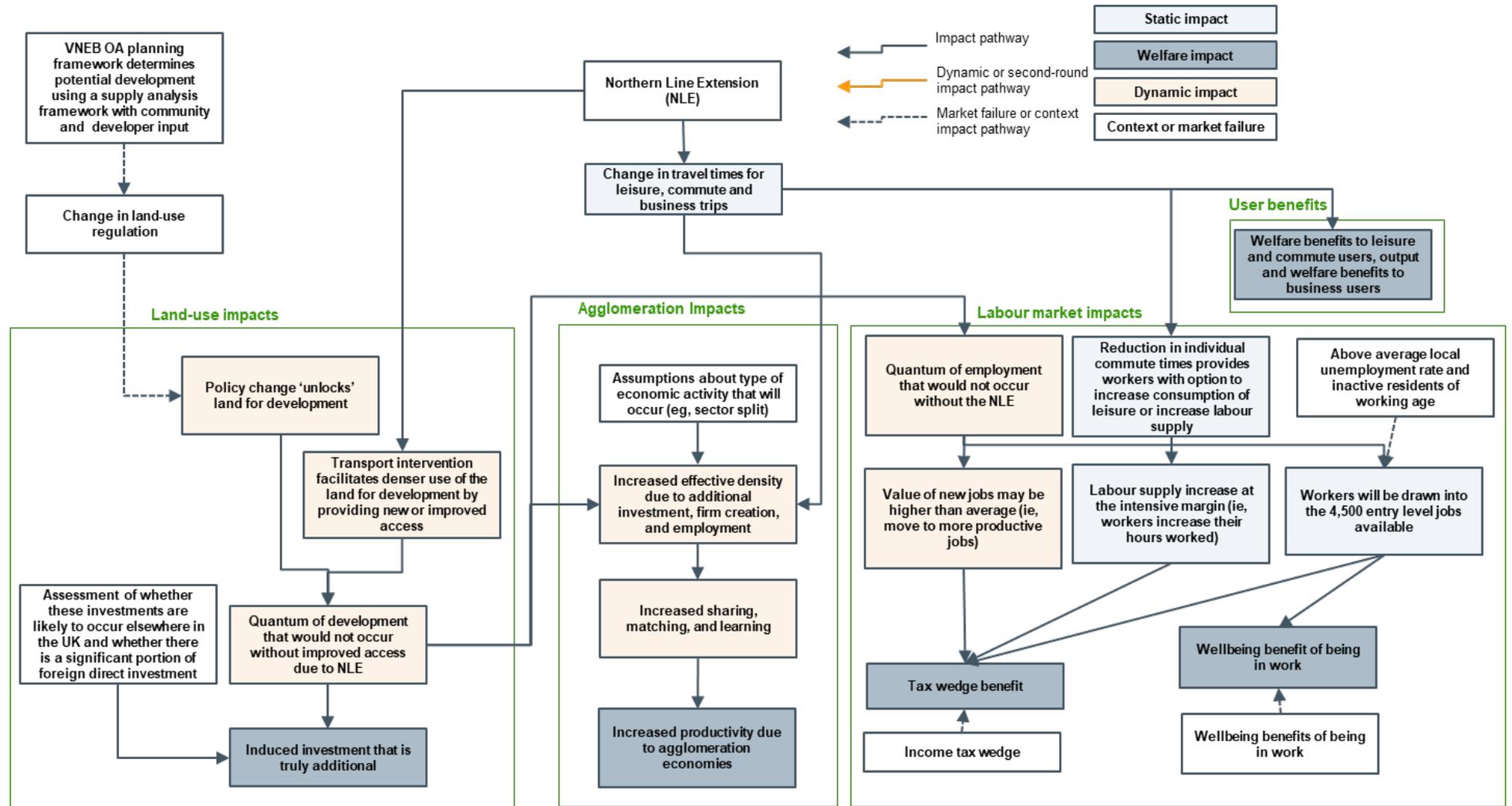
4.3.8   Assessing the impacts

In this section we walk through the actual assessment of impacts in the four areas identified in the previous section. We quote extensively from the Economics and Business Case.

4.3.8.1   Economic scenarios – development impacts

The first element of the assessment involves developing scenarios. A reference case or counterfactual scenario is required to quantify economic benefits. The assessment will take the benefits that accrue under the scenario where the NLE is built and compare those against a scenario where it is not built.

The Economic and Business Case sets out two economic scenarios that have been assessed to generate the marginal economic benefits attributable to the NLE scheme:

- development with the NLE (do something)
- development without the NLE (reference case).

The NLE will provide the capacity and accessibility required to deliver the higher-density development in the VNEB OA that will fulfil the regeneration objectives for the area. Accordingly, a 'Without-NLE Reference Case' with a lower level of development scenario and a 'With-NLE Do Something' scenario that reflects the additional development enabled scheme were developed in the Economic and Business Case.

Planning data used to support the NLE Economic and Business Case is based on the actual levels of consented developments of population/residential units and employment (in each planning application submission) in the OA, rather than estimates provided in the Opportunity Area Planning Framework.

The Without-NLE Reference Case includes all consented development up to February 2013.

The With-NLE Do Something scenario includes all consented development (as per the Reference Case) plus:

- additional development at Battersea Power Station [building] that is dependent on the NLE
- additional housing and employment associated with the remaining (ie, currently unconsented) development sites that would be more likely to come forward with the NLE.

The total development in the With-NLE and Without-NLE scenarios is presented in Table 4.4. It should also be noted that many of the consented schemes included in the Without-NLE Reference Case have, in fact, been consented on the assumption that the NLE would come forward. For example, the Wandsworth Planning Committee Report for Riverlight Tideway and Market Towers (as cited in Steer Davies Gleave & Volterra, 2013, p. 19) states that:

> The Northern Line Extension (NLE) is inextricably linked to the development of the Opportunity Area and the densities proposed may not be sustainable without such a mass transport system.

As such, the assumption about the additional VNEB development that would come forward because of the NLE is considered to be conservative.

Table 4.4   Additional VNEB development – with-NLE vs without-NLE scenarios

	Jobs	Homes
VNEB development without the NLE	9,822	12,778
Additional Battersea Power Station development with the NLE	13,086	2,419
Remaining sites assumed to come forward with the NLE	937	3,168
Total additional VNEB development with the NLE	**14,023**	**5,587**
Total VNEB development with the NLE	**23,845**	**18,365**

Source: Steer Davies Gleave & Volterra (2013, p. 19)

The delivery of the NLE will make possible an additional 14,023 jobs at standard density assumptions for this type of development. The output of these roles will be that associated with the CAZ. It is estimated that in 2031, when the development is complete, the output generated will be £1.1 billion per year. This is the total activity generated by the investment and which would not otherwise be in existence.

4.3.8.2   Displacement

London has the highest levels of foreign direct investment of any city in the world, reflecting its importance to the city's economy. Foreign direct investment has been a key driver of economic growth in London, generating 42% of the city's economic growth between 1998 and 2004, as well as 29% of its increase in earnings and the majority of its new jobs. Overall, foreign direct investment has generated more than 500,000 jobs, or 13% of all employment, in the city.

It is likely that this project could attract higher-than-average levels of such investment. Indeed, decisions on foreign direct investment are made on a range of factors, including the size of the economy, the strength of the business environment, the availability of skills, and, importantly, the quality of infrastructure. With new facilities in VNEB, the area could score well.

For the central scenario, the average figure of 13% is used as an appropriate estimate for the proportion of net additional jobs in the VNEB OA due to the NLE. However, given that such estimates are uncertain, the central scenario is tested against a range of 0% to 20% of net additional jobs. Sensitivity tests have therefore been undertaken at higher and lower levels than the 13% average and are presented later in this chapter.

This means that the Without-NLE Reference Case has a level of jobs consistent with the London Plan forecasts (for each of 2021 and 2031), while the With-NLE Do Something scenario will exceed this level (by only 0.03% of overall jobs in 2031). Population is constrained to London Plan levels in all scenarios.

The VNEB planning assumptions assume a higher level of jobs and population in the VNEB area with the NLE. For the purposes of the economic and transport modelling, these jobs (all but the 13% assumed to be 'net additional') and people need to be redistributed or 'balanced' from elsewhere. The central scenario reflects the most likely and realistic scenarios in terms of the economic impact of the scheme – namely, that the NLE will support the overall expansion of activity in the CAZ. The modelling assumption is therefore that the additional VNEB jobs and population would be balanced from Outer London.

This has implications for the productivity assumptions that are used in the estimation of the WEIs for both the moves to more productive jobs and pure agglomeration.

A key issue is whether to apply current productivity levels (across all Wandsworth) rather than the future levels in VNEB (which will reflect productivity levels elsewhere in the CAZ). The mix of employment activity within VNEB does not reflect the type of businesses that are likely to be located within the OA following

development – particularly if this is enhanced by the transport infrastructure that will be brought about by the NLE.

Accordingly, an adjustment has been made to the Productivity Index for Wandsworth and Lambeth based on the economic data provided by the Department for Transport to include an Inner London analysis. Within the modelling, therefore, it is assumed that future VNEB jobs have a productivity index equivalent to the Inner London average. It should be noted that this index is lower than the CAZ average, and therefore represents what was considered to be a prudent basis for estimating the economic benefits. For the pure agglomeration analysis, an Inner London weighted analysis is also used.

4.3.8.3   User benefits

For the NLE, strategic modelling has been undertaken using the London Transportation Studies model. This model is underpinned by the representation of the demand-side (population, employment, floor space) and supply side (representation of public transport and highway networks).

The planning inputs for the two forecast years (2020 and 2031) are based on Greater London Authority population and employment forecasts. The forecasts are based on two forecast years, 2020 and 2031. The 2020 forecast shows demand and benefits shortly after opening, and the 2031 forecast represents the 'end-state' level of development in the Opportunity Area Planning Framework area. The planning inputs have been refined at a detailed level to better reflect the VNEB area assumptions described above, and to reflect the 'balancing' assumptions that underpin the With-NLE Do Something economic scenario.

London Transportation Studies adopts the traditional 4-stage modelling approach process comprising trip generation, distribution, mode choice and assignment. The key output of London Transportation Studies is demand matrices that provide the demand inputs into Transport for London's established public transport model (Railplan), and the Central London Highway Assignment Model. These models are used to estimate the public transport benefits and impacts of the NLE.

Both the public transport and highway models include funded and committed schemes for each future year. These include schemes such as Crossrail, London Underground upgrades and train lengthening. Specifically, the Northern Line Upgrade 2 (NLU2) is assumed to be in place from 2022, so is represented in the 2031 future year. The 2020 forecast year assumes that only NLU1 is completed.

Figure 4.9 and Figure 4.10 show the journey time and accessibility improvements due to the NLE, respectively.

Figure 4.9 **Forecast change in public transport generalised journey time from Battersea resulting from the NLE, 2031**
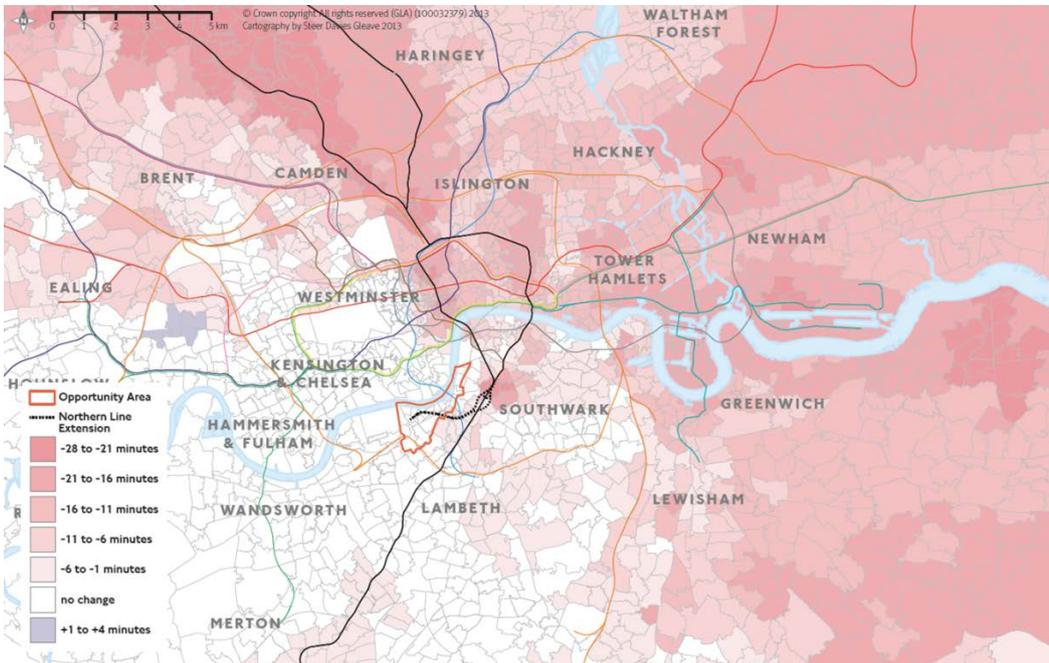
Source: Steer Davies Gleave & Volterra (2013, p. 27)

Figure 4.10 **Change in Public Transport Accessibility Level with the NLE, 2031**

Source: Steer Davies Gleave & Volterra (2013, p. 27)

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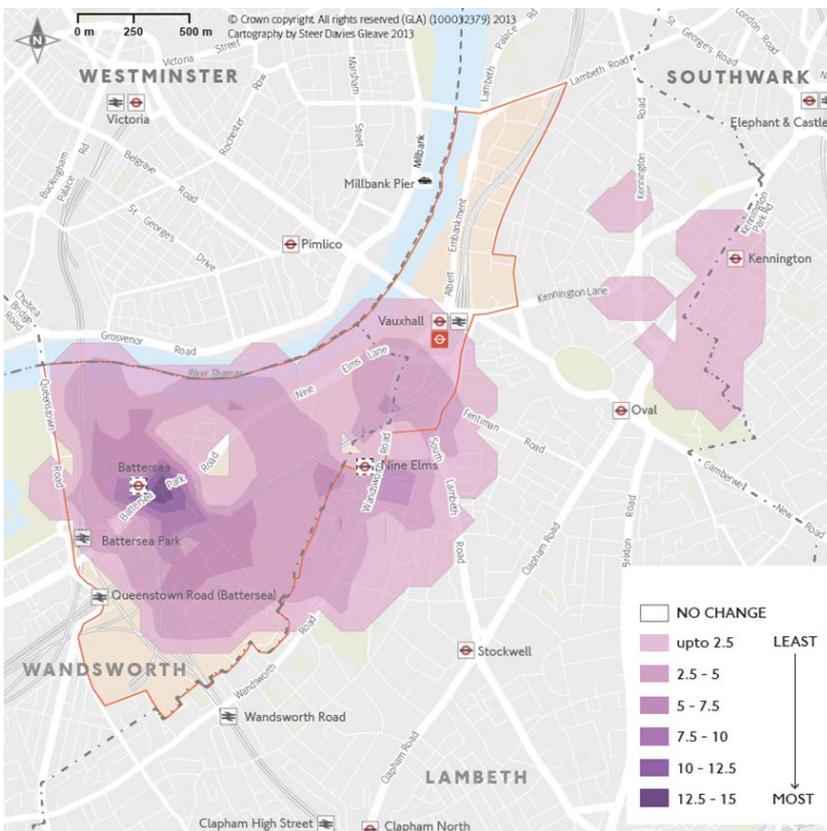
The following types of user benefits have been quantified.

- **Time saving benefits** to users on NLE who gain from reduced journey times and enhanced accessibility (as per Figure 4.9 and Figure 4.10).

- Impacts upon the wider public transport network in the form of **crowding**. The NLE will relieve crowding on key crowded sections of the network (eg, the Victoria line between Vauxhall and Victoria). The additional demand attracted to the NLE will also result in increases in crowding on some sections, such as the Northern Line Bank Branch. The overall increase in public transport demand on the network, resulting from the development additionality, also results in minor crowding impacts (imperceptible for an individual passenger) across the wider network. These small impacts, however, apply to a large number of people, and this 'disbenefit' has been valued in the economic appraisal. Essentially, the imposition of crowding disbenefits from additional public transport users is essentially the 'cost' of enabling the additional VNEB jobs to take place.

- **Additional revenues to Transport for London** from additional public transport trips on the network. The NLE attracts additional public transport trips, and the balancing of activity from Outer London (with a lower public transport mode share) to VNEB (with a higher mode share, reflecting its more central location) also increases the total number of public transport trips.

- **Time savings to highway users**. The redistribution of activity from Outer London results in a reduction in highway demand that, in turn, leads to decongestion benefits for remaining users across the wider network. The accident and emissions benefits resulting from the reduction in overall highway kilometres on the network have also been valued.

Table 4.5 quantifies the benefits described above, as well as the benefits from reduced accidents, greenhouse gas emissions, and improved air quality.

Table 4.5   Transportation benefits

Impact	Value (£millions, 60-year present value)
Transport for London revenues	400
Public transport benefits (time savings and crowding)	300
Highway benefits	40
Accidents, greenhouse gas emissions and air quality	10

Source: Steer Davies Gleave & Volterra (2013, p. 31)

4.3.8.4   Labour market impacts

The main quantified labour market impact is the move to more productive jobs facilitated by the additional density due to the NLE. Other labour market impacts that have not been quantified could include reduction in local unemployment or increase in the labour supply.

Moves to more productive jobs measures the productivity benefits of existing workers being able to move into more productive forms of employment as a result of a transport investment. In the case of the NLE, the benefits arise from the 13% additional jobs (of the total additional employment in VNEB with the NLE), and the fact that the productivity of jobs in VNEB is higher than if they were to be located outside the CAZ. In order to estimate any benefits that result from existing workers moving into more productive forms of employment, it measures where workers would be located and how productive they would be both with and without the transport investment.

This analysis crucially assumes that the workers relocate from a job where they were less productive to a job where they are more productive. This means that this values the net increase in productivity of a worker and does not allow for any of the jobs to be completely new, or gross. In essence, moves to more productive jobs is a large improvement in productivity applied to a relatively small number of workers.

The total benefits from moves to more productive jobs was estimated to be £3.6 billion in present value terms, over the 60-year appraisal period. This is shown in Table 4.6 below.

Impacts on local employment (unemployment and labour force participation) could result from the NLE but may be difficult to predict with certainty or to quantify. Instead of trying to quantify this and include it in the top-level estimate of benefits, an alternative approach was taken to discuss the potential for this type of impact qualitatively.

In this case some contextual evidence may be useful to show why these impacts may be expected. The evidence for the impacts on local employment comes from the Proof of Evidence provided by Bridget Rosewell (2013) for Transport for London, which states that:

- of the total jobs created in the VNEB area, around 5,300 are likely to be entry level or lower skilled
- the 2011 Census recorded 4,500 people as economically active and unemployed in the wards surrounding the VNEB area
- 18,800 people of working age are inactive in these wards
- the largest component of the additional employment generated by the NLE is that at the Battersea Power Station building site, where the widest range of opportunities, including commercial and retail roles, will be focused (these are included in the numbers above). These will be easily accessible to local residents in both boroughs served by the NLE, from around Kennington as well as Nine Elms.

While it is not possible to state with certainty that the additional employment opportunities due to the NLE will result in better local labour market outcomes, it is a plausible assertion and could be included in the overall case.

4.3.8.5   Agglomeration economies

The processes that underpin agglomeration economies have been discussed in sections 2 and 3. As a result of the NLE, productivity improvements could be expected across the CAZ and surrounding areas.

First, the reduction in transport costs helps bring firms closer, reducing effective density. Second, the additional development enabled by the NLE increases actual job density in the CAZ.

The quantitative analysis of the agglomeration benefits was done following the transport analysis guidance approach, with modified GVA per worker for the VNEB OA to reflect that it is likely to attract higher value employment. We discuss the quantification of agglomeration impacts in more detail in sections 2 and 3. The practical element here involved adjusting the quantity of employment in different regions and the GDP per worker in those regions (based on the economic scenarios). The productivity formula then gives the difference in output between the two scenarios.[15]

The total benefits from agglomeration was estimated to be £800 million in present value terms, over the 60-year appraisal period. This is shown in Table 4.6 below.

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[15] See Equation 2.3 in Department for Transport (2016b).

Table 4.6   Wider economic impacts

Impact	Value (£millions, 60-year present value)
Pure agglomeration	800
Move to more productive jobs	3,600
Total	**4,400**

Source: Steer Davies Gleave & Volterra (2013, p. 30)

4.3.9   Conclusion

The analysis of economic benefits for the NLE involved an assessment of the potential for dynamic clustering to occur at the site. Using data from the planning framework and a transport assessment of the site and NLE project, it was possible to show how a significant quantum of development was dependent on the NLE project. Not only that, but the development involved additional jobs through foreign direct investment, and these jobs are likely to be high productivity jobs that exist in part due to their location in London's CAZ. The result is a high level of employment and agglomeration benefits, which justify the cost of the project.

4.3.9.1   Key assumptions

The key assumptions that underpin the analysis are worth repeating here. They give a sense for the kind of assumptions that may be required when analysing dynamic clustering of similar projects. They include the following.

- The productivity of jobs in the VNEB OA would be on par with the average of Inner London (rather than the boroughs of Wandsworth and Lambeth in which the OA sits).

- The jobs are likely to abstract away from lower productivity jobs. The productivity of the abstracted jobs would be on par with the average of Outer London. This is justified because the overall population growth of London is assumed to be constant, and the jobs growth is also fixed (other than the foreign direct investment discussed in next bullet point).

- Some jobs in the VNEB OA are 'net additional' – that is, they only exist due to foreign direct investment in the OA and would not occur elsewhere in the UK without the NLE. The proportion of such jobs is assumed to reflect the total London average for jobs created due to foreign direct investment, which is around 13%.

- The other key elements of analysis, such as the dependency of the development, the time savings and agglomeration impacts, all stem from analysis of planning documents and transport models. Those are generally viewed as robust evidence. The robustness of the analysis therefore turns mostly on the above assumptions.

4.3.9.2   Lessons learned

The NLE project is expected to open later in 2021 and the Battersea Power Station development is expected to open in 2022. It may be too soon to fully speak to whether the predicted benefits will materialise. A complete *ex-post* analysis of the jobs and homes provided and the ridership of the NLE would be a good test of the predicted benefits.

Some lessons that we have learned through this process that may be relevant for other similar projects include the following.

- Political alignment is important for major projects that involve multiple levels of government. This project involved two different London boroughs and the mayor of London and was influenced by central government. The long timescales involved spanned across different governments. A consistent political effort was required to begin and see through this project.

- There are benefits that can be unlocked through the coordination of land use and transport planning. In many places the management and regulation of land use and transport fall under different branches or levels of government. This project illustrates that coordination between those responsible for transport, land use, and private sector developers was essential to its eventual delivery. While the conditions of this scheme were unique, the general lesson that coordination has the potential to generate benefits is worth repeating.

- While the success of the development remains to be seen, the NLE has been built and the Battersea Power Station has been refurbished. Moreover, at present the funding and financing arrangements have worked with funding at around expected levels – at least prior to the impact of COVID-19.

- It may be worth analysing this project in some detail in the future – near-derelict land so close to the CAZ is rare, and in most other cases it tends to be difficult to get anything like 100% of the costs from development. There has also been a clear effect on the development of the wider area. It could be particularly useful to analyse whether and the extent to which the NLE truly generates additional economic activity rather than simply displacing it from other parts of London. This might be done in a way similar to the analysis by Pogonyi et al. (2021), who explored these issues for the Jubilee Line Extension and found that the impact was primarily to displace economic activity.

5 Conclusions and recommendations

In this section we briefly summarise the findings of the report and make some recommendations for further study and the application of this framework by Waka Kotahi.

5.1 The nature of our task

Our fundamental research question was how to analyse and quantify one of the most contentious areas in transport project appraisal today – dynamic clustering brought about by transport investment. This area of research is important because transport projects are increasingly seen as a way to transform places, rather than solely to improve or increase transport links.

At a high level, our task was to develop a framework for assessing:

- whether, the extent to which, and how transport interventions will trigger dynamic clustering

- how to analyse this in a way that allows us to assess the economic impact of dynamic clustering (ie, on welfare and potentially also on GDP) – in other words, what is the value to society of the dynamic clustering, and to what extent is it additional to other impacts caused by the transport intervention?

We broke this fundamental research question down into smaller constituent questions. In order to evaluate dynamic clustering in transport appraisal, the questions we really want to answer are:

1. What do we mean by terms such as agglomeration, dynamic clustering, and land-use change?

2. At a high level, how, when, and under what conditions do agglomeration externalities (positive and negative) occur?

3. What more fundamental micro-economic processes occur in the lead-up to (and after) the agglomeration externalities themselves (eg, location decisions), and what feedback loops exist within and between these processes?

4. How and to what extent do transport policies or investments affect the micro-economic processes from (3) and therefore agglomeration externalities?

5. How can different models or analytical tools be used to trace the cause and effect from transport intervention (4) to micro-processes (3) to agglomeration externalities (2)? These tools may be step-wise – that is, only effective at modelling the link between (4) and (3) or only (3) and (2).

6. Which approaches should be incorporated into guidance for transport CBA practitioners?

7. What would the recommended approach look like as shown in a case study?

8. What areas might be productively analysed through future research, given the very considerable conceptual and empirical challenges in the area?

We have done this by:

- carrying out a literature review

- developing a methodology report where we developed and explained a number of analytical tools

- applying the methodology in practice through two case studies.

5.2　Recommendations

The key points of conclusion for practitioners are as follows.

First, the key question of whether dynamic clustering will occur as a result of a transport project and how to incorporate this into appraisals is an important one, given how transport projects are increasingly seen as ways to transform places rather than just reducing the time it takes to travel between places. It is, however, also a complex and challenging area.

Second, practitioners should be guided by literature, which is extensive and evolving. Key points to note include the need to understand the different reasons why businesses and individuals might relocate as a result of changes in connectivity, and the different reasons why agglomeration benefits are likely to materialise and over what timeframes.

Third, there is no 'one size fits all' approach to assessing dynamic clustering impacts. A great deal depends on the specific context. Practitioners would be well advised to inform their appraisals using a well-developed economic narrative that sets out what economic impacts are expected from the project and why, which could be usefully informed by the tools we have developed, particularly:

- **logic maps**, which set out the impacts that the transport project is expected to have, given the various contexts and market failures that are specifically relevant to the project that is being appraised

- **appraisal summary tables**, which summarise the various impacts that could be expected to materialise as a result of the project, depending on whether the analysis is static or dynamic in nature

- **the methodology funnel**, which helps to assess which specific types of analytical approach are likely to be most relevant and appropriate for any given project

- **a checklist** of the types of reasons why dynamic clustering might generate impacts that are truly additional rather than displacement

- **a brief summary** of the likely magnitudes of different impacts, although it is vital to recognise that this is intended to serve as a very high-level guide – the magnitudes of any impacts caused by transport projects vary considerably, particularly when we consider the way in which they can transform places

- some **model selection criteria**, including:
  – the use of rigorous and context-specific narratives and evidence
  – ensuring that analysis is as soundly based on economics as possible
  – validation of results – for example, by showing the extent to which the model or quantitative technique is able to forecast impacts that have actually materialised in the past
  – the use of uncertainty quantification to avoid the considerable risk of spurious accuracy – uncertainty can arise for numerous reasons, including:
    ▪ the quality of the data used
    ▪ the economic principles and parameters that are applied
    ▪ the inherent challenges in forecasting complex systems over long periods of time
  – the use of a 'trust-test' – in view and experience, it important to be able to explain to a non-expert:
    ▪ the approach that has been used
    ▪ why this approach is the best approach to use given the specific context
    ▪ the results that have been generated
    ▪ why these results are likely to transpire.

Fourth, and building on the model selection criteria above, it is crucial to recognise that it is very challenging to quantify many of the impacts of dynamic clustering in a robust manner – whether individually or together. In our view, it is critically important that analysis is carried out – rather than simply sticking to static analysis – to ensure that sound decisions are made on specific projects and also to advance the frontier of best practice in the area. But it is equally vital that analysis is carried out robustly with the strengths and potential shortcomings of such analysis being clearly articulated and recognised. This can help to ensure that the area advances in a way that people are able to understand and trust, instead of the opposite, with practitioners advancing appraisals with implausibly high results based on analysis or techniques that are less than transparent and/or found to be less than sound when exposed to scrutiny.

Fifth, there is a great deal more work that could and should be done in the area, which we summarise below.

5.3   Areas for further study

We highlight some areas that could warrant further study below. These are areas that define the frontier of best practice and are things that could usefully be addressed by future research.

1. Our framework could be applied on a 'live' project. This could be done at a high level and semi-illustrative basis or on a much more detailed and quantitative basis.

2. The use of S-CGE models could be developed by, for example, using simple or 'stripped-down' versions alongside fuller models – in order to help users to test and explain their results. It could also be useful to ensure these models better analyse and capture location choice by individuals and businesses, and more granular analysis of land use.

3. Refinements could be made to existing approaches to LUTI modelling – in particular, to increase their transparency and the extent to which they are founded on sound economics and context-specific narratives and evidence.

4. The induced demand approach to benefits estimation could be further developed and evaluated alongside a robust WEI framework approach.

5. A deeper understanding of the labour market is needed. The main areas here include a more thorough understanding of:

    a. situations where increased labour supply generates truly additional welfare (rather than assuming that the only increase in welfare is generated through a tax wedge)

    b. the elasticity of labour supply, which affects the above point as well as how the benefits of transport projects might ultimately flow through to labour rather than the labour market

    c. the impact of employment on wellbeing and life opportunities (over and above wages paid)

    d. the value of leisure time or other time not in employment that may be valuable (eg, cleaning, caring, teaching, volunteering).

6. A fuller understanding of the magnitude of the relevant elasticities of land supply would be useful. This parameter was identified as a key determinant of land and property prices, and the extent to which dynamic clustering occurs depends on whether more intensive land use is possible.

7. Further research could be carried out into locational choice models. Further understanding of how location choices are made by both firms and individuals/households would improve how these decisions are analysed in LUTI or S-CGE models or in ad-hoc analysis.

8. There could be further analysis of consumption amenity benefits, which may provide welfare benefits that are additional to the welfare benefits generated from production externalities (which are generally the focus of this report and framework).

5.4   In conclusion

We hope that our work will help to ensure that the correct investment decisions are made and that we have helped to lay the foundations for continued advances to be made in this important area.

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Appendix A: Complete literature review

A.1 Definitions

In this section we develop our definitions, making references to the literature where relevant.

A.1.1 Dynamic clustering

The terms 'agglomeration' and 'clustering' are often used interchangeably. However, we prefer to draw a distinction between them. In this report we refer to dynamic clustering as relating to density of activity, in contrast to agglomeration economies, which we define as the economic effects of density.

Dynamic clustering involves firms or households locating themselves in space – usually near each other (hence 'cluster'). Dynamic clustering is therefore related to a change of density or concentration, rather than a level. 'Static clustering' could be used to refer to the level of density, but in most cases we simply refer to this as 'density' or 'concentration'. In other words, dynamic clustering is the change in density over time, or the process by which changes occur.

This definition of clustering as relating to density is consistent with some of the literature. For example, Laird and Venables (2017, p. 3) refer to 'economic density – the clustering of activity in towns and cities', and Duranton and Puga (2004, p. 2065) refer to 'the extent to which people cluster together in cities and towns'.

A.1.2 Agglomeration economies

We will use the term 'agglomeration economies' to refer to the (external) benefits or costs of density. The most prominent of these is the productivity benefit that firms experience when they are located in more spatially concentrated places.

In transport appraisal, the terms 'agglomeration economies' or 'agglomeration benefits' are often used to describe the productivity benefits that arise from the physical proximity and connectivity of increased density (or 'economic mass'). However, increased density can also result in costs, such as the costs associated with increased urban congestion. As such, it can make sense to separately distinguish between agglomeration benefits and costs, or to refer to 'agglomeration effects' or 'agglomeration externalities', where both positive and negative externalities exist. The literature uses these various descriptive terms (economies/benefits, and separately effects/externalities) interchangeably. We use the term 'agglomeration economies' for consistency. The question of how clustering can generate positive and negative impacts is covered well by Duranton (2011) through a graph that shows how the gains to agglomeration start to diminish with increasing costs.

Note that the term agglomeration is sometimes used to refer to the relationship between density and productivity. We do not find this useful, not least because it makes phrases like 'a change in agglomeration' highly ambiguous and potentially meaning a change in concentration, a change in productivity, or a change in the relationship between productivity and concentration. Instead, we therefore use terms like 'agglomeration elasticity' or 'agglomeration relationship' to refer to the relationship between density and productivity.

A.1.3 Static vs dynamic agglomeration economies

There appears to be something of a split in the literature between the appraisal guidance literature and academic literature on the topic of dynamic vs static agglomeration. Much of the appraisal literature (eg, guidance documents in the UK and New Zealand) treats 'static agglomeration' and 'dynamic agglomeration'

as synonyms for appraisal under conditions of static or dynamic land use. Academic literature (such as Combes & Gobillon, 2015) use static and dynamic agglomeration to refer to agglomeration processes that are relatively instantaneous (static) or take time to occur (dynamic). This can get confusing because there are little or no empirical models that actually measure the different static and dynamic effects. We have chosen to use the academic definition because it better reflects the real-world processes that occur and are being described. It is also worth noting that the terms 'static agglomeration' and 'dynamic agglomeration' used in appraisal guidance are somewhat loose because the agglomeration elasticities used reflect a combination of both static and dynamic processes.

The appraisal of agglomeration economies under assumptions of static and dynamic land use yields different results. This is because dynamic clustering affects agglomeration economies. The UK Department for Transport's transport analysis guidance and the Waka Kotahi (2020) *Monetised Benefits and Costs Manual* use the term 'static agglomeration' to refer to appraisal of agglomeration economies with land use remaining static. The *Monetised Benefits and Costs Manual* refers to this definition of static agglomeration occurring when 'transport investment alters the effective density by allowing individuals and firms to move around the location more easily, lowering transaction costs, thereby facilitating interactions. This does not change land-use patterns' (p. 74). In this formulation, the jump to dynamic agglomeration occurs when the strong assumption of fixed location is relaxed. Instead of referring to this as 'static agglomeration' and 'dynamic agglomeration', we refer to 'static land use' or 'dynamic land use', both terms that reflect a model-based simplification of reality.

The use of the term 'static/dynamic agglomeration economies' that we argue is more consistent refers to the time dimension instead of land use. Camagni et al. (2017, p. 134) compared static and dynamic agglomeration economies by discussing the former as 'the absence of a time dimension', while the latter involves 'a comparison among cities in terms of time performance'. Combes and Gobillon (2015) developed a model that accounts for agglomeration impacts that may occur instantaneously (static) or that take time to occur (dynamic) – another way they put it is that dynamic agglomeration economies are influenced by mechanisms from previous periods/years, while static agglomeration economies involve a one-time 'boost'. Tveter and Laird (2018, p. 5) refer to dynamic agglomeration economies as 'the manner that agglomerations may change productivity over time', whereas static agglomeration economies are fixed (in time). These authors note that, because of real-world frictions (eg, search and transaction costs) dynamic agglomeration economies will not occur instantaneously. Drawing on empirical studies (while acknowledging a relatively small evidence base), Tveter and Laird show that most agglomeration economies take 10–20 years to fully materialise in the economy.

We note that Tveter and Laird (2018, p. 4) also state that static and dynamic agglomeration economies 'should not be confused with the transport economic terms of static and dynamic clustering, which relate to changes in land use – though of course there is an inter-relationship'. Our interpretation is that Tveter and Laird therefore apply 'dynamic agglomeration' to mean agglomeration economies with a time dimension, and 'dynamic clustering' to mean density/concentration with a time dimension.

A.1.4　Land use

We define land use as the intensity and type (ie, sector mix) of activities that occur in an area (eg, a change in the number of residents, businesses or employees constitutes a change in land use). Most changes in the deployment of capital, labour or other resources are therefore a change in land use. This is in accordance with most guidance. The *Monetised Benefits and Costs Manual* states that land-use change is 'affecting the scale, sector mix and the density of a location by inducing a change in the level and/or location of economic activity' (Waka Kotahi, 2020, p. 74). TAG unit 2.1 defines changes to land use as 'changes in the purpose or intensity of usage' (Department for Transport, 2016a, p. 5).

Land use is sometimes used to refer to the type of activity that is permitted to occur in a given area. To avoid confusion, we will refer to this as 'land-use regulation' or 'zoning'.

A.1.5   Market failure

Properly functioning markets lead to an optimal allocation of resources, in that the net benefits to society are maximised. In practice, however, various factors undermine this and lead to an inefficient allocation of resources. These factors are 'market failures'. There are several different causes of market failure, including imperfect competition, externalities, asymmetric/imperfect information, and irrational behaviour.

In its discussion of wider economic benefits, the *Monetised Benefits and Costs Manual* says a market failure occurs when 'interactions between different economic agents that are not fully internalised' occur (Waka Kotahi, 2020, p. 75). When agglomeration economies occur, we are often dealing with mechanisms that do not operate via markets (eg, knowledge spillovers, or public goods) or situations where social benefits/costs of an action are different from private benefits/costs (eg, location decisions or network congestion). In these circumstances a market failure is occurring because, as an example, the socially optimal level of concentration of firms may be higher than what the market would provide, due to external benefits of agglomeration economies not being internalised by firms, or coordination problems to deliver the infrastructure required to achieve that density.

Dealing with land use also involves market failures specific to that market. Cheshire (2009, p. 3) explains how externalities specific to characteristics of land lead to market failures:

> *Left unregulated, land markets in general, and urban land markets in particular, suffer from endemic problems of 'market failure'. These problems arise in part because of the locational specificity of any legally defined plot of land, and the fact that the value that can be generated from that land and the welfare or enjoyment associated with its occupation are strongly influenced by the uses and characteristics of neighbouring plots of land. There are important and systematic externalities associated with land use, especially in the more densely developed context of cities.*

Land-use regulations evolved over time to limit negative externalities and provide benefits, but they also impose costs due to restricting supply (Cheshire, 2009). We discuss in more detail how land-use regulation impacts land supply in later sections.

A.1.6   Additionality

Additionality is a concept in CBA related to whether a benefit is truly additional to the economy, rather than displaced from elsewhere or double counting of another benefit (whether one that has been monetised, or one that has been considered qualitatively but still factored into the analysis).

As a general but fundamental point, when appraising multiple wider economic impacts, whether static or dynamic, it is important to ensure that there is no additionality between the different elements. For example, the extent to which dynamic clustering or agglomeration economies are truly additional to travel time savings is discussed in the literature. If we take agglomeration economies as productivity impacts, then Venables (2007) shows a theoretical modelled example of why agglomeration economies are additional to travel time savings. Graham and Gibbons (2019) elaborate on this to explain that in the UK context user benefits are calculated using the pre-intervention and spatially constant value of time, which ensures that the wage/productivity impact of concentration is additional. An approach that uses variable values of travel time, which increase when wages increase (as a result of agglomeration economies) could, in theory, capture agglomeration economies, but we are not aware of any user benefit models that do this. Graham and

Gibbons (2019) do note that there are gaps in our knowledge and recognise that there may be ways that agglomeration economies flow through to user benefits.

Another related debate is the issue of displacement. If activity occurs in a certain location due to a transport intervention, does this represent economic growth or just re-organisation of activity? Redding and Turner (2015) conducted an extensive review on the growth vs re-organisation debate and concluded that context matters. In non-urban settings, new highways tended to result in re-organisation of activity, while in cities the new economic activity could be approximately equally split between growth and re-organisation. This urban growth factor is likely due to agglomeration economies.

Kline and Moretti (2014) also deal with the question of additionality resulting from a large infrastructure programme, the Tennessee Valley Authority. Their unique study design shows that even after the subsidies from the programme ended, there was a structural economic change that grew the economy due to agglomeration economies. They state that such projects have the potential to be welfare enhancing but note that under assumption of constant elasticities of agglomeration, moving a job from one place to another may not change welfare due to the potential negative amenity effects. We are not sure if this finding is generalisable or specific to their model.

We also highlight three other points in relation to additionality:

1. **Dynamic clustering brought about by relocation**
   If a transport intervention causes dynamic clustering in an area, this will increase the density of this area. It is, however, also likely to reduce density in another area. If agglomeration elasticities are considered to be constant, this means that most such impacts will net-out. If, however, agglomeration elasticities increase with the level of concentration in an area (which might well be the case in service sectors), or if clustering causes people and businesses to switch between sectors with different agglomeration elasticities, then there is more scope for genuinely additional impacts.

2. **Whether land value uplift is additional to changes in travel time savings**
   The *Monetised Benefits and Costs Manual* (Waka Kotahi, 2020) considers land value impacts to be not additional, but rather a capitalisation of travel time savings, which the literature supports. However, productivity increases due to agglomeration economies may also flow into land values, which could further limit the extent to which land value uplift can be treated as being additional to impacts more generally analysed in appraisals. Indeed, land value uplifts might be better viewed as a different but complementary way of estimating the size of these same impacts.

3. **Use of a social welfare function**
   This could be particularly important given the focus placed by some policymakers on the re-distributional impacts of policies. If society places a greater weight on the additional wealth or utility accruing to certain individuals or groups, then a transport intervention that simply displaces economic activity from one area or sector to another can have an impact that has additional value. The economic rationale for this is that there is likely to be diminishing marginal utility of income as individuals increase their wealth (ie, a wealthy individual may value an additional £1 earned/saved less than individuals in lower-income brackets). In short, a transport intervention that simply 'displaces' one unit of economic activity from a wealthy area to a poor area could result in a net positive impact on welfare.

A.1.7 Partial vs general equilibrium

Transport appraisal can sometimes be based on the assumption that prices and demand in non-transport markets are held constant. Any changes to the price or demand of transport are reflected in the market for transport, but not in any other markets. If there are any such changes, then these will simply reflect and be equal to impacts in the primary (transport) market. In economics this is defined as a partial equilibrium

framework. When the only market being analysed is the transport market, then this simplifying assumption may be helpful and consistent with economic theory.

Indeed, economic theory has shown that when markets are perfectly competitive and prices in secondary (in this case, non-transport) markets do not change as a result of interventions in the primary (in this case, transport) market, then an assessment of the benefits and costs in solely the primary market will capture all of the relevant social benefits and costs – see, for example, Boardman et al. (2017) and Just et al. (1982).

However, when we begin to analyse agglomeration economies or dynamic clustering impacts, there is an inconsistency with the partial equilibrium framework. Introducing changes to productivity, levels of competition, employment levels etc involves recognising that (a) other markets are not working perfectly (ie, there is some market failure), and (b) that prices and demand/supply in other markets may change as a result of changes in the transport market (and in a way that does not simply reflect and is equal to the change in the transport market).

This is where a general equilibrium approach, which allows for changes to prices in other markets, can become relevant. General equilibrium models 'simulate the function of entire economies with micro-economic behavioural functions. These represent the actions of households, firms and others, solved simultaneously to trace non-linear relationships throughout an economy' (Robson & Dixit, 2017, p. 990).

While most CBAs are carried out within a partial equilibrium framework, there is an increasing amount of use of general equilibrium approaches – particularly for interventions that could have transformational impacts (such as dynamic clustering). This is recognised in the UK, where we are aware of a number of appraisals having been carried out using various forms of general equilibrium approach.

A.2 Mechanisms

There are many different mechanisms at work with agglomeration economies. We divide mechanisms into:

- agglomeration mechanisms
- endogenous micro-economic mechanisms that generate or reinforce agglomeration economies
- exogenous micro-economic mechanisms.

A.2.1 Agglomeration mechanisms

At the outset we note that there is strong empirical evidence for the existence of agglomeration economies. Agglomeration elasticities are a metric used to indicate the percentage increase in productivity that results from a percentage increase in effective density. A review of this literature finds a consistent positive relationship, though the magnitudes vary. Graham and Gibbons (2019) conducted a survey of 47 empirical studies and found a range of elasticities from −0.800 to 0.658 with an average value of 0.046 and median equal to 0.043. In New Zealand, elasticities of agglomeration have been estimated by industry (Maré & Graham, 2009), and they range from around 0.03 to 0.09, which is slightly different but the same order of magnitude as those used in the UK Department for Transport's transport analysis guidance. The latest guidance from Waka Kotahi (2018) suggests using elasticities developed in Maré and Graham (2009). Most empirically defined elasticities are agnostic to the mechanisms of agglomeration – it is difficult to disentangle multiple mechanisms, some of which will occur simultaneously.

In this section we explore the mechanisms that explain how greater concentration results in higher levels of productivity. We investigate both theoretical models and empirical evidence for specific agglomeration economic processes.

A.2.1.1   Positive externality mechanisms

Duranton and Puga (2004) develop three mechanisms that drive agglomeration economies: sharing, matching and learning. They derive these using theoretical models. We also look at empirical evidence for the mechanisms that has been compiled in Rosenthal and Strange (2004).

A.2.1.2   Sharing

Sharing involves 'sharing indivisible facilities, sharing the gains from the wider variety of input suppliers that can be sustained by a larger final-goods industry, sharing the gains from the narrower specialisation that can be sustained with larger production, and sharing risks' (Duranton & Puga, 2004, p. 2066).

Indivisibility of some amenity, production facility or marketplace implies increasing returns, which helps to explain concentration in a homogenous area. This is because larger indivisible facilities may be built where firms locate together that would otherwise not be economic if the firms were located too far apart to share it. *Sharing gains from variety* features in a theoretical model developed by Duranton and Puga, and they show this results in urban specialisation, which also results in gains from narrower specialisation. Lastly, the *sharing of risks* in Duranton and Puga's formulation has mostly to do with the benefits of thicker labour markets to both firms and workers. Where firms and workers in the same specialisation agglomerate, there are efficiency gains to firms because they do not know *ex ante* how much labour input they will need. On the worker side, concentration reduces the risk of unemployment because with more firms there will be higher variance in wages, which provides more options to workers and reduces the risk of receiving zero income.

Empirical evidence for the sharing of indivisible facilities comes from Holmes (1999). Using US data, Holmes (1999) shows that highly concentrated industries have higher input purchase intensity, which is what would be expected if spatial concentration allows for more input sharing.

A.2.1.3   Matching

Matching involves 'mechanisms by which agglomeration improves either the expected quality of matches or the probability of matching, and alleviates hold-up problems' (Duranton & Puga, 2004, p. 2066).

Duranton and Puga create a labour market model where the skills mismatch is represented as the distance between workers and employers located on a circle. Competition between firms for workers can drive up wages and drives down equilibrium profits to zero. Firm entry and competition also provide aggregate increasing returns to scale because the number of firms increases proportionately less than the number of workers, so in the presence of fixed production costs, output per worker increases.

The fact that the more agents trying to find matches increases the expected quality of matches was first highlighted by Helsley and Strange (1990). The Duranton and Puga model shows that as the number of firms in the city increases, the expected skills *mis*match decreases (more firms on the circle reduces the average distance between workers and firms). The decrease in skills mismatch is not considered in firm entry decisions and is therefore an externality. The socially optimal number of firms would need to balance the better matching with the size of the fixed costs per firm. In the example given by Duranton and Puga (2004), the equilibrium actually has too many firms, indicating that the 'business stealing' externality overrides the 'matching' externality, but this is not necessarily the case.

Other formulations of the increase in expected quality of matches exist. For example, Venables (2011) developed a model based on matching of workers with a partner to produce. In this model, workers can be high-skilled or low-skilled, but both benefit from being matched with a high-skilled partner. The returns to working with a high-skilled partner are higher to high-skilled workers. The result of the model is that spatial sorting occurs, with high-skilled workers choosing to pay the extra cost of locating in the city (because they will earn more), and low-skilled workers preferring the lower-cost hinterland (because they benefit relatively

less than high-skilled workers from being in the city). In this model, if an individual is willing to bear the costs of living in the city, this acts as a signal that the individual is high-skilled.

In contrast to the previous mechanisms about the expected quality of matches, another reason for concentration is improving the *probability* of matching. Intuitively, this makes sense. Theoretically, it tends to be based on the literature where equilibrium unemployment is subject to job search frictions. When there are search frictions with fewer agents, those frictions are relatively more costly. With more agents the proportional cost of frictions is lessened. This results in aggregate returns to scale, even when individual production occurs under constant returns to scale.

Evidence for better matching could be that workers become increasingly specialised. In this regard, Baumgardner (1988) shows that physicians in larger markets perform a narrower range of activities.

A.2.1.4   Learning

Learning involves 'generation, the diffusion, and the accumulation of knowledge' (Duranton & Puga, 2004, p. 2067).

Jane Jacobs (1961) was one of the first academics to discuss the benefits of diverse urban environments and their relationship with innovation and experimentation. 'Jacobs agglomeration economies' (also called 'urbanisation agglomeration economies') are defined as the benefits from access to economic mass in general, referring to the diversity typically found in a large city. This is often contrasted with Alfred Marshall's (1919) 'Marshallian agglomeration economies' (also called 'localisation agglomeration economies'), which are based on locating near other firms of the same specialisation, which is what might be found in a factory town (or, indeed, districts in a city).

Duranton and Puga (2004) relate the mixing that occurs in diverse cities to knowledge generation. They propose a model where firms are trying to develop their own unique production process, which benefits from learning by being near other firms with different processes. They suggest that where specialised and diverse cities co-exist, it is because firms have invested time (and money) in the diverse city to learn and improve their production before relocating to a specialised city with lower congestion costs.

Regarding diffusion of skills, Duranton and Puga (2004) develop a two-period model where workers choose whether to locate in the city with other workers or alone in the hinterland. Being in the city involves additional costs but also the opportunity to learn from other skilled workers. The model theorises that all young workers will move to cities to learn skills, and skilled workers will remain in cities to transmit their skills.

Recent empirical work (De la Roca & Puga, 2017) has shown that learning in big cities may be a substantial boost to lifetime earnings for workers. They posit three hypotheses why wages are higher in big cities:

- spatial sorting of more productive workers
- static wage benefits related to location
- learning in bigger cities.

Somewhat controversially, they reject the first hypothesis based on their econometric findings using fixed effects, but confirm that there is a static wage premium and increasing productivity due to experience. Particularly interesting is that the additional value that workers develop in bigger cities persists even after workers move to other smaller cities. While they reject their hypothesis regarding the spatial sorting of productive workers, this seems to be inconsistent with theoretical work from, for example, Venables (2011).

Other evidence of knowledge 'spillovers' comes from patents citations, which are 5 to 10 times more likely to come from the same area (Jaffe et al., 1993).

A.2.1.5   Timing of agglomeration economies

When considering agglomeration mechanisms, it should become clear that most if not all of them would take time to occur. Particularly in the context of dynamic clustering brought about by a transport intervention, it will take time before a new equilibrium city/region size is reached. Even once the dynamic migration effects occur, productivity benefits will not be instantaneous due to real-world frictions – for example, search and transaction costs. Tveter and Laird (2018) suggest that matching and sharing impacts would be relatively short term but that the learning effects generated though agglomeration economies are longer-term. In their review of empirical evidence, they suggest that *ex-post* evaluation of transport projects finds that it takes several years for commuting and traffic adjustments to occur, if they occur at all. The authors suggest that agglomeration economies take 10–20 years to fully materialise. They acknowledge this is drawn from a small evidence base, and in general this is an area that warrants further study.

A.2.1.6   Crowding

Running counter to the forces of agglomeration economies described above are factors that reduce the productivity of firms and the attractiveness of locations to households. The trade-off between benefits and costs of density is well known, and this equilibrium is what determines city size – as Duranton and Puga (2004, p. 2075) state: 'The efficient size of a city is the result of a trade-off between urban agglomeration economies and urban crowding.' We refer to these offsetting forces as agglomeration dis-economies.

There are many potential negative externalities due to density, including congestion, environmental disbenefits, crime, risk of disease or infection, and amenity disbenefits, to name just a few. The majority of these fall beyond the scope of the study. We particularly mention congestion because this is an important element in direct user benefits of a transport intervention.

Congestion costs are an externality imposed by transport users on other users due to the higher marginal social cost of transport. According to a global mobility data platform, the average driver in Auckland spent 50 hours in congestion in 2019 (INRIX, 2019). The benefits of having traffic operate at free-flow speeds across Auckland have been estimated to be between $1.4 billion and $1.9 billion (New Zealand Institute of Economic Research [NZIER], 2017).[16]

Empirical evidence of the relative (or aggregate) costs and benefits of concentration seems to be less frequently studied than the positive impacts. Combes et al. (2019) conducted an analysis of the costs of concentration, measured in house prices and household expenditure, using a dataset of French cities. For urban areas with a population over 100,000, they found an elasticity of 0.03 – in other words, for a 10% increase in population, household expenditure would need to increase 0.3% to remain equally well off. For larger cities (such as Paris) they find a higher elasticity of around 0.08. These estimates are under the assumption of a constant spatial extent of the city – which is mostly consistent with land-use policies in France. Relaxing this assumption, the authors find that 'Allowing cities to increase their physical footprint as they grow in population reduces the magnitude of the elasticity of urban costs by a factor of about two' (Combes et al., 2019, p. 1557).

In terms of magnitude, it seems plausible that the elasticity of costs may be a similar order of magnitude as the elasticity of productivity impacts. Venables (2016) recognises this and suggests that if labour supply is

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[16] A 'back of the napkin' analysis of these two estimates shows they are roughly comparable. Assuming a (relatively high) value of travel time savings of $20/hr, and Auckland's population of 1.65 million, the INRIX estimate could be valued at around $1.65 billion (50 hours/person × 1.65 million people × $20/hr = $1.65 billion). Waka Kotahi recommends using generally lower values of travel time savings, ranging from $5.20 to $23.85 depending on trip purpose and time.

elastic, then all the productivity benefits actually flow to landowner. In a situation where labour supply is somewhat inelastic, then the productivity benefits are shared between workers and landowners.

A.2.2 Endogenous micro-economic mechanisms that generate or reinforce agglomeration economies

Endogenous mechanisms are those that are always occurring as part of the normal functioning of the economy of a place. These are processes that need to occur in order for dynamic clustering to occur, which is why we have set out to understand them each in more detail here. Each area explored here is relevant for later questions of how to predict or model dynamic clustering. In the next section of this report, we consider how different methods such as LUTI or S-CGE can capture the mechanisms explored here.

It is worth emphasising the ongoing nature of these mechanisms. These mechanisms are always occurring, and they are influenced by, and affect, the nature and level of concentration in a particular place. This bi-directional causality (being influenced by agglomeration economies and influencing agglomeration economies) results in the possibility of virtuous cycles of development (or doom loops of dereliction).[17]

A.2.2.1 Firm location decisions

Firms locating in a denser area is a key mechanism that reinforces agglomeration economies, the theoretical foundations of which we discussed in the previous section. If sharing, matching and learning are important for firm growth and success, and these features are dependent on spatial relationships (ie, it is easier to do these things when in closer proximity to other firms), then it should influence firm location decision. If firms prefer to locate in denser areas, that could mean they recognise and want to benefit from agglomeration economies. It also would mean there is a recursive or circular mechanism – as agglomeration economies increase, there is an increased tendency for firms to locate where these impacts are largest, causing larger agglomeration economies and so on. We are also interested in how firm creation or expansion is influenced by locational externalities. We find evidence that location matters for firm creation and investment, but note that the additionality of such increases in growth need to be tested carefully.

De Bok and van Oort (2011) tested the hypothesis that agglomeration economies are an important factor in firm location decisions. They tested several hypotheses using longitudinal firm data from South Holland, a populous province in the Netherlands, and found that the main driver of relocation is firm characteristics, such as age and size of the firm. Some sectors such as transportation and producer services have a higher probability of relocating. De Bok and van Oort found evidence that firms relocate to specialised locations, near other firms in the same sector, which could be interpreted as evidence of localisation (Marshallian) externalities. They did not find evidence that firms relocate to diverse locations, which would have been interpreted as evidence for urbanisation, or Jacobs, externalities. An interesting point though is that younger firms do prefer to move to diverse locations, which supports the theory of Duranton and Puga (2004) that learning externalities draw in younger firms before they move to specialised locations. De Bok and van Oort found some evidence that accessibility of locations matters to firms, but these results were not statistically significant and should be viewed with caution.

Ellison et al. (2010) explored firm location decisions specifically with regard to localisation (Marshallian) agglomeration economies. The authors used cross-sectional industry data from the United States to test three Marshallian reasons for clustering: reduced transport cost for goods, people, and/or ideas. They also

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[17] See, for example, Gunnar Mydal's theory of circular cumulative causation, which emphasises the role of self-reinforcing processes in regional development (Myrdal & Sitohang, 1957), or principles of homeostatic feedback loops from biology.

acknowledge that clustering may occur without these locational proximity advantages, and lump other locational advantages into 'natural advantages', which may include natural inputs such as coastal access or access to energy. The authors found that no Marshallian factor has a larger impact on clustering than natural advantages – that is, natural advantages were the most important single factor in this analysis. However, all the three tested Marshallian factors together were found to be more important than natural advantages in determining clustering. In comparing the individual factors, the authors caveat the results due to the imperfect identification mechanism. Despite caveats, they found that supplier input–output linkages were the most important factor (transport), followed by shared labour supply (people), followed by intellectual spillovers (ideas).

Other locational impacts on firm decision-making could flow through to firm creation or market entry. There is a strand of literature showing that regional economic conditions matter for firm formation (see, for example, Reynolds et al., 1994). Agglomeration economies have also been shown to be an important factor in firm creation. A study from the Netherlands (Bosma et al., 2008) found that urbanisation (Jacobs) agglomeration economies are particularly important for new subsidiaries, while localisation (Marshallian) agglomeration economies are more important for the creation of new ventures. Regarding market entry, studies of foreign direct investment (Devereux et al., 2007; Head et al., 1995) found that agglomeration economies are an important consideration for firms choosing plant location. Jofre-Monseny et al. (2011) looked at new firm location choice through the lens of localisation (Marshallian) agglomeration and found evidence that within-industry employment levels, worker similarity, and technology similarity all affect location choice.

With regard to the influence that dynamic clustering may have on firm creation, we note that the literature presents a case that agglomeration economies and firm creation are correlated and that agglomeration economies may be a determinant of firm creation. However, these effects are not necessarily additional. The investments may have occurred otherwise, in the same or a different location. Or to put it another way, it is not necessarily the transport investment that facilitates firm or investment creation, but some other unrelated mechanism. It is therefore possible that measures of productivity (eg, agglomeration elasticities) already capture the influence of agglomeration on net output.

A.2.2.2   Resident location decisions

In this section we explore city-scale approaches to resident location through economic models, starting with the bid-rent model. We also consider the choice-model approach.

Bid-rent models of household location choice assume that distance to the central city is the defining feature for household location decisions and that all households value that access the same (eg, Alonso, 1960). In reality, multiple equilibria for household and firm locations exist. There is also evidence that households consider many factors other than distance to work in location decisions.

There have been various advances on the monocentric model of Alonso that reflect the real diversity in how cities are actually spatially organised. A few other modelling approaches are discussed in this paragraph, with each representing a more complex approach to modelling resident location choices. Fujita and Ogawa (1982) modelled firm and household location as a linear city with multiple equilibria and include agglomeration economies as a factor in location choice. Further relaxing the central business district assumption and moving away from the linear city to a circular city, Lucas and Rossi-Hansberg (2002) developed a yet more sophisticated model of firm and resident behaviour. Building further on this by including congestion costs, Kantor et al. (2014) developed a model that results in mixed-use regions – which seems to better reflect how many cities are largely mixed use. Ultimately, none of these models come close to emulating the complexity of large cities in the real world. They do, however, show that agglomeration economies matter for firm location (as discussed above) and that resident location and firm location are linked because residents and firms need access to each other.

Another strand of literature treats household location as a choice problem from the perspective of the individual. These typically use revealed preference or stated preference data to estimate logit models. Kim et al. (2005) used a nested multinomial logit structure that first estimates the decision of whether or not to move, and then estimates the housing choice decision. Factors that affect propensity to move include housing and commute characteristics (eg, longer travel times or costs are associated with a higher propensity to move, quality of schooling is associated with a lower propensity to move) and household characteristics (age has a negative association with propensity to move, number of children has a positive association with propensity to move, etc). Residential location choice as estimated in Kim et al. (2005) takes the opposite sign for housing variables as propensity to move (ie, travel times to work are negatively associated with propensity to select that housing option etc). Choice models are able to capture the ways in which many different factors influence house location. The elasticities from this approach represent the marginal influence of a factor on the average resident. In the real world, of course, decisions are very complex because of how people have very heterogeneous and variable preferences.

Comparing the two approaches above, we find that the partial vs general equilibrium framework may be usefully applied here. Bid-rent style approaches are closer to general equilibrium in nature as they account for both transport and housing prices, which vary with respect to one another based on resident preferences. Choice models are closer to partial equilibrium in that only the value of housing is considered directly.

Consumption activity is also an important factor, but difficult to model. One study that explored this issue (Teulings et al., 2018) found that the job availability is about twice as important in location decisions for households than consumption amenities (this is looking at observed consumption amenities; unobserved consumption amenities make up a larger share, but we are not sure how to interpret these). This indicates that focusing on the production (ie, job and commute) factors may be more important.

A.2.2.3   Labour market decisions

Labour market decisions that are made by individuals can be affected by spatial or locational factors in a number of different ways.

First is the quantity of labour supplied, which may increase or decrease with commute time. The mechanism here is similar to that of how income tax can affect labour supply – the cost of commuting can reduce the incentive to work. Workers that are faced with an increase (decrease) in commute costs could therefore decrease (increase) hours worked per day or days worked. This type of assumption is relatively widespread with labour supply impacts as a result of transport schemes being included in New Zealand and UK analysis guidance (Department for Transport, 2019; Waka Kotahi, 2018). Empirical evidence is, however, mixed. Some work has found no reduction of labour supply as a result of exogenous firm relocation (Gutiérrez-i-Puigarnau & Van Ommeren, 2010), while other work has found a positive relationship between work location accessibility and hours worked (Sanchis-Gaurner, 2012). The theoretical framework imposed on worker decision-making seems to affect results in this research – that is, the assumed model of worker decision-making matters – by which we mean whether or not people decide the number of days or hours per day to work (and whether this varies depending on the amount of time spent travelling) (Gutiérrez-i-Puigarnau & Van Ommeren, 2010). In addition to changing labour supply on the intensive margin, it is possible that transport accessibility affects extensive labour supply – that is, whether someone is in the labour force or not. Empirical evidence from the UK suggests that shorter public transport times are associated with higher employment levels (Johnson et al., 2017). In the long run, with dynamic location choice it is possible that workers sort spatially to an equilibrium commute distance and keep working hours constant – there is evidence that the amount of time people spend working has remained relatively constant over time (PricewaterhouseCoopers LLP [PwC], 2019).

Second is job choice, which may be affected by commute times. The theory tends to frame this in terms of monopsonistic competition where firms have some labour market power due to geographically limited labour markets. Transport interventions then increase accessibility, reducing the firms' market power and resulting in more efficient outcomes (Morrison et al., 2006). Using data from New Zealand, Morrison et al. (2006) found that wages of workers in more isolated locations (ie, where employers have more market power) were more responsive to changes in the local employment rate (ie, employers use market power to influence wages when market conditions change). Interestingly, they state that New Zealand is a good case study because of the low population density, which results in relatively thin labour markets and relatively high employer market power due to geography. Empirical work elsewhere has also found a positive relationship between work location accessibility and worker wages (Sanchis-Guarner, 2012).

A.2.3 Exogenous micro-economic mechanisms that affect agglomeration economies

In this section we explore how accessibility is measured, what impact it has on economic performance, and how land supply is regulated. Transport infrastructure or policy affects accessibility, and changes to land-use regulation affect land supply. Either of these mechanisms could be viewed as exogenous changes that could influence economic density and therefore agglomeration economies. In the context of dynamic clustering, accessibility is often used in methods such as LUTI models, while elastic land supply is an important and often necessary condition for changes in land use to occur.

A.2.3.1 Accessibility changes

Transport infrastructure has the potential to radically alter the accessibility of locations. In theory, new infrastructure that increases accessibility could drive agglomeration economies and increase output. The way that the Jubilee Line Extension and Docklands Light Railway have catalysed the Docklands area in London (a previously under-utilised and derelict area that is now effectively the Eastern part of the City of London), is often cited as an example of this. We note that accessibility is an important catalyst but is likely a necessary rather than sufficient condition. Causality is important too: did the projects referred to above cause the increased concentration or did a latent demand for concentration cause the projects to occur?

Accessibility metrics use a combination of transport costs (eg, travel times) and activity (eg, population or employment densities) and are 'an important determinant of the spatial distribution of economic growth and urban development' (Jacobs-Crisioni & Koomen, 2017, p. 80). The measure of accessibility to use in this type of analysis matters, and there does not appear to be a consensus (Vickerman et al., 1999). Recent studies have begun to explore perceived accessibility rather than only objective measures using travel time or distance, and it is believed that perception is particularly important for sustainable modes such as cycling, walking and public transport (Lättman et al., 2018).

Empirical studies that try to link transport infrastructure to accessibility changes and regional economic development are more mixed. In one paper using European data, the authors confirm previous empirical findings that accessibility matters for population growth (Jacobs-Crisioni & Koomen, 2017). Another study using Polish data from 2004 to 2014 found only a weak and statistically insignificant relationship between accessibility improvements and employment growth (Rokicki & Stepniak, 2018). A US study, on the other hand, found strong and significant relationships between accessibility changes and economic development (Ozbay et al., 2003).

A.2.3.2 Changes to land supply

Land supply (which in the literature is sometimes broadly interpreted as including floorspace like our 'land use' definition above) is a critical input for land-use changes and therefore dynamic clustering. Changes to

land supply can come about through either or both of (a) changes to regulation of land use, and (b) the way in which land is developed (eg, to increase effective floorspace by building up). This is addressed in Glaeser et al. (2006, p. 71), where the authors find 'the elasticity of housing supply helps determine the extent to which increases in productivity will create bigger cities or just higher paid workers and more expensive homes'. Glaeser et al. (2006) compare the population growth with respect to labour demand and finds that population growth is 50% less responsive to labour demand in 'high regulation' cities.

Land supply is very important to appraisals involving dynamic clustering for two main reasons. One is that land supply is an input to land-use change – that is, in most cases for land use to change there is a need for additional development (exceptions exist such as when vacant offices become tenanted, or when the amount of floorspace per person is reduced). The second is about the distribution of benefits. The elasticity of land supply could be an important determinant of whether the benefits of clustering accrue to landowners (through property prices) or workers (through higher wages). Indeed, it is worth noting that dynamic clustering can occur without a transport intervention if land-use regulations are relaxed in a high-demand location.

In most of the developed world, land supply is kept artificially low through planning regulations such as zoning. The restriction of land use brings important benefits, but also costs. Cheshire (2009) catalogued and quantified the impacts of planning regulations in the UK and found that for densely populated areas of South-East England (ie, London), there was a net loss of welfare equivalent to a 3.9% income tax. Cheshire suggests that one way to reduce the negative impact of land-use restrictions would be to allow urban areas to expand into 'green belt' zones that limit the urban extent. Cheshire estimates that if constraints on urban extent were relaxed, the urban area would increase by 70% (nearly half the size of the green belt zone around London), and presumably this would reduce the costs imposed by the regulations.

Land-use regulation in New Zealand is also known to increase land prices and housing costs. Land-use regulation varies by local or municipal government, and due to the level of detail in regulations, it is time consuming and difficult to make direct comparisons. However, at least one study used an accepted survey methodology and found a high degree of variation in land-use regulation in New Zealand cities, with Tauranga and Wellington having the most regulation and Hamilton the least (NZIER, 2015). Another study by Lees (2017) used multiple methods to show the cost of regulation in New Zealand. Using estimates of construction costs and hedonic estimates of land value, Lees estimated a price wedge caused by regulation of nearly 56% in Auckland, the most populous and most expensive (in respect of house prices) city (Table A.1).

Table A.1   House price wedge due to land-use regulation for seven regions in New Zealand

City	(A) Mean house price	(B) Construction cost estimate	(C) Hedonic land value estimate	(D) Cost of land use regulation tax estimate	(E) Reg tax (% of price)
	P	−K	−p(L)	=T	T/P (%)
Auckland	$949,429	$359,710	$58,930	$530,790	55.91%
Christchurch	$524,605	$311,626	$45,892	$167,445	31.89%
Hamilton	$464,053	$299,455	$37,005	$128,634	27.66%
Palmerston North	$345,105	$272,954	$20,714	$51,806	15.00%
Queenstown	$787,994	$414,896	$67,822	$305,276	38.74%
Tauranga	$552,578	$338,413	$61,142	$153,023	27.69%
Wellington	$633,151	$302,621	$27,851	$302,678	47.81%

Source: Lees (2017, p. 43)

In addition to inflating house prices, regulation can affect the speed and efficiency of new construction (Mayer & Tsuriel Somerville, 2000). This is because regulations, in addition to affecting land values, can cause uncertainty and delays to construction.

A.3   Modelling and analytical tools

We divide modelling and analytical tools into those that help to describe what the future may look like (predictions/forecasts) and those that measure the economic impacts.

A.3.1   Forecasting

A.3.1.1   4-stage traffic assignment models

Traffic demand models are very important to the analysis of the impacts of transport projects generally (eg, they are key element in estimates of journey time savings that are generated by the project) and agglomeration economies in particular. Specifically, in relation to agglomeration economies under static land use, traffic demand models are used to estimate changes in access to economic mass, which are then fused with agglomeration elasticities to estimate changes in productivity. And when dynamic clustering is analysed, traffic demand models need to capture the changes in journey time savings and agglomeration economies before and after such clustering occurs. Traffic demand modelling is an evolving discipline with, for example, significant developments being made using high frequency data from mobile phones and machine learning techniques, but 4-stage traffic assignment models are still generally and widely used to develop travel costs.

The classical transport model was designed as a sequence of 4-stage sub-models: trip generation, trip destination, mode choice, and route assignment models (de Dios Ortúzar & Willumsen, 2011). These conceptual models were developed independently. The four stages are:

1. **trip generation stage**, aiming at estimating the number of person-trips originating in, and/or ending in given zones

2. **trip distribution stage**, which consists of distributing across various destinations each of the trip origins from a specific zone obtained in the first phase

3. **modal split stage**, where each of the origin–destination trip volumes are distributed in the various alternative transportation modes

4. **traffic assignment stage**, where the modal trips from a given origin to a given destination on a given mode are assigned to the network's link, or specifically routes between a given origin–destination pair.

### A.3.1.2   Land use–transport interaction (LUTI) models

Summary of LUTI

LUTI models are predictive tools that account for the bi-directional causal links between transport and land use. Reviewing LUTI models in a general summary is challenging because of the wide variety of approaches used. Models vary by level of detail or granularity and by the types of interactions that are included. In this section we provide a high-level summary of how various LUTI models work. We draw heavily from Wegener and Fuerst (2004), which, despite its age, is still cited often and the models included in that review are still among the LUTI models most used today.

LUTI models are grounded in theory and empirical evidence. They account for a wide variety of relationships, including firm and resident location choice, labour market decisions, travel choices, and others. There is no pre-determined set of relationships that must be included in a LUTI model, and therefore models vary considerably. The relationships included are most often individually estimated and then linked together sequentially to form a series of relationships. For example, one might have a function to determine how many households are likely to move in a given period, then a model to determine where those households move given different parameters, then a model to determine where they will work and commute to, and then a traffic assignment model – and so on and so forth. Each of these functions or models will be estimated or calibrated using actual data if possible. However, linking individual models in this way may not lead to a consistent economic approach to evaluating impacts.

Diagrammatic representations of LUTI

Diagrammatic representations of LUTI models can be useful to understand the flow of data between models/sub-models, time periods, and across scenarios. The image in Figure A.1 specifically refers to the DELTA model, but the flow of information between models is relatively generalisable to other similar models. In this diagram we see that base year data is a key input, with other inputs having bi-directional relationships (ie, demographic scenarios are inputs to the land-use model, but also outputs of the land-use model). The flow of land-use and transport model outputs from one model to the other is generally achieved through an iterative process that may take multiple model runs.

**Figure A.1: High-level diagram of DELTA LUTI package**
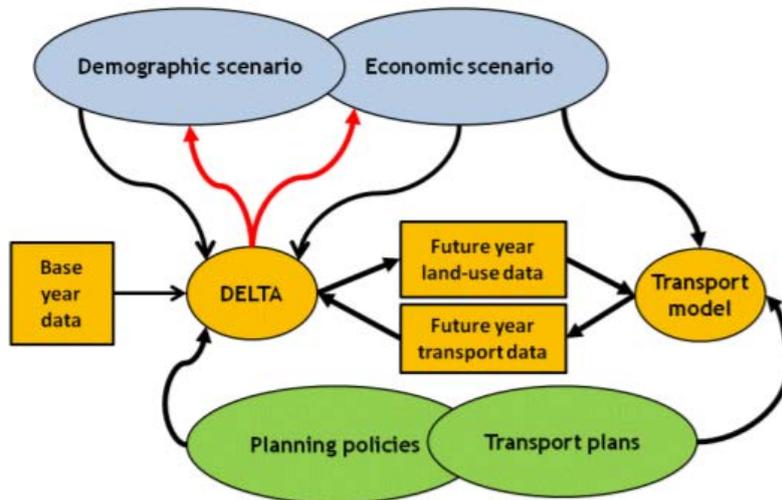
Source: Simmonds (2017, p. 2)

Acheampong and Silva (2015) also developed a conceptual model of the types of relationships that are contained in LUTI models. Figure A.2 shows how many inter-relationships are contained within the LUTI framework.

Figure A.2   Conceptual model of general LUTI framework
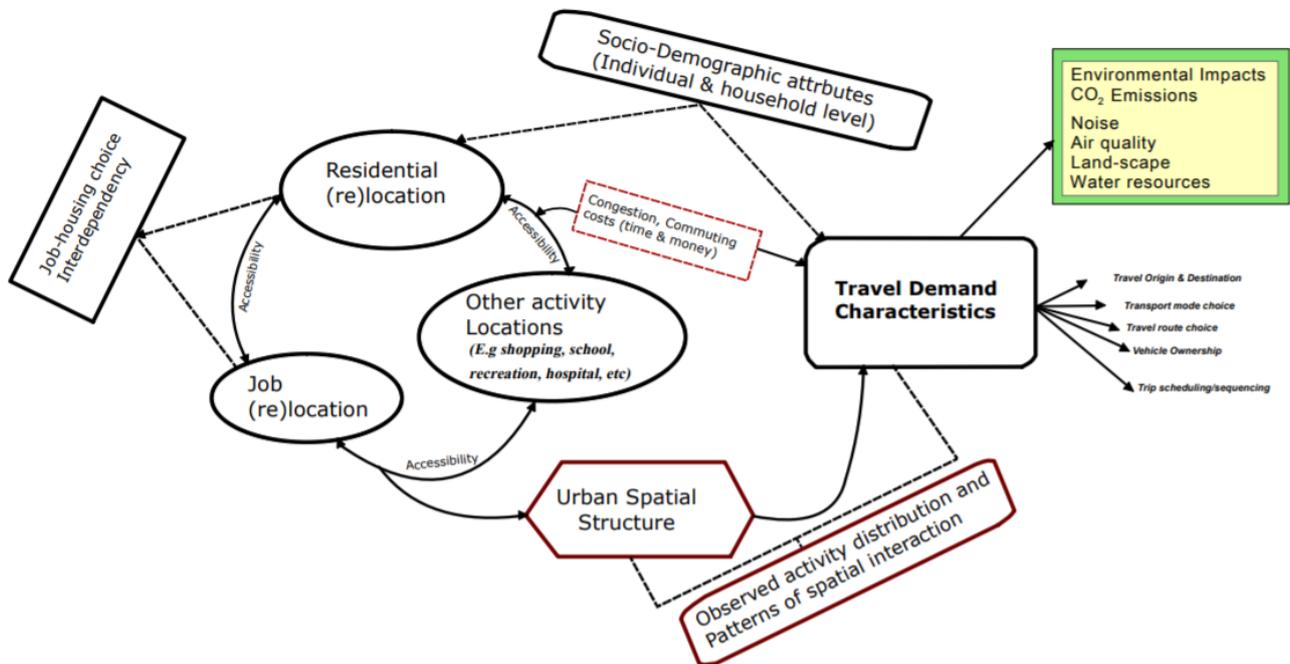
Source: Acheampong & Silva (2015, p. 16)

Review of multiple LUTI frameworks via Wegener and Fuerst (2004)

Wegener and Fuerst (2004) conducted a comprehensive survey of LUTI models.[18] Their paper begins with the theoretically expected impacts of transport on land use and vice versa, and then reviews the empirical evidence for these relationships.

Moving on to the modelling approach, the authors assess 17 LUTI models and categorise them across key features, such as theory, technique, and calibration. Here we summarise the common approaches to LUTI models in this survey.

Theory

- Nearly all models use choice models to explain and forecast the behaviour of agents such as households, firms, travellers, and investors.

- The land market is commonly represented with endogenous prices and market clearing in each period or with delayed price adjustment. Other models use choice models or bid-rent models for the land market.

- Models with transport sub-models tend to use choice models or gravity models for modelling destination and mode choice.

- LUTI models are usually partial equilibrium models that operate in the transport and land markets. Some balance prices in both markets simultaneously (ie, there is an interaction between agents operating in both markets). More commonly, models determine the equilibrium outcome of the transport market only, transport and location markets separately, or transport and location combined but without endogenous prices.

Modelling techniques

- Urban regions tend to be represented as a set of discrete sub-areas or zones. Time is typically subdivided into discrete periods of one to five years, and modelling is done through recursive simulation.

- In one group of models, transport and location are simultaneously determined in spatial-interaction location models. In the other group of models, a transport model is used to derive accessibility indicators, which then affect location choices.

- Multi-regional input–output methods are used to represent flows of goods.

Calibration and validation

- Most models are (or can be) calibrated using maximum-likelihood estimation of logit models, which estimate the various relationships/choices included in the model.

- According to Wegener and Fuerst (2004, p. 48):

    Calibration of cross-sectional models … provides the illusion of precision but does little to establish the credibility of models designed to look into the far future. There has been almost no progress in the methodology required to calibrate dynamic or quasi-dynamic models.

    In the face of this dilemma, the insistence of some modellers on 'estimating' every model equation appears almost an obsession. It would probably be more effective to concentrate instead on model validation*, i.e. the comparison of model results with observed data over a longer period.*

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[18] Wegener and Fürst's (2004) paper is a large review of LUTI models and widely cited in the literature. Though the state of the art has advanced since 2004, as far as we are aware the analysis remains valid and many of the models included in that review continue to be used and represent best practice.

In other words, the number of relationships (equations) that are modelled and calibrated may become so large that calibration of each individually may not result in outputs that reflect reality, particularly over longer periods of time.

- A similar issue arises with the data that LUTI models use, which is often highly granular data and often less reliable than more spatially aggregated data (particularly when this more aggregated data is generated or validated by national statistical authorities).

LUTI in New Zealand

Our review identified at least one LUTI model in New Zealand being used for strategic planning in Auckland. Known as the Auckland Transport Models (ATM2) project, it employs a combination of land-use modelling (using the DELTA software package developed by David Simmonds Consultancy) and a regional transport model (using Emme software). According to a joint paper from David Simmonds and Auckland Regional Council modellers (Feldman et al., 2009, p. 1), 'The ATM2 models are intensively used by Auckland Regional Council to forecast land use and transport demands in the region to assist planners and decision makers in developing efficient and effective strategies to guide regional development'.

A.3.1.3 Supply analysis

Supply analysis can be used to test whether the type and scale of dynamic clustering that one expects to occur can actually occur. Economic analysis of dynamic clustering may predict a certain quantum of development, but the options for development are typically constrained by land-use regulations. This type of analysis is therefore useful to make realistic predictions about land-use changes, or to explore land-use change scenarios. Supply or capacity analysis is commonly used by planning authorities to evaluate the quantum of land development that is likely to occur in the future, taking into account regulations and sometimes market conditions. In the context of dynamic clustering, this approach estimates the potential for 'unlocking' additional development through reducing costs of private development or allowing the relaxation of planning controls (Waka Kotahi, 2019). In this section we discuss how unlocking development through changes to land-use regulation might be estimated. In the following section we address reducing costs of private development.

Supply analyses can be completed for small parcels of land on an *ad hoc* basis or at a more aggregate (ie, city) level. Developers of individual parcels will work within planning and zoning regulations and ensure that the economics of the project stack up so that they earn a profit. In some cases, they will need to conduct environmental and/or transport assessments to ensure that the development does not exceed the local capacity for traffic or pollution.

Supply analyses in New Zealand typically focus on the number of dwellings that could be developed or the number of years of demand that could be met (Ministry for the Environment, 2016). Approaches differ: some councils consider housing capacity to be equal to theoretical capacity, some apply a discount rate to recognise that not all capacity will actually be built, and some attempt to identify the quantum of capacity that is commercially feasible to be developed (Ministry for the Environment, 2016). In our view, assessing demand as well as supply is crucial to accurately predicting whether development will occur. In New Zealand, demand assessments are occasionally conducted by councils using local growth projections from Stats NZ or independent projections from consultants (Ministry for the Environment, 2016).

A.3.1.4 Game theory techniques

Transport interventions or complementary policies may reduce the cost of development or increase the payoff (ie, profit) of development. Reducing costs or increasing profits to private development could result in unlocking development that otherwise would not have occurred. One way to show how a change in policy

'unlocks' private development is by using game theory. Game theory uses decision trees that could be used to replicate the decision-making process of developers and simulate the payoffs at each turn – thus shedding light on the decision-making process that occurs in reality.

Policies that reduce development costs may do so by addressing a market failure. One example of a market failure in the urban land market is the so-called holdout problem. The holdout problem 'arises when individual owners, realising that they can impose substantial costs on the developer, seek prices well in excess of their true reservation prices' (Miceli & Sermans, 2007, p. 311). Miceli and Sermans draw a link between the holdout problem and spatial structure of cities. They use a simple two-period game theory model to illustrate that land assembly is plagued by delay and extra costs due to strategic action by landowners. This analysis may provide justification for the use of compulsory purchase to solve the holdout or other policy tools that may somehow alter payoffs and lead to new strategies and a new equilibrium.

Another paper that models strategic decision-making to understand development market outcomes is from Samsura et al. (2010). It presents a more complex decision tree for greenfield residential development in the Netherlands. The authors make a few suggestions for using game theory. First, they argue that empirical (ie, real world) data on payoffs is important if it is to be used for actual decision support – they say that stated preference techniques could also be used or that outcomes could be tested with stakeholders to enhance realism. Second, they suggest that their model, which assumes perfect information, could be adjusted to account for possible incomplete, imperfect, or asymmetric information that may better approximate real-world conditions. Third, they question the assumption of perfect rationality of actors. Lastly, they recognise that game theory models represent an abstraction of reality.

We are not aware of much literature that covers how game theory could be used to model dynamic clustering specifically. However, we think it could be used to show how policies overcome market failures, resulting in a structural change or catalyst for development.

A.3.2   Impact assessment

The second class of modelling approaches that we explore are those that focus on changes to economic outcomes brought about by transport projects. LUTI models also fall into this category but have been covered above.

A.3.2.1   Current wider economic impacts (WEIs) in cost–benefit analysis

CBA is a systematic process for defining the project and any alternatives (based on the important concept of opportunity cost), then identifying, measuring, and valuing the benefits and costs of each. It has been used for identifying and monetising (when possible) the economic, social and environmental impacts of transport projects for decades (see Mackie, 2013; Waka Kotahi, 2020; and the UK Department for Transport's TAG units A1.1 through A2.4[19]).

The CBA methodology applied to transport project appraisals tends to assess the impacts on users through the demand curve, which is a function of generalised costs (including travel time, cost of travel, and quality), and on the community through externalities such as noise, pollution, and accidents (Robson et al., 2018). Changes in demand and generalised costs are estimated with external transport models that account for mode choice and congestion, then the change in consumer surplus is computed.

This CBA methodology has evolved over time to include WEIs as the linkages of transport intervention on economic development have been recognised. As illustrated in Figure A.3, Level 1 and Level 2 impacts in

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[19] https://www.gov.uk/guidance/transport-analysis-guidance-tag#guidance-for-the-appraisal-practitioner

the UK's transport analysis guidance (see TAG unit A2.1) and the Waka Kotahi (2018) *Economic Evaluation Manual* include the direct impacts of a transport intervention (eg, the value of journey time savings and certain wider economic impacts) and the WEIs without land-use change (eg, agglomeration economies under static land use, the impact of imperfect competition and certain labour market effects). Further knock-on effects of a transport intervention with changing land use (ie, dynamic clustering) are treated in the UK as Level 3 impacts.

The methodology for quantifying Level 3 agglomeration productivity impacts in the UK is the same as for Level 2 agglomeration impacts, except that changes in land use are included in the quantification of impacts. This leads us to one of the primary difficulties with this approach for dynamic clustering: determining the extent to which land-use changes occur as a result of a transport scheme.

Economic impact analysis (using techniques such as CGE and S-CGE models), which aims to forecast the impact on the economy of an improvement of transport infrastructure, allows for the impacts to be modelled that are not covered by the Level 1 and Level 2 analysis. Reduced form and other (ie, partial equilibrium structural) econometric models are also often used to inform S-CGE models. We are aware of a considerable amount of work on the successful use of S-CGE in the appraisal of transport projects in the UK, including on a number of major road projects. We also note this work has been peer reviewed by academics, but also that most of it has not been published for reasons of commercial confidentiality. Our understanding of it is summarised later in this report in section A.3.2.3.

LUTI models (discussed above) are also extensively used to analyse Level 3 type impacts.

**Figure A.3   Illustration for economic effects of a transport intervention**
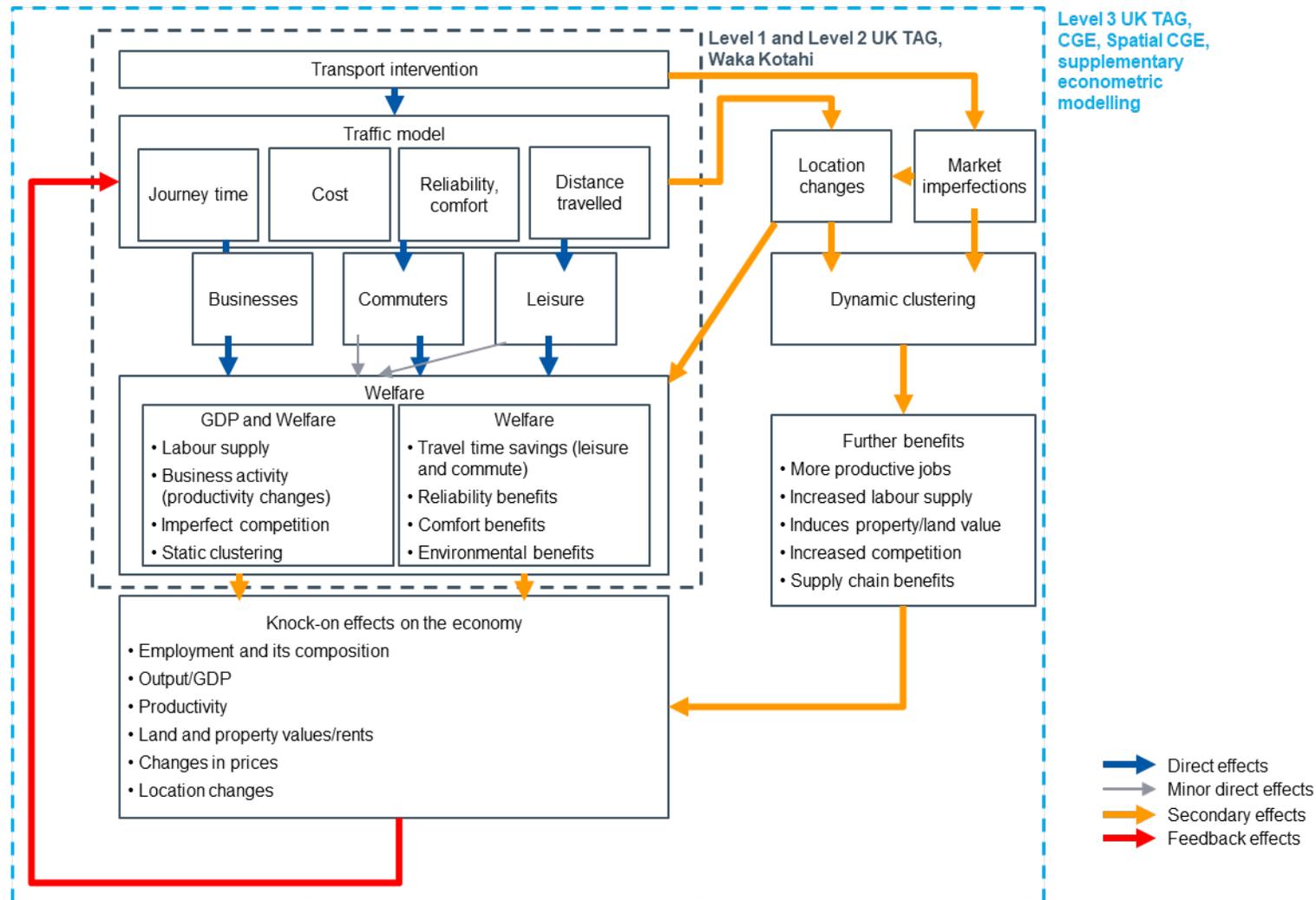
Source: NERA

A.3.2.2 Induced demand shift

Overview of the approach

As discussed earlier, definitions of dynamic clustering often refer to transport investments making locations more attractive, leading to (for example) worker and firm relocations and land-use change (see, for example, Graham & Gibbons, 2019). This increase in attractiveness may induce an outward shift in the demand for transport. That is, as people and businesses relocate or intensify their activity within a given location, they may increase their demand for transport. This scenario is analogous to a more general increase in product quality, which would induce a similar outward shift in the demand curve as consumers demand more of a higher quality product at a given price (or are prepared to pay a higher price for a given quantity). Indeed, this is how the approach has been conceptualised by Bates (2006), who (as shown in Figure A.4 below) shows an outward shift of the demand curve from D_1 to D_2 to represent a change in transport service quality.

Figure A.4   Consumer surplus equivalence from outward shift of demand curve
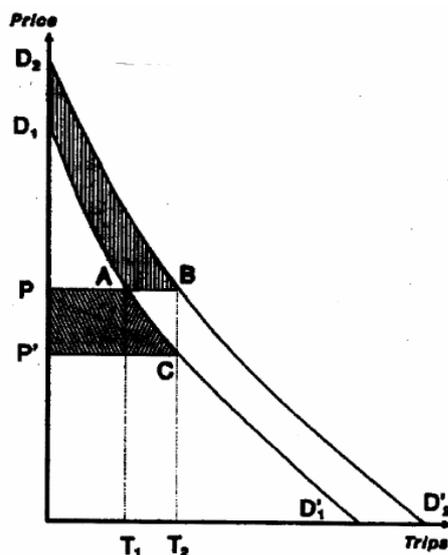

Source: As shown in Bates (2006)

By conceptualising dynamic clustering benefits as an outward shift in the demand curve, it is possible to quantify these benefits using supply and demand relationships. We refer to this as the 'induced demand shift' approach for quantifying dynamic clustering benefits. Along with Bates (2006), variations of this approach have been developed by NZIER (2013) and Geurs et al. (2010), which we outline in more detail below.

Bates' (2006) depiction of the induced demand shift is shown in Figure A.4 above, where demand shifts outward from D_1 to D_2. In a standard demand curve relationship such as is shown, the benefit to consumers ('consumer surplus') is given by the area above the market price and below the demand curve. As a result, the change in consumer surplus from the demand curve shift is given by the shaded area AD_1D_2B. Alternatively, the area PACP' is a reasonably good approximation to this consumer surplus increase (the areas AD_1D_2B and PACP' are equal if the new demand curve is parallel to the original demand curve). Essentially, the idea of the Bates approach is that the value generated from how a transport intervention can make a place more attractive can be calculated from the area between two demand curves, but it can more simply be calculated from the area under the original demand curve bounded by the original price and the price that would generate the increase in demand generated from the outward shift in the demand curve (ie, the 'shadow price' P').

In other words, an approximation of the consumer surplus can be determined with information on the values of P, P', A and C.

The NZIER (2013) framework is somewhat similar but also includes a reduction in generalised travel cost brought about by the scheme, as shown in Figure A.5.

Figure A.5   Consumer surplus equivalence from outward shift of demand and supply curves
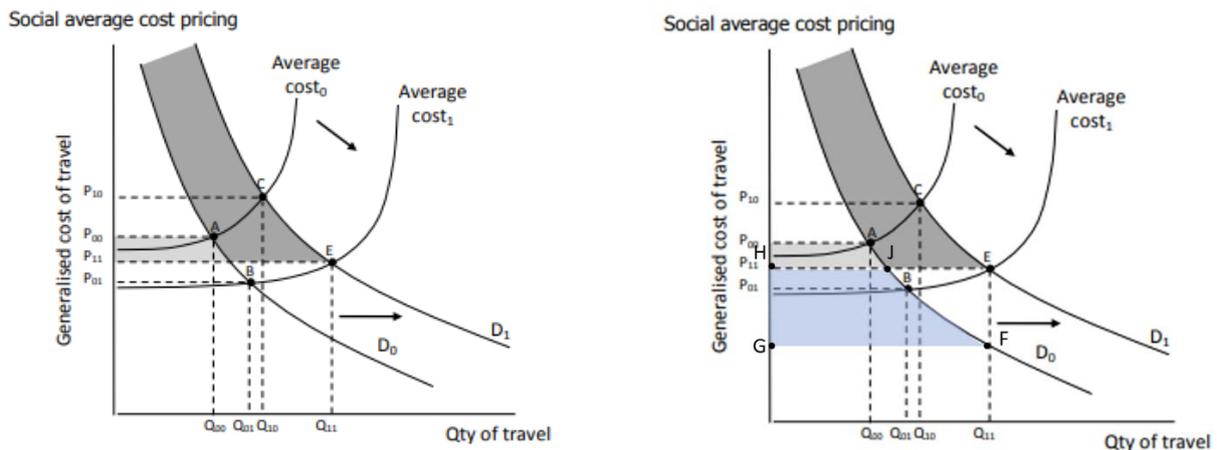
Source: Left: NZIER (2013, p. 22); Right: Modified from NZIER (2013)

With these shifts in the supply and demand curves as shown on the left-hand side of Figure A.5, the consumer benefits are shown in the above figure by the light and dark shaded areas. NZIER (2013) developed mathematical formulae for estimating the size of this area, which depend in part on the underlying function of the demand curve (eg, whether linear, log-linear, or constant elasticity). By incorporating shifts in both the supply and demand curves, this approach aims to capture both the conventional transport user benefits from a transport investment, and the dynamic clustering benefits. We think it may be useful and potentially important to analyse whether a Bates-type equivalence finding holds in that the area under the original demand curve bounded by P_{00} or P_{11} on the one hand and G (the shadow price) on the other is equal to the dark and light grey shaded areas – see the right-hand side of Figure A.5.

Geurs et al. (2010) describe a similar approach, which they note has 'much in common' with the approach of Bates (2006). Their approach captures the change in consumer surplus arising from an improvement in the attractiveness of a location by using what is known as the 'log-sum'. The log-sum is a measure derived from a logit model, which is a model of the choice probabilities of decision makers. Geurs et al. (2010) show that (using a logit model) the logarithm of the sum of choice probabilities is a measure of consumer surplus, and the change in consumer surplus can be evaluated by comparing the log-sums before and after the relevant transport investment.

Geurs et al. (2010) note that log-sum values can be determined from logit models used in the travel demand component of LUTI models. As Geurs et al. note, this is one of the key distinctions between their approach and that of Bates: the latter assumes a linear demand curve, while Geurs et al. use the estimated demand curve from a LUTI model. In addition, NZIER (2013) notes that Geurs et al. (2010) do not directly discuss how the log-sum approach reconciles with a more conventional approach to CBA.

Commentary

The output of our literature review is not intended to be a comprehensive assessment of the different approaches. Nonetheless, we do make three preliminary observations regarding the induced demand shift approach.

First, it will be important to check the maths in these approaches and assess whether and under what types of demand conditions they work – for example, if a transport intervention brings about a 'kink' or change in slope of the demand curve rather than just an outward shift that might occur if a transport intervention prompts changes in underlying preferences for travel.

Second, while this type of approach could be a useful and relatively wide-ranging measure of the potential impacts of a transport investment, it is unlikely to be a holistic metric that incorporates transport user benefits and dynamic clustering impacts into a single metric without double counting because of the need to consider the following.

- **Externalities and non-travellers**
  While the approach could capture the additional consumer surplus generated from faster trips by existing and new travellers (in a way that also takes into account how some people might have relocated as a result of the scheme), it is difficult to see how it can capture the benefits that accrue to individuals and businesses simply as a result of a place being better connected and therefore more productive. Agglomeration economies are, by definition, an externality and do not all manifest themselves in the market for transport. This can be seen most clearly by considering those who do not travel at all. Examples include people who work remotely for businesses that are located in or near to the newly agglomerated areas, and businesses and people in the better connected area that benefit from the general externalities of improved productivity (eg, through greater sharing, matching and learning) but without actually travelling.

- **The extent to which travellers bid value into trips**
  If we then consider those who do travel, the price that they bid into – or pay for – travel is unlikely to encompass all the benefits they get from increased connectivity. An increase in demand for a location due to increased attractiveness is not necessarily the same thing as an increase in demand for *travel* to (or from or in) that location.

- **Displacement**
  This may be an issue when quantifying consumer surplus based on an outward shift of the demand curve. Some of the new users who have relocated were presumably making journeys elsewhere that afforded them consumer surplus. It is likely to be difficult to be sure how much of the benefit is truly additional rather than displaced.

Third, setting aside the questions of the maths and what the induced demand shift approach does and does not tell us, we think the approaches will be difficult to quantify in practice. A lot will depend on the elasticities and form of the demand curves that are used in the analysis. Given the potential for large shifts in supply driven by significant changes in journey time, and the importance of segmenting demand into groups with similar characteristics (ie, values of time), estimating the demand curves in a convincing manner is likely to be a challenge.

A.3.2.3 Computable general equilibrium

PwC (2015) used S-CGE models to appraise transport projects in the UK. Their report to the Airports Commission states:

> *A CGE model combines economic data and a complex system of equations in order to capture the interactions of the three main institutions in an economy – households, businesses and the government. Each institution is defined and interlinked through labour market or capital market flows, household consumption, intermediate product demand, taxes or government transfers. ...*
>
> *The economic systems that CGE models proxy are complex. The multiple households and businesses that are defined in each model engage in repeated local microeconomic interactions that in turn give rise to macroeconomic relationships affecting variables such as employment, investment and GDP growth. These macro relationships also feed back into the determination of local micro interactions. Because of this relationship, CGE models are often referred to as micro-macro models… .*
>
> *CGE models are used to analyse the implications of different scenarios. The equations in CGE models tend to be calibrated to relevant economic data and a baseline view of the economy is created. A particular new scenario is then imposed on this baseline scenario and the CGE model measures the difference between the new scenario and the baseline scenario to produce key changes in economic metrics such as GDP, employment, household consumption, exports, imports, investment, tax receipts etc. More detailed results at the industry and household level can also be generated.* (PwC, 2015, pp. 31–32)

CGE models focus on issues related to resource allocation across different supply sectors, relative prices of goods and factors of production, and welfare levels of different income groups.[20] They can determine the distribution of direct and wider economic impacts among every market and agent in the economy, while guaranteeing no double counting (Robson et al., 2018). The magnitude and distribution of both direct and wider economic impacts can be assessed within CGE models through welfare, GDP, and prices. In CGE models, prices and wages adjust such that supply and demand in all markets remain in equilibrium. However, CGE models do tend to struggle with spatial granularity (Forsyth, 2014). Spatial computable general equilibrium (S-CGE) models have, however, been applied in order to estimate the spatial and economic impacts of transport policies (see, for example, section A.3.2.4 below, which summarises the appraisals carried out in the UK for Highways England by PwC). The S-CGE framework explicitly models price and wage change accounting for local variations (eg, local constraints on growth, employment), and allows for the estimation of level and location of employment, investment, GDP, and welfare (Department for Transport, 2019).

S-CGE models have long been the tool of choice for analysis of the long-term effects of large-scale reforms (eg, policy changes, tax, international trade) because they capture the many complex direct and indirect effects of these reforms on the structure of the economy. Their use in the appraisals of transport projects is, however, more recent and nascent.

Some of the commonly identified advantages of CGE models are as follows.

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[20] Standard CGE models simulate the entire economy by disaggregating sectors, industries, regions, and countries, and by using a system of sector demand and supply equations. CGE models are solved by finding a set of prices and outputs that results in equilibrium in every market simultaneously. They simulate the behaviour of consumers and the production process through representative households and firms, respectively. Sector equilibrium conditions, with appropriate treatment of interdependence and aggregate consistency (eg, demand and supply in each market are functions of every price in the economy, not just the price in their own market), therefore determine the economy's general equilibrium. Once a base-case solution is found and numerically determined, the effects of particular policy changes on equilibrium prices and quantities, and on welfare levels of different population groups, can be assessed (Bröcker & Mercenier, 2011).

- CGE modelling allows the construction of a theoretically consistent framework capturing both direct and indirect inter-sectoral, inter-regional, and inter-temporal effects induced by an infrastructure investment and/or policy change.

- They can be used to simultaneously model the welfare and GDP impacts of interventions.

- They provide a highly flexible framework that allows for the simulation of a wide range of interventions.

- They have the capability to account for some of the market imperfections that are prevalent in the real economy (rather than the simplistic textbook models relied upon by partial equilibrium appraisal frameworks that assume that markets work perfectly and that resources in the economy are fully and productively utilised).

- They can be used to provide information on the extent to which resources are displaced from one location to another (eg, location choice of individuals and businesses). This is a key strength of the CGE framework.

- They can assess distributional impacts, allowing for dynamic clustering effects.

On the other hand, the disadvantages of CGE models include the following.

- CGE models can be very complex and difficult to understand. This is often referred to as the 'black-box' challenge.

- They can be data intensive and costly to develop and run.

- S-CGE models tend to operate at a much higher level of spatial granularity than, say, LUTI models, which can be a challenge when appraising issues such as dynamic clustering. In our view and experience, it is therefore likely to be necessary to fuse S-CGE analysis with other techniques such as 'attractiveness mapping' (that we know has been used in the UK), which allows for the prediction of granular impacts within a robustly defined overall growth envelope.

- It is a technique that is inherently based on equilibria and is therefore better at predicting what these new equilibrium positions will be than it is at explaining how the equilibrium has been achieved.

- Firms and consumers tend to be assumed to be relatively homogenous, which can be an issue given how their location decisions will vary so much.

- Most S-CGE models that we are aware of are capable of analysing dynamic clustering and the impact of land-use change but have not been specifically designed to do so.

A.3.2.4 S-CGE modelling in the UK

We are aware that a number of major road projects in the UK (eg, the Lower Thames Crossing, the A303 and A14) have been appraised by PwC for Highways England using an S-CGE model which was composed of six or seven regions. This is a relatively complex model that was developed by PwC but is based on a model used by the UK Government.

A transport modelling suite was used to generate inputs to the S-CGE model (eg, the value of journey time savings that accrue to different types of business and that are treated as an increase in the productivity of these businesses). The S-CGE model and the transport modelling suite were not iterated – that is, the impacts on economic activity estimated by the S-CGE model were not then used to analyse how demand would be affected – but it would have been possible to do this in order to capture the impacts of dynamic clustering more fully.

A technique called 'attractiveness mapping' was also used, which is a way of enhancing the granularity of the analysis: the technique was used to drill down from outputs at the level of the six or seven regions in the S-CGE model into the many Lower Super Output Areas in each of these regions. It allowed analysis to be

carried out of how growth and land-use change in a particular region might be distributed geographically. It is a relatively simple but flexible form of analysis that uses basic econometrics and/or correlation analysis in conjunction with a geographic information mapping platform, and it generates visual results that are similar in appearance to what can be obtained from a LUTI model, but some would consider it to be more robust because of how it is based on the robust economics of CGE modelling.

This analysis also made use of two strands of econometric analysis of the relationship between connectivity and business productivity.

The first strand was an update of the 'standard' agglomeration elasticities that are used in the UK. The update used up-to-date data, was based on travel times rather than crow-fly distances, and explored issues such as functional form. The analysis found that the agglomeration elasticities (for service sectors) vary with the level of aggregation.

The second strand looked at whether these effects exist over very much longer distances and trips than is normally considered. On the face of it, one would expect these long-distance effects to exist, but these effects had not previously been estimated, possibly because the existing data did not show much variation in connectivity: most major roads in the UK were built decades ago.

The analysis used data on road travel times from around Europe, which was fused with air travel times around Europe. This combined dataset had significant variability in travel time – mainly because of liberalisation of the aviation market – which allowed the identification of statistically significant agglomeration elasticities for long-distance trips that were distinct from the short-distance elasticities, albeit the short-distance elasticities were lower than previously estimated. Importantly, though, the combined impact of these two different types of elasticity was greater than the impact of the previously estimated short-distance elasticities. In other words, standard practice might underestimate the overall impact of agglomeration economies on some schemes and skew appraisal results towards short- rather than long-distance schemes.

Finally, these appraisals pioneered an approach to reconciling the GDP and welfare impacts of projects, which allowed the appraisals to robustly support statements like: 'the £5bn project will generate £3 for every £1 spent on it, boost GDP by £7bn over time and create 10,00 new jobs by 2030'. This approach was then developed for more general application – see the *Squaring the Circle* report that was subsequently published by the Department for Transport (PwC, 2019).

A.3.2.5   Land value uplift

The theoretical and empirical linkages between land value and accessibility have been previously discussed. There is a strand of literature and guidance that focuses on land value uplifts as the primary economic benefit that results from infrastructure or policy interventions. The *Monetised Benefits and Costs Manual* considers land value impacts to be the capitalisation of travel time impacts, and therefore double counting (Waka Kotahi, 2020). In this section we explore in more detail when and how land value benefits could be used to quantify the economic impacts of transport and dynamic clustering.

In general, we can think of three ways that this could be done:

1. the increase in property prices could be used as a way of valuing the impact of the scheme or as a cross-check on a more standard appraisal;

2. using the increase in property prices as a way of identifying the size of wider impacts (eg, agglomeration economies) alone by somehow netting off the typical travel time impacts; or

3. incorporating into the appraisal how different land-use and coordination policies affect each of the above.

One of the leading academic figures opposed to using travel time savings in transport appraisal is David Metz, who has written several articles critical of the time-saving approach. In his view, the time savings

benefits of a transport intervention are short-run, while the long-run benefits involve changes to land use and value (Metz, 2017). He states that the magnitude of benefits from travel time savings is only tenuously linked to the land-value benefits and that travel time also fails to recognise the spatial distribution of benefits accurately (Metz, 2017). A key piece of evidence he cites is that the long-run average travel time of journeys has remained fairly constant over the period 1970–2005 in the UK (Metz, 2008). Metz proposes that stated preference techniques could be used to gauge the value of increased accessibility. An alternative to that is to look at land values.

To estimate the capitalisation of benefits in land values, 'hedonic price models are widely considered to be the best method available' (Cervero, 2011, p. 23). Hedonic models are used to understand to what extent consumers appreciate, and are willing to pay for, different features of a product. They are commonly used with house prices, and will reflect different household features such as number of rooms and quality of school.

Linking hedonic house price studies with the impact of a transport intervention can be done by including accessibility or travel time/cost variable(s) and estimating their values. For example, a study for the Lisbon area found that proximity to one or two metros significantly affected property values, and the authors suggest that the method provides a 'basis to forecast the property value changes derived from transportation investment' (Martinez & Viegas, 2009, p. 127).

A.4 Conclusion

This literature review is intended to investigate the research questions set out in section 1.1 and be a foundation for the methodology presented in section 3. Table A.2 refers back to the research questions and provides a short summary of findings from the literature review.

Table A.2   Summary of research questions and literature review findings

| Research question	Literature review findings
1. What do we mean by terms such as agglomeration economies, dynamic clustering, and land-use change?	We develop definitions for key terms and report whether there is consensus in the literature for the definition of the term. For *agglomeration economies, land use, market failure* and *partial/general equilibrium* we find that there is consensus. *Dynamic agglomeration* is a term that can be interpreted in different ways, due to the lack of clarity on when agglomeration impacts are expected to occur. *Additionality* is well defined in economics and appraisal but has not been well defined with respect to dynamic clustering.
2. At a high level, how, when, and under what conditions do agglomeration externalities (positive and negative) occur?	We explore the ways in which positive agglomeration externalities manifest through *sharing, matching* and *learning*. All these mechanisms are expected to occur more as density increases. *Sharing* and *matching* are viewed as occurring more immediately after a change in density, while *learning* is a process that is viewed as taking some time to occur. Negative agglomeration externalities are acknowledged in the agglomeration literature. The main transport-relevant negative externality is *congestion*, but other cost increases such as land prices are also mentioned (while recognising that these are not necessarily externalities). We find few, if any, studies that measure the all-in effects of transport interventions comprising all the various positive and negative impacts.

3. What more fundamental micro-economic processes occur in the lead-up to (and after) the agglomeration externalities themselves (eg, location decisions), and what feedback loops exist within and between these processes?	We investigate what influences *firm and resident location choices*. For firms we find that firm characteristics and the economic environment are the main drivers of firm relocation and expansion/creation, respectively. However, agglomeration economies and the potential to benefit from them also drives firm decision-making. Residential location choice is typically considered either in a spatial equilibrium framework or choice model framework and is influenced by many factors such as access to amenities and distance to work. The fact that both firms and residents/employees wish to be close to areas of work shows that there is a recursive element to the attractiveness of places. *Labour market decisions* with respect to commute travel times appear in appraisal guidance, but the literature on the impacts of changes in travel time on labour supply are mixed.
4. How and to what extent do transport policies or investments affect the micro-economic processes from (3) and therefore agglomeration externalities?	The main impact of transport policies and investments is to influence *accessibility* through reduced travel times and *land supply* through unlocking areas for development. We find that the evidence for the link between accessibility and the micro-processes such as location choice is strong. There is evidence that the link between land supply and the price of land/real estate is important in places where land supply is constrained, and that 'price will influence decisions' is a fundamental tenet of economics.
5. How can different models or analytical tools be used to trace the cause and effect from transport intervention (4) to micro-processes (3) to agglomeration externalities (2)? These tools may be step-wise – that is, only effective at modelling the link between (4) and (3) or only (3) and (2).	We review the state of the art in several models for forecasting and analysing economic impacts. Of the forecasting models, *traffic demand models* are widely used for assessing travel patterns and the changing user costs associated with transport schemes. They are used mostly to assess direct user benefits. *LUTI models* are used to assess how land use changes under different policies/schemes, and they may incorporate many different elements in land and transport markets, but there are issues with the validation of these models. *Supply analysis* can be used for assessing development pipelines. *Game theory* may be important for situations where strategic interaction is a driver of whether dynamic clustering occurs, but it is not widely used and there may be difficulties in properly applying it.

Wider economic impacts techniques apply economic research into agglomeration elasticities to determine how productivity will change as a result of a change in effective density. This family of techniques is widely used, but estimates of dynamic impacts are only as good as the input assumptions/models of land-use change. *Induced demand* and *land value uplift* approaches are intended to capture all or most of the benefits through changes in place attractiveness, but both methods may be incomplete in that they leave out some benefits. For land value uplift, there is also the risk of double counting user benefits. *Spatial CGE* models can potentially capture all the benefits of dynamic clustering without double counting, but to do so requires the S-CGE model to be robust and transparent and for it to be integrated with other modelling techniques. The level of spatial granularity is also generally relatively low. |

Appendix B: Imperfect competition

This appendix explores the impact of imperfect competition on welfare benefits generated by a transport intervention that are additional to the ones that are generally considered in appraisals. To illustrate this point, we consider a standard monopolist maximisation problem, as shown in Figure B.1. In this example, marginal revenues decrease as the monopolist sells additional units of output, while we assume marginal costs to be constant.

Figure B.1   Impact of imperfect competition on the welfare benefits generated by a transport intervention
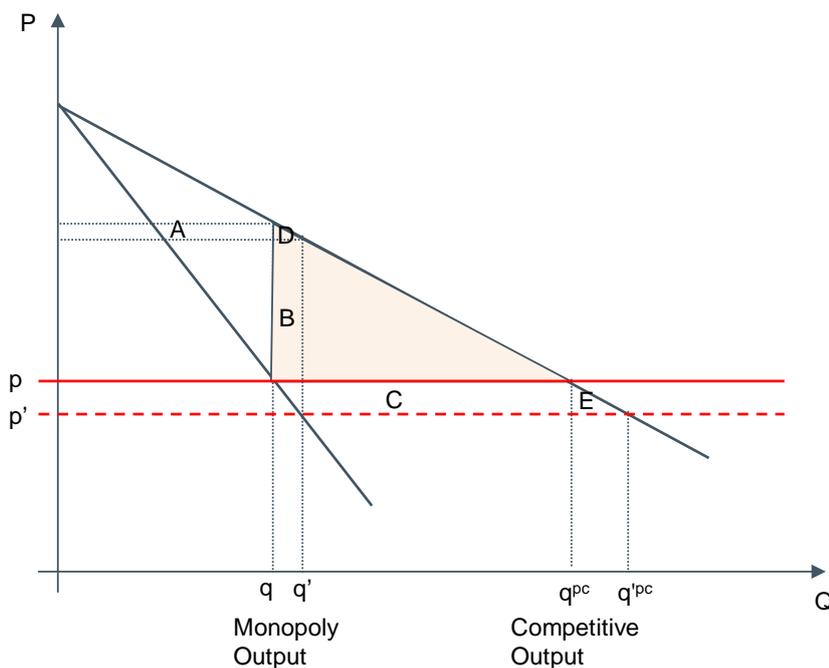
A transport investment increases the firm's costs by reducing travel times and the costs of its production inputs. This results in a shift of the marginal cost curve from p to p' and consequent increase in output from q to q'.

A shift in the marginal cost curve produces welfare effects for the economy. A first effect consists of a shift in welfare from producers to consumers. This shift corresponds to a decrease in producer surplus of an amount that is identical to the increase in consumer surplus and that has no effect on the aggregate economy. This shift in welfare is depicted by the area A in Figure B.1 above.

A second effect on welfare of a decrease in the marginal cost curve is an increase in deadweight loss. A deadweight loss refers to welfare cost that arises because the monopolist produces less output than the optimal amount produced under perfect competition.

An increase in output following a shift in the marginal cost curve reduces the deadweight loss by an amount equal to B+D because the new output level is closer to the one achieved in competitive equilibrium. Deadweight loss, however, also increases by an amount equal to C+E as a result of a decrease in marginal costs, which increases the optimal amount of output produced under perfect competition. The overall change in deadweight loss is thus equal to C + E – B – D.

Appendix C: Labour market impacts

Reductions in travel times and costs brought about by transport interventions are likely to induce changes to supply of and demand for labour. This appendix explains the mechanism through which a transport intervention can affect employment and how its welfare implications could be computed.

Standard practice in the appraisal of transport investment is to assume that there is no private benefit from this increased work because people are perfectly compensated for their foregone leisure time. The validity of this approach, however, turns on whether firms pay workers their exact reservation wage rather than a more general 'market clearing' wage.

We can see from Figure C.1 below that for a market clearing wage equal to W_0, all workers who are willing to supply labour at a wage lower than W_0 will enjoy private benefits because they will be paid more than their reservation wage. Individuals whose reservation wage is instead higher than W_0 will decide not to work.

We can now consider what happens to individual private benefits following a transport intervention. Suppose that a transport investment increases both labour demand and supply (ie, outward shifts in the relevant curves). The shifts can be illustrated on a standard labour demand/labour supply diagram. In Figure C.1, LS_0 is the labour supply curve before transport investment, and LS_1 is the labour supply curve after transport investment. LD_0 is the labour demand curve before transport investment, and LD_1 is the labour demand curve after transport investment.

The demand shift from LD_0 to LD_1 and the movement along LS_0 from Point A to Point T represent the increase in demand for labour as a result of increase in productivity. It is important to note that the increase in productivity does not shift the supply curve. Employment increases from E_0 to E_T. The supply curve shift from LS_0 to LS_1 and the movement along LD_1 from Point T to Point B represent changes in demographic factors (eg, due to the location having been made more accessible and attractive for individuals causing a rise in the active labour supply).

In the new equilibrium B, an increase in the market wage from W_0 to W_T can increase individual private benefits of those individuals who are already employed in the labour market (the intensive margin) who simply get paid more, as well as of those individuals who were previously either unemployed or outside the labour force (extensive margin). These people get paid more than the value of the leisure time foregone. The only individuals for whom the increased wage is roughly equal to the value of time foregone are those at the very margin. Much also depends on labour supply elasticities.[21]

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[21] An increase in the labour supply following an increase in real wages depends on income effect (people feel richer and want to work less) and on the substitution effect (leisure becomes more expensive and individuals want to work more).

Figure C.1   Welfare impacts from changes to the demand and supply for labour caused by a transport intervention
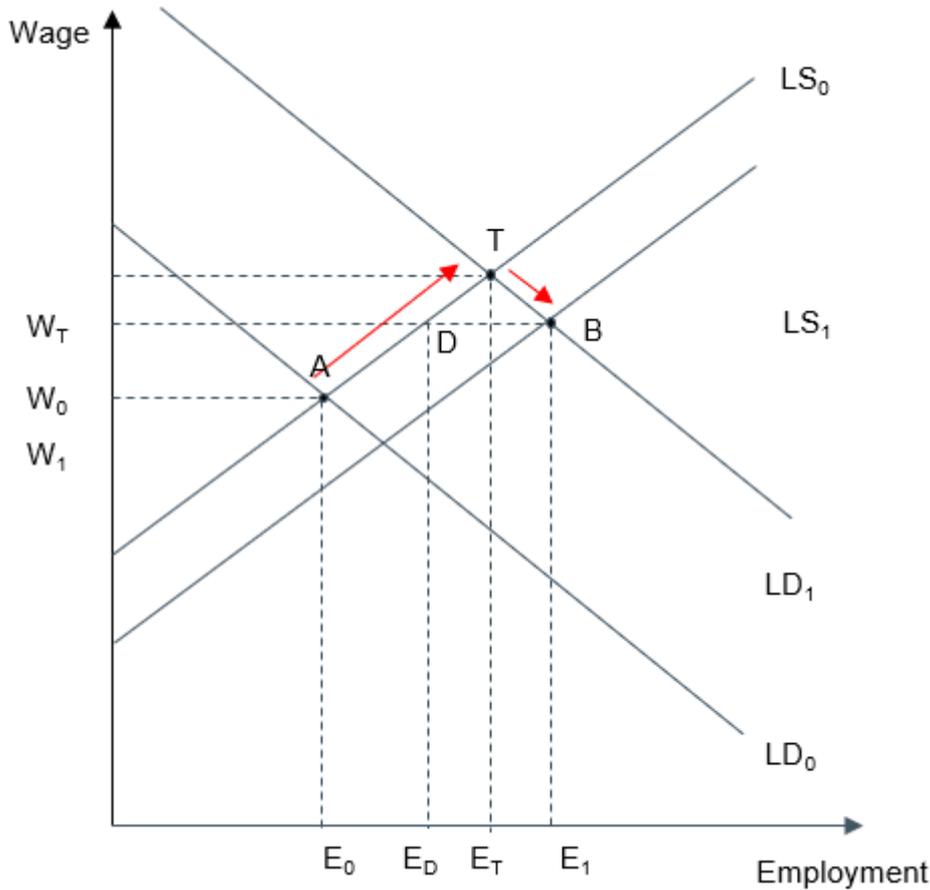
Source: NERA analysis

The welfare impact described below applies to both static and dynamic impacts. In the static case, firms and workers experience travel time savings, pushing out their respective labour curves. In the dynamic case, that effect is augmented by further shifts due to relocation. What the below analysis shows is how these effects can be disentangled using parameters such as elasticities of supply and demand, and the magnitude of shifts.

$$\%\Delta \; Employment = \frac{\epsilon_s * \%\Delta \; Demand \; for \; Labour + \epsilon_d * \%\Delta \; Supply \; for \; Labour}{\epsilon_d + \epsilon_s} \qquad \text{(Equation C.1)}$$

$$\%\Delta \; Wage = \frac{\%\Delta \; Demand \; for \; Labour - \%\Delta \; Supply \; for \; Labour}{\epsilon_d + \epsilon_s} \qquad \text{(Equation C.2)}$$

where:

- ϵ_d is the elasticity of labour demand
- ϵ_s is the elasticity of labour supply
- %Δ wage is the percentage change in the equilibrium wage
- %Δ employment is the percentage change in equilibrium employment

- %Δ demand is the percentage change in labour demanded at a given wage level (ie, the size of the horizontal shift of the demand curve, expressed in percent)

- %Δ supply is the percentage change in labour supplied at a given wage level (ie, the size of the horizontal shift of the supply curve, expressed in percent).

We observe the initial equilibrium (point A) before transport investment, and the parameters in demand and supply equation are estimated or calibrated using an econometric model (eg, S-CGE models). Then the final equilibrium (point B) is simulated by plugging in the change in productivity and the change in demographic factors. The elasticities can be obtained from models or assumed based on an extensive literature review. The intersection of demand and supply curves, Point T (ie, transitory equilibrium), can be computed by elasticities, the initial equilibrium, and the final equilibrium. These give us the following information:

- Employment at Point A (E_0)

- Wages at Point A (w_0)

- Employment at Point B (E_1)

- Wages at Point B (w_0)

- Elasticity of labour demand (ϵ_d)

- Elasticity of labour supply (ϵ_s)

- Employment at Point T (E_T)

- Wages at Point T (w_T)

Equations C.1 and C.2 can be used to analyse the impact of a supply shift alone (assuming %Δ $Demand\ for\ Labour$ is zero), and the demand shift alone (assuming %Δ $Supply\ for\ Labour$ is zero) given the elasticities. The percentage of workers displaced can be computed by:

$$\%\Delta\ Supply\ for\ Labour - \%\Delta\ Employment = -\epsilon_s * \%\Delta\ Wage \qquad \text{(Equation C.3)}$$

The changes in employee and employer surpluses are demonstrated in Figure C.2, and the changes are reported in Table C.1.

Figure C.2   Welfare analysis of changes in labour demand and supply caused by transport intervention
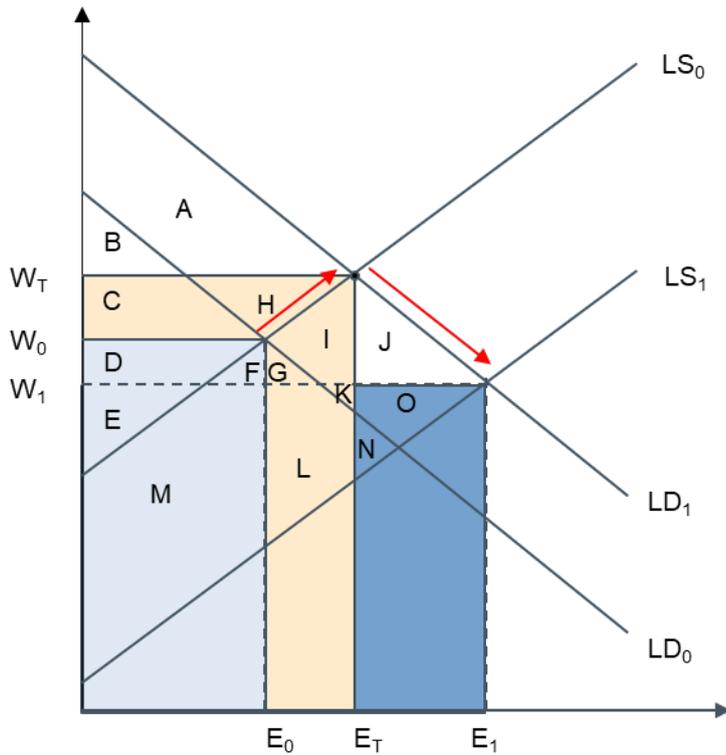
Source: NERA analysis

Table C.1   Welfare analysis of changes to labour demand and supply

	Initial	Change in relation to labour demand shift	Change in relation to labour supply shift	Net effect
Employee surplus	D+E	+C+H	+K+L+M+N+O-C-H-D	K+L+M+N+O-D
Employer surplus	B+C	+A-C	+C+D+F+G+H+I+J	A+D+F+G+H+I+J
Total	D+E+B+C	+A+H	+K+L+M+N+O+F+G+I+J	K+L+M+N+O+A+F+G+H+I+J
Total wage	w0*E0	wT*ET	w1*E1	

Source: NERA analysis