The economic impacts of connectivity
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An important note for the reader

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Executive summary

The effect on regional economies of large transport projects can be significant but it can also be challenging to measure and predict. The traditional transport appraisal bypasses the identification of specific benefits by estimating the welfare benefits to transport users with well-researched methods, as laid out in the NZ Transport Agency's *Economic evaluation manual*. However, there will be occasions when the quantum of the estimated welfare benefit will be incomplete and there will always be unanswered questions with regard to gross domestic product (GDP) effects and spatial distribution. This research paper explores two models that can provide insights to these unanswered questions. In particular, focus is on how improved connectivity between regions could lead to benefits beyond the traditionally measured user benefits and how the combined effects of reduced travel time and increased accessibility and connectivity would alter the spatial distribution, especially within a scenario of population growth.

The research consisted of a literature review, the building of two economic models and the application of these models in a case study region, chosen to be the combined areas around the cities of Auckland, Hamilton and Tauranga.

Transport changes can produce economic benefits through four major channels: (1) the transport user benefits, as mentioned above; (2) other productivity benefits; (3) efficiency benefits, resulting from reduced market distortion; and (4) land use benefits, resulting from changes in where we locate residences and work places. Of these, (1) to (3) are largely included with the NZ Transport Agency appraisal process, including productivity gains resulting from agglomeration of people under (2). The extensive research around agglomeration effects also shows these effects attenuate quickly over distance.

However, productivity effects have also been observed amongst regions close to large cities and to large air and sea ports. The hypothesis tested here is transport changes that reduce travel costs, including travel time, between regions will also lead to a productivity increase. This project shows how this productivity improvement might occur via specialisation of industry. It also confirms with a gross value added (GVA) model that higher productivity amongst several industries did accompany connection to the larger centre (via airports in this case) and that specialisation within New Zealand regions does lead to higher GDP in the region beyond the specialist sector. The project could not negate the above hypothesis but, equally, the project does not provide rigorous proof that improving connectivity in the future will result in specialisation and productivity gains away from the centre.

In fact, the findings of the project when it comes to land use changes, see (4) above, are that forces exist that may bias growth towards the major centre(s). This need not entail productivity declines in places away from the centre but the greatest benefits of the transport change may instead occur within or near the major centres.

The spatial dimension was provided by building a spatial computable general equilibrium model for the case study region – a first for New Zealand – that balances out prices, productivity and preferences. The model is presented as an early stage development of models in this genre. A more sophisticated model, including more sectors and imperfect competition, would be able to provide richer insights into the spatial dynamics around connectivity. However, for now, the first order effects resulting from relative pricing, productivity advantages and amenity attractiveness provide a representation of effects that would normally be expected – and provide a strong case to disproof in any appraisal should other transformational factors be hypothesised to be more significant. Other such factors are likely to be around specialisation. They could also include facilitation of international trade.

International trade is one area where research points to the likelihood of growth-enhancing externalities. This could come from specialisation and economies of scale and/or the channel of influence may be foreign direct investment and/or technology transfer. This project did not add to research about the transmission channel from transport to international trade to growth. But, again, this channel is put forward as a viable way that connectivity can lead to regional benefits in excess of transport user benefits.

More generally, the project does confirm that transport changes can interact with land use changes to provide benefits that exceed the user benefits, even when the standard wider economic benefits are added. Thus the potential for unreported benefits can be high when considering growing economies.

Using a hypothetical transport improvement in the study region, a one-off 0.2% gain in GDP and utility was estimated within the general equilibrium model under a nil population growth scenario, albeit the effect may require some years to fully emerge. This was approximately the same as the time saving input when weighted by the value of travel services. A further 0.1% GDP and utility was estimated as a result of agglomeration and connectivity effects on productivity. A standard transport cost-benefit analysis (CBA) was not available for the hypothetical transport improvement but such an analysis is likely to produce a result similar to the sum of these two effects (ie 0.3%). Unlikely to be captured in a transport CBA, a further 0.1% GDP productivity gain and an even higher utility gain were estimated to occur under a 1% higher population scenario. The model illustrates that improved connectivity can allow people, particularly at the margin, to better choose their residential and work locations to take advantage of higher wage rates on offer in zones that were previously too expensive for regular commuting. This may also enable them to live in zones with a greater amenity value.

Last, as alluded to above, the spatial model enabled the effects of the transport intervention to be described in terms of GDP and jobs, including how these would distribute spatially. For the transport improvements in mind for this project, the welfare benefits exceeded by a large margin the GDP benefits. The model, though, reinforced that further GDP effects are possible but these require coinciding investment in other production inputs, such as developed land, physical capital and labour.

The project thus provides two models that can be applied to major transport projects. Neither model is expected to shift emphasis in transport appraisal from transport user benefits but the models can complement the standard analysis in five ways. First, the models provide relatively accessible ways to test likely effects of major projects without the need for extensive traffic modelling, useful in the early stages of business case preparation. Second, the models provide a means to validate the currently derived benefit estimates, possibly leading to an iterative process of improvements to traffic demand assumptions. Third, the models provide a means to quantify benefits associated with land use change and, fourth, the models estimate the spatial effects of a major transport improvement. These land use and spatial effect estimates are unlikely to provide a definitive measure of what will occur, as the estimates are sensitive to the assumptions in the model, but the process of testing within the model will lead to more probing into and understanding of the dynamic effects. Fifth, the models also provide measures of effects that are more readily understood by stakeholders, namely effects in terms of GDP and jobs.

Abstract

Two econometric models were built to test the effects of reduced travel time between regions within New Zealand. A gross value added (GVA) model showed productivity was positively related to population density and to accessibility to international airports across New Zealand. A spatial computable general equilibrium model built for a subset of these regions near the major city of Auckland enabled estimation of the spatial and employment effects of both the direct time savings achieved in a road improvement and the subsequent productivity improvement derived from the GVA model. The findings included that road improvements favoured residence and work in the major centres, albeit this advantage was reduced by the productivity improvements, that marginal gross domestic product (GDP) and utility gains as a result of the road improvement would be higher with population growth and that utility effects exceeded GDP and employment effects. These results confirm for a scenario of changing land use that there can exist benefits from a transport improvement that exceed those measured by the standard transport cost-benefit analysis, even with the current NZ Transport Agency add-ons for wider economic benefits. However, these situations are likely to apply only to large projects.

1 Introduction

The core topic of this research was to assess what gains could occur as a result of a transport change and how these gains – and losses – would then be distributed across regions. For brevity the phrase inter-city is commonly used in the report but 'city' is intended as a village, town, city, district or region and inter-city is used inter-changeably with inter-territory or inter-urban or inter-regional.

There are two key contexts for the research report.

First, the general. Cost-benefit analysis (CBA, or more strictly social CBA) has been widely shown to provide a rational and practical approach to investment decision making. However, in some cases the claim is that CBA does not measure all benefits while, in contrast, there are other cases where claimed benefits have been difficult to find after the investment. Meanwhile, studies have failed to show the superiority of methods such as the computable general equilibrium model (CGE) or land use transport interaction (LUTI) model over CBA. This creates a challenge. From an observational perspective, there are many examples where growth and transport links have been closely intertwined. From a theoretical perspective, externalities and path dependencies are known to exist that undermine CBA. And from an analytical perspective, the counterfactual used in a CBA is not necessarily independent of the investment under consideration and a CBA does not cater well for subsequent adaption to unfolding events. This leaves the unsatisfying situation where:

1. In some situations a CBA **may** omit large benefits (or dis-benefits).
2. The CBA model does not provide much insight into the GDP and employment effects that **will** eventuate.
3. The CBA model often provides no information at all about the spatial distribution of benefits and costs.

Second, the specific. An earlier NZ Transport Agency research report (Byett et al 2015) into gross value added (GVA) models revealed, amongst other things, there was evidence of gains to be had from better transportation links between the territories, and possibly between territories and ports, and reiterated the finding that current modelling offered very few, if any, insights into the spatial distribution of gains from transport improvements.

This project looked further into both these issues: a spatial computable general equilibrium (SCGE) model was developed to consider how economic activity might relocate after any transport improvement; and the GVA model previously established would be refined – and updated – to show how inter-territory transport improvements might add further to national economic productivity. The study primarily addressed 2) and 3) from above but also makes contributions to 1).

An overview of how the models fit together is shown in table 1.1.

The current *Economic evaluation manual* (EEM) (NZ Transport Agency (2016) approach captures the welfare gains resulting directly from reduced travel time per trip and from agglomeration effects on productivity. No spatial or GDP insight is offered from this approach.

The GVA model aims to measure the productivity effects resulting from improved intra-city and inter-city access but may also capture benefits relating directly to transport use. The measurement is in GDP terms and identifies where the productivity improvement is to be expected but does not establish whether these locational productivity improvements result from higher or lower GDP activity at the location.

The SCGE model can take transport user benefits and productivity gains and show how these gains might generate further welfare and GDP effects as people relocate in response to relative price shifts (or locate in a growth situation). The model provides welfare and GDP measures at a locational level.

Each model was built from explicit or implicit assumptions as to why the various effects might occur, based on various strands of research but without necessarily testing the validity of these assumptions.

Table 1.1 Overview of effects measured in models within this report

Welfare benefit	Modelling welfare benefits		Modelling GDP effects		Modelling spatial effects	Plausible reasons for effects to exist[(a)]
Transport user benefits			(b)			Low (or zero) utility is gained from time spent travelling (hence reduced travel time is of value).
Externalities due to intra-urban urbanisation and localisation	EEM		GVA MODEL			Increased competition. Improved coordination. New firm nursery. Better job matching. Increased skill specialisation. More knowledge exchange.
Externalities due to inter-urban localisation						Specialisation around existing industry. Increased innovation derived from higher international trade and investment.
Changes in land use		SCGE MODEL		SCGE MODEL	SCGE MODEL	Better able to match work-residence locations with preferences, leading to changes in locations of firms and households.

(a) Many of these effects are postulated to occur and are reasons to expect the model effects but have not explicitly been modelled

(b) It is possible the GVA model may be picking up some productivity effects related directly to reductions in travel time

The focus in this report is economic benefits. The safety and environment benefits that also exist with a transportation intervention are ignored but this by no means implies these benefits are unimportant.

The report is structured as follows. The literature review forms the bulk of chapters 1 and 2, chapter 3 is a link chapter into the next stage of the research. Chapters 4 and 5 describe the construction of the GVA and SCGE models. These are then applied as case studies in chapters 6 and 7 while chapters 8 and 9 wrap up the report with discussion of and recommendations from the findings.

2 Literature review

2.1 Introduction

The following literature review considers previous work relevant to the construction of a SCGE model and a GVA model. Besides a general overview of issues, attention is paid to how improved inter-territory transport could potentially affect territory production and employment, and in particular to how these effects are currently included or excluded from the standard transport CBA.

The NZ Transport Agency (the Transport Agency) appraisal, as per the EEM, has at its core a microeconomic approach that estimates the benefits to transport users. This approach has been shown to neatly estimate the magnitude of gains to society under conditions of perfect competition, even though changes to consumption and production in non-transport markets may be many faceted. Importantly, the approach avoids the double-counting of benefits to society that can easily eventuate by adding and deducting losses and gains within non-transport markets. This transport-focused approach may not capture all the gains to society when markets are not perfect; nor does the approach provide much insight into the industrial and spatial nature of any economic effects. It is into these two domains that this research project delves, keeping in mind the requirement to align any analysis with the existing EEM framework.

The Transport Agency has already undertaken other research into appropriate add-ons to the standard transport CBA that might capture wider economic benefits. Kernohan and Rognlien (2011) categorised these under the headings of agglomeration, competition, labour supply, employment redistribution, inward investment and gains from trade. The EEM today incorporates procedures for estimating effects relating to agglomeration, imperfect competition and increased labour supply (p2-7).

The GVA and SCGE models developed here are likely to sit alongside the transport user approach. Internationally Lakshmanan and Anderson (2002) categorise three approaches to transport appraisal being pursued, namely: the microeconomic approach (as per the EEM); the macroeconomic approach (as per the GVA); and the general equilibrium approach (as per the SCGE). This project is within the domain of the second and third approaches, and as such is expected to fit more closely with developing better information about distributional effects of a major transport improvement rather than upscaling the currently estimated benefits.

One of the key findings of research into connectivity is that the context matters. There can be potentially large effects beyond the transport market but these depend on local situations. Thus when applying the GVA and SCGE models to a case study, it is important to understand the make-up of this area. Various papers describing and modelling the area are considered within this literature review, both to provide an initial assessment and to enable quick reference later. When it comes to the case study, a number of people and reports have advocated developing the Auckland–Hamilton–Tauranga (AHT) triangle as an important means to advance New Zealand productivity (McCann 2009a; Grimes 2008; Proctor 2011). The challenge is to show how this productivity improvement might emerge and to make a judgement as to whether it can occur in this region. These are issues addressed within this report. More generally the report is concerned with the economic effects of connectivity, with ‘connectivity’ taken to mean in this report the linkages between places, as opposed to linkages within an urban environment. That is not to say that intra-urban linkages are not important but rather there is a large body of research and accepted wisdom around gains to be had from larger cities that has already been incorporated into the Transport Agency appraisal system via the ‘agglomeration effect’. The issues of interest here are as follows:

- How will businesses and people re-organise after a transport intervention?
- Are there further productivity gains to be had by connecting cities and regions better than are already likely to be picked up in the standard transport appraisal?

There is a body of research presented here that shows transport interventions will lead to re-organisation. This research also points to the need for fast-growing regions to continually learn, adapt and build human capital. The research also warns there will be winners and losers as a result of change. Just how these changes might play out is the topic of the third phase of this project where a SCGE model will be constructed to estimate how people and firms react to the price signals resulting from an initial change in travel costs.

The research also points to the possibility of external effects that may increase the net gains to be had from change that are not otherwise captured within the standard transport CBA. Generally these have been referred to as agglomeration effects but it is more useful in this report to separate agglomeration into 'urbanisation' and 'localisation' effects. Within a city the two effects work together: more people in general (urbanisation) leading to more information diffusion; and more co-location within industries or functions (specialisation) leading to external economies of scale. Between cities, the research suggests the distance is too great for urbanisation effects but there is still the possibility of localisation effects.

Some relocation of people and firms away from the central city is to be expected as higher rents and wages in the more productive city incentivise people and firms to relocate to where profits will be higher and/or personal income net of travel and housing costs will be higher. In some cases, though, this re-organisation can also lead to a wider spin-off for the smaller community should their specialisation lead to external economies of scale, eg clustering effects that, in turn, initiate a virtuous cycle of learning, upskilling and human capital accumulation.

Potentially the benefit from inter-urban localisation externalities over a long period of time could be huge but more often the gains are likely to be modest. The challenge for decision makers is to know when the former is more likely than the later. This is not pursued in this project. Rather the second phase of the project will be to expand the GVA model that was previously developed to further explore the possibility that better connectivity between cities might be generating positive effects beyond transport users, including via inter-urban localisation effects.

There is potentially a fourth welfare benefit, ie on top of direct travel benefits, intra-city agglomeration benefits and inter-city localisation benefits that may also eventuate from any change, namely improvements in allocative efficiency, sometimes referred to as general equilibrium (GE) effects. This can be easily forgotten in transport appraisal but it is one component that will be explicitly considered in the SCGE modelling.

Returning to the specific, it is worth recalling that the Auckland–Waikato-Bay of Plenty regions include eight of the 10 fastest growing towns/cities in New Zealand between 1926 and 2006 (Grimes et al 2014). Irrespective of any marginal inter-urban connectivity effect, there is likely to be continued strong population growth and there are likely to be substantial intra-urban effects from inter-urban transport investments. These reasons will also be behind the widespread advocacy of more investment in the region.

The following sections are as follows.

1 A brief overview of the New Zealand GVA model previously developed.

2 A general overview of what connectivity is and how it might affect (a) productivity and (b) spatial activity

3 What can be learnt from New Zealand models, research and experience?

4 What SCGE models exist and how do they include connectivity effects?

5 How is improved connectivity incorporated into transport decisions?

2.2 The GVA model

An earlier Transport Agency research project developed a GVA model to examine the territorial impacts of travel time savings (Byett et al 2015. The model has two-stages: first expressing employment by territorial authority as a function of some people-based explanatory variables and a set of several accessibility variables, and second expressing GDP as a function of employment and the accessibility variables; as below.

$$Employ_t = f(Pop_t\ XVAR_t\ A40_t,\ A120_t,\ AAir_t,\ ASea_t) \quad \text{(Equation 2.1)}$$
$$GDP_t = g(Employ_t\ XVAR_t\ A40_t,\ A120_t,\ AAir_t,\ ASea_t)$$

Where $Employ_t$ and GDP_t are vectors of number employed and real GDP by territorial authority (TA) area at time t for an industry sector.

$XVAR_t$ is a matrix of people attributes associated with each TA area at time t.

The four access vectors (the As) are as defined in table 2.1.

Table 2.1 Access variables used in GVA model

Variable	Alstadt et al (2012)	This project (with code used)
Local labour market	Proxy of population within a 40-minute drive (being 80th percentile for US commute time) from population centroid less county population.	A40 – Proxy of working age population within 40-minute drive of population centroid. The drive time calculated using 2014 roads and speeds but using 2001 or 2006 populations by meshblock. The population of the meshblock was included in the drive time total if the meshblock centroid was within the 40-minute polygon.[1].
Regional delivery market	Proxy of employment within 120-minute drive from population centroid less 40-minute population total from above (approximately captures same-day deliveries).	A120 – Proxy of working age population within 120-minute drive of population centroid, calculated in same manner as above, less A40 working age population.
Access to domestic airport	Number of annual operations at nearest commercial airport to the county divided by drive time to nearest airport	AAIR – Drive time to port divided by average number of flights between New Zealand airport and Australian ports per month, where New Zealand port was closest airport with flights to Australia (except Auckland used in place of Hamilton airport north of New Plymouth). 2006 flights were for the year ending March 2006 and 2001 were for the year ending June 2004 (the earliest available data). Flight data was sourced from www.bitre.gov.au/publications/ongoing/airport_traffic_data.aspx Drive time was as at 2014.
Access to seaport	Drive time to closest marine port (weighted by size of operation at port in subsequent research – personal correspondence)	ASEA – Drive time to seaport divided by number of port visits during 2013, where port was closest seaport with international visits. Visits data was sourced from www.transport.govt.nz/ourwork/sea/figs/ Drive time was as at 2014.

[1] Less than 20% of people commuting to work in 2006 travelled more than 20km, a distance that can be reached within 40 minutes travelling at 30km/h.

The study found that under different circumstances there were effects of wider accessibility (termed connectivity in this report) on local GDP but it was difficult to differentiate which of the wider accessibility variables – to delivery markets, to airports or to seaports – were of key influence.

Two further difficulties with that study of relevance to this project were (a) sensitivity of the results to small changes in travel time around the 40 and 120 minute thresholds, implying this was not a good measure for practical application and (b) the inability to say much about the location of any benefits predicted. The development of a CGE model in this project addresses (b).

The first difficulty is investigated by establishing an updated GVA model in this project. This entails exploring which connectivity variables might be suitable to include within a GVA model, ie to find an appropriate term(s) for $Connect_{it}$, a measure of connectivity that influences GDP for the defined industry sector within territory *i* at time *t*.

$$GDP_{it} = g(Employ_{it}\ XVAR_{it}\ Access_{it},\ Connect_{it}) \qquad \text{(Equation 2.2)}$$

Connectivity measures[2] related to population within two to three hours and travel time to airports and seaports were considered and shown to be of some influence in the initial GVA study.

A model update will also include new data from the 2013 census.

2.3 What is connectivity and why is it important?

2.3.1 Connectivity, agglomeration, urban form and transportation

In broad terms connectivity means 'the state of being or being able to be connected' (Collins Dictionary). This could occur through people and businesses being near to each other, as is the case in urban environments, or it could occur through distant masses of people and businesses being linked via transport and/or communication channels. It is the latter inter-urban effect that is the major focus of this report. For the sake of brevity, this report will use the term 'accessibility' when discussing intra-city effects and 'connectivity' when discussing inter-city effects. However, it is noted the distinction is not always clear cut.

More precisely, connectivity refers to not just direct links between urban environments but also considers the indirect links provided by nodes such as airports, seaports and intermodal rail-road land ports. Alstadt et al (2012) define these indirect nodes more generally to be feeder transit, rail or air services to long haul or high speed lines.

Connectivity is one factor that shapes where we live and where we work. It is generally acknowledged that a change in firm connectivity will change these spatial distributions and can lead to higher productivity but there is no consensus at present as to how any change in connectivity fits with other factors that determine urban form.

Some results and observations are uncontentious, such as those listed below (see appendix A for detail).

- There is strong population growth within international cities.
- Productivity gains occur within cities due to agglomeration effects or scale and are termed 'urbanisation' and due to specialisation effects within industries (eg finance) and within economic functions (eg management), termed 'localisation'.

[2] It may be that an interaction term(s) between connectivity and employment is also required

- While these productivity gains have largely occurred due to spatial concentration, intra-city transport improvements can increase these productivity gains by bringing people and business closer together in terms of travel time.
- This urbanisation effect attenuates quickly over 5–30km.
- Cities are dynamic, including some industries shifting from the central business district (CBD) to the suburbs, and eventually to the hinterland as resource costs within cities increase.
- Transport costs have generally decreased over time but demand for complex and customised transportation has increased transportation costs for some products.
- Inter-city transport improvements have contributed significantly to the spatial and industrial shape of cities and regions today, affecting migration and trade patterns.
- Inter-city transport improvements can facilitate specialisation between cities.
- Which firms and regions win and lose from improved transportation will vary in different situations.

The later point lies at the heart of the differing approaches to explaining urban form. Cities are different, cities are often dynamic and change is not the same in all places and at all times. Storper (2011) says economic geographers tend to focus on the specific forces that determine an observed economic development – to them context is fundamental – while economists tend towards models that generalise across many situations, typically categorised as models of new economic geography (NEG) and urban economics, both in turn parameterised with average effects.

The NEG models show how firms can use economies of scale to create excess profits and high wages through a process of innovation and differentiation. A typical conclusion is that products will concentrate within specific firms, as economies of scale force specialisation, and firms may also spatially concentrate to take advantage of spillover effects from similar firms or firms using similar inputs. Thus specialisation and higher productivity go hand in hand. The higher wages plus cheaper and more varied products also create the amenity to attract new workers. Trade costs act as barriers to protect monopolistic competition, or once reduced may act to set in motion the endogenous process of competition, innovation and differentiation again. This is one channel through which connectivity matters to urban form, ie via trade. These models, though, are silent on what starts the process and largely agnostic as to the spatial relocation of firms and people in the process[3]. For example, a reduction in trade costs between Auckland and Hamilton may mean that firms relocate from Auckland to Hamilton or from Hamilton to Auckland or that both occur.

The urban economic models do have something to say on the spatial relocation but also have little to offer about the source of the initial shock. These models put emphasis on the trade-off people make between wages, housing costs and local amenities. Thus higher housing costs in Auckland not accompanied by higher wages or improved amenities would be expected to prompt migration to places with lower housing costs and/or greater amenity. This in part is occurring now as people shift to the Bay of Plenty and the Waikato in the face of lower real wages in Auckland, at least amongst non-house owners.

Economic geographers do not tend to put emphasis on a narrow set of universal forces and instead focus on the specifics. However, Storper (2011) does refer to three generalisations noted by economic geographers, broadly defined[4]. First, there exists a divide between the activities that are innovative or uncertainty-dominated and those that can be made routine. This matters when it comes to potential relocation. Activities of the first kind are likely to be place bound, and hence people are likely to shift to

[3] Other than NEG models forecasting whether it might be spatial concentration or dispersion

[4] Some of these generalisation are also built into NEG models

these locations once trade costs are reduced, while the second group of activities may be more inclined to relocate in the face of lower trade costs. Again the connectivity channel is via trade and the cost of trade. Transport improvements in both cases are likely to accelerate the concentration of activities. Second, economic geographers offer partial answers to the 'where' of agglomeration, pointing to 'radical innovations' – as often seen in the US – as providing starting points for locations and not being dependent on existing resources and infrastructure versus those 'related-variety innovations' that evolve out of the existing co-location of firms, labour and institutions, as is more typical in Europe. Third, specific situations bear some consideration – not all differences are simply the noise or random effects assumed within economic models. In particular, there are the specific industrial and political institutions – the regional 'dark matter' – that can advance or hinder the dynamic tendencies created by changes in technology, trade costs, agglomeration and migration. This has relevance as to where the much sought-after endogenous growth process may occur. In turn, these institutional factors may act to facilitate or hinder a trade and relocation response to any improvement in connectivity.

In sum, there is no one model or set of models that explain the dynamics of cities. The key role of connectivity is likely to come via trade but any trade effects, and the associated relocation of activities, will likely involve price changes within monopolistic markets, with these markets and the people involved not necessarily flexible and fully informed, and with a coinciding change in real wages. These dynamics do present some challenges for economic modelling and hence investment appraisal.

2.3.2 Better connectivity leading to higher productivity

This section shows ways that inter-city connectivity might improve productivity, bringing together the appraisal undertaken by the Transport Agency today and the connectivity channels introduced above.

The starting point and the partial framework for the following discussion are the four mechanisms through which welfare can be affected by transport interventions as discussed by Laird and Venables (2016):

1. User benefits
2. Agglomeration
3. Induced investment and land use change
4. Employment.

The user benefits capture welfare changes to users of the transport system, which in turn also capture the welfare changes in the wider goods and labour markets that derive from use of transportation as a factor of production under conditions of perfect competition. Some of these welfare changes from a transportation improvement will manifest as higher productivity when the saved time and resources used to travel are applied to production; some will simply show as more leisure and, in New Zealand's case, less imported fuel. For simplicity, all three types of benefit are referred to as 'productivity' gains in section 2.3.

The more contentious channels for productivity gains are the non-user channels, ie 2 to 4 in the above list. Previously SACTRA (1999) had categorised the non-user channels as situations when:

- prices diverge from marginal costs in the transport-using sector, in the goods market, or the labour market, or
- innovation effects are induced, or
- changed growth rates of the capital stock in the transport-using sector occur[5], or

[5] This will generalise to non-transport sectors as well

- economies of scale exist which reduce production costs but are not reflected in extra road traffic.

Likewise Kernohan and Rognlien (2011) in research for the Transport Agency categorised the non-user channels as below, with the EEM now incorporating procedures for estimating effects relating to agglomeration, imperfect competition and increased labour supply (pp2–7).

- agglomeration
- imperfect competition
- labour supply
- employment redistribution
- inward investment
- gains from trade.

Lakshmanan (2011) provides a similar list of wider economic benefits, with the major difference being the separation of coordination possibilities (discussed under 3) by Laird and Venables (2016)):

- gains from trade
- technology diffusion
- coordination device and the 'big push'
- gains from agglomerations.

These respective channels are investigated to consider benefits in general and benefits related to inter-city connectivity in particular. The channels are discussed under four headings, with further differentiation as to whether the channel is fully included in the EEM at present or not (as per table 2.2).

Table 2.2 Categorisation of benefits

Nature of benefit	Fit with EEM	Benefit
User benefits	Within EEM	User benefits
	Not within EEM	Forecasting inaccuracy not otherwise revealed
Agglomeration	Within EEM	Urbanisation
	Not within EEM	Localisation
		Technology transfers
Other market failures	Within EEM	Market power
		Tax distortions
		Congestion
		Business variety
	Not within EEM	Thin labour markets
		Household variety
Land use changes	Within EEM	Only those assumed to occur 'independent' of the investment
	Not within EEM	Co-ordination failure
		Public goods
		Path dependency

2.3.2.1 User benefits

Any change in the transport market can lead to changes across many other markets. The challenge to economic appraisers is to measure the total social effect of what might be a long chain of events.

Measures currently within the EEM

Two situations exist when this exercise reduces to having to simply measure the benefits to transport users: Boardman et al (2011) show that any change in social welfare can be measured in the primary market, eg the transport market, when *prices in other markets are unchanged*, as is likely when the transport intervention is small; and likewise, if prices in secondary markets do change, the total social welfare effects will be measured in the transport markets *when markets are perfectly competitive*. Both results depend on conditions of perfect competition outside the transport sector and therefore exclude the effects of externalities (to be discussed below).

Jara-Diaz (1986) reduced the issue to elasticity of demand functions. He takes a goods market that is independent of other markets and shows that the consumer surplus in each location will equal the surplus in the adjoining transport market for perfectly competitive markets but not necessarily be equal for monopolistic markets. He infers the defining factor to be the degree of elasticity of demand, ie if demand is elastic, as per perfect competition, then change of consumer surplus in the transport market will approach the change in consumer surpluses in the two locations for the given goods market and otherwise could be above or below the sum of changes in non-transport consumer surpluses.

In the situation where prices do change, there might be changes in the production and consumption of goods across many industries and locations. Thus the gains that can be measured in the transport market – mainly travel time savings and lower transport operating costs – may manifest themselves in other economic guises (eg more non-transport production) but separate accounting of other economic benefits that do not result from a productivity gain is likely to be a double-counting of benefits to society.

Given focus in this report on inter-city connectivity, it is worth noting the resulting multi-market re-organisation may include relocation of firms. Under conditions of perfect competition and ignoring externalities for now, the societal benefit of this relocation will be included within the measurement of user benefits. The logic of this follows by example. Prior to a transport improvement, a firm may choose to locate in Hamilton to service the needs of Hamilton consumers. There may exist some productivity advantage of relocating to Auckland, including possibly internal economies of scale (see more on this below), but the delivery costs exceed this potential benefit. After a transport improvement to the Hamilton–Auckland route, the cost of delivery from Auckland to Hamilton may reduce sufficiently to enable more goods to be produced in Auckland at a price that, even after delivery, achieves the same or lower price to the Hamilton consumer than previously. The relocation of production represents a rightward shift of the transport-using goods supply curve and is also part of the movement down the transport demand curve.

More generally, in a perfectly competitive market, the lower transport costs result in a lower consumer price for transport-using products and this can entail relocation of activity so distant producers pass through a delivery cost reduction, as above, or local producers take advantage of the lower transport costs of inputs from distant locations (eg Hamilton producers may switch to Auckland suppliers). The spatial direction of relocation will depend on the balance of transport costs for input and outputs, among other factors, but the total societal benefit will be measured within the transport user benefits.

As an aside, one implication of relatively high transport costs is that firms within industries without economies of scale and a large local input cost will tend to locate near consumers and use local inputs (eg cafés). Conversely, internal economies of scale and lower transport costs will tend to favour fewer firms (Minken 2014) and will expand the range of firm locations (Lakshmanan and Anderson 2011).

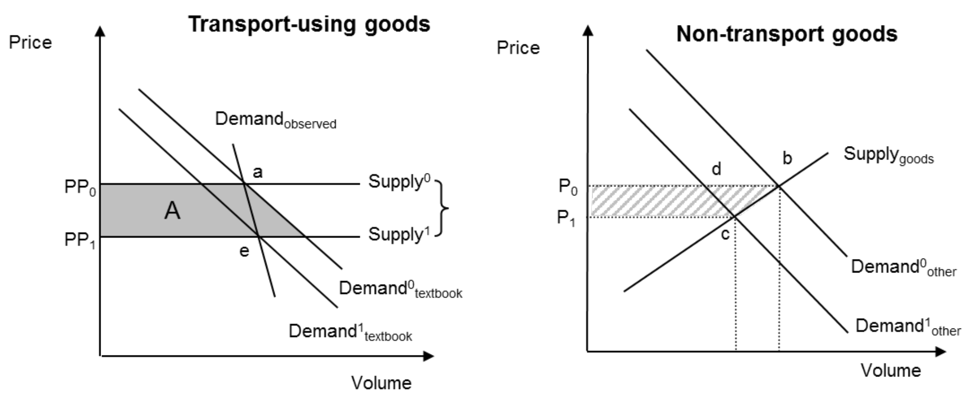
The example above extends to a situation where economies of scale exist with the transport-using firm, as shown in previous research. Mohring and Williamson (1969) looked at the situation of a transport improvement for a transport-using firm that had increasing returns to scale and monopoly of a goods market. They showed the benefits in the transport market would match the benefits in the goods market, ie the transport analysis would capture the internal economies of scale. Mohring and Williamson (1969) go one step further and infer that, in their monopolist situation, 'reorganisation' benefits[6] were conceivably only around 13% of 'direct' benefits, based on the economies of scale estimated for US sectors in 1947. They distinguish between 'direct' benefits that result for previously established production and 'reorganisation' benefits that result from new production. Hence, the inference from this paper is that not only can the user benefits in the transport sector fully capture the total societal benefits but also the benefits pertaining to existing production and consumption can provide a reasonable first-order estimate of total benefits.

The difficulty with application of both inferences is the presumption that, as in all the above situations, a socially optimal allocation of resources exists prior to the transport intervention. If that is not the case, as discussed by Minken (2014), then it is possible a transport intervention can lead to improvements in allocation (ie benefits additional to the user benefits) *or* movements away from a socially optimal allocation in which case there will be dis-benefits that are additional to the user benefits. This is explored in a section 2.3.2.3 but, first, we return to the Boardman et al (2011) proposition that user benefits match total benefits.

Boardman et al (2011, chapter 5) illustrate that a price decrease in a primary goods market – say the sole transport-using sector – will lead to changes in other goods markets, which in turn will feed back into a change in demand in the primary sector. Consider a transport improvement that leads directly to a lower price in the sole transport-using sector, referred to as the primary sector. The shift along the downward sloping demand curve leads to a higher quantity demanded and the usual measure of increased consumer surplus can be derived (depicted as A in figure 2.1). Under a scenario of unchanged total productivity, the demand curve for the secondary good moves leftwards (due to the relative price change) which leads to a lower secondary good price. This leads to an increase in consumer surplus for the secondary good (say B measured by P_0dcP_1) and a decrease in the producer surplus (say C equal to P_0bcP_1). The lower secondary good price, in turn, leads to a leftward shift of the demand curve in the primary market (due to the second relative price change). The eventual net effect is that the quantity demanded for the primary good is less than implied by the initial 'textbook' demand curve, based on its ceteris paribus assumption. Boardman et al (2011) apply the eventually 'observed' quantity demanded to estimate the change in consumer surplus in the primary market, namely PP_0abPP_1. They illustrate that this *approximates* the net of the three changes in social surplus, namely A + B - C. Thus:

- the calculation of user benefits is based on an 'observed' or 'GE' demand curve, and not the textbook or partial equilibrium variety
- the calculation includes adjustment for allocative efficiency that results from relative price shifts, but
- the resulting measure of user benefit is only approximate, albeit a close approximation for small changes.

Figure 2.1 Primary and secondary market effects



[6] In this context 'reorganisation' benefits are the transport benefits associated with induced demand.

Measures currently not within the EEM

Two key implications follow from this approach to approximating total benefits from user benefits, putting aside issues of market failures.

First, the measure of user benefits derived is the improvement in societal welfare. This will generally differ from GDP effects and it does not reflect the spatial distribution of GDP effects. An interest in the spatial effects leads to consideration of transport investments in an SCGE framework, as taken up in section 2.5.

Second, full consideration of the interactions in markets following a transport intervention, as in a SCGE model, will generate a different total benefit than the above partial analysis approximation – slightly different for small transport changes but potentially very different for large changes. This is because it models how resources are redistributed within an economy, and takes into account not just the benefits that might arise from improved productivity within individual production units but also any redistribution of production that results from further trade (Lakshmanan and Anderson 2002, chapter 7). This is the subject of a subsequent section on SCGE models.

Forecasting accuracy

For now it is noted, though, that the ‘observed’ demand curve used within the standard CBA is in fact an *expected* observed demand curve, ie it is not actually observed but is an ex ante derivation. Such an estimate requires balancing (somehow) a potentially large set of forecast changes to relative prices and real incomes – a challenging proposition. This is undertaken more explicitly by a SCGE model. To reinforce the point above, for small changes or changes which have little effect on relative prices and real incomes outside the transport-using sector then the partially derived benefits and those derived from an SCGE should be similar; for large transport changes, where the complexity of interactions between markets invariably increases, the two benefit estimates are likely to vary significantly.

Furthermore, difference between the two methods can arise even though perfect competition may exist. The issue at this stage is simply estimation of demand.

Of course, this issue of forecasting is a more general problem. Measuring effects within the transport market does rely on accurately forecasting the level of transport demand, which in turns derives from many forecasts of a wide range of economic interactions, a point discussed by Lakshmanan and Anderson (2002) but noted as a particular challenge for a ‘major infrastructure improvement’.

To complete this section, for now it is noted that SACTRA (1999) reports the above types of non-user issues and interactions can be provided for in a SCGE model but, also, rather than expecting any CGE results to be used for appraisal, it is envisaged the value of the SCGE model is in providing ‘diagnostic checks on whether it is likely that conventional appraisal methods might be seriously biased’; this would especially apply to large projects.

2.3.2.2 Agglomeration

Various externalities exist within an economy. These create social benefits and costs not captured within any measure of transport user benefits. One set of positive externalities of importance to cities and to transportation within and between cities is that relating to agglomeration effects. Note in practice agglomeration benefits derive from a mix of externalities and monopolistic competition but the agglomeration effects are presented here within a discussion of externalities; section 2.3.2.3 will broaden the discussion on imperfect markets.

Measures currently within the EEM

Amassing people together has been shown to lead to higher productivity. This is a widely researched finding. McCann (2009) notes the agglomeration effect is multi-dimensional and includes increased competition, improved coordination, a nursery role for new enterprises, labour market matching, increased skill specialisation and increasingly knowledge exchanges. Any resulting comparative advantage need not be at a sector level but could be at a task level, often embodied in intermediate goods and/or services (Grossman and Rossi-Hansberg 2006). Kernohan and Rognlien discuss two non-user benefits – agglomeration and employment redistribution – that can be combined within agglomeration effects.

An important distinction is between urbanisation and localisation agglomeration economies. Productivity increases can result from urbanisation, being higher density and variety in general, and localisation, being higher co-location of firms within an industry. Localisation is often associated with city or regional specialisation.

This urbanisation agglomeration economy effect is currently appended to the standard EEM analysis as a wider economic benefit (WEB). It is also an effect that shows in the previous GVA model as a positive elasticity of GDP to the working age population within a 40-minute drive to many industries. The key relevant finding of the literature is that this effect attenuates quickly. In other words, the agglomeration effect, being the sum of urbanisation plus localisation effects, is mostly pertinent to intra-city transport projects. This is discussed further in appendix C.

Before moving on, it should be noted that the attenuation of density effects may differ for high speed rail projects. One thread of research starts with Overman et al (2009) estimating UK accessibility effects using a generalised travel cost (GTC) inverse weight of nearby employment. They inferred a 20-minute reduction in train travel time between Leeds and Manchester (a scheduled train trip of approximately one hour at present) would provide a one-off wage rise in and around Leeds and Manchester of between 1.1–2.7%. The results of Graham et al (2010) suggest a relevant accessible mass at this distance apart may be around 25% of the level assumed by Overman et al (2009) and hence the benefit could be overstated. However, KMPG (2013) show the travel propensity does indeed diminish quickly with GTC but not as quickly for rail and car business trips[7]. The World Bank (2014) report a higher percentage of business travellers on high speed rail between Changchun and Jilin (40%) and also between Beijing and Shanghai (63%). These facts suggest the channel of effect and the effect of distance may be different for high speed rail than road – possibly reflecting the differing levels of productivity that can be achieved by the business traveller.

Measures currently not within the EEM

a) Localisation

While the above results point to rapid attenuation of agglomeration effects, it is possible that improved inter-city transportation links can still lead to localisation economies if the inter-city connectivity leads to specialisation in (ie increased concentration of) industries. Neighbouring businesses in an industry may benefit from the relocation or expansion of that industry. This type of clustering effect can occur at locations within the major city or within the now better-connected hinterland. The subsequent clustering of information, skills and possibly employment functions are external effects that can lead to higher productivity not otherwise captured within the standard CBA.

Rosewell and Venables (2013) and an accompanying working paper by Venables (2013) identify the relevance of these effects to appraisal. They differentiate inter-urban connectivity effects into (a) direct

[7] This study used these propensities to estimate accessible masses but did fail to take into account people effects, so their findings also likely overstate the benefits of HSR improvements.

travel cost savings, as captured within a standard transport appraisal, and (b) urbanisation economies of scale within a city, as typically captured within the agglomeration benefits identified within the Transport Agency's EEM, and (c) inter-city connectivity benefits in the form of external economies of scale that result from specialisation of industries or tasks. Venables (2013) estimates these specialisation scale economies can be potentially large but warns that a transport improvement may be a necessary but not sufficient condition for the gains to be realised. This is consistent with the discussion around context and geography in section 2.3.1.

To be clear, specialisation within one city may occur as a result of an inter-city transport improvement. Simplified[8] versions of the three possible situations are described below.

1. There are no external localisation economies of scale to be had from any specialisation. The welfare benefit of any specialisation of industry and tasks between cities will be captured within the direct transport benefits as in a standard transport appraisal.
2. There are external localisation economies of scale possible as a result of specialisation and this specialisation *does* occur. The welfare gain will be the direct benefits already included within the standard transport appraisal plus the productivity gains that result from localisation and not otherwise measured. The magnitude of the productivity gain and the spatial distribution of direct and productivity benefits is an empirical matter.
3. There are external localisation economies of scale possible as a result of specialisation and this specialisation *does not* occur, possibly due to a lack of coordination. The transport investment in this case has been a necessary but not sufficient condition for specialisation and hence for any productivity gains to eventuate.

Venables (2013) shows how these three situations can be represented by a model but the issue of what the combined effects will be then becomes an empirical issue, and one that to date has not received much research. Rosewell and Venables (2013) describe the sort of growth defined by (2) and potentially by (3), quoting Leunig, as connecting up 'places that are synergistic'. The subsequent specialisation may occur because of comparative advantage or, for similar cities, because firms will develop new ways to access suppliers and markets. As mentioned previously, the spatial implication of this specialisation will not be picked up within a CBA but can potentially be estimated within an SCGE model[9].

b) Technology transfers

Implicit in the gains from trade is the introduction of new products and possibly new capital investment into one or more of the cities affected by any transport intervention. The benefit from this trading and investment is largely captured within user benefits, as discussed above. However, there is the possibility, as suggested by Lakshmanan (2011) that any new goods and services brought into the city, either from other cities or from abroad, could incorporate new technology which enables knowledge diffusion. This technology transfer externality is likely to be confounded with any localisation effects and is probably best considered under that category.

2.3.2.3 Other market failures

[8] Other assumptions also define the situations

[9] Note, the model later derived in this study partially captures the spatial effect of extra productivity by taking the quantum of extra production resulting from agglomeration, comprising urbanisation and localisation, and deriving the spatial respond to existing relative wages, house prices and travel costs but does not capture the spatial effects that might result from specific externalities and consequent wage changes (eg other factors dictate that the specialisation occurs in Hamilton and leads to higher wages in Hamilton).

As mentioned above, the approximation of transport user benefits to total benefits may break down when market failures exist. This is typically presented as marginal prices not equating to marginal costs, as discussed by SACTRA. However, it is appropriate to be reminded of the previously mentioned paper by Mohring and Williamson (1969), who show the user benefit approximation can apply under circumstances when marginal prices are not equal to marginal costs – in this case there was a single monopolist bearing all the transport costs. Minken (2014) showed the existence of economies of scale amongst multiple producers in the transport-using market – as opposed to the one producer assumed by Mohring and Williamson – will lead to effects beyond the user benefit approximation, some of which, by the way, could be realised by means other than a transport improvement. Hence, the more general issue appears to be sub-optimal initial allocation.

A sub-optimal market outcome – in the sense that welfare is not maximised due to situations existing where the marginal social benefit from a trade exceeds its marginal social cost – can occur when some parties hold market power (hence they may not price at marginal cost) and/or when public goods exist (which would constitute incomplete markets if not publicly provided or which can provide price distortions when provided and funded by government) and/or when externalities are present (hence price equal to marginal cost may not mean the marginal social benefit is equal to marginal social cost) and/or when information asymmetries occur (hence trading that could improve total welfare does not take place).

The practical implication, as discussed further below, is that sometimes the user benefit approximations will hold even under imperfection competition but often they will not, and they can both under-estimate or over-estimate the total benefits.

This section considers market imperfections that might lead to additional positive benefits from a transport investment.

Measures currently within the EEM

a) Market power

Kernohan and Rognlien (2011) provide extensive discussion of the general issue of prices exceeding marginal costs. This market imperfection is likely to be of particular relevance outside major New Zealand cities. McCann (2009) argues small local markets have resulted due to high spatial transaction costs, implying improved transportation may improve competition within New Zealand. The EEM now includes an add-on for estimating the extra benefits of improved competition from a transport investment. Note this WEB is not capturing an improvement in productivity within the imperfectly competitive market, but rather the reduction of excess profits as a result of more competition – an effect that is absent in the cost-based estimate of consumer surplus. It is possible more trade might increase competition and hence improve productivity, a point mentioned in the discussion of agglomeration effects.

SACTRA (1999) points out that potentially any market power effect can work both ways, the transport improvement either increasing a firm's market power (and hence reducing wider welfare gains) or decreasing a firm's market power (and hence increasing welfare gains).

b) Tax distortions

Likewise the Kernohan and Rognlien study analysed the possibility of a tax wedge distorting labour supply decisions and an EEM add-on has been developed. These are also discussed by Laird and Venables (2016). The existence of market power and tax WEBs included within the current EEM framework can be significant and of relevance to travel outside major urban areas.

c) Congestion

A lack of investment may also hinder optimal production and spatial arrangement due to the existence of externalities such as congestion. Minken (2014) has generalised Mohring and Williamson's model to show reorganisation benefits can be as much as the direct transport benefits when congestion is significant. This can arise due to the market having too many firms and too little transport to be economically efficient. Elsewhere, Desmet and Rossi-Hansberg (2013) show congestion costs are a (negative) explanatory variable in a CGE model of US city sizes. This externality is expected to relate more to intra-urban travel but, to the extent that it hinders growth in Auckland, say, it potentially redistributes growth to Hamilton and Tauranga, as suggested by urban economic models. The EEM has congestion calculations at present.

Measures currently not within the EEM

a) Thin labour markets

It is possible the combination of thin labour markets and high levels of imperfect competition can combine to create significant opportunity for transport improvements. Laird et al (2014) show these wider benefits were significant in remote rural areas of Scotland. Estimates of wider benefits ranged from 0% to 55% of direct transport benefits in five case studies, mainly due to improved competition and lower search costs in labour markets but also including increased labour supply. They infer the WEBs of transport projects in remote areas are relevant to transport appraisal but warn the results require confirmation via GE modelling and a general build-up of evidence.

2.3.2.4 Land use changes

The EEM default is to take a fixed land viewpoint in the calculation of future user benefits. This is not always the case, as land uses may change in response to a transport investment.

Measures currently within the EEM

In a fixed land viewpoint any increase in transport demand represented by a shift along the observed demand curve is included within the user benefit calculation, keeping in mind the observed demand curve endeavours to capture shifts of the textbook demand curve that result from relative price shifts, but excluded is any rightward shift of the transport demand curve – textbook or observed – that might result from new transport activity not expected to occur unless significant investment were to be undertaken by other parties (eg private sector development around a new train station or near a new highway).

To be more precise, the same fixed land use is used to derive the traffic demands in the 'do minimum' and the 'do something' scenarios. An approach where transport affecting land use (eg prompting private sector development of more dwellings or more businesses in a zone) would require a different land use in the do minimum and do something traffic forecasts. Effectively this creates an area between the 'fixed' and 'variable' transport demand curves that represents an otherwise unmeasured welfare benefit.

Methods have been suggested to measure this area (Parker 2012; Lakshmanan 2011) but, as Laird and Venables (2016) point out, there is the problem of attributing benefit if these land use changes are associated with multiple cross-sectoral public sector investments (as there are multiple primary markets). We will return to this point below after discussing ways that a transport investment might be responsible for inducing private sector investment.

Meanwhile, the EEM does allow the textbook demand curve to shift right in situations where the expected traffic demand under the fixed land use scenario exceeds the capacity of the current road. The resulting calculation of user benefit is then derived by allowing the *observed* demand curve to cross the equilibrium point on the now rightward *textbook* demand curve, giving rise to the usual rule-of-half formula, from which a 'resource cost correction' is deducted. This is different from the methods mentioned above.

a) Variety

Laird and Venables (2016) point to the possibility of a variety externality linked to land use change. The variety externality is associated with changes in attractiveness of land (ie changes in land use). It is closely related to the externality discussed by Parker (2012). This need not be an increase in GDP so much as an increase in welfare as the variety made possible by a development – be it retail, industrial, commercial or hospitality – better matches the consumers' preferences and hence increases utility. This variety effect when associated with commercial activities (eg co-location of businesses makes a location more attractive to business) is closely related to agglomeration effects and hence would double count the agglomeration WEB add-on in the EEM. The full 'commercial' variety effect, however, would only be captured if land uses are altered to change in response to the transport scheme. When associated with households (eg provision of additional of retail opportunities) the variety externality is not currently captured in the EEM.

Measures currently not within the EEM

The following section discusses channels that potentially lead to a higher growth rate in the economy, at least for a period that may extend to two to three decades. It is a moot point whether they are fundamentally different from the endogenous growth process discussed under headings of agglomeration or NEG. It may be the factors below are the triggers that set in train a period of endogenous growth. Whatever the actual process, these factors have been identified as likely to affect growth rates within the Transport Agency policy horizon of 30 years[10]. As such they are large effects that may be difficult to capture within previously discussed analysis. It should be stressed, though, that ultimately any future pathway will be subject to some form of labour and capital constraints – factors that will require consideration in any modelling of possible futures.

a) Coordination failure

One externality suggested that can alter future development is coordination failure. Laird and Venables (2016)[11] refer to the possibility that local property development may not proceed simply due to coordination of the individual players not occurring. This may happen for gaming reasons – who wants to take the early mover risk? – or may be due to information asymmetries. A local transport investment can improve this coordination: (a) by reducing the information uncertainty around the provision of supporting infrastructure such as roads, and probably also coincidentally about other infrastructure; (b) by signalling to private developers the expected demand in the vicinity; and (c) by simply 'starting the ball rolling', thereby providing an incentive for others to coordinate their efforts. Laird and Venables also mention the potential reduction in monopoly power of developers or planners that might result from a transport investment, a channel of effect that would also fit within the aforementioned reduction in market power benefit measurement – care is needed to avoid double-counting benefits in this situation. Returning to reducing coordination problems, several important appraisal challenges emerge with transportation investment acting as a catalyst to local development:

1 The transportation investment alone is not sufficient to generate the benefit – it requires others to act also.

2 It is difficult to separate: what part is user benefits, as relocation can fit within user benefits, and what is the additional benefit that results from the transportation investment.

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[10] Growth models infer that any change in growth rate is ultimately transitory but that that the transition may occur over decades.

[11] This type of logic could also apply to 'big push' industrial policies (Lakshmanan 2011)

3 It is possible – indeed likely in many cases – that the extra local investment has displaced activity elsewhere.

4 It is also difficult to establish whether the expected benefits would have occurred, either here or elsewhere in New Zealand, should the transport investment have been withheld.

b) Household variety effect

Similar to the commercial variety effect discussed above, Laird and Venables (2016) also refer to a variety effect whereby households benefit from greater variety, possibly arising from retail property development following a transport intervention. This would not be captured within the EEM but is not considered within this report.

c) Path dependency

Returning to coordination failure, the more general issue is transport as a public good and the path dependency that this can sometimes create. This means interaction between the supplier (ie Transport Agency) and the consumer differs to that of a private good. It does not change the fundamental challenge around any capital investment faced by the public sector and private sector alike, in that estimates have to be made as to future consumer requirements and judgements are required about the response of policy makers and suppliers of complement and substitute products. The difference, though, is that without the public good provision, the future pathway *can* be very different.

Three future pathways exist.

1 The transport investment could be undertaken and an ensuing period of private sector investment follows. This may be judged a success. In which case it is appropriate to apportion some of society's net social benefit (ie the net gain over and above Transport Agency's costs) to the transport investment. However, the subsequent private sector investment and consumer demand may not eventuate, at least to the degree envisaged, in which case there may be a net societal loss. This too is partially attributed to the Transport Agency investment. Without defining explicitly what these measurements of attribution would be at this stage, the key conclusion is that there is an extra benefit (or loss) that can be attributed to an investment in a public good but any measurement of this benefit would be on an ex ante basis, taking into account the probability of success or failure.

2 Alternatively, the transport investment is not undertaken and there is little likelihood of this decision being revisited. There is no competitor, as in private sector investment, who will come along and undertake the investment instead. In this case, the private sector development that might have eventuated will probably occur in another place. To the extent that development elsewhere leads to lower social welfare than with the transport investment, then this is the net benefit denied to society.

3 However, and likely in many cases, a decision to not proceed with an initial transport investment will be perceived as 'delaying the inevitable' and private sector development will proceed, but possibly in a slower manner and/or with heavy reliance on nearby existing transport infrastructure. In this case, the counter-factual is more congestion in the existing transport network and a delay to some private sector development or, in welfare terms, a combination of benefits (due to some growth) and dis-benefits (due to congestion) in the short term and a delay to a potentially large portion of growth benefits until the transport investment is ultimately undertaken.

Viewed from this perspective, there are two major challenges. First, is there a high probability of scenario 2 versus scenario 3? Scenario 2 may eventuate when it is physically possible to undertake the transport investment later but the opportunity to coordinate with others is lost. This is the risk inherent in the above example of coordination failure. Second, what is the extent of net societal benefit that should be attributed to the transport investment over and above the already measured user benefits under a fixed land use scenario? Both questions are the topics of ongoing research: Laird and Venables (2016) refer to some research into measurement of wider benefits of this nature; the Transport Agency is undertaking research into real options, a component of the first question.

Path dependency is inferred when coordination otherwise fails. More generally it can occur because the service provided by the public good (ie the road, bridge) can be provided elsewhere. Government – local and central combined – is the only provider of roads in New Zealand but there are often alternatives if a road, say, is not provided. Scenario (3) above provides an example of using nearby roads. It is also possible that people and goods within the project area can be transferred by air, rail or sea. Of more significance to path dependency is the relocation of firms and people – relative to the counterfactual of the project infrastructure being provided – to other locations to undertake the desired activity. This relocation may be to other parts of New Zealand (eg film making expanding in Wellington rather than Auckland). In some cases there will be a potential social benefit loss to New Zealand; in other cases there may be no loss or the loss is relatively small. Alternatively the relocation could be to Australia or elsewhere offshore (eg manufacturer shifts to Brisbane). The likelihood of a welfare loss to New Zealand is now much greater due to the loss of resources and the loss of the opportunities embedded in these resources. In all cases, there are spatial wins and losses which will be of interest to regional stakeholders.

With these background comments in mind, some examples of path dependency are presented below. These largely revolve around the feedbacks possible with investment and innovation and also with international trade. The resulting appraisal issue can either be viewed as one of improving accuracy of the 'fixed land use' forecasts or of trying to estimate or at least describe the extra benefits attributable to the transport investment[12].

Most of the previous discussion has focused on level effects, ie improve the level of transportation and the level of welfare or level of production may increase more than the cost of providing the extra transportation investment. It is also possible that the initial higher investment may produce a *persistent* shift towards a more capital-intensive or innovation-focused economy, as suggested by SACTRA (1999), and hence a higher growth rate. In modelling terms, a persistently higher growth rate could result from a drawn-out adjustment to a large transport intervention or it could be a shift to an economy which fundamentally has a higher rate of capital accumulation and/or innovation. An example of a fast-growing economy resulting from a transport intervention is increased market proximity leading to increased inward investment, in turn leading to more technology transfer and possibly a shift towards a more innovation-focused economy. While such examples are likely to be exceptional and difficult to attribute, SACTRA (1999) did conclude 'at the national level, the evidence seems to be very clear that reducing barriers to trade raises TFP [total factor productivity] growth'.

Both the capital and innovation pathways considered by SACTRA above are consistent with NEG research. NEG holds that comparative advantage may not result from natural endowments but from a city's previous pathway of knowledge acquisition and building economies of scale. One of the findings of NEG research is that places can go along a virtuous[13] and endogenous pathway of innovation, capital investment, specialisation and information dissemination, and also growth of firms and population. It may be possible to accelerate this process by transportation changes or at least not hinder the process by withholding

[12] The point is that some of this discussion could have been presented within the 'forecast accuracy' section as understanding these issues will improve demand forecasting but more literally they are issues of path dependency and attribution of wider benefits.

[13] At least in terms of economic growth

transportation investment. At an observational level, support comes for this view by noting some of the findings reported in appendix A:

- City growth tends to be dynamic, rather than simply a replication of itself.
- Cities tend to shift from industry specialisation to functional specialisation as they grow from medium to large.
- Emphasis is believed to be in knowledge exchanges, by nature an externality.
- Cities with strong transportation infrastructure have been observed to grow faster than average and be more productive.
- Business has tended to increase near major transport.
- High productivity cities tend to be well connected globally.
- A decrease in travel time is associated in the US with more trade (more so weight than value).
- And, enticingly, all the world's most productive cities are bigger than Auckland.

Closely aligned with this line of research is path dependency resulting from *networking effects*. There has also been a line of connectivity research that takes the perspective that economic production is organised as networks. Carvalho (2014) shows by way of a model where production is specialised and takes place at 'n' nodes that small shocks can propagate through the network to cause the sort of business cycle fluctuations commonly experienced. Carvalho and Voigtlander (2014) show this network approach can provide important insights into how innovation may be adopted. Using US data, they show that firms were more likely to adopt inputs used by their current suppliers. They were also more likely when looking elsewhere to develop new input linkages to look amongst their suppliers' network neighbourhood (neighbouring being next in supply chain rather than spatially nearby). This shows the importance of path dependency on current economic production, and also presents a challenge as to how to ensure that the most efficient production systems are being pursued.

In a parallel field of research, Jackson et al (2015) highlight the following significance of social networks, again suggestive of the importance of connectivity between people when it comes to innovation in economic activities and, hence, a potential influence on future growth rates. They report:

- Societies with social density above a critical threshold can exhibit substantial diffusion of ideas.
- High variance in social connectivity also adds diffusion.
- Conversely homophily and segregation can hinder diffusion.
- The formation of friendships can be governed not only by the preferences of individuals, but also by biases in the opportunities that individuals have to meet each other.

One strand of this networking research shows how adjacent cities could evolve along quite different pathways. Glaeser et al (2015) constructed a model on assumptions of idea-based growth and endogenous amenities which provides insights into why local conditions and preferences might be suited to a mega city or instead to networked cities. The model, though, is ambiguous about which system is best. Furthermore empirical evidence is required before confidence can be gained in any model inferences. Nonetheless the research does reinforce the importance of pathways, learning and accumulated capital, be it human or physical. They report:

- Interest is in the sort of urban networks like Randstad, the Dutch megalopolis of Amsterdam, Rotterdam, The Hague and Utrecht (note, widest gap is Amsterdam–Rotterdam at 73km).

- A model is constructed based on endogenous amenities within cities and idea-based growth.
- Within such a model, larger cities will mean more firm creation, higher income levels and high utility levels;
- However, a trade-off between amenity value and housing costs/supply could lead to the sort of reliance on networks seen in Europe, as a natural means of adapting to land constraints.
- In the long run, either expanded networks or larger cities will mean significantly more growth (given the accumulation of ideas and new firms) – an important point.

This suggests the size of the agglomeration externality discussed earlier is dependent on the pathway and ultimately the network shape. This remains very much an area of further research and nothing more can really be said on the subject for the moment.

d) International trade and foreign direct investment

One link with growth rates where transportation is pivotal is via international trade and foreign direct investment (FDI), with the role of local sea and airports of significance. Research in this area shows transport costs are significant, that lower trade costs can lead to more exporting and although higher international trade is commonly associated with higher growth, there is mixed evidence on the channels of influence.

Before considering some of the interactions between external trade and transport costs, there will be welfare gains that accrue from more external trade that cannot, ex ante, be attributed to either the importer or exporter. This extra welfare gain would not be captured in a CBA. Of more interest below, is discussion around other ways that external trade and investment might stimulate more investment and/or innovation and hence even more growth.

The transport costs associated with international trade are significant for New Zealand. The NZ Productivity Commission (2012) cites research that estimates Australia and New Zealand experience a decrease of about 12% GDP per capita relative to the OECD average as a result of distance to market, as opposed to places like Belgium and The Netherlands which experience a 6% relative gain. Guillemette (2009) reports 'that a 10% increase in distance reduces trade by around 10%, and that this effect has not diminished over the last 30 years', citing Nicoletti and Scarpetta (2003) and OECD (2008b).

Local transport costs can have a significant effect although the results may not transfer directly to New Zealand as it is not a landlocked country[14]. Limao and Venables (2001) show 40% of transport costs for shipping containers to non-landlocked countries is explained by local infrastructure. In a similar study of over 280,000 bilateral trade flows from 1988 to 2002, Francois and Manchin (2007) find infrastructure and institutional quality are significant determinants not only of export levels, but also of the likelihood exports will take place at all. NERA (2010) concludes these land costs are more likely to be significant for emerging, landlocked countries.

Lower transport costs can lead to growth rates through both extra trade and network effects. Kernohan and Rognlien (2011) cite Crafts and Leunig (2005) submission to the Eddington review in the UK, suggesting a 5% reduction in trade costs at a national level could lead to economic growth of 2.5–4.4%. Wacziarg (2001) shows there are three key channels by which trade influences growth: investment (63% of trade's total growth effect); improved technology (22.5%); and macroeconomic policy stabilisation (18%). Interestingly, higher productivity plays a relatively small growth contribution according to these findings,

[14] PWC (2012) shows 56% of the cost of moving a container from Napier to Singapore via Auckland is within New Zealand.

which is supported by mixed evidence elsewhere. In a Wagner (2007) review of empirical studies, the evidence supported the case that highly productive firms are more likely to become exporters rather than exporting firms becoming more productive. NERA (2010) refers to international research that fails to find support for exporting improving productivity. Fabling and Sanderson (2010) research for New Zealand is broadly consistent with this, finding New Zealand exporting firms do exhibit gains from exporting but these are largely limited to growth of employment and capital inputs. Conversely other studies find effects running from exports to productivity, such as Baldwin and Gu (2004) amongst Canadian manufacturers and Harris and Li (2007) amongst some, but not all, UK industry groups. Hong et al (2011) and IATA (2007) outline three channels through which improved port access may increase local productivity: (a) wider market access; (b) improved organisation of business networks; and (c) easier cross border investment. These factors can all apply in a regional setting within a country but take on more significance at a global level. Hovhannisyan and Keller (2011) show how business travel is associated with higher innovation.[15]. PwC (2015) refers to several studies showing a relationship between aviation growth and GDP growth, although the relationship is likely to be two way.

In the US, connectivity to ports has been included in economic evaluation to capture some of the above effects, with justification due to papers cited such as Shepherd et al (2011), Targa et al (2005) and Berrittella (2010). The latter two studies show business activity being higher near airports and intermodal sites. Reference is also made in Appalachian Regional Commission (2008) to 'Empirical research has established functional relationships between access to international gateways (as measured by driving time) and the total amount of shipments to overseas locations on a port-specific basis'. This research is not explicitly referenced. This line of research has led to the use of a connectivity score for each port to be used in evaluation of transport investments. This approach is not taken in the UK.

A common factor in some of growth studies is the FDI channel. IATA (2012) infers that New Zealand's FDI would improve with higher connectivity (see section 2.3.3. of this report for measures of connectivity). NERA (2010) reports that several studies point to spillover effects from FDI in the form of knowledge sharing. Although, contrary to this, recent research in New Zealand shows foreign investors tend to target larger and better-performing New Zealand firms that then continue to exhibit higher growth in average wages and output, relative to similar domestic firms, but these firms do not appear in general to increase their productivity or capital intensity (Fabling and Sanderson 2014). A stronger innovation link appears to be via recent migrants introducing new marketing methods, new goods and services and new organisational and managerial practices (McLeod et al 2014).

There are some reports of FDI responding to road investments such as Coughlin et al (1991) in the US and Hill and Munday (1992) in the UK, but NERA (2010) concludes there is insufficient evidence on which to generalise a FDI elasticity to investment. Interestingly, Oxford Economic Forecasting (2006) reports that access to air transport links was not a large factor in determining investment in the UK, although Button and Taylor (2000) point to a long list of industries that rely on air transport, especially amongst 'new economy' industries.

One further international channel of particular relevance to New Zealand is via tourism. Changes in transport infrastructure can show quickly in tourist flows (World Bank 2014). Numerous studies claim to show the impact of tourism on a local economy (including the IATA 2012 submission to the NZ Ministry of Transport) but there appears to be little research into what effect local transport infrastructure has on international tourist inflows. There is the inter-related challenge of showing that any production effects of tourism are not simply the result of crowding out other activity.

[15] A similar effect to that found in New Zealand with recent migrants by McLeod et al (2014).

As an aside and consistent with NEG concepts, cities that started as ports need not have a heavy reliance on the port today. Fujita and Mori (1996) point to cities that started as major ports but continue to grow today in spite of the now minor role of the port. Equally, the hinterlands of ports can be dynamic, warns Ferrari et al (2011), changing as a result of factors such as economic cycles and technological breakthroughs, and that a traditional ‘distance-decay’ perspective does not fit well with the wider use of inland ports today.

These mixed set of papers generally point to lower trade costs leading to more international trade and investment and in turn higher economic growth, although the channels of influence are not necessarily the same in all cases and are the subject of ongoing research.

2.3.2.5 Summary

Bringing section 2.3.2 to a conclusion, a quote from Rosewell and Venables (2013) is insightful: ‘Long run prosperity requires that each region has a strong tradable sector (or export base), and this in turn requires the presence of firms that are world class, competitive against international competition. Attaining this efficiency requires both competency in core tasks and ready access to inputs of intermediate goods and services from other firms that are world class in their field. For most economic activities, this is simply not possible in an autarkic or remote region. Specialisation is needed to attain efficiency, and connectivity is needed to foster business linkages and allow this specialisation to develop’.[16]

But the earlier SACTRA warning is also insightful: ‘there is no ready reckoner that can be applied to adjust the results of [a standard CBA analysis] for the consequences of transport interventions on incentives to invest and innovate’.

More practically, it was recommended any potential growth effect should be questioned as to:

- ‘Is there reason to expect that investment or innovation will be increased/decreased? If so, in the aggregate or only in one region at the expense of another?
- Are there likely to be favourable effects on incentives for productivity improvement?
- Are there important consequences for productivity in the transport-using sector to be considered?
- Is there an effect on the efficiency of resource allocation?
- Is it likely that there will be any material effect on the integration of the market?’

Vickerman (2007) suggests the following approach:

- For small to medium sized schemes the effort needed to estimate the wider impacts may be regarded as out of proportion to the likely size of the impacts.
- Otherwise direct user benefits are likely to constitute a relatively large proportion of the impact of a project with WEBs generally less.
- There are some transport infrastructure projects where WEBs could be particularly important, including large projects through to smaller projects such as a road to a hitherto poorly connected town – the key criterion is likely to be whether the project has the potential to induce significant change in behaviour or activity.

[16] This is a line of research that the NZ Productivity Commission is currently undertaking, looking into whether local firms benchmark locally instead of nationally or globally, hence limiting their quest for productivity.

And, as summarised in a recent Norwegian study by the Transport Economics Institute (2014): 'Investments in transport infrastructure can help to create larger and more competitive regions. Still, Norwegian experience shows the effect of such investments is dependent upon the local context. In particular, the industry structure in the regions that is connected is important. Travel time is also an important factor. Shorter travel time is associated with greater effect'.

In other words, transport improvements can enhance trade, specialisation and growth but effects differ according to local circumstances and they are difficult to predict. Nonetheless the starting point for evaluating the potential benefit of transport investments having effects along the lines suggested by the NEG is to be able to provide the appropriate narrative that can at least be tested against economic models. This, in the first case, will lead to better forecasts of 'fixed land use' to use when estimating user benefits and will provide some insights into the probability and extent of additional benefits not otherwise measured (which may in time be estimated using methods under research at present).

2.3.3 Measures of connectivity and agglomeration

The following section provides a brief overview of various measures of agglomeration and/or connectivity that are being applied.

Accessibility measures were first employed in land use situations by Hansen (1959), who was looking for a measure of a potential of opportunities for interaction. Guers et al (2015) categorise a large set of accessibility measures used today. Before describing these categories, it is worthwhile considering how a measure of accessibility can fundamentally differ.

2.3.3.1 Measure of accessible mass

A commonly used measure of people accessible within a commuting distance is the effective density measure used by Graham (2007) and by Maré and Graham (2009) when estimating New Zealand agglomeration elasticities.

A widely used measure of the mass of people likely to provide agglomeration effects is the general equation below, with its many variations.

$$Accessibility\ (A_i) = \Sigma y_j \times w_{ij}^{-1} \qquad \text{(Equation 2.3)}$$

Where: A_i = the accessibility of area i (usually termed effective density)

And 'y' could be:

- $employment_j$ = the level of employment in area j (as used within EEM)
- $population_j$ = the level of population in area j, or working age population
- GDP_j = the level of GDP in area j, as used in Japan to measure 'regional attractiveness' (World Bank 2014)

And 'w' (ie the weight) could be

- GTC_{ij} = the generalised travel cost (travel time plus cost) of travelling from area i to area j (as used within EEM)
- $distance_{ij}$ = the distance from area i to area j, either by road or as the crow flies

Or even more generally,

$$Accessibility\ (A_i) = \Sigma y_j \times w_{ij}^{\alpha} \qquad \text{(Equation 2.4)}$$

Where: α = a decay parameter.

Graham et al (2010) showed alpha is likely to be above 1 for UK industries and cities, implying a rapid diminishment of any people mass effect with distance.

The DfT (2014) use this form of accessibility measure, with the decay parameter varying by industry.

Donaldson and Hornbeck (2013) use a ‘gravity’ measure of population to measure market access. This is calculated as the inverse travel time weighted sum of county populations. A large travel time will imply a low ‘gravitational’ effect. They also use a variation as a restricted gravity measure which excludes nearby counties.

Cervantes and Hernandez (2015) use a variation of this calculation to measure market access for new Mexican highways.

Differs from a measure of concentration

For completeness, there are also various indices that have been developed to measure the degree of agglomeration, such as the Ellison and Glaeser (1999) index of agglomeration in equation 2.5 and others discussed by Kominers (2008). These statistics measure concentration whereas the measures required to test for connectivity are that of mass, eg the mass of ships or planes accessible.

$$\text{EG-index } \gamma = [G-(1-\Sigma_i x_i^2)H] / [(1-\Sigma_i x_i^2)(1-H)] \quad \text{(Equation 2.5)}$$

Where: $G = \Sigma_i (x_i - s_i)^2$ is a Gini index where x_i is location i's share of total employment and s_i is the location's share of employment in a particular industry.

Where: $H = \Sigma_j z_j^2$ is a Herfindahl index of the J plants in the industry, with z_j representing the employment share of the jth plant.

Measure of accessible masses

Returning to measuring mass, a more general method than the effective density measures above is to measure mass at discrete intervals, ie have several measures of mass that is accessible. Rather than define parameters which restrict the effect of distance mass to monotonically decrease, the use of discrete measures of mass allows the influence at each interval to be tested. The disadvantage of this type of measure is that sensitivity is created around the interval thresholds when used to estimate the changing mass accessible within set distances or times, eg a small time change that takes a large population from one interval of accessibility to the next can imply a large effect (when the time saving is relatively minor).

$$\text{Accessibility } (A^k_i) = \Sigma y^k_j \quad \text{(Equation 2.6)}$$

Where: A^k_i = the mass accessible at location i that is in areas j that are an interval k away from i

Where interval k could be defined as:

- a distance, eg 10–20km away from location i
- a travel time period, eg within a 40–120 minute drive of location i.

Discrete measures of accessible mass such as this have been used by Alstadt et al (2012), Byett et al (2015) and Rice et al (2006).

Measure of proximity

A direct method to measure accessibility is to measure the degree of separation or its opposite, proximity.

Proximity (P_{ij}) could be:

- $time_{ij}$ = time to drive, fly, boat and/or rail to destination k from location i

- $distance_{ij}$ = distance to destination k from location I, either by to drive, fly, boat and/or rail or as the crow flies.

As above, proximity could be weighted when the scale associated with the destination is of importance, ie use P_{ij}/w^k where w^k is some measure of the importance of destination k (eg an airport with 20 daily flights may be considered just as important as another airport with 10 flights per day that is half the distance away). In practice weights appear to have been arbitrarily chosen rather than derived by theory or empirics.

An example of the use of a weighted average travel time is Mukkala and Tervo (2013). They use a geographical accessibility variable, which measures a weighted average travel time to 202 NUTS level 2 regions in Western Europe. The measure is multimodal, taking into account the best combination of air, rail and road travel. The weight used is the relative GDP or 'market share' of each region.

Measures of cost

More generally time and distance are likely to be related to the cost of travel which will include other components such as transport operating costs, waiting time and, with freight, inventory costs. This could be used directly as a measure of access, to the extent that lower costs are likely to increase the willingness to access.

Again a weighting mechanism can be used. Note that weighted travel cost or weighted time using, say, population is equivalent to weighting population using travel cost or travel time.

Proxies for access costs

In some cases it may be difficult to measure travel costs directly but costs may be closely linked to the level of service provided by, say, a sea port. In this case, measuring the number of ships visiting per year or container capacity per week may provide an approximation of travel costs. A variation of the proxy method is a combination of proxies, such as the liner shipping connectivity index (LSCI). The UN calculates a LSCI, combining the following five factors using principal component analysis:

- number of ships
- their container-carrying capacity
- maximum vessel size
- number of services, and
- number of companies deploying containerships to and from an economy's ports.

The LSCI is not available at a port level but rather is reported per country. New Zealand currently has a score of 21 (relative to 100 for best connected country, Singapore, in 2004; Australia scores 31.3)[17]. Paflioti et al (2014) have proposed an alternative index. It is uncertain whether this index is available at present and whether it is, or will be, available by port.

In the aviation industry, there are similar indices including those reported by IATA (2012) based on available plane seats and the size of the destination airport and is expressed in terms of country GDP. The index value for New Zealand was 0.34 in 2009, sixth highest in the world (IATA 2012). As above, the index is reported per country rather than per port.

[17] http://data.worldbank.org/indicator/IS.SHP.GCNW.XQ

Returning to the categorisation listed by Guers et al (2015), there are four different categories of accessibility measures:

1. Infrastructure-based measures, analysing the performance or service level of transport infrastructure
2. Location-based measures, analysing accessibility of spatially distributed activities, typically on an aggregate level
3. Person-based measures, founded in the space–time geography, analysing accessibility at the level of the individual level
4. Utility-based measures, analysing the welfare benefits that people derive from levels of access to the spatially distributed activities.

Also these measures include one or more of four components

1. The land-use component reflecting the amount, quality and spatial distribution of opportunities
2. The transportation component describing the disutility of travel in terms of time, cost and effort
3. The temporal component reflecting the temporal constraints and variability
4. The individual component reflecting the needs, and abilities of individuals.

As an example of the myriad of choices, it is possible now to measure the number of local amenities such as restaurants and gyms nearby, to vary this by cycling or walking travel time, to weight it by time of day that travel is undertaken, to calculate it according to people's perception of distance rather than actual distance and to apply a weighting to reflect the utility that an individual may gain from access. In other words, an accessibility variable can take on many forms.

Unfortunately, it does not appear that one measure has emerged that can capture the opportunity for localisation effects. Hence some exploration is required in the GVA model building phase to establish which amongst the above measures include mass and time (or cost) components and are practical, and to then to test for suitability.

2.4 Connectivity research in New Zealand and the Auckland–Hamilton–Tauranga area

The following section looks at background research into the case study area. One important finding of the international research was that potential connectivity benefits are likely to be contextual. These notes do not attempt to determine what parts of the local context will influence the model building phase of the project but rather collate the material together for initial consideration and quick reference later. Detail of specific studies is provided in appendix B. The appendix also contains background detail on some other models that exist and can potentially examine connectivity in the study area.

As initial background, McCann (2009) recommends developing the AHT triangle. Proctor (2011) and Grimes et al (2014) concur. Guillemette (2009) says it creates an infrastructure advantage, citing research[18] that indicates 'past [New Zealand] investments in road infrastructure have yielded the greatest growth benefits' (p22). And yet the New Zealand research to date appears not to support these

[18] Égert et al (2009) report that New Zealand is the country with the highest estimated effect of road density on economic growth across all OECD countries, possibly due to the high benefit-cost ratio hurdle set on roading investment (Guillemette 2009)

recommendations, at least in terms of offering compelling supporting evidence that large productivity gains will follow large transport investments between AHT (as opposed to within Auckland).

A review of New Zealand research related to connectivity in the region is presented below.

2.4.1 McCann thesis

McCann (2009) offers the following thesis about New Zealand's relatively low productivity:

- New Zealand experiences, including low productivity growth, are consistent with new economic geography approach.
- Namely, relocation is to centres of high productivity, with agglomeration in turn adding to productivity (eg Sydney, Auckland).
- This suggests the appropriate policy response is (a) increasing New Zealand agglomeration effects (ie more knowledge spillovers and innovation) and/or (b) reducing spatial costs between Australia and New Zealand, ie increasing backward knowledge spillover and feedback effects from Australia.
- 'In the case of promoting domestic agglomeration effects, the agenda here should focus primarily on increasing the scale of the Auckland-Hamilton-Tauranga triangular city-region' (p301), including via more immigration.
- 'The primary focus here should be on upgrading the connectivity of Auckland to the rest of the country' (p302), including via more competition or regulation for airports and domestic airlines.

MBIE and LGNZ (2012) also state there is value to be gained out of better connections between cities, and with cities from other countries.

2.4.2 Research into the case study area

A key finding of research into the AHT is there appears to be little evidence of an 'integrated city system' existing now, nor emerging between the three major cities (Paling et al 2011). The authors noted the insular nature of the three cities within the area. Between the three cities, there was relatively little commuting and relatively little migration. Also, there was anecdotal evidence to suggest each city was well serviced internally and there was only isolated reliance on Auckland for specialist services. Auckland was a major market for firms in the rest of the area and also a port for entry and exit of people and goods but there was little to show that goods were being sent to Auckland for on-processing. The authors concluded there was merit in policies to intensify employment in all three cities, especially Auckland, and improve intra-urban transportation networks, with the spinoff that quicker travel within each city also contributes significantly to quicker travel between each city centre.

Other reports also note the low commuting between Auckland and Waikato (Gooderham et al (2014), MartinJenkins (2013), MBIE and LGNZ (2012)); one reason suggested by Paling et al (2011) is the relatively long distances between the cities. Anecdotally the distance between Hamilton and Tauranga was considered far enough to require overnight stays if travelling and working in the other city.

Another strong theme is the high population growth within the area. This has been the fastest growing area in New Zealand. Some of this growth was attributed to natural factors (land use capability and sunshine hours), some to the already existing scale (population and human capital) and some to the proximity to Auckland (Grimes et al 2014). These influences vary within the AHT area. Also of difference, the majority of migration into Auckland was from abroad, including returning New Zealanders, while migration into the rest of the AHT area was predominantly from the rest of New Zealand, including possibly people who had earlier immigrated to New Zealand.

Auckland is easily the largest of the three major cities, with a population of 1.4 million. It is worth noting the diverse nature of Auckland, as observed by Le Heron (2013): Auckland City now is 'an area of 4,999km^2 comprising a metropolitan space of 559km^2, an urbanized area of 483km^2, and 350000ha of land zoned for rural lifestyle'. Auckland also has high productivity, especially in the CBD, and experiences productivity spillovers from specialisation of industries within the city (Maré and Timmins 2006). These localisation effects were considered greater than any urbanisation effect. Major industries are finance, business services and wholesale distribution.

Hamilton City with a population of 141,000 is slightly larger than Tauranga City with 114,000 people but has a much larger surrounding urban area. Both have roots as service centres to the surrounding primary producers, including dairying, forestry and horticulture, and continue that role today. Tauranga also services the seafood industry. Hamilton and Tauranga are above the 'less than 75,000' population level in the US where specialisation was very strong, as per Davis and Dingel (2013), but below the 'greater than 1.5 million' level where the ratio of management exceeds production workers. Productivity, as measured by GDP per employee in 2012/13, is below the national average in Tauranga City and in the wider Bay of Plenty region, including within the typically more productive business services sector. Conversely the Waikato region has productivity levels above the national average, mainly due to activity outside of Hamilton City. Export growth is strong but FDI is not.

One large industry in Tauranga – although not the largest – is shipping through the Port of Tauranga. Hughes (2006) estimated that the Port of Tauranga was a significant part of the Bay of Plenty economy, being associated with 9.2% of New Zealand-wide production in 2006.[19]. Once stevedoring and freight activities related to the port were included, the regional revenue related to the port was 5.7% of Bay of Plenty revenue and 1.9% of Bay of Plenty employment.

In terms of road and rail transportation, freight volumes are high in the AHT area, with volumes highest between each region amongst the 'other manufacturing' and aggregate sectors. Strong freight growth within and through the regions is forecast (UNISA 2013, McDonald and Smith 2012, Donovan et al 2010, PwC 2012). The area also experiences strong international tourism activity, although these transport flows are not separated from other light vehicle traffic flows.

Both the Waikato and Bay of Plenty regions have prepared economic growth strategies recently. Both regions are reporting strong growth and growth aspirations. Themes within the two strategies are to:

- leverage off the land- and water-based industries and resources that exist in the regions
- leverage off the proximity to Auckland
- emphasise skills building, and attraction of labour to the regions (with skilled labour reported as a constraint on growth)
- increase collaboration, including amongst governing bodies
- attract FDI
- develop industries seen as having strong potential such as, for example and not exclusively, tourism, agribusiness, aquaculture, engineering, renewable energy
- manage the growing demands on the transport network.

2.4.3 Some observations relating to the Auckland–Hamilton–Tauranga area

[19] At the time (Jun 2005/06) Port of Tauranga had revenue from operations of $122m and 156 full-time employees.

Based on the research reported in section 2.3 and appendix B, it is reasonable to expect Auckland still has much potential for higher productivity and that functional specialisation will increase and urbanisation advantages emerge. A likely dynamic is some businesses and people further concentrating in places while others more sensitive to property prices and loss of amenity are likely to shift outwards, including possibly to other parts of the AHT. Gooderham et al (2014) include within this process a shifting of 'unwanted' industries (eg waste processing) to the regions.

The dynamics around the rest of the AHT area are likely to be influenced by relative property prices, amenity value and specialisation. Given the history of Hamilton and Tauranga and their proximity to Auckland, it is likely that any productivity gains would come from localisation effects due to clustering around existing businesses. Some relocation of businesses from Auckland is likely and these industries may be able to reinforce localisation effects but they are likely to be industries of relatively low productivity (ie those sensitive to Auckland property prices). Local productivity gains may also come from improved competition as connectivity increases, especially if the spatial monopoly posited by McCann is prevalent in the area. Both Hamilton and Tauranga risk losing production to Auckland (or international) as connectivity improves, where larger (positive) externalities and economies of scale are likely to exist.

All cities within the AHT region appear likely to experience fast population growth.

2.5 CGE models and connectivity

Section 2.2 introduced the GVA model and section 2.3 discussed the agglomeration benefits that the GVA approach intends to capture – essentially productivity improvements. However, as noted in Byett et al (2015), a GVA provides no guidance on the spatial distribution of the benefits. For this we need a SCGE model.

2.5.1 A SCGE model

CGE models have been discussed in previous Transport Agency research (Wallis 2009). For an initial set of resources and resource allocation, a CGE model will simultaneously solve sets of equations to provide the optimum mix of production, trade and consumption. One set of equations will represent household choices and constraints around consumption, saving and work – and residence in a SCGE. Another set of equations represent the business choices and constraints around production. Yet another set of equations represent trade between the household sector and the business sector. It is typically assumed that households will maximise utility and firms will maximise profits.

The spatial dimension is added to the model by specifying a location where consumption and production activities take place, ie the variables denoting these activities will have a spatial subscript. This then introduces specific transport costs between locations that will influence the locations of consumption and production.

At the heart of the model is trade. People and firms will trade until it is no longer beneficial to trade any more. Trade – and price changes – will bring together production and consumption (and savings). Trade will provide the competitive forces. The spatial dimension is influenced by the same pressures.

Key issues in the construction of a small spatial CGE model envisaged for this project revolve around:

- the assumed form of the welfare function
- the assumed form of the production functions, especially around the treatment of imperfect competition
- the extent to which industries and goods/services are differentiated

- the methods employed to model trade costs and transport costs in particular
- the closure assumptions which specifies how equilibrium is reached after a shock (eg flexible or fixed labour supply, flexible or fixed fiscal balance).

Some of these issues are raised in papers to be discussed below. But first, what are the key differences between a SCGE model and a standard CBA as employed in transport analysis?

2.5.2 Substitution and income effects in CGE models

To understand what an SCGE model does we first need to understand what such a model without a spatial dimension – a CGE model – does. The key difference to a partial analysis is that a CGE model will explicitly consider the interaction between markets and the interplay with real incomes.

Imagine a road improvement that reduces the cost of transport to a bread factory. Perhaps fewer drivers and trucks are required as travel times are shorter. In a competitive industry these lower production costs will feed through into lower bread prices. Consumers may increase their consumption of bread by a small amount, but are more likely to use the effective gain in income to purchase more of a product with a higher income elasticity of demand – say movies.

A standard CBA is agnostic about where the benefits of an improvement in transport eventually materialise. In that sense it is not inconsistent with a switch in consumption from bread to movies. What it may miss, however, is the welfare gain that consumers achieve by that marginal switch in consumption. The economy achieves allocative efficiency when the price ratios between goods equal their marginal rates of substitution in consumption.

Even if there is no change in resource use – no change in total employment, no change in capital stock and perhaps no change in GDP – aggregate welfare will increase via the improvement in allocative efficiency. In essence this is the gain from resources being able to be deployed to where they are most valued by consumers. A GE model captures these effects.

2.5.3 Spatial effects in SCGE models

The above discussion makes no reference to the spatial distribution of economic activity. If movie producers are located in a different region to bakeries, the gain in welfare could be quite uneven between regions, although this depends on whether workers can easily commute (or migrate) between regions, where they spend their income, what they spend it on, and from where that demand is met.

An SCGE model provides an indication of how the welfare gain is spatially distributed. It is entirely possible that some regions could incur a net loss. An SCGE model will capture, say, workers moving from a relatively low paying job in one region to a relatively high paying job in another region. In a non-spatial model this may simply be the spatial manifestation of a move between industries. There may also be spatial movement within an industry if an industry were to expand in one region and contract in another as result of the connectivity improvement. Presumably this would occur only if the industry secured some productivity advantage from doing so. This would not be captured in a non-spatial model, unless the productivity enhancement was exogenously imposed. To this extent, then, there may be some additional aggregate welfare gain that is captured in a CGE model with a spatial dimension.

The main reason for developing an SCGE model as part of this research project was to learn something about the spatial distribution (notably between Auckland, Hamilton and Tauranga) of the changes in GDP that arise from connectivity improvements through better transport links, and from their associated agglomeration effects (if any). That is, the emphasis is more on spatial disaggregation than on allocative efficiency effects per se.

2.5.4 (S)CGE models in the literature

CGE models are widely used by the International Monetary Fund and World Bank and many other institutions. There are also many SCGE models being used today. The World Bank (2014) presents a useful summary of SCGE models:

> *These models are typically comparative static equilibrium models of interregional trade and location based on microeconomic theories, using utility and production functions with substitution between inputs....*
>
> *While they have a sound theoretical basis from the academic viewpoint, their primary problems are the ability to obtain the empirical data required for any detailed analysis and the computational effort required to obtain a result. Consistent estimation of the necessary consumers' and producers' substitution elasticities is difficult because of the lack of adequate data and regional elasticity estimates. These models are generally calibrated to historic data and maintain the calibrated relationships into the future; while technological change can be incorporated into the models, there is no easy way of doing so. In addition, many of these models are constructed from national accounts data, which excludes in particular consumers' time. Any project involving user time benefits, such as an HSR [high speed rail] project, will therefore introduce challenges in reproducing realistic consumer choices, such as increased tourism.*
>
> *The existing, still young SCGE models have contrasting properties to the LUTI models, namely a lack of detail or sound empirical foundation, but a sophisticated theoretical foundation and rather complex, non-linear mathematics. Because of this, SCGE models are able to model (dis)economies of scale, external economies of spatial clusters of activity, continuous substitution between capital, labour, energy and material inputs in the case of firms, and between different consumption goods in the case of households....*
>
> *SCGE models lead to a direct estimation of the non-transport benefits of new infrastructure, which are absent in most LUTI models.*

Redding and Turner (2015) also provide a nice summary of the difficulties of estimating the effect of transport infrastructure (for both commuting and freight transport) on economic growth and economic re-organisation, given the difficulty of dealing with endogeneity.

For the differences between a CBA approach and an SCGE approach, Forsyth (2013) notes:

- A CGE model is different from standard CBA in that it allows the estimation of GE effects, relative to the partial effects estimated within CBA. In particular, the string of reactions outside the transport sensitive sectors can also be explored.
- A CGE model explicitly identifies the macroeconomic effects of a project whereas the CBA provides an estimate of the overall effect. CGE modelling is a more relevant approach when the objective is to find the impact on GDP or unemployment. While CGE modelling does not provide an unambiguous answer in these areas, it does provide a framework for calculating sensitivities.
- However CGE analysis can be constrained by the formal model it uses, and often this model will be at a reasonably high level of aggregation.
- Also CBA can capture welfare effects that are not within the CGE model (typically non-market effects).
- A CGE model can model distributional effects.

An early SCGE model of relevance to this project is that developed by Horridge (1994). He calls his model a prototype, but it is in fact a rather sophisticated model of intra-urban commuting with a strong theoretical link between household choices and aggregate outcomes. Households select in which zone to work, in which zone to live, and at what degree of housing density. Land costs, which tend to be inversely related to distance from the CBD, are traded off against travel (essentially commuting) costs. There are two types of good, transport and other, but consumption of the former provides no utility. It is merely a cost that reduces the amount of income that can be spent on other goods and land for housing, which enter the utility function. Freight is not included in the model.

Relevance to this project: The model was initially structured for intra-urban travel and location choice but can readily be applied in an inter-urban context. It provides a useful starting point to the development of a New Zealand SCGE. This is pursued in chapter 5.

The rest of this section considers models and issues of interest to this project, rather than an overview of many CGE models.

Tavasszy et al (2011) discuss challenges involved specifying the Dutch SCGE model RAEM. As the authors note:

> *… we found that the translation of theory behind the spatial equilibrium models into practical model specification and empirical application is a challenging task...*

They favour the monopolistic competition approach of the Dixit and Stiglitz (1977) type which allows for heterogeneous goods and trade between regions of very similar goods, although they advise against actually trying to quantify the number of varieties.

The authors rightly criticise the iceberg approach to modelling transport costs – where goods 'melt' while being transported. Lower transport costs imply, for a given level of demand, less output needs to be produced. Thus a transport-intensive industry is in a relatively disadvantageous competitive position when transport costs fall! Especially in a multi-industry model in which transport is a separate industry, the iceberg approach makes no sense. The cost of the good, which may include a transport margin, needs to be distinguished from the quantity of the good, which does not change when transport costs change. It is not entirely clear, however, what approach is used in the RAEM model, although later versions move away from the iceberg approach.

The authors also caution against SCGE models producing too much locational flexibility: ignoring hysteresis in choice of location, ignoring location specific inputs (such as natural resources) and ignoring location specific outputs (such as services provided by local authorities). Some options are presented to deal with these potential problems.

There is also a brief discussion of the labour market closure rule in SCGE models. As in standard CGE models, different labour market closure rules should allow for fixed total employment or endogenously determined employment. For all but the largest infrastructure projects, however, (perhaps those that attract new migrants) a change in total employment is unlikely.

Relevance to this project: The paper has some useful tips about interfacing SCGE models with transport models.

Brocker et al (2010) have a SCGE model that has a household sector, one industry that produces local goods and one industry that produces tradable goods. The latter operates under monopolistic competition with one good variety per firm. There are 260 European regions plus a region for the rest of the world, which trade with one another subject to transport costs. As usual, new transport links reduce transport cost. However, transport costs are modelled using the iceberg approach, applying it to a composite of tradable goods defined for each destination.

Congestion is not simulated as the transport network is insufficiently detailed in the model, but can be simulated through exogenous adjustment

This is quite an elegant model with only four equations per region. However, its emphasis is very much on freight. The movement of people is captured in only an implicit change in consumer surplus consequent to a change in generalised transport costs.

Relevance to this project: The model has an appealing way to simulate the effects of transport infrastructure, although the sharp distinction between tradable goods and non-tradable goods could be problematic for our region of interest.

Overman et al (2009, ch 6) use a CGE model to estimate the potential spatial effects on GDP of various scenarios including travel time savings of 20 and 40 minutes. They caution that:

> *.. the spatial distribution of changes in response to the counterfactuals is complicated.* (p61)

They go on to say that modelling of spatial impacts is still in its infancy. Their approach is to use a structural model that was originally developed to estimate the gains from trade across the Canada–US border. It is not a model in the usual tradition of CGE, but rather based on heterogeneous firms and selection effects. More connectivity drives out non-competitive firms because of pressure from cheaper imports, while competitive firms grow by increasing exports. Thus productivity is effectively endogenous. Wage growth moderates the impacts of differences in competitiveness.

The emphasis of the model is on inter-city movement: namely between London, Leeds, Manchester, which is not dissimilar to the AHT triangle in terms of distances (albeit not population).

Schemes that reduce transport costs between Leeds and London, or Manchester and London produce the largest absolute economic gains in London, but the largest relative gains are in Leeds and Manchester. It will be interesting to see if this applies to AHT.

Suitability for this project: Although locational choice is implicit, land use is not explicitly captured. Nevertheless the model is appealing and could be a fruitful avenue for further research.

Donaldson (2010) estimates how railroads in colonial India affected economic welfare.

Most of the paper describes the meticulous econometric estimation of a reduced form model with panel data, taking particular care to deal with potential endogeneity of railroad placement.

While the results clearly demonstrate that expansion of the rail network raised economic welfare, a GE model is developed to demonstrate that the mechanism which delivers the gain is the exploitation of comparative advantage associated with productivity differences over firms and space. As in Overman et al (2009), the model emphasises the effect of increased trade on driving out low productivity producers by imports of lower priced, but similar, goods from neighbouring regions.

The model uses the iceberg approach to handle transport costs as there is no explicit transport industry with its own production function, but as its emphasis is on the production and trade of agricultural commodities the model is more akin to a single industry model (albeit with 17 agricultural commodities) than a multi-industry model.

Interestingly the impact of the railroad network on economic welfare is largely captured (86%) by its effect on one variable, the share of the district's expenditure that it sources from itself.

A final point raised by Donaldson is that while the research showed improved transport infrastructure raised the average level of economic welfare, it was silent on the volatility of welfare. In India's case the monsoons were the prime cause of volatility, but the issue is relevant to New Zealand insofar as the transport network is resilient to natural disasters such as droughts, floods and earthquakes.

Relevance to this project: Unsurprisingly, given its subject, the model excludes commuting and migration. It has a very tidy way of modelling heterogeneous firms (in this case small farm holdings), but this is not applicable to New Zealand, although the general point about aggregate productivity gains from increased trade may be applicable to better connectivity between Auckland, Hamilton and Tauranga.

Hensher et al (2012) combine a transport model (TRESIS) with an SCGE model (SGEM), and analyse Sydney's north-west rail link. This link it intended primarily for commuting, so freight is not part of the analysis.

The authors caution that consistency between such models is important and thus appeal to the theoretical link between discrete choice logit models used at the level of individual choices about transport (route, mode, location etc).[20] and aggregate CGE models.

Agglomeration elasticities are estimated on the basis of wage rate differences (on the assumption that wages reflect the marginal product of labour) as data on output, employment etc is not available at the required fine spatial level. Their results are comparable with those in other studies although the authors point out that agglomeration elasticities can be quite industry and place specific.

The simulation analysis proceeds by exogenously setting changes in travel time in the transport model, which then produces changes in travel patterns – mostly in favour of train travel unsurprisingly. Changes in where people work generates changes in employment density in most zones. Hence agglomeration benefits occur, leading to higher wage rates in line with higher labour productivity. In contrast the GE effect is the increases in the total wage bill brought about by workers having access to better paying jobs, although agglomeration may lead to further employment redistribution. Not all benefits are manifested in lower travel costs. Some workers may elect to spend more on travel because higher wages make then better of overall. (This is true in normal cost-benefit analysis as well.)

The authors ascertain that the pure GE effects (that is with no agglomeration benefits) account for 86% of the increase in the total wage bill. There are some sign reversals at the zone level; namely zones which have negative agglomeration effects nonetheless have overall positive effects because of strongly favourable GE effects. And of course the zonal distribution of effects depends on whether one looks at residential zone or work zone.

Agglomeration effects are essentially (labour) productivity effects – higher wage rates – generated by changes in effective density of the (working age) population.

In contrast GE effects change the distribution of workers between industries and/or zones, thereby raising average incomes. Wage rates do not necessarily change, but may do if there are changes in the overall demand for and supply of labour.

Relevance to this project: Although the focus of this paper is on intra-city travel, the methodology can also be applied to inter-city travel commuting. Its key finding is that the ability of workers to access higher paying jobs is considerably more important than the increases in wage rates due to agglomeration effects. It will be interesting to see whether this is true for changes in connectivity between Auckland, Hamilton and Tauranga.

Robson et al (2015) covers some of the models discussed above, notably RAEM and Horridge's model, so they are not referred to below.

[20] See for example Stephenson (2015)

Echoing the World Bank (see above), as background the authors note that LUTI models have substantial detail with regard to transport networks and land use, with a solid empirical grounding, but do not measure welfare and thus do not accommodate externalities. In contrast CGE models have a solid theoretical base that does enable welfare to be measured, but lack the detail of LUTI models.

The capacity to incorporate externalities (in a consistent manner) and variable prices distinguishes CGE models from CBA gives. SCGE models add the ability to simulate the gains from spatial reorganisation of economic activity. However (S)CGE models are less transparent compared with CBA.

Apart from the degree of disaggregation with respect to industries, households and space, most of the differences between (S)CGE models seem to be in terms of:

- How transport is modelled – the iceberg approach versus an explicit cost margin, perhaps entering into industry production functions (with a surprising number of models using the former). The authors describe a model of proposed state highways in Korea (Kim et al 2004) in which accessibility enters the production function using a gravity model.
- Returns to scale and perfect competition – heterogeneous firms as discussed above.
- The emphasis on the movement of people versus the movement of goods.
- The degree to which travel time is endogenous, as opposed to being set exogenously based on the results from a transport model.

Relevance to this project: Incorporating an accessibility measure based on the gravity model is a useful innovation when data on inter-zonal flow of goods (their origin and destination, and which industries are producing and consuming them) is scarce.

A number of other papers of lesser relevance to this project include those below.

- Anas and Liu (2007). A large part of the paper deals with the solution algorithm (which is complex) to an SCGE model that has four agents: consumers, producers, landlords and developers. It is not readily apparent what extra insights the latter two agents add to an assessment of the benefits of transport projects. Indeed no applications of the model to transport projects are given in the paper. In other respects the model is reasonably standard with a mix of Cobb-Douglas and constant elasticities of substitution (CES) functions for utility and production. An interesting feature of the model is that travel routes have flow rates and capacity rates so congestion can be modelled.
- Berg (2007). The emphasis of the paper is on the distributional effects of a carbon price in Sweden, but with a CGE model in which household transport demand has been disaggregated by income group, trip purpose, trip length and population density (as proxies for spatial effects). The extra detail is shown to affect the reliability of the results.
- Martin and Reggiani (2007). To measure the effect of high speed trains in European cities the paper presents a number of ways of measuring accessibility, including standard measures based on market size and density, and more novel measures based on principal components and data envelop analysis.
- Allen and Arkolakis (2014) explore in the first half of the paper the conditions for the existence, uniqueness, and stability of a spatial economic equilibrium. In the second half of the paper the model is used to estimate the proportion of the observed spatial variation in income across the US that can be explained by geographic location (result: 20–70%), and to examine the effect of removing the interstate highway system (result: a loss in welfare of 1.1–1.4%). Allen and Arkolis do not adopt the fairly standard approach of assuming that firms operate in monopolistic competition, opting instead for perfect

competition, but with Armington elasticities as typically used in GE trade models to simulate imperfect substitution between varieties of goods. The model uses the iceberg approach for trade costs.

- Ahlfeldt and Wendland (2015) demonstrate the trade-off between land prices and commuting costs. Employment potential at a given location is the sum of employment across all potential commuting destinations, weighted by bilateral transport costs. The resultant pattern of spatial decay in bilateral commuting probabilities is very close to the actual decay observed in commuting data. A corollary of this finding is that commuting decays can be inferred from the spatial distribution of land prices and employment, if suitable data for the estimation of a commuting gravity model are not available.
- Monte et al (2015) are interested in establishing the elasticity of local employment to changes in the economic and geographic environment. Using a SCGE model that incorporates spatial linkages between locations for trade in goods (employing the iceberg approach), commuting and migration (employing the iceberg approach) they find large differences in local employment elasticities because of differences in commuting links. Also, the effect on the spatial distribution of economic activity of a reduction in freight costs is sensitive to the costs of commuting, a finding that is likely to be relevant to the AHT region.

2.5.5 Conclusion of section

This section has revealed that a parsimonious SCGE model suited to examination of large transport interventions can be constructed, based on that of Horridge (1994). In particular the model can be readily adapted to study inter-urban transport effects in the AHT area.

Such a model would focus on the reduction in trade costs brought about by a transportation improvement. Thus people and production will shift to the optimal location relative to other costs and preferences[21].

The Horridge model would not at present be able to provide directly the effects working through changes in imperfectly competitive markets – a key channel for NEG – but an equivalent exogenously determined productivity shock could be fed into the model to derive the likely spatial redistribution that would be result from an effect of that scale. Note this is different from specifically modelling urbanisation and localisation effects within the model but the outcomes are expected to be of a similar order of magnitude.

It is important to stress that any SCGE model is specific to the issues and area the model was designed to address; in this case, major transport interventions in the AHT area. That is, the model will not immediately be available to consider other areas, nor all issues within the AHT area. The model envisaged can, though, be further adapted to consider other areas and other disaggregations as required, albeit this requires more data gathering and model testing.

2.6 Applying connectivity in decision making

It is one thing to theorise how improved connectivity might improve productivity but applying these ideas has its own challenges, as discussed in this section.

The World Bank (2014, p2) reports different approaches to appraisal amongst countries:

- Germany uses regional development scoring as a complement to conventional transport CBA.
- Japan uses SCGE.

[21] Albeit in the model the shift is treated as a costless relative shift, possibly best perceived as where future businesses would likely locate.

- UK uses partial equilibrium studies, well supported by micro foundations.
- The World Bank advocates for a Chinese high speed rail the corroboration of appraisal with business surveys.

In each case there is an acknowledgement the CBA does not provide complete information for decision making, at least for large investments.

The UK approach is evolving. To the extent that connectivity improves agglomeration and labour markets then these effects are currently estimated as add-ons to the standard CBA as WEBs, as outlined in DfT (2016). Note, these analyses should include sensitivity testing. UK experience is that agglomeration is usually the largest WEB and WEBs in total are generally in the range of 10–30% of user benefits.

Only the urbanisation component of the intra-urban agglomeration effect is currently calculated. This intra-urban urbanisation effect is broken into a 'static clustering' and 'dynamic clustering' effect, the latter entailing re-organisation and the former no reorganisation after the transport intervention, either with or without additional policy changes or incentives. The total urbanisation estimation process:

- requires spatial modelling (eg with a LUTI model)
- requires a breakdown of benefits due to a) a shift in employment and b) an increase in clustering
- requires a tax wedge to be estimated as an additional effect
- is restricted to zones with larger populations or in zones adjacent to large populations which attract significant commuting[22]
- requires estimation of effective employment density, using GTC and a standard distance decay parameter that varies by industry[23] (ranging from 1.097 for manufacturing to 1.746 for producer services), thus limiting the agglomeration to a radius of less than 75km, and
- requires the GDP effect of shifting to a different employment location to be estimated by applying standard zonal productivity differentials.

The DfT is also moving towards a system that considers economic effects more widely, extending the WEB add-ons but also standardising approaches to describing how the user benefits are expected to spread through the economy. These are being considered under the three unit headings listed in table 2.3.

Table 2.3 UK DfT framework under consideration

Units to do with economic impact	Involves	Weak points
Strategic	Strategic narrative	
Productivity	Agglomeration Variable land use Clustering	More required on inter-city productivity
Investment and employment	Effect on employment Effect on investment	DfT requires guidance on GVA, LUTI, SCGE models Including standardised approaches

[22] www.gov.uk/government/uploads/system/uploads/attachment_data/file/427123/tag-workbook-functional-urban-regions-lookup.xlsx

[23] www.gov.uk/government/uploads/system/uploads/attachment_data/file/427528/tag-workbook-wider-impacts-dataset.xls

The 'strategic' unit is expected to require business cases to include a narrative, describing the transport intervention, what impacts are expected to occur, the reasons for their existence and how they will be assessed within the economic appraisal.

The 'Investment and employment' enhancements centre on relaxing the fixed land use assumption in existing CBA appraisal. The core assumptions of the standard CBA is that the transport demand curve can be forecast, that the downward shift of the transport supply curve resulting from intervention can be predicted and then that the shift along the demand can be estimated, providing the change in consumer surplus due to the intervention. This is the benefit to society to be netted off against the cost of intervention. Implicit in this analysis is that the transport intervention itself does not shift the demand curve – it only changes the cost of travel. This assumption will not be valid should market failure exist.

'Market failure' is to be understood here as any misallocation of resources (which, in a perfect market, would not occur) due to some imperfection in the market mechanism. Imperfect knowledge and externalities are key potential mechanisms of market failure[24]. For example, people may not realise the full extent of the benefits they could receive by locating in an area, for business or residence. They may become fully aware only after a transport intervention is announced and/or they observe other development in the area. The effects of lack of information and uncertainties are very difficult to isolate, eg would an observed relocation after a transport intervention have occurred without the intervention?

The DfT are investigating means to append estimates of Investment and Employment benefits to the other benefits on a case by case basis, should sound justification exist. Measurement of the extra benefit *may* be with GVA, LUTI and/or SCGE models. Note that any gross benefit adjustment will also require estimation of congestion effects resulting from any shift of the demand curve to calculate the net extra benefits otherwise missed within the current standard analysis. The types of extra benefits under consideration arise from effects related to 1) induced private investment 2) labour supply and 3) imperfect competition.

Another mechanism, although potentially inter-related, is that there may be external benefits from persons or firms moving to a location. These external benefits to others will not be reflected in the transport demand of the firms and people. Subsequent benefits to society may be higher than estimated from an ex ante user benefits appraisal.

The DfT is also investigating how to extend the 'productivity' transport analysis guidance (TAG) unit to include localisation effects resulting from externalities between firms within a co-located business sector that arise from an inter-urban transport intervention. This is not envisaged as an add-on in the base case scenario but rather a sensitivity test to be explored. The effect can be estimated using similar effective densities as in the currently calculated urbanisation effect, but with lower elasticities applied. Inter-urban localisation effects are expected to be less than 43% of dynamic clustering effects estimated for manufacturing industries within the current urbanisation effect estimation, and less than 5% for services industries. Productivity sensitivity tests of a similar nature are also planned for 'freight trips' and for when the zone includes a large proportion of public sector organisations.

In the US, there is no one consistent approach to transport appraisal. The Government Accountability Office (GAO) (2010) records that the state departments of transportation (DoT) select projects for inclusion in their improvement programmes 'based on a range of factors, but funding availability and political and public support were of greater importance than the results of economic analysis of a transportation project's benefits'. A 2004 survey, cited by ConnDot (2013), showed only 16 of 26 states

[24] Government is providing transport infrastructure in the first place because market failures are believed to exist in that transport infrastructure has the characteristics of a public good and a natural monopoly and generates external effects (Duncan 2009).

that responded conducted a study analysing the economic impacts of transportation projects. It is relevant to note that between 2008 and 2011, 75% of the $200 billion per year government spending on US transportation infrastructure projects was by local transportation agencies and only 25% was spent by the federal government. The ex-post analysis of US case studies is telling: Fitzroy et al (2014) observe that the focus of case studies is on economic impacts, with the objective of identifying factors that might mitigate negative and accentuate positive potential economic impacts. Conversely European ex-post studies have concentrated on validating the CBA methodology.

ConnDot (2013) reports that regional economic models (REM) are the most commonly used tools for economic impact analysis (EIA) for large-scale transportation investments, although CBA is also widely used and the difference between 'net benefit' and 'net economic impact' is often noted[25]. An example of a state that does employ economic impact analysis is Indiana. A combination of CBA and the REM system REMI were used to evaluate an expansion of a state highway. In Kansas, the REM system TREDIS has been adopted into their planning process, culminating in projects being scored and ranked based on gross state product (GSP), employment and travel user benefits, and with economic impacts given a 25% weighting in a multi-criteria ranking process. Michigan DoT has combined a travel demand model with REMI to predict GSP, employment and cumulative income effects. They then seek public feedback on the ranking of projects.

REMI is a CGE model. TREDIS employs partial equilibrium analysis. Both include input-output and NEG methods. Both also provide CBA outputs. An example of how a transportation improvement would feed through REMI is provided by Fan et al (2000): 'as transportation costs decrease industries with a high use of intermediate inputs and relatively low land intensity tend to agglomerate. On the other hand, industries with fewer backward linkages and higher land use are more dispersed'.

An example of the dual use of CBA and EIA is the 1999 business case (Fletcher Harris Inc 1999) for a bridge to cross the Mississippi River near the existing Chalmette–Algiers ferry crossing in New Orleans[26]. Transport modelling was undertaken to provide traffic demand in 2020 for 'no-build' and 'build' scenarios. User-benefits due to reductions in travel time, operating costs and accidents were estimated and a benefit-cost ratio (BCR) of 1.2 was derived for one of several bridge configurations. A parallel EIA was conducted for the same configuration using REMI to estimate the present value of the GSP impact over 33 years and compared against construction and maintenance costs[27] to derive an economic impact to cost ratio of -0.5. In other words, the welfare benefits, some possibly to non-Louisiana residents, were not expected to be realised as output benefits in Louisiana. Conversely, if new Federal funding equivalent to 80% of costs were instead to be employed, the state economic impact ratio rises to 2.3, ie it would now be beneficial to the economy of Louisiana. The EIA provided further information to the CBA and enabled exploration of state benefits under different funding systems, as well as describing benefits in terms that local decision makers could easily grasp, such as output and jobs.

A recent innovation in the US has been to provide tools to enable quicker and less expensive 'early stage planning' analysis. In this context, the above analysis, although relatively small, could be considered as an example of 'later stage planning'. The Strategic Highway Research Program (SHRP2)[28] has provided a database of completed projects and a tool that enables a quick look-up to estimate the probable like-for-like benefit.

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[25] Also noted by ASSHTO, Transportation Research Board and others

[26] This bridge was not build at the time but investigations continue today.

[27] Funded by state bonds backed by toll and fuel taxes

[28] Sponsored by ASSHTO and FHWA

A third approach is also provided for ‘middle stage planning’. Again SHRP2 has provided standardised methods and spreadsheets[29] to estimate wider benefits categorised as (a) travel time reliability; (b) intermodal connectivity and; (c) market access. These can then be used as add-ons to the standard CBA. Warnings are provided that some double-counting may occur and should be taken into account but no explicit methods are provided to remove any double-counted effect. EDR (2014) discusses the potential for double counting, noting that any overlap between the three effects is reduced since seldom are all effects relevant in a specific project.

Table 2.4 Classification of transportation project benefits (EDR 2014, p13)

Benefit or Impact Element	Units for Measuring Change in $
Traditionally Measured Benefits	
Travel Time Savings	Value of driver + passenger travel time savings
Vehicle Operating Cost Savings	Cost savings from reduced vehicle-miles or vehicle-hours of travel
Safety Improvement	Value of reduction in crash incidents
$ Value of Environmental Benefit	Value of reduction in tons of emissions
Wider Economic Benefits	
Reliability Benefit	Cost savings or income gain from less nonrecurring delay
Market Access Benefit	Income or GDP gain from effective size or density gain
Intermodal Connectivity Benefit	Income or GDP gain from intermodal connectivity benefit
Other External (Environmental and Social) Benefits	
Other Environmental Impact	Value of reduction in water, noise, visual, other pollution
Social Impacts	Value or enhancement in social factors

The market access tool provides two measures of effects: the agglomeration effect resulting from commuting; and a productivity gain resulting from improved truck access to buyers and suppliers. The first is equivalent to the EEM agglomeration effect; the second is similar to the market delivery variable used in the Transport Agency GVA model. The market delivery effect is calculated by estimating the increased employment mass within three hours, weighted by distance or GTC using, if desired, a decay parameter, multiplied by a GDP elasticity. Variations include use of industry employment as the determinant of mass when there is evidence of industry concentration. The SHRP2 report concedes the actual magnitude of this delivery zone effect is ‘still debatable’ but argues there is ample evidence of association between productivity and mass.

The intermodal connectivity tool derives an estimated productivity improvement by multiplying the number of vehicles associated with the port by the value of travel time saved per vehicle from the road project, weighted by the relative connectivity index for each port. The underlying connectivity index for ports within categories such as air passenger ports, bulk freight sea ports and container sea ports is based off the volume and reach of the port. For example, William B Hartsfield International Airport (ATL) in Atlanta, putting through 86 million passengers and connecting to 363 locations, has an ‘air passenger connectivity index’ of 31,484 (=86x363) or 100% in relative terms as it is the ‘most connected’ airport for passengers[30]. One million vehicle trips per year travelling to this airport saving $50/trip would equate to ‘connectivity benefits’ of $50 million pa. Whereas a similar magnitude of trip savings to Logan

[29] www.tpics.us/tools/

[30] Figures taken from the SHRP2-C11-Intermodal-Connectivity-Tool workbook.

International Airport in Boston, with only 23% of the connectivity of ATL, would equate to 'connectivity benefits' of $11.5 million pa. It is considered that an improvement in travel time leads to an increase in the breadth of markets accessible and supply chain innovations, in turn leading to a productivity improvement (EDR 2013).

3 Overview of GVA and SCGE models

The intention of this project was to refine a GVA model and develop an SCGE model. Chapter 2 has established the need for models that can provide insights into economic effects to complement the current user CBA, and suggests the following ways forward in the development of these models.

First, the need. The standard CBA approach is based on sound principles and has a long history of application. But it does have at its core the unrealistic assumptions that (a) a shift along the transport demand curve at discrete points in the future can capture all the responses to a transport intervention and (b) that this shift in quantity demanded can be forecast. The presence of imperfect competition, differing income elasticities of demand, economies of scale, government intervention and externalities means that (a) will not apply. The sheer interdependence of the economic system, let alone the uncertainties about the future, mean that (b) will never apply also. Nonetheless, it may be that (a) is adequate and (b) is reasonable, especially relative to how uncertainty might be treated within any other model chosen. That is, the user-benefit CBA approach will provide a solution that is likely to at least rank projects in accord with the unknown 'correct' ranking.

The short-coming of the CBA approach may not be fully understood outside micro-economist circles but there is widespread acknowledgement that something more than a user-benefit CBA is required for large projects. The UK DfT is going down the path of creating more add-ons to the standard CBA. The US has long put emphasis on other measures of impact, sometimes with and sometimes without a CBA. Germany takes regional backwardness into account. The World Bank is recommending complementary economic modelling and corroboration with business surveys and traffic monitoring. For the most part, the user-benefit CBA is a widely used measure of importance for a transport project but other criteria are also widely considered.

Second, the literature does point to channels through which transport changes translate into economic activity. These provide the obvious relationships to include in any economic models.

For the GVA model, the literature review:

- reinforces the significance of agglomeration effects, so any GVA should continue to include an accessibility variable.[31]
- also suggests a decay parameter is required in any measure of effective density, so consider building this feature into the model
- concludes inter-urban agglomeration effects are likely to result from industry localisation which, in turn, points towards industry concentration and industry scale economies as important signals of potential inter-city productivity gains, so test measures of concentration within the model
- also shows connectivity to ports is considered important by many people although the micro-economics are not as well defined, so continue to explore measures of port connectivity within the model
- clearly shows context is important in determining how an economy will evolve after any large transport intervention, so look to refine the model to match the circumstances of the AHT area where possible.

[31] The need to take account of people- and place-based effects on GDP, and the need to take into account endogeneity, were not revisited in this project

For the SCGE model, it is evident from the above studies that while a number of features are common to most SCGE models, they nonetheless vary significantly in scope and focus. This is a natural consequence of three factors that compete for resources within limited research budgets:

1. The objectives of the research issue
2. The challenge of turning SCGE theory into practical SCGE models
3. The size of the empirical task with regard to data requirements.

For this research project the objective was to understand the spatial distribution of the effects of changes in connectivity between three urban areas and their links to the rest of the world (via one major international airport and two seaports). Given that objective, our emphasis has been on specifying a model with the right number of spatial zones to capture both freight movements and inter-urban commuting. As the data requirements of this are not inconsiderable, industry disaggregation is given a lower priority, as long as land transport is separately identified. Consequently we have not used the iceberg approach to simulate transport costs.

We use as the basis of our SCGE model, the model developed by Horridge (1994) with two main differences:

1. Removal of the disaggregation of household income groups and suburban density, which is more relevant to intra-urban commuting; the focus of Horridge's model
2. Addition of equations to include transport margins and freight flows between zones and between the zones and the rest of the world (including the rest of New Zealand).

While these GVA and SCGE models will provide more insights into output effects and the spatial distribution of these effects, the models planned will not capture the endogenous growth process whereby a transport investment might set an economy (or region) on a higher growth path as a result of higher human and physical capital raising productivity which, in turn, feeds back into even more investment and innovation, and so on[32]. Rather the two models provide a static estimate of how an economy will adjust to a transport intervention at one point in time. Implicit in the use of these models is that larger forces are at play to influence national or regional growth – this may not always be the case but it is beyond the scope of this project.

[32] Higher investment may result in response to any change in the planned SCGE model as part of closure conditions but this is not an ongoing growth process.

4 New Zealand GVA model

The initial GVA model built for New Zealand (Byett et al 2015), as discussed in section 2.2, confirmed an agglomeration effect existed in New Zealand and hinted that populations and/or ports beyond the territory might also influence productivity. One difficulty with establishing this later relationship was the crude measures (A40 and A120) of accessible population mass used in the model and their estimation. The following section shows the results from (a) considering a more refined measure of the effective mass that will measure the intra-urban agglomeration effects and from (b) re-visiting measures of likely candidates to pick up inter-urban activity. Before doing so, the current model is updated using new and revised data. Equation 2.1 is repeated as equation 4.1.

$$Employ_t = f(Pop_t\ XVAR_t\ A40_t,\ A120_t,\ AAir_t,\ ASea_t) \qquad \text{(Equation 4.1)}$$
$$GDP_t = g(Employ_t\ XVAR_t\ A40_t,\ A120_t,\ AAir_t,\ ASea_t)$$

Where

- $Employ_t$ and GDP_t are vectors of number employed and real GDP by TA area at time t for an industry sector.
- $XVAR_t$ is a matrix of people attributes associated with each TA area at time t
- The four access vectors (the As) are as defined in table 2.1.

Recall, the coefficients of the mass variables (A40, A120 and AGTC introduced in 4.2 below) are expected to be positive, with more accessible people expected to lead to higher productivity. Conversely the coefficients of the drive time variables (AAIR and ASEA) are expected to be negative, with quicker times expected to lead to higher productivity.

4.1 Re-statement of model and data

The earlier GVA study analysed data from the 2001 and 2006 censuses. The results have since been made available for the 2013 Census. There have also been revisions to 2001 and 2006 data.

First, some revisions have occurred as a result of creating consistency of 2001 and 2006 data with the 2013 Census data, which used redefined meshblocks. The redefinition of meshblocks also led to revisions to the number of working age people accessible within 40 and 120 minutes of area centroids, both due to relocation of centroids and recalculated travel times between area centroids and meshblocks. More details on the travel calculation follow in section 4.2.

Second, refinements to the earlier data were made to provide an Auckland local board area breakdown in lieu of the seven Auckland TAs merging into one Auckland City in 2010. Data for all variables were collated for 19 of the 21 Auckland local board areas, with the 2 island Auckland boards excluded.

The first step in this model-building phase was to re-run the earlier GVA model but with the revised data for 2001 and the new data for 2013. These results for the A40 parameter (ie the elasticity to the number of working age people within 40 minutes) are tabled below for two sectors where the agglomeration effect shows in repeated studies[33].

[33] Results for the A120 coefficient in each step are shown in section 4.3

Table 4.1 Agglomeration elasticities based on working age population within 40 minutes (A40), using original and updated data (Auckland units in brackets)*

Industry sector	2001 and 2006 (territories) as at 2014 orig XVAR <run 1>	2001 (territories) as at 2016 orig XVAR <run 7>	2001 (board areas) as at 2016 orig XVAR <run 10>	2001 (board areas) as at 2016 more XVAR <run 10a>	2013 (board areas) as at 2016 more XVAR <run 11>
Wholesale trade	**0.087**	**0.070**	**0.077**	**0.081**	**0.060**
Professional, scientific and technical services	**0.061**	**0.040**	**0.039**	**0.041**	**0.032**

* Estimates significantly different than zero at 95% are shown in bold red.

These results still show a significant A40 effect on GDP within these two sectors but the estimate is now smaller. The downward revision to 2001 figures is due largely to revisions to GDP and employment data.

One observation made when the larger breakdown of Auckland City was undertaken was the distinction between areas that were predominantly commercial and others that were largely residential. An additional explanatory variable was added to the XVAR matrix to take account of this difference. The proxy chosen was the ratio of total jobs filled to working age population in the area (within Auckland) or territory (outside Auckland). Adding this extra explanatory variable (coded EMP2POP) resulted in a slight increase in the A40 parameter estimate (see <run 10a> in table 4.1).

Using the expanded XVAR set, the new GDP and EMP data for 2013, and a measure of the 2013 working age population within 40 minutes provided agglomeration elasticities that were lower than the original elasticities (the last column in the table). However the original, the 2001 and the 2013 elasticity estimates share overlapping 95% confidence intervals so caution is required about inferring any difference between the elasticity estimates.

4.2 Re-defined measure of effective mass

4.2.1 Labour market mass redefined

In theory the effect of a nearby mass of workers is that people mingle and ideas are shared, plus there is better matching of skills and jobs. Research has revealed this effect diminishes with distance. The previous GVA research also showed that not taking this diminishment into account created implausible effects, namely a five-minute time saving by someone 44 minutes away having the same effect on productivity as a five-minute saving by someone 10 minutes away; the former is unlikely to change behaviour while the latter may lead to some change.

The modelling response has been to weight the number of people inversely by the time or distance or cost of travel. In this project, the cost of travel, ie the generalised travel cost (GTC) was used as the weight, to maintain consistency with the EEM.

Thus effective mass was used to replace the A40 variable in the previous model. This mass, coded AGTC, was calculated from the time and distance to drive at the road limit speed from the population-weighted centroid of each area (territory or local board area) to the surrounding meshblocks. An arbitrary two-hour and 200km cut-off was applied to reduce calculations. The GTC of each journey from centroid to meshblock was calculated as the

maximum of $1 or [$0.36*(minutes of drive time) + $0.22*(distance) - $8.2], where the $0.36 and $0.22 are travel time and vehicle operating costs representative of those in the EEM. Putting aside the issue of a 'decay parameter' for now, the two adjustments to the otherwise standard GTC equation are (a) deducting $8.2 from all costs and (b) treating all GTC less than $1 as $1. The latter adjustment implies populations that are very close are not given a weight above 1 (again putting aside the issue of a decay parameter). The former adjustment is a pragmatic response to the use of centroids for relatively large and sometimes dispersed areas. Effectively the formula treats the centroid as an approximate 15-minute drive polygon and any drive times, distances and GTC are calculated from the edge of that polygon. One implication for interpretation of results is that any reference to GTC in sections below potentially understates the actual cost of travel from point to point.

The effective mass (AGTC) for each territory and area was then calculated by summing the working age population in each meshblock within two hours and 200km of the widened centroid, with each meshblock working age population inversely weighted by the GTC between centroid and meshblock. For example, the AGTC for Waitakere Ranges Local Board Area in 2013 was 319,772 made up from people in 15,555 meshblocks. By comparison, the working age population in the area at the time was 34,500 and was 1,011,900 in the wider Auckland City. The estimated working age population within 40 minutes' drive of the widened centroid was 873,709. For most territories/areas, the AGTC was less than the A40 measure of mass.

Replacing A40 with AGTC in the above model produced the results tabled below for the two key sectors previously mentioned. Estimated agglomeration elasticities were higher than estimated using the A40 variable, although this difference would not be statistically significant.

Table 4.2 Agglomeration elasticities based on GTC- weighted working age population (AGTC)

Industry sector	2001 (board areas) as at 2016 more XVAR <run 12>	2013 (board areas) as at 2016 more XVAR <run 13>
Wholesale trade	0.119	0.092
Professional, scientific and technical services	0.064	0.051

4.2.2 Decaying effect of distance

Research also suggests the GTC weight should increase in a non-linear fashion. Modellers have incorporated this finding by applying a 'decay' exponent to the GTC weight, which would mean calculating AGTC in this case as $AGTC=\sum GTC\text{-}\alpha$ x working age population. An exponent (α) of 1 will give the results reported in the previous section. Appendix C shows the results from considering the best fit with GDP of a range of decay exponents from 0.8 to 1.8 within this project. At this stage, the data does not imply any one decay parameter as best. With no compelling evidence otherwise, this model-building phase proceeds with a decay exponent of 1, as currently recommended in the EEM.

4.3 Candidates for inter-urban connectedness

In the previous sections two access variables have been included in the models fitted, namely the various forms of the agglomeration variable as detailed above and a variable measuring the working age population between a 40 and 120 minute drive away (A120). Until now the detail of A120 estimates in the above runs have not been presented. The A120 results for two key sectors from the three steps: data revised and updated; A40 replaced by AGTC; AGTC calculated with decay parameters, are shown below in tables 4.3 to 4.6.

The A120 parameter estimate was not significantly different from zero for the professional, scientific and technical services sector in all the above runs, as was the case in the initial GVA model.

The A120 estimated elasticity for the wholesale trade sector was lower than in the initial GVA model using the 2001 revised data and lower again when A40 was replaced with the GTC-weighted agglomeration variable. The estimate increased as the decay exponent on the agglomeration variable increased. This is consistent with the AGTC variable providing a weaker measure of wider populations as the decay exponent increases and the A120 variable picking up some of this effect. However, as in the previous section, all estimates have overlapping 95% confidence intervals and hence are not statistically different.

Table 4.3 Estimates of the A120 elasticity as new and revised data are added

Industry sector	2001 and 2006 (territories) as at 2014 orig XVAR <run 1>	2001 (territories) as at 2016 orig XVAR <run 7>	2001 (board areas) as at 2016 orig XVAR <run 10>	2001 (board areas) as at 2016 more XVAR <run 10a>	2013 (board areas) as at 2016 more XVAR <run 11>
Wholesale trade	0.070	0.053	0.059	0.056	0.056
Professional, scientific and technical services	-0.004	0.001	0.008	0.007	0.004

Table 4.4 Estimates of the A120 elasticity following change to AGTC

Industry sector	2001 (board areas) as at 2016 more XVAR <run 12>	2013 (board areas) as at 2016 more XVAR <run 13>
Wholesale trade	0.034	0.037
Professional, scientific and technical services	-0.008	-0.008

Table 4.5 Estimates of the A120 elasticity for varying decay parameters applied to AGTC (2001 data)

Industry sector	2001 decay=0.8 <run 12a>	2001 decay=1.0 <run 12>	2001 decay=1.2 <run 12b>	2001 decay=1.4 <run 12c>	2001 decay=1.6 <run 12d>	2001 decay=1.6 <run 12e>
Wholesale trade	0.019	0.034	0.046	0.055	0.062	0.067
SE	0.015	0.014	0.013	0.013	0.013	0.013
R2	0.9962	0.9961	0.9959	0.9958	0.9956	0.9955
Professional, scientific and technical services	-0.017	-0.008	-0.001	0.005	0.009	0.012
SE	0.011	0.010	0.010	0.010	0.010	0.010
R2	0.9968	0.9967	0.9966	0.9965	0.9964	0.9964

Table 4.6 Estimates of the A120 elasticity for varying decay parameters applied to AGTC (2013 data)

Industry sector	**2013 decay=0.8 <run 13a>**	**2013 decay=1.0 <run 13>**	**2013 decay=1.2 <run 13b>**	**2013 decay=1.4 <run 13c>**	**2013 decay=1.6 <run 13d>**	**2013 decay=1.6 <run 13e>**
Wholesale trade	0.026	**0.037**	**0.045**	**0.052**	**0.057**	**0.060**
SE	0.016	0.015	0.014	0.013	0.012	0.012
R2	0.9952	0.9952	0.9952	0.9952	0.9951	0.9951
Professional, scientific and technical services	-0.016	-0.008	-0.002	0.002	0.005	0.008
SE	0.010	0.011	0.010	0.010	0.009	0.009
R2	0.9966	0.9966	0.9965	0.9965	0.9964	0.9964

For a decay parameter of 1, the A120 estimate was only positive and significantly different from zero in one other sector in 2013 (health care and social assistance) and one other sector in 2001 (central government administration, defence and public safety). Thus it was of limited use as a measure of inter-urban connectedness.

The A120 variable also has practical limitations as any transport improvement that brings people within the 40-minute polygon can also reduce the 40–120 minute mass, thus creating heightened sensitivity of results to people around the 40-minute threshold.

As an alternative measures of wider connectivity, access to air and sea ports have also been used. These are now considered.

Replacing A120 with ASEA (ie weighted time to international sea port) does not generally lead to significant ASEA effects or improvements in goodness of fit. There was only one sector (road transport) that showed a significant effect of the sign expected and that was only in 2013. This variable was no longer considered for model inclusion.

Conversely, replacing A120 with AAIR (ie weighted time to international airport) did generally improve goodness of fit, albeit slightly, and did provide coefficients significantly different from zero and of the sign expected for 18 of the 47 sectors fitted in 2001, and for 12 sectors in 2013. Of those significantly different from zero in either year, only two were significantly different from each other in the two years (motor vehicle and motor vehicle parts and fuel retailing, other store-based retailing and non-store retailing).

The replacement of A120 with AAIR in the two sectors detailed previously results in a slightly better fit in both sectors in 2001 and in 1 sector in 2013 (see table 4.7). The AGTC estimates declined in the presence of the AAIR variable in both sectors in 2001 and in 1 sector in 2013.

Table 4.7 Estimates of alternatives connectivity measures

Industry sector	2001 decay=1.0 A120 <run 12>	2001 decay=1.0 AAIR <run 14>	2001 decay=1.0 ASEA <run 15>	2013 decay=1.0 A120 <run 13>	2013 decay=1.0 AAIR <run 16>	2013 decay=1.0 ASEA <run 17>
Wholesale trade	0.034	- 0.040	-0.003	0.037	- 0.039	0.003
SE	0.014	0.013	0.014	0.015	0.013	0.013
R2	0.9961	0.9964	0.9957	0.9952	0.9954	0.9948
AGTC	0.119	0.107	0.144	0.092	0.096	0.128
Professional, scientific and technical services	-0.008	- 0.015	-0.006	-0.008	-0.010	0.009
SE	0.010	0.006	0.010	0.011	0.008	0.010
R2	0.9967	0.9968	0.9967	0.9966	0.9965	0.9964
AGTC	0.064	0.045	0.055	0.051	0.037	0.045

The AAIR variable thus has two advantages over the A120 variable as a measure of inter-urban connectedness: it generally fits better with the data (albeit the difference is statistically insignificant); and is measured in way that has a less direct relationship with AGTC.

However, previously this relationship was shown in the earlier GVA study to differ between large territories and the remainder. This was investigated again. The previous GVA found that generally the AAIR effect was present mainly amongst the large territories only, including the seven territories of Auckland. The current study considers Auckland as 19 local board areas with only 10 defined as large (ie GDP in 2001 above $2 billion). The AAIR effect is now found to hold for eight sectors amongst the non-large territories and areas in 2001. Furthermore the 18 sectors in 2001 where a significant AAIR effect was found either amongst the large, the non-large or all territories/areas had overlapping 95% confidence intervals, ie there was no proof in the 2001 data that the estimated parameters were different. A similar result was found amongst the 2013 runs with large and small territories/areas.

Hence the recommendation is to employ the AAIR variable as a measure of inter-urban connectivity in future GVA models.

Two further model runs were undertaken in light of the similarities between 2001 and 2013 results.

First a test was undertaken to test for any effect of the change in accessibility between the two years on productivity. This showed there was no significant effect of the change of AGTC or change of AAIR on GDP in general. The interpretation of this result is twofold: some of the accessibility effects are likely to play out over many years and hence GDP in 2013 will in part relate to improved accessibility that evolved up to 2001; and there are likely to be other larger influences on territory/area GDP growth that could over-shadow any change in accessibility.

The second run, in view of these and earlier results, was to combine 2001 and 2013 data to provide elasticities reflective of the average of the two years.

Table 4.8 Combined 2001 and 2013 elasticity estimates <run 19>

Industry sector	AGTC	AAIR
Wholesale trade	0.101	- 0.039
Professional, scientific and technical services	0.041	- 0.013

4.4 Evidence of wider effects of specialisation

One finding of the literature review was that improvements in inter-regional transportation links could lead to higher productivity if specialisation increases.

The dataset was examined to find evidence of specialisation effects on productivity. A measure of specialisation was devised as the percentage of national GDP produced within the territory/area for each sector. For example, 11% of New Zealand horticulture and fruit growing GDP was produced in Hastings District in 2013. This was reduced to 1 number per territory/area by taking the maximum New Zealand share across all sectors for the territory/area. For Hasting District in 2013, for example, the maximum New Zealand share was 11% with all other Hastings sectors having a lower share of New Zealand sector production (the next highest was 10% for pulp, paper and converted paper product manufacturing). This maximum sector share for each territory/area was then added as a variable to the combined 2001 and 2013 AGTC and AAIR model derived above.

There were two effects of note. First there was Taranaki effect that had been noted in the previous GVA study and included as a dummy variable in all model runs since. The three territories around Taranaki tend to have higher productivity across many sectors. The region has three sector specialisations, as measured in 2013, being mining (New Plymouth 30% of New Zealand), electricity and gas supply (New Plymouth 15% of New Zealand) and dairy product manufacturing (South Taranaki 19% of NZ). These specialisations show as non-energy GDP per filled job in 2013 being 14% above the national average. In terms of the GVA model, there is a significant fixed effect parameter estimate of 0.21 over the two years, implying extra GDP effect of just over 21% across the non-energy sectors. Within this total, the combined business services sector has a significant estimated fixed effect of 0.081, implying an 8% productivity out-performance while there were also significant fixed effects of -0.193 and -0.041 for the government and community services grouping of sectors, implying under-performance of 19% and 4% respectively.

Second the coefficient on the New Zealand sector share variable was generally significantly different from zero amongst the manufacturing sectors. Combined the estimated coefficient for the manufacturing sector was 2.102, implying an increase in the sector share of 1% correlates with a productivity increase of 2% (e.g. share goes from 0.20 to 0.21 and log (GDP) increases 2.1x0.01=0.02, implying 2% GDP increase). The addition of maximum sector share into the model also had the effect of lowering the magnitude of the AAIR coefficient to a still-significant -0.058, a coefficient closer to that estimated amongst other sectors (the AGTC effect was insignificant for the manufacturing sector).

While these results support the proposition that specialisation can lead to higher productivity effects beyond the specialist sector and suggests another XVAR for the model, the results do not show the linkage between transportation and specialisation. This would require further investigation.

4.5 Summary

This model run brings to an end the refinements of the model. The preferred coefficients are tabled below for each sector, with comparison to the previous GVA model results and the EEM recommendation. The current results are shown only for those coefficients of expected sign that are significantly different from zero. The model includes data from 2001 and 2013. The set of explanatory variables include the employment/working age population ratio and the maximum sector share. The access variables are AGTC and AAIR.

Table 4.9 Preferred GDP- to- access coefficients for further application <run 20a>

Industry sector	Ln(A40)	Ln(A120)	Ln(AGTC)	Ln(AAIR)	EEM
	Initial GVA model		Current GVA model		
Horticulture and fruit growing	- 0.070				0.032
Sheep, beef cattle and grain farming	- 0.085				
Dairy cattle farming	- 0.078				
Poultry, deer and other livestock farming					
Forestry and logging					
Fishing and aquaculture					
Agriculture, forestry and fishing support services and hunting	- 0.087				
Mining					0.035
Meat and meat product manufacturing	- 0.061	0.070		-0.052	0.061
Seafood processing					
Dairy product manufacturing					
Fruit, oil, cereal and other food product manufacturing		0.048		- 0.039	
Beverage and tobacco product manufacturing					
Textile, leather, clothing and footwear manufacturing		0.052			
Wood product manufacturing		0.059		- 0.046	
Pulp, paper and converted paper product manufacturing					
Printing		0.058		- 0.055	
Petroleum and coal product manufacturing					
Basic chemical and chemical product manufacturing		0.065		- 0.067	
Polymer product and rubber product manufacturing				- 0.069	
Non-metallic mineral product manufacturing		0.068		- 0.053	

Industry sector	Ln(A40)	Ln(A120)	Ln(AGTC)	Ln(AAIR)	EEM
	Initial GVA model		Current GVA model		
Primary metal and metal product manufacturing					
Fabricated metal product manufacturing		**0.063**	0.050	**- 0.050**	
Transport equipment manufacturing		**0.068**	0.056	**- 0.047**	
Machinery and other equipment manufacturing		**0.067**		**- 0.055**	
Furniture and other manufacturing		**0.061**		**- 0.069**	
Electricity and gas supply					0.035
Water, sewerage, drainage and waste services	**0.085**	0.083	0.086		
Building construction					0.056
Heavy and civil engineering construction					
Construction services					
Wholesale trade	**0.087**	**0.070**	**0.099**	**- 0.041**	0.086
Motor vehicle and motor vehicle parts and fuel retailing	**0.028**	**0.021**	**0.017**		0.086
Supermarket, grocery stores and specialised food retailing	**0.031**	0.018	**0.017**		
Other store-based retailing and non-store retailing	**0.029**	0.019	**0.017**		
Accommodation and food services					0.056
Road transport		**- 0.044**			0.057
Rail, water, air and other transport		**- 0.038**			
Postal, courier transport support, and warehousing services.		**- 0.033**			
Information media services	**0.077**		**0.046**	**- 0.046**	0.068
Telecommunications, internet and library services	**0.107**		**0.099**	-0.027	
Finance	**0.065**		**0.058**	**- 0.028**	0.087
Insurance and superannuation funds	**0.077**		**0.059**		
Auxiliary finance and insurance services	**0.070**		**0.065**	-0.021	
Rental and hiring services (except real estate)				**- 0.030**	0.079
Property operators and real estate services				**- 0.031**	
Owner-occupied property operation					
Professional, scientific and technical services	**0.061**		**0.041**	**- 0.013**	0.087
Administrative and support services	**0.051**		**0.024**	**- 0.015**	0.087
Local government administration	**0.056**		0.020	**- 0.015**	

Industry sector	Ln(A40)	Ln(A120)	Ln(AGTC)	Ln(AAIR)	EEM
	Initial GVA model		Current GVA model		
Central government administration, defence and public safety	**0.081**				
Education and training		**0.026**	**0.030**	**- 0.018**	0.076
Health care and social assistance		**0.043**	**0.024**	**- 0.019**	0.083
Arts and recreation services	**0.089**		**0.057**	**- 0.077**	0.053
Other services	**0.096**	**0.069**	**0.104**	**- 0.050**	

Notes: Only coefficients significantly different from zero at 90% level are reported (95% in bold red). Shaded cells are coefficients scored with high sensitivity (6–10) by Alstadt et al (2012). US sectors are not an exact match to New Zealand.

To recap the section, the analysis has provided the following results.

1. An agglomeration effect was confirmed for revised 2001 data and for new 2013 data.
2. But the effect was not shown at the margin, ie the model and data were unable to detect any improvement in agglomeration between 2001 and 2013 leading to higher productivity.
3. The GVA model was refined by replacing the crude A40 measure with a GTC-weighted measure of effective mass.
4. The model and data were unable to detect any optimal decay parameter to apply when calculating AGTC, and hence offer little reason to move away from the current decay parameter of 1.
5. The GVA model was also refined by replacing the A120 variable with AAIR, a weighted measure of time to an international airport that was shown to be significantly associated with higher productivity in 26 sectors.
6. The model and data confirmed a specialisation effect on productivity but do not provide a direct measure of a transportation effect on specialisation.

The significant coefficient results are tabled above. In practice, elasticities are likely to be applied in groupings, as below. Generally these show the agglomeration effect to be largely amongst the service sectors, and productivity in the manufacturing and some service sectors being related to airport connectivity. Note that due to sea ports and large urban populations also generally existing near international airports, the AAIR effect is likely to capture a range of 'delivery market' effects rather than literally a connection to air services.

Table 4.10 Preferred GDP- to- access coefficients for grouped sector <run 20a>

Industry sector	Ln(AGTC)	Ln(AAIR)	EEM
	Current GVA model		
Primary sectors			0.032
Mining			0.035
Manufacturing		**- 0.058**	0.061
Utilities			0.035
Construction			0.056
Wholesale trade	**0.099**	**- 0.041**	0.086
Other retailing	**0.017**		0.086

Industry sector	**Ln(AGTC)**	**Ln(AAIR)**	**EEM**
	Current GVA model		
Business services	**0.041**	**- 0.013**	0.087*
Owner-occupied property operation			0.079
Government	**0.046**		0.087
Community services	**0.028**	**- 0.030**	0.076*

* approximate average

5 New Zealand SCGE model

5.1 Introduction

This section sets out a pilot SCGE model of connectivity between the cities of Auckland, Hamilton and Tauranga, and their ports. The model has the ability to examine how consumer welfare (utility) and GVA are affected by changes in travel time, through changes in the connectivity of industries to ports and population centres and through the movement of people between the zones of interest. The movement of people includes both migration and commuting. The commuting structure of the model draws heavily on that developed by Horridge (1994), but is applied to inter-city travel rather than to intra-city travel.

As noted by Venables (2015), where modelling is undertaken the model needs to capture the strategic arguments and be tailored to the context, and simple targeted models are better than large black box models. At this stage the model incorporates the types of structures that relate to the objective of the research project. However, to keep the model aligned with Venables' recommendations some aspects of it may need to be altered when it is applied to a case study.

5.2 Overview of model

The basic unit of the model is a zone, which expands to be a combination of work-residence zones. For example, if there are eight zones then there are 64 cells that represent the potential combinations of work-residence pairings, although some pairs may be zero. Each cell may have different characteristics.

Potentially people live and production occurs within each zone, although again not all zones need include residences and/or production. Utility is derived from consumption of goods and services and from location, the latter reflecting an amenity value associated with each work-residence pairing. No utility is gained from travel per se.

People commute between residence zones and work zones, at a cost. The cost of travel thereby reduces income available for utility-enhancing consumption of non-transport goods and services.

Production occurs within work zones and is constrained by the amount of labour and land available in each work zone, and by an exogenous productivity factor in each work zone. Having potentially a different productivity factor per zone can take account of past agglomeration effects in a zone but, because the factor is exogenous, the model does not allow for future changes to the agglomeration effect, a point returned to in the next paragraph. Products and services are freighted between zones, and to/from the rest of the world through designated port zones, at a cost. Potentially there could be multiple goods and services, each with different freight costs, but in this simple model there are only two 'goods', namely transport services and other goods and services, produced by a single industry. Thus, the model at present also does not allow for specialisation.

It should be noted the SCGE approach models the effects of transport improvement differently to that of a standard transport CBA. Instead of time and costs saved feeding directly through to a welfare benefit, the SCGE model channels travel savings in three ways. First, less time spent travelling shows as less income spent on commuting and on freight. This is similar to the time saving benefit within the standard transport CBA except only travel for commuting and freight is taken into account and the endogenous value ascribed to each unit of time saved in the SCGE model may differ to that used in the CBA. This lower income and freed-up time flows through into more spending on, and production of, non-transport goods and services. Missing from the model are benefits derived from leisure travel and non-freight business travel. Second, it is assumed the freed-up capacity in the transport services sector also creates a productivity increase, which is engineered by changing the exogenous productivity factor in each zone. This leads to higher production, income and utility. Third, as a result of changes above, there will be relative price changes and hence further changes in production, income and utility. These will not be captured in a CBA based on 'textbook' demand curves but may be captured when based on 'observed' transport demand curves. This third channel is likely to produce changes in welfare that exceed changes in production or income, as people and firms change their residence and work locations in response to changes in relative prices, thereby improving the allocative efficiency within the economy. The third channel is likely to be amplified if other changes were also to occur, such as an increase in population. This interaction is explored in the case study (see chapter 7, scenario 2). Note, as with specialisation of production, the simple two-good structure of this model probably means any allocative benefit is understated.

The combined effect of transport improvements shows as improvements in utility and GDP relative to a base case. The base case is akin to a do minimum in a transport CBA but is not actually simulated in the model, being implicit in the data on which the model is based. Of course it is possible to simulate alternative do minimum scenarios

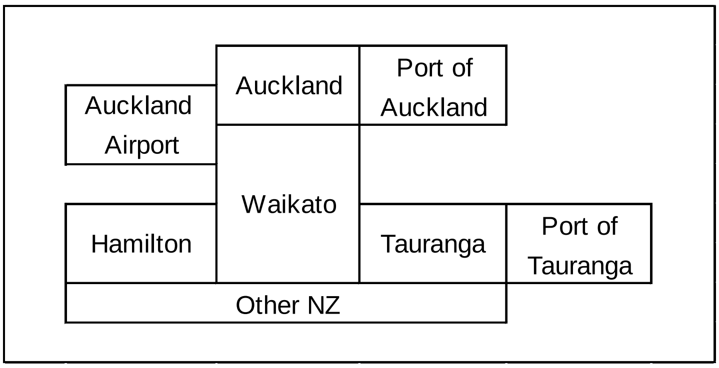
As noted above, the model does not include agglomeration and specialisation effects. However, the first round effects of both can be added to the model as a change in the productivity factor in each zone which then allows the second round effects to be explored within the model. This is done with the case study, where the weighted average of the first round agglomeration effects was estimated from the GVA model (see chapter 7, scenario 3).

The detail of the model follows.

5.3 Zone configuration

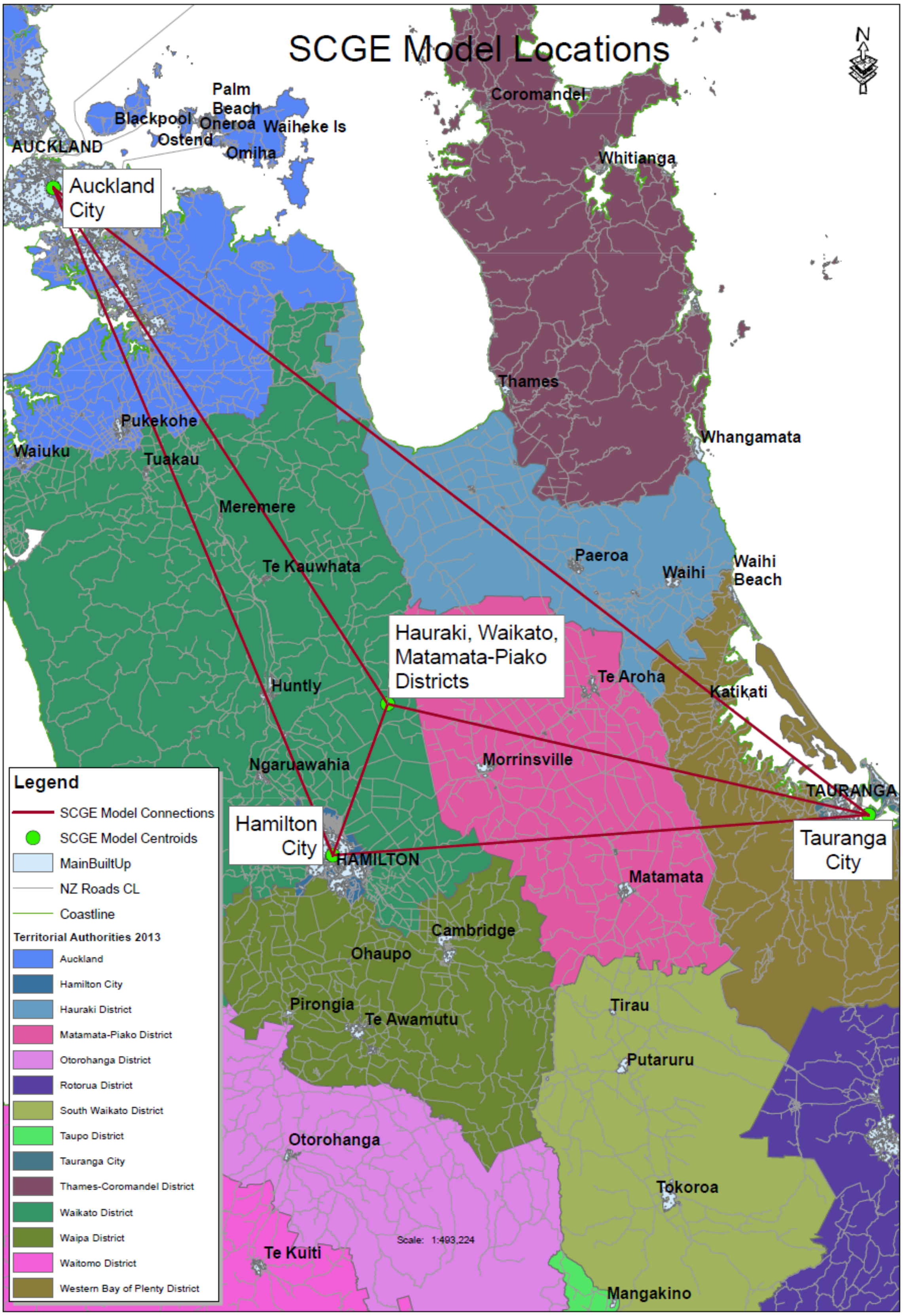
There are four residential (r) and work (w) zones; Auckland, Hamilton, Tauranga and the rest of Waikato,[34] and four port (p) zones; Auckland Airport, Port of Auckland, Port of Tauranga and Other New Zealand for goods that are transported into and out of the study region by rail or road. See figure 5.1 for a schematic of the model's zones and figure 5.2 for the actual geographic configuration.

Figure 5.1 Zonal schematic of SCGE model



[34] The rest of Waikato comprises the local authorities of Waikato, Hauraki and Matamata-Piako. Arguably western Bay of Plenty could be included, but more of this authority is outside the AHT nexus than within it.

Figure 5.2 SCGE zonal map and travel time routes



5.4 Equations

5.4.1 Production

The measure of real output (X) in work zone *w* is a Cobb-Douglas function of value added inputs of labour (L) and land (N). Intermediate inputs are implicit in the constant term λ_w. Each work zone has its own constant term, which would include changes in productivity such as those driven by agglomeration effects. It is where the results of chapter 4 would be incorporated into the model.

$$X_w = \lambda_w L_w^{\beta} N_w^{(1-\beta)} \qquad \text{(Equation 5.1)}$$

A different form of production function such as the less restrictive[35] CES function could also be adopted.

Profit maximisation ensures that the prices and quantities of inputs of labour and land satisfy the following equation, where r_w denotes rent and w_w is wages in zone *w*:

$$\beta_w r_w N_w = (1 - \beta_w) w_w L_w \qquad \text{(Equation 5.2)}$$

Total land for used by industry in each work zone is (usually) exogenous, but could be changed as part of policy simulation.

$$\sum N_w = \overline{N_w} \qquad \text{(Equation 5.3)}$$

Equations 5.2 and 5.3 imply rents will increase as labour increases in the fixed land zones. Equation 5.1 implies real output will increase at a rate of (1-β) times any percentage change in the quantity of labour.

5.4.2 Households

The utility (H) of household j which selects option k (where to live and where to work[36]) is given by:

$$H_{kj} = V_k + \varepsilon_{kj} \qquad \text{(Equation 5.4)}$$

Here V_k is the general utility attached to live/work option k and ε_{kj} is an idiosyncratic element of utility. From the standard multinomial logit model the proportion of households (L) who select option k is given by:

$$\frac{L_k}{\sum_k L_k} = \frac{e^{V_k}}{\sum_k e^{V_k}} \qquad \text{(Equation 5.5)}$$

In other words the ratio of the utility of option k to total utility is the equal to the proportion of households who choose that option. So the number of households choosing any given live/work option k is:

$$Ln(L_k) = c + \sigma Ln(U_k) \qquad \text{(Equation 5.6)}$$

Here c is a constant to ensure that sum of L_k (ie all labour across all live/work options) equals the total population of households and σ is the elasticity of the number of households choosing option k with

[35] The Cobb-Douglas function assumes constant returns to scale and a constant income share of labour and land (ie rents increase as the L/N ratio increases) whereas the CES function relaxes this latter assumption (Miller 2008).

[36] Households can choose their work zone to be different to their residence zone (ie k can potentially be as large as the sum of work zones squared).

respect to the utility associated with that option. In the model option k is distinguished by residential zone (r) and working zone (w). Hence:

$$Ln(L_{rw}) = c + \sigma Ln(U_{rw}) \qquad \text{(Equation 5.7)}$$

And

$$\sum L_{rw} = \bar{L} \qquad \text{(Equation 5.8)}$$

Note that the terms households and labour are used interchangeably so in effect each household supplies all of its labour to the same zone[37].

We define a Cobb-Douglas utility function as:

$$U_{rw} = \theta_{rw} G_{rw}^{\alpha} N_{rw}^{(1-\alpha)} \qquad \text{(Equation 5.9)}$$

Utility is gained from the consumption of goods and services (G) and from land (N). No utility is gained from consuming transport services. Note, theta varies by residence-work pairing and provides a means for amenity value for pairings to be incorporated into the model. Minimum 'subsistence' levels of G and N could be stipulated as in Horridge (1999).

Total land for housing in each residential zone is defined as the number of people multiplied by land use per unit, summed over all (r,w) combinations.

$$\sum L_{rw} N_{rw} = \overline{N_r} \qquad \text{(Equation 5.10)}$$

The right-hand side of equation 5.10 – the residential land supply in a zone – is usually an exogenous policy variable.

Household income (Y) is the sum of labour income and income from land rents paid by industry and by households. (This includes owner occupiers as defined in the national accounts who in effect pay rent to themselves). Subtracted from the total income available (YR) is an amount B which accrues to and is spent by other types of final demand[38].

$$Y_{rw} = w_{rw} L_{rw} + \phi_{rw} YR \qquad \text{(Equation 5.11)}$$

$$YR = \left(\sum_w r_w N_w + \sum_{r,w} r_h N_{rw} - B\right) \qquad \text{(Equation 5.12)}$$

Household expenditure on commuting transport is the product of the price of travel (P), measured in \$/hour, and the amount of travel (D), measured in hours or minutes (or distance if necessary):

$$C_{rw} = P_T D_{rw} \qquad \text{(Equation 5.13)}$$

The demand for goods and services, denoted as price (P_G) times quantity (G_{rw}), exhausts all income after payment for land, transport services including the cost of freighting goods between zones (F):

$$P_G G_{rw} = Y_{rw} - r_h N_{rw} - C_{rw} - F_{(w+p)r} P_T \qquad \text{(Equation 5.14)}$$

Thus consumption on non-transport goods and services will increase as the cost or the amount of travel decreases, and vice versa. This equation provides the link between transport improvements and changes in general demand, output, and work and home location.

---

[37] And all residence zones are work zones (i.e. sum of r equals sum of w) although some zones may have a low amount of work activity and conversely some zones may have a low number of residences.

[38] This ensures that the income and expenditure measures of gross domestic (or regional) product equate.

Note that the price of other goods is the numéraire of the model. Thus by definition:

$$P_G = 1 \quad \text{(Equation 5.15)}$$

The model does not solve for the absolute level of prices – only relative prices matter.

Other goods and services consumed in zone r can be sourced from any work zone (w) and from outside the region via any port zone (p) – see equation 5.25, but incur freight transport margin. For transport between work and residential zones the freight margin is related to distance, but for goods entering via port zones freight costs are a proportion (from base year data) of the volume of the goods being transported:

$$F_{wr} = D_{wr} G_{wr} \quad \text{(Equation 5.16)}$$

$$F_{pr} = f_{pr} G_{pr} \quad \text{(Equation 5.16a)}$$

As with commuting, consumers derive no direct utility from transport margins, but their presence reduces disposable income.

Rent on residential land is related to rent on industrial land by a simple proportion, but this equation may change with different assumptions about land supply:

$$r_r = \mu r_w \quad \text{(Equation 5.17)}$$

5.4.3 Trade

Each work zone produces exports that are sent outside the region[39] via the port zones. In this initial model exports from each zone (except those exiting via one port (p*) so as not to over-determine the model) are a simple function of travel time (D) and the price of transport.

$$E_{wp} = \varphi_{wp} (P_T D_{wp})^{\eta} \qquad p \neq p^* \quad \text{(Equation 5.18)}$$

For p* in the meantime we adopt the rest of New Zealand, but this is not entirely satisfactory as it essentially treats those exports as a residual. We will revisit this in the context of the case study scenario to be investigated later.

Imports of other goods from outside the region are determined as for exports.

$$M_{pr} = \varphi_{pr} (P_T D_{pr})^{\eta} \quad \text{(Equation 5.19)}$$

The balance of payments (B) is defined as:

$$B = \sum_{wp} E_{wp} - \sum_{pr} M_{pr} \quad \text{(Equation 5.20)}$$

There is no economic reason why the region should maintain a given trade balance so it is not usually exogenous, but an equation of this type is needed to ensure national accounting consistency with equation 5.12.

[39] Note that trade between w/r zones within the region does not move via the port zones.

5.4.4 Other equations

Total transport demand by households (T) in residential zone r measured in say person hours (or person kilometres) is the sum of the number of people who travel (commute) from residential zone r to work zone w, multiplied by the time involved, plus transport margins on goods.

$$T_r = \sum (L_{wr} D_{wr} + F_{(w+p)r}) \quad \text{(Equation 5.21)}$$

Total transport supply from each work zone is derived by applying an origin-destination conversion matrix (Ω) to household transport demand.

$$T_w = \Omega * T_r \quad \text{(Equation 5.22)}$$

The Ω matrix is assumed to be diagonal for commuting, but not for freight margins.

Similarly for the demand and supply of other goods:

$$G_r = \sum L_{wr} G_{wr} \quad \text{(Equation 5.23)}$$

$$G_w = \Gamma * G_r + \sum E_{wp} \quad \text{(Equation 5.24)}$$

That is, the goods produced in work zone *w* are either supplied to residential zones or exported out via ports *p* (equation 5.24) while the demand for non-travel goods in residential zone r is the sum of consumption by all workers originating from zone r and working in zone w (equation 5.23).

For the non-transport goods, the base year Γ matrix is calculated from estimated data on inter-zonal freight flows, which are calibrated to a simple gravity equation that relates demand for other goods in a zone to alternative sources of supply. For goods consumed in zone u coming from zone v (where u can be a residential zone or a port zone for exports, and v can be a work zone or a port zone for imports):

$$G_{uv} = g_u \frac{L_u L_v}{(D_{uv})^{\delta}} \quad \text{(Equation 5.25)}$$

Intra-zonal flows of goods (that is where u=v) are treated as a residual to balance supply and demand. Intra-zonal flows occur only between residential/work zones, not between port zones. That is, the model does not capture re-exports.

For the time being δ=2 which is a common value in the literature, but this is readily changed. The scaling factor g_u ensures that total demand from u equates to the sum of supply from all sources v, as per the base year data. An alternative to this type of equation would be assume that trade occurs only between contiguous zones, as in Stephenson (2015).

Rather than specify totally separate production functions for each industry, which requires considerably more data and greatly expands the size of the model, we assume in the meantime that resources in each zone can be used to produce either transport or other goods, but with a difference in productivity. The productivity parameter θ is exogenous.

$$X_w = \theta G_w + T_w \quad \text{(Equation 5.26)}$$

This implies that the price of transport (for freight margins and commuting) is related to the price of other goods:

$$P_T = P_G / \theta \quad \text{(Equation 5.27)}$$

In other words, the relative price of transport is a function of the relative productivity of resources in producing transport versus other goods.

Finally, equation 28 is an identity to ensure that costs equate to the value of output for industry in each work zone.

$$r_w N_w + w_w L_w = G_w + P_T T_w \quad \text{(Equation 5.28)}$$

5.5 Solution

A solution to the model requires the simultaneous calculation of all unknown variables within all equations, keeping in mind that unknowns and equations exist for multiple zones. The number of e unknowns and equations is calculated below.

Not all of the above equations are independent of each other so there is more than one way to set up the model. Further, the set-up may change depending on the scenario under consideration. The default specification below is one option.

5.5.1 Unknowns

6rw (per household: income, labour supply, commuting, consumption of other goods, transport margins on other goods, utility)

+

5w (industrial land rent, industrial land use, wage rates, supply of transport, total production)

+

4r (housing land, housing land rent, and demand for total other goods and total transport margins in each residential zone)

+

2w(r+p) for pairwise travel times (with both-directions between w and r), and for sources of goods demanded by each residential zone

+

w+p transport margins

+

wp-2 exports by each source through each port. (In this pilot version two combinations are zero).

+

3 (total income to households, price of transport, balance of payments).

There are four residential and work zones (w=r=4) and four port zones (p=4). Thus the number of unknowns is 221.

5.5.2 Equations

w(r+p) exogenous pairwise travel times, 2-way differentiation between r and w.

+

6rw of equations 5.7, 5.9, 5.11, 5.13, 5.14, 5.16

+

6w of equations 5.1, 5.2, 5.3, 5.22, 5.24, 5.26

+

5r of equations 5.10, 5.17, 5.21, 5.23, and either 5.3 or 5.28.

+

rp of equation 5.19

+

r(w-1) of equation 5.25 (excluding diagonal flows to preserve equation independence)

+

w+p of equation 5.22

+

w(p-1) -2 of equation 5.18

+

3 (equation 5.8 for total labour supply, equation 5.12 for total rental income available to households, and equation 5.20 for the balance of payments)

For w=r=p=4 the above implies 221 equations or exogenous values.

The model is solved by logarithmically differentiating each equation which then produces an invertible 221x221 matrix. This procedure will produce linearisation errors, although there are methods to deal with this if the problem becomes significant. In most cases linearisation errors would be within normal error margins.[40] The advantage of the matrix inversion method is that it is relatively straightforward to alter the endogenous/exogenous mix of variables.

5.6 Base year calibration

The model has been calibrated to 2012/13 as far as practical. Most data was sourced from official figures, but considerable use has also been made of unofficial estimates, including estimates by the project team. In addition the model has some features that entail departures from the System of National Accounts as practised, but not in principle.

The main aspects of the calibration are outlined below.

[40] As the matrix is sparse and contains numbers that differ by numerous orders of magnitude it is essential to use a matric inversion algorithm with a very high degree of precision. Experience suggests that Excel does not usually meet this requirement.

5.6.1 Alignment to 2013

Regional input-output (IO) tables were estimated (by Butcher Partners) for 2006/07 – the latest year for which official IO data is available.[41] These have been 'uprated' to Infometrics' GDP and employment estimates, by industry and zone/region, for 2013.

Similarly commuting flows (which come from census data) have been aligned with Infometrics' employment estimates for 2013. And inter-zonal trade flows were scaled to align with IO data, and to ensure that inter-zonal exports between the four work/residence zones equal inter-zonal imports between these zones.

5.6.2 Commuting

As the time spent commuting is assigned a value and is part of household expenditure, income has to be increased commensurately. This is analogous to the treatment in the System of National Accounts of owner-occupied dwellings, where a synthetic industry is used to collect the implicit rent that owner occupiers of dwellings pay to themselves.

5.6.3 Transport margins

Transport margins consumed by industry as recorded in the IO tables are reallocated to private consumption as margins on goods, so that they form an explicit part of the household budget constraint without being part of utility.

The IO tables do not distinguish between the use of transport services to carry goods (transport margins) and the use of transport services to carry people. This means that the reallocation of the latter to households also captures the former. This is not necessarily too inconvenient provided one accepts the implicit assumption that the benefits of lower transportation costs to industry – in whatever form they appear – are passed on to consumers in the form of lower prices for goods and services.

5.6.4 Housing land rent

Housing costs, whether for owner occupied dwellings or rented properties, are disaggregated into a pure land component and an improvements component, as the model distinguishes the utility of place or location from the utility of the consumption of housing services such as shelter – which is part of other goods. Again there is a corresponding adjustment on the income side.

To disaggregate the cost of land between land area and rent per unit area we assume, for each residential zone there is an average land use per household and an average ratio of land value to capital value.

5.6.5 Industrial rent and profit

To preserve overall income-expenditure balance in each work zone, rent is defined to include the gross return to capital, namely consumption of fixed capital (depreciation) and operating surplus. As buildings, plant and equipment need to be physically located somewhere, we can think of these factors of production together with land as a composite input. In reality there is scope for substitution between the components, but this could be simulated in the model by changes in land productivity.

For work zones, estimated land requirements and land rents are loosely based on QVNZ data.

[41] Our understanding is that new IO tables relating to 2012/13 will be made available in late April 2016.

5.6.6 Income and expenditure

Butcher Partners' regional IO tables were estimated largely on the basis of employment by location of place of work. This leads to some divergence between the IO measures of expenditure GDP and what is implied by known commuting patterns. It also means that in each of the four residential/work zones Expenditure GDP does not equal income GDP, although for the four regions combined the identity holds. There is nothing inherently askew here; it is just a consequence of commuting between zones. Auckland and Hamilton 'lose' some income as recorded in the regional IO tables (which is assumed to be wage income) to Waikato and Tauranga.

5.6.7 Equalisation of wage rates in transport and other industries

Production capacity in the model can be used to produce either transport goods or other goods with a linear transformation frontier. That is, the quantities of labour and land (and capital) used to produce the two types goods differ, but factor prices are independent of the output mix. This entails a very minor recalibration of the IO data.

5.6.8 Reside-work elasticity

The elasticity of labour with respect to the utility associated with each live-work option (σ in equation 5.7) is 1.2.

The process of refining the data is ongoing, although for a pilot model such as this diminishing returns set in quickly. As the case study takes shape we will gain a better idea of what data is important and will direct data discovery efforts accordingly.

5.7 Model limitations and enhancement

While data quality is always a limitation when developing GE models, there are also structural limitations, which in some cases could be more important than data limitations. The main structural limitations in the model described above are as follows:

1 The Cobb-Douglas production function (equation 5.1) restricts the elasticity of substitution between labour and land/capital to be unity. A CES function would allow more flexibility.

2 The same argument applies to the consumer utility function (equation 5.9).

3 The broadly defined other goods (G) may be too broad. If there are substantial changes in the composition of consumption, apart from changes in either the spatial source of goods or in the relative mix between transport and other goods, the model will under-estimate changes in consumer utility arising from a reduction in travel costs.[42] Thus there may be merit in disaggregating other goods (G). However, further disaggregation is both data-intensive and adds considerably to the size of the model, but it is not particularly challenging from a model construction perspective. Two changes would be required:

   - Either nest a CES function within other goods (G) or re-specify equation 5.9 as a CES function to accommodate more other goods (G), and change equation 5.25 accordingly (although CES

[42] Not all transport researchers accept that such compositional changes in consumption generate a change in welfare that is additional to what is captured in standard cost-benefit analysis.

functions themselves do become rather limiting with more than two or three goods unless they are nested).

– Match the disaggregation of G in consumption by specifying separate production functions akin to equation 5.1, including for transport.

4 Disaggregating G would also present an opportunity to distinguish between relatively transport-intensive goods such as logs and cement and less transport-intensive goods such as food and services. The latter could also be more closely tied to agglomeration benefits.

5 Elasticity values such as σ in equation 5.7, η in equations 5.18 and 5.19, and δ in equation 5.25 need more research and/or more sensitivity testing in the model.

6 Business time savings are not directly captured in the model, as distances, unlike the situation for commuters, do not enter directly into firms' production functions. Instead business time savings are simulated as productivity improvements (see chapter 7), but only in relation to transporting freight. An enhancement to the model would be to include distance (or travel times) in firms' production functions in order to capture all business travel, not only that related to freight.

6 Case study – the GVA model effects

6.1 Potential Waikato Expressway and Kaimai Ranges improvements

The AHT region provides an insightful region to apply the GVA and SCGE models. The region includes large populations which are growing quickly but with major population centres over 80 minutes' drive time apart. Also there are projects underway, planned and proposed that have the potential to reduce drive-times significantly.

This research project had calculated in the model-building phase – using a road network hereafter referred to as the 'before-network' – the quickest journey between each area centroid (local TA outside of Auckland and local board area within Auckland) and each mesh block on the same island using the speed limits per road section, thus providing drive times and distances for each trip (ie over 800,000 trips in total).

In this case study, a shock was engineered to match a scenario that approximated some of the projects completed, planned or proposed for the SH1–SH29 route, including the recently opened Cambridge bypass that was not completed at the time of the model building phase. The resulting 'after-network' includes alterations to achieve the following travel time and distance reductions. In fitting with the construction of the GVA and SCGE models, the time savings are calculated at speed limits.

Table 6.1 Time and distant reductions to model

	Time saving	Distance saving
Between Pokeno and Horotiu turnoff to Hamilton	-14min	-3.0km
Between Horotiu turnoff to Hamilton and Cambridge South	-10min	-2.5km
Between SH24/SH29 intersection and bottom of old Kaimai road	-7min	-2.5km

The optimal journeys were again calculated for the North Island areas, using the after-network. This resulted in time and distance reductions for journeys that passed through the altered parts of the network (ie on SH1 north and east of Hamilton and where SH29 crosses the Kaimai Ranges). It is important to point out that the time and distance saving applied to individual origin-destination pairs was the difference in the optimal journey time and distance. The actual route taken in the before- and after-network need not be the same. Thus, for example, the table above shows the total uncongested time saving on a journey along SH1-SH29 between Auckland and Tauranga as just over 30 minutes but the time and distance saving that was achieved in the network model runs is the difference between the two fastest routes, which was not SH1-SH29 in the before-network.

The re-calculated time and distance between areas and mesh blocks enabled re-estimation of the effective population densities (ie AGTC for each area) and the weighted time to Auckland Airport (ie AAIR for each area near Auckland). Thus, for example, the effective population density accessible to the Waikato District increased by 27.5% and the weighted time to Auckland Airport decreased by 4.7% as a result of the changes in the road network (see columns 2 and 3 in table 6.2 below for the full list of AGTC and AAIR changes).

6.2 The GVA model effects

The next step was to estimate the GDP effects of these changes in population densities and airport travel times.

The following procedure was taken for measuring the GDP effect from the GVA model:

- The AGTC and AAIR elasticities for the eight sector groupings were taken from the 2001–2013 model constructed in the model-building phase of this research project, which used existing travel times, distances and travel costs.
- The differences were calculated for each area (LTAs and LBs) of the natural log of the before- and after-AGTC (ie weighted people near the LTA centroid) and of the natural log of the before- and after-AAIR (ie weighted time to airport).
- For each variable, the model elasticities within each sector grouping were multiplied by the respective difference in logged AGTC and AAIR.
- The exponential of the resulting product for each area and sector grouping then provides an estimate of the productivity gain to be expected in millions of dollars. These figures were then aggregated as required to give various summed productivity gains for different combinations of sectors and areas (eg all sectors in the Waikato areas or all Auckland, Waikato and Bay of Plenty areas).

The results are as shown in table 6.2 below. For example, a productivity gain of $8.5 million is expected as a result of the reduced travel costs to/from Hamilton City within the manufacturing sector. Across all sectors, the total productivity gain for Hamilton City is estimated to be $36.1 million or a 0.54% increase in GDP for the non-transport sectors of the Hamilton City economy.

Table 6.2 GDP productivity gains ($millions 2010 prices) for areas and for regions

Area or region	AGTC change	AAIR change	Primary	Manufac-turing	Utilities	Construct-ion	Consumer services	Business services	Government	Community services	Sum of 8 combined sectors	As % of ALL sectors less transport
AGTC elasticity			0.000	0.000	0.000	0.000	0.088	0.020	0.046	0.028		
AAIR elasticity			0.000	-0.058	0.000	0.000	0.000	-0.026	0.000	-0.030		
By area:												
Rodney Local Board Area	0.9%	0.0%	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.3	0.02%
Hibiscus and Bays Local Board Area	1.5%	0.0%	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.2	0.7	0.04%
Upper Harbour Local Board Area	0.2%	0.0%	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.01%
Kaipatiki Local Board Area	0.3%	0.0%	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.01%
Devonport-Takapuna Local Board Area	0.3%	0.0%	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.3	0.01%
Henderson-Massey Local Board Area	0.2%	0.0%	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.01%
Waitakere Ranges Local Board Area	0.2%	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01%
Great Barrier Local Board Area	0.0%	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00%
Waiheke Local Board Area	0.0%	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00%
Waitemata Local Board Area	0.3%	0.0%	0.0	0.0	0.0	0.0	1.1	0.5	0.1	0.1	1.8	0.01%
Whau Local Board Area	0.3%	0.0%	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.01%

Area or region	AGTC change	AAIR change	Primary	Manufac-turing	Utilities	Construct-ion	Consumer services	Business services	Government	Community services	Sum of 8 combined sectors	As % of ALL sectors less transport
Albert-Eden Local Board Area	0.2%	0.0%	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.1	0.3	0.01%
Puketapapa Local Board Area	0.3%	0.0%	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.01%
Orakei Local Board Area	0.3%	0.0%	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.01%
Maungakiekie-Tamaki Local Board Area	0.3%	0.0%	0.0	0.0	0.0	0.0	0.8	0.1	0.0	0.1	1.0	0.01%
Howick Local Board Area	0.5%	0.0%	0.0	0.0	0.0	0.0	0.5	0.1	0.0	0.1	0.7	0.02%
Mangere-Otahuhu Local Board Area	0.5%	0.0%	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	1.0	0.03%
Otara-Papatoetoe Local Board Area	0.4%	0.0%	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.1	0.5	0.01%
Manurewa Local Board Area	0.7%	0.0%	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.1	0.4	0.02%
Papakura Local Board Area	1.0%	0.0%	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.1	0.4	0.03%
Franklin Local Board Area	1.4%	0.0%	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.1	0.6	0.03%
Thames-Coromandel District	18.5%	-12.4%	0.0	0.8	0.0	0.0	2.5	1.1	0.2	1.3	5.9	0.66%
Hauraki District	10.7%	-13.0%	0.0	0.4	0.0	0.0	0.6	0.5	0.1	0.7	2.4	0.30%
Waikato District	27.5%	-4.7%	0.0	0.4	0.0	0.0	3.2	1.3	0.8	1.5	7.2	0.32%
Matamata-Piako District	8.0%	-9.6%	0.0	2.1	0.0	0.0	1.2	0.8	0.1	0.7	4.9	0.31%

Area or region	AGTC change	AAIR change	Primary	Manufac-turing	Utilities	Construct-ion	Consumer services	Business services	Government	Community services	Sum of 8 combined sectors	As % of ALL sectors less transport
Hamilton City	7.9%	-16.4%	0.0	8.5	0.0	0.0	7.9	8.0	0.9	10.8	36.1	0.54%
Waipa District	8.7%	-12.6%	0.0	1.5	0.0	0.0	1.9	1.6	0.1	1.4	6.5	0.39%
Otorohanga District	23.4%	-9.1%	0.0	0.2	0.0	0.0	0.8	0.5	0.5	0.3	2.1	0.43%
South Waikato District	33.3%	-8.0%	0.0	0.7	0.0	0.0	2.1	0.6	0.2	1.4	5.0	0.55%
Waitomo District	18.9%	-7.6%	0.0	0.4	0.0	0.0	0.6	0.2	0.1	0.4	1.6	0.28%
Taupo District	1.7%	-6.1%	0.0	0.3	0.0	0.0	0.3	0.5	0.0	0.4	1.6	0.10%
Western Bay of Plenty District	11.5%	-9.1%	0.0	0.9	0.0	0.0	1.7	1.5	0.1	0.7	4.8	0.36%
Tauranga City	6.8%	-11.6%	0.0	3.1	0.0	0.0	5.8	3.9	0.5	3.9	17.1	0.44%
Rotorua District	3.8%	-6.7%	0.0	1.0	0.0	0.0	1.5	0.9	0.2	1.3	4.9	0.21%
Whakatane District	8.0%	-7.7%	0.0	0.5	0.0	0.0	1.2	0.7	0.2	0.9	3.4	0.30%
Kawerau District	2.8%	-5.3%	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.1	0.6	0.21%
Opotiki District	0.1%	-6.5%	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.2	0.07%
Gisborne District	0.0%	-3.0%	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.2	0.6	0.05%
Wairoa District	0.0%	-4.7%	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.09%
Hastings District	0.0%	-3.5%	0.0	1.2	0.0	0.0	0.0	0.5	0.0	0.5	2.1	0.07%
Napier City	0.0%	-4.0%	0.0	0.5	0.0	0.0	0.0	0.4	0.0	0.3	1.3	0.07%
Central Hawke's Bay District	0.0%	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00%
New Plymouth District	0.0%	-4.0%	0.0	1.3	0.0	0.0	0.0	0.7	0.0	0.6	2.5	0.05%
NEW ZEALAND	**0.0%**	**0.0%**	**0.0**	**25.6**	**0.0**	**0.0**	**37.5**	**26.1**	**4.2**	**29.5**	**123.0**	**0.06%**
By region:												

Area or region	AGTC change	AAIR change	Primary	Manufac-turing	Utilities	Construct-ion	Consumer services	Business services	Government	Community services	Sum of 8 combined sectors	As % of ALL sectors less transport
Northland			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00%
Auckland			0.0	0.0	0.0	0.0	6.2	1.4	0.4	1.2	9.2	0.01%
Waikato			0.0	15.4	0.0	0.0	21.1	15.1	3.0	18.7	73.4	0.42%
Bay of Plenty			0.0	5.9	0.0	0.0	10.2	7.2	0.9	6.9	31.0	0.33%
Gisborne/Hawke's Bay			0.0	2.1	0.0	0.0	0.0	1.1	0.0	1.1	4.2	0.06%
Taranaki			0.0	1.3	0.0	0.0	0.0	0.7	0.0	0.6	2.5	0.03%
Manawatu			0.0	0.9	0.0	0.0	0.0	0.7	0.0	1.0	2.6	0.03%
Wellington			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00%
Marlborough/ Nelson/Tasman			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00%
West Coast			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00%
Canterbury			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00%
Otago			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00%
Southland			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00%
Combined BOP/ Waikato/Auckland			0.0	21.4	0.0	0.0	37.5	23.7	4.2	26.8	113.7	0.12%

The results show the effect of the network improvements is a permanent increase in GDP as follows.

- The total productivity gain across New Zealand is estimated to be $123.0 million.
- This gain is largely spread across the manufacturing, consumer services, business services and community services sectors.
- Almost all of this productivity gain occurs in the regions of Waikato, Auckland and Bay of Plenty, ie the three regions that include Hamilton, Auckland and Tauranga.
- The productivity gain in the combined AHT regions amounts to 0.12% of non-transport GDP in these regions (note these productivity gains form the productivity shock subsequently added to the SCGE model, as reported in the next chapter of this report).
- Not shown in the table above, the split between productivity gains due to increased density and due to decreased drive time to Auckland Airport is approximately 50/50.

Implicit in these productivity gains is an implied reduced need for employment. The above GDP estimates result from a two-stage model that, first, measures the effect of AGTC and AAIR on employment, and then measures the combined effect of estimated employment, AGTC and AAIR on GDP. Implicit in the productivity gains reported above are first-stage employment effects. For the case study scenario, the implied employment change in the Auckland–Waikato–Bay of Plenty region is -4,499 people, ie 0.21% less employment. In effect, the model is inferring that GDP would typically not require the current employment levels given the improved working population density and airport drive time.

The two-stage GVA model does not, though, provide any guidance as to where this ‘released labour’ would otherwise be employed. In a fully employed economy, there would be an increase in employment that matched the ‘released labour’ but the sectors and areas to subsequently increase employment are unknown. This is an insight that requires an SCGE model, the topic of the next chapter.

7 Case study – the SCGE model effects

7.1 Introduction

Section 6.1 outlined a scenario of travel time improvements for sections of the SH1–SH29 route between Auckland, Hamilton and Tauranga. The largest component of the benefit comes from effects that mimic the Waikato Expressway, with smaller components coming from the Hamilton bypass, the Cambridge bypass and a tunnel, say, under the Kaimai Ranges. When the network used to model journeys was altered to include these road improvements, a time saving of 17 minutes was achievable between Auckland and Tauranga, a saving of 12%.

The benefit of quicker journeys has been calculated for travel between the eight zones using the earlier reported SCGE model (see chapter 5). In practice, user benefits will arise due to reduced travel time and costs, especially for trucks and other heavy vehicles where the reduced gradient from a tunnel would have a significant impact on vehicle operating costs. However, for modelling purposes we consider only the changes in travel time as that is how connectivity has been defined in the SCGE model.

The details of the calculations are available from the authors. The summarised changes in travel times for the routes identified in the model are presented in table 7.1. They are incorporated into the model as changes to amount of travel (ie the D's) in equations 5.13 (for commuting) and 5.16 (for freight), 5.18 and 5.19 (for trade outside the region), and 5.25 (for trade within the region); and as changes in productivity (λ) in equation 5.1. For the entire AHT region the value of travel weighted by the above changes is approximately 0.22% of regional GDP. In other words this is the direct productivity effect.

Table 7.1 Estimated changes in travel time in case study

Origin- destination pair		% change
Auckland	Waikato	-6.4
Auckland	Hamilton	-16.2
Auckland	Tauranga	-12.2
Waikato	Tauranga	-8.2
Hamilton	Tauranga	-19.0
Port of Auckland	Waikato	-6.1
Port of Auckland	Hamilton	-15.4
Port of Auckland	Tauranga	-11.9
Auckland airport	Waikato	-6.9
Auckland airport	Hamilton	-17.0
Auckland airport	Tauranga	-12.6
Port of Tauranga	Auckland	-12.7
Port of Tauranga	Waikato	-8.7
Port of Tauranga	Hamilton	-20.0
South, other New Zealand	Auckland	-6.0
South, other New Zealand	Tauranga	-2.1

We initially consider two scenarios, one with resources tightly constrained and one with more flexibility. In a third scenario we incorporate the agglomeration benefits that accompany the changes in effective density consequent to the changes in travel time, as reported in chapter 6. A final scenario is a sensitivity test where the location elasticity is doubled.

In all scenarios, the results are presented as the change on welfare and GDP that would result from (a) changes in transport and (b) other input changes, with interest in the former but with particular interest in how transport effects may vary under different situations.

7.2 Scenario 1

In scenario 1 the travel time improvements are incorporated into the model in two ways: as reductions in commuting distances between origin and destination pairs (as tabled above) and (because distances do not feature directly in firms' production functions) as improvements in industry productivity in each zone according to each industry's supply of transport services. This captures business time savings as transport costs to firms will fall. For the four work zones the productivity changes are:

- Auckland: 0.24%
- Waikato: 0.17%
- Hamilton: 0.12%
- Tauranga: 0.18%.

The weighted average change is 0.22%, as noted above.

The supply of industrial land is fixed in each zone and the total regional supply of labour is fixed, but is flexible between zones. Given that residential density is fixed in each zone, the labour market assumption effectively translates to a fixed total supply of residential land, but flexible between zones. We should think of this as allowing different paths for the location of population growth over time in response to land and transport prices, not as mutually compensatory changes in land use at a point in time.

The SCGE model can measure the result of transport improvements in terms of changes to work-residence patterns, zonal GDP and household utility.

Tables 7.2 and 7.3 show the percentage changes in utility for each residence-work (r-w) zone combination, first without allowing for any changes in the number of people in each r-w combination, and second allowing for people moving between zones by commuting or, as mentioned above, by population growth occurring with a different spatial pattern because of the transport improvement.

Both utility tables show an increase in overall household utility.[43] About half the gain is attributable to lower freight costs with the other half coming from changes in commuting and changes in residential location. Collectively Auckland residents gain the most, with the largest proportionate gain being experienced by those who live in Auckland and work in Tauranga – albeit that the absolute number of people involved (372 in the base data) is small.

Auckland also gains most from a work perspective, while other zones lose jobs – or alternatively, as shown in the next scenario, experience slower job growth than they would without the transport improvement.

As expected with an improvement in inter-zone connectivity, there is more inter-zone commuting at the expense of intra-zone commuting.

[43] Strictly speaking it is not usually valid to add utility over different individuals.

Table 7.2 Scenario 1: Changes in utility excluding commuting and migration by residence and work zone

		Work zone				
		Auckland	Waikato	Hamilton	Tauranga	Total
Residential zone	Auckland	0.1%	4.4%	9.7%	17.0%	0.2%
	Waikato	3.1%	-0.8%	0.3%	7.9%	0.0%
	Hamilton	5.2%	-0.5%	-0.8%	7.3%	-0.5%
	Tauranga	14.2%	6.5%	10.3%	-0.7%	-0.2%
	Total	0.2%	-0.3%	-0.2%	-0.3%	0.1%

Table 7.3 Scenario 1: Changes in utility including commuting and migration by residence and work zone

		Work zone				
		Auckland	Waikato	Hamilton	Tauranga	Total
Residential zone	Auckland	0.2%	9.8%	21.3%	37.4%	0.5%
	Waikato	6.9%	-1.8%	0.8%	17.4%	0.1%
	Hamilton	11.3%	-1.1%	-1.7%	16.0%	-1.0%
	Tauranga	31.1%	14.2%	22.6%	-1.5%	-0.4%
	Total	0.5%	-0.7%	-0.5%	-0.6%	0.2%

Table 7.4 shows the changes in employment location by r-w combination (note: the numbers are in thousands of people, not percentages). There is a clear movement to Auckland, with all the other zones experiencing a decline in population. Waikato loses 1,000 people from a residence perspective, but 3,000 from a work perspective – the result of the quicker commute to Auckland.

A road is a two-way link. Improving it makes it easier for people and goods to move to a given location and to move out of a given location. Which effect dominates depends on the whole network of relative journey times and land costs. A business in Hamilton can more readily send goods to the Auckland market if the journey becomes quicker, but it may instead make more sense for the business to locate in Auckland (with its very large market) and send goods to Hamilton, especially if improvements elsewhere in the network also make it easier to send goods to places other than Hamilton. The results suggest the latter effect dominates. That is, the quicker journey times (in this case study) encourage businesses to locate in Auckland and supply other markets from Auckland, rather than supplying the Auckland market from a different location.

Table 7.4 Scenario 1: Changes in employment by residence and work zone (‘000)

		Work zone				
		Auckland	Waikato	Hamilton	Tauranga	Total
Residential zone	Auckland	0.6	0.1	0.1	0.1	0.9
	Waikato	0.2	-0.4	0.1	0.0	-0.1
	Hamilton	0.1	0.0	-0.6	0.0	-0.5
	Tauranga	0.1	0.0	0.0	-0.5	-0.3
	Total	1.0	-0.3	-0.4	-0.3	0.0

While the initial impact of an improvement in travel time is a reduction in the amount of inputs (such as labour) needed to produce a given output, by assumption total inputs are held constant so output can increase – which it does. Table 7.5 shows some macroeconomic results. Unsurprisingly, with limited opportunity for the economy to reallocate resources, the change in real GDP is 0.2%, in essence just what went into the model by way of productivity shock as a result of reduced travel costs.

While the real income of the economy increases with a productivity boost, on the expenditure side of the GDP account this could be manifested as either more consumption or more net exports. In this scenario there is a small decline in real private consumption. This is not inconsistent with the observed increase in household utility, as consumption of commuting and freight confers no utility, but households consume less of them.

All the expenditure side effect is manifested in more net exports, with both exports and imports benefiting from the lower transport costs. The trade balance improves by $197m, or about 0.3% of baseline GDP (of $73,245m). This effectively comes at the expense of private consumption, but why?

Table 7.5 Macroeconomic results (percentage changes)

	Scenario 1	Scenario 2	Scenario 3
Private consumption	-0.1	1.7	1.7
Exports	5.4	-0.8	-0.3
Imports	4.6	3.4	3.4
GDP	0.2	0.9	1.0

As aggregate utility in each r-w zone combination is proportional to the number of people in each r-w zone combination, and as the total amount of labour is fixed, aggregate utility can increase only by people shifting residence or changing their commuting.

As shown in table 7.3 the change in aggregate utility is small (albeit twice as large as the change in private consumption), implying that the changes in the components of utility – land and other goods – also cannot change by very much. This, together with the drop in real spending on transport (freight and commuting) produces the small observed reduction in real household consumption even though household utility increases.

However, one cannot be too definitive about the direction of causality as the model is just a set of simultaneous equations. At the same time land and labour restrictions are limiting the change in household utility and consumption, exports and imports are responding to the lower transport costs, pulling resources out of consumption goods.

While the whole picture may be somewhat artificial, a number of useful inferences may be drawn from this initial scenario:

- Enhancing connectivity between zones will have little effect on measured private consumption if there is no residential land available for population growth, whether via greater density or more land in total.
- Nonetheless consumer utility can still rise because commuting costs fall, providing access to better paid employment.
- Some of the benefits of better connectivity may be in the form of a trade surplus or, by implication, greater net savings. This might assist investment, and thus growth in the longer run – such a potentially GDP-enhancing scenario is not considered further.

Given the story around scenario 1, an obvious next scenario is to ease the labour restriction.

7.3 Scenario 2

In the second model run, the same assumptions and input shocks as in scenario 1 prevail, but total labour supply is raised by 1% which also means, given fixed residential density, that the amount of residential land is increased by 1%. The 1% is arbitrary, but such a growth rate is perhaps not unrealistic within the AHT region and provides an indication of the effects of population growth that could be induced by the transportation improvements. Note, it should not be inferred that any transport intervention caused the 1% labour supply increase but rather the intention is to consider transport effects within a growing economy and show effects will differ under static and growing scenarios (ie between scenarios 1 and 2). We do not consider whether the increase in labour comes from offshore or from elsewhere in New Zealand.

Tables 7.6 and 7.7 present the changes in utility. As in scenario 1, allowing for the effects of commuting and migration (or different population growth paths to be more realistic) roughly doubles the gain in aggregate household utility. The distributional pattern is much as before; Auckland still does best in a relative sense, but all zones benefit absolutely, with regard to both residential location and employment location.

Table 7.6 Scenario 2: Changes in utility excluding commuting and migration by residence and work zone

		Work zone				
		Auckland	**Waikato**	**Hamilton**	**Tauranga**	**Total**
Residential zone	Auckland	0.9%	5.0%	10.3%	17.6%	1.0%
	Waikato	3.8%	-0.2%	1.1%	8.6%	0.7%
	Hamilton	6.1%	0.4%	0.2%	8.2%	0.5%
	Tauranga	14.7%	7.0%	10.9%	0.2%	0.7%
	Total	1.0%	0.3%	0.7%	0.6%	0.9%

Table 7.7 Scenario 2: Changes in utility including commuting and migration by residence and work zone

		Work zone				
		Auckland	**Waikato**	**Hamilton**	**Tauranga**	**Total**
Residential zone	Auckland	2.0%	11.1%	22.7%	38.7%	2.3%
	Waikato	8.4%	-0.3%	2.3%	18.9%	1.6%
	Hamilton	13.4%	0.8%	0.5%	18.1%	1.1%
	Tauranga	32.3%	15.4%	23.9%	0.5%	1.5%
	Total	2.3%	0.8%	1.5%	1.4%	2.0%

The macroeconomic picture (see table 7.5 above) is rather different from scenario 1. Regional GDP is up by 0.9% and private consumption is up by 1.7%. Exports decline slightly and the trade balance worsens by $633m.

Within the private consumption change of 1.7%, real consumption of other goods and services increases by 1.9% and real consumption of transport services (commuting and margins) increases by 1.3%. As the price of the latter has fallen we would expect an increase in demand. Commuting has an indirect effect on utility by enabling access to better paying jobs, so at the margin there is more commuting. Lower freight costs translate into cheaper goods and services so more are demanded from zones that are now better connected. Nonetheless, the income effect clearly favours goods and services that directly generate utility.

The change in the mix of production (relatively less transport services and more other goods and services) captures the 'first order' effect on industry composition of the improvement in regional connectivity. It also suggests, however, that disaggregation of the other goods bundle could reveal further opportunities for change in industrial composition with concomitant increases in consumer utility.

Interestingly the increase in GDP relative to scenario 1 is somewhat more than is implied by the additional 1% labour, as the labour share in output is only 57% whereas the increment in GDP is 0.7%, suggesting that the benefits of spatially relocating economic activity rise with increasing factor supplies. This is not unexpected as the mobility of new resources is not restricted by the inertia in existing spatial allocations of households and businesses. Table 7.8 shows where the changes in employment occur.

Table 7.8 Scenario 2: Changes in employment by residence and work zone ('000)

		Work zone				
		Auckland	Waikato	Hamilton	Tauranga	Total
Residential zone	Auckland	6.4	0.1	0.1	0.1	6.7
	Waikato	0.2	-0.1	0.2	0.0	0.4
	Hamilton	0.1	0.0	0.2	0.0	0.3
	Tauranga	0.1	0.0	0.0	0.2	0.3
	Total	6.8	0.1	0.5	0.3	7.7

Reflecting the change in utility, all zones see a population/employment increase, although employment in Waikato by those who live in Waikato is still lower than without the improvement in travel time. Unsurprisingly, Auckland gains the most in absolute terms. As in scenario 1, Waikato performs better from a residence perspective than from a work perspective.

7.4 Scenario 3

In scenario 3 the same assumptions and inputs, including the extra 1% labour, as applied in scenario 2 prevail, but this time we incorporate the agglomeration benefits resulting from the changes in effective density that accompany the changes in travel times, as reported in chapter 6.[44]

For the four production zones in the SCGE model the agglomeration shocks, which are modelled as additional productivity changes (that is, additional to the direct effect of lower travel times) are:

- Auckland: 0.01%
- Waikato: 0.31%
- Hamilton: 0.54%
- Tauranga: 0.44%.

The weighted average productivity effect is about 0.1%. As with the initial travel time shock, while the economy needs less employment to produce a given amount of GDP (4,500 less as estimated in the previous chapter), total employment is held constant (at the scenario 2 level) so GDP can increase, although where it increases is not necessarily where the productivity shocks occur. Tables 7.9 and 7.10 summarise the changes in utility. To one decimal place the changes in aggregate utility are the same as in

[44] Note that the agglomeration benefits are calculated with regard to the initial levels of population and labour force, not with the extra 1% labour incorporated in scenario 2. However, while this is theoretically inconsistent, as the model is expressed in percentage changes (logarithmic differentials) the effect of a 1% difference in base levels is negligible.

scenario 2, but the spatial distribution differs. (At two decimal places aggregate utility does increase.) Comparing tables 7.8 and 7.10 for scenarios 2 and 3 respectively shows the following results.

From a residential perspective:

- Auckland is down by 0.1 percentage points.
- Waikato, Hamilton and Tauranga are all up by 0.2 percentage points.

From a work perspective:

- Auckland is down by 0.1 percentage points.
- Waikato is up 0.1, Hamilton is up by 0.3, and Tauranga is up by 0.2 percentage points.

The relative changes in welfare viewed by industry location are broadly similar to the relative agglomeration gains. Viewed from a residence perspective, some of the industry gain to Hamilton converts to a residential gain for Waikato.

Table 7.9 Scenario 3: Changes in utility excluding commuting and migration by residence and work zone

		Work zone				
		Auckland	**Waikato**	**Hamilton**	**Tauranga**	**Total**
Residential zone	Auckland	0.9%	5.2%	10.6%	17.8%	1.0%
	Waikato	3.7%	-0.1%	1.3%	8.7%	0.8%
	Hamilton	5.9%	0.4%	0.3%	8.2%	0.6%
	Tauranga	14.5%	7.0%	11.0%	0.3%	0.8%
	Total	1.0%	0.4%	0.8%	0.7%	0.9%

Table 7.10 Scenario 3: Changes in utility including commuting and migration by residence and work zone

		Work zone				
		Auckland	**Waikato**	**Hamilton**	**Tauranga**	**Total**
Residential zone	Auckland	2.0%	11.4%	23.3%	39.1%	2.2%
	Waikato	8.1%	-0.1%	2.8%	19.2%	1.8%
	Hamilton	13.0%	0.9%	0.7%	18.1%	1.3%
	Tauranga	31.8%	15.5%	24.3%	0.7%	1.7%
	Total	2.2%	0.9%	1.8%	1.6%	2.0%

Table 7.11 helps to understand these changes. While the Auckland–Auckland r-w combination still has the largest absolute gain, it is slightly smaller than in scenario 2 (table 7.8). The relative beneficiaries are Hamilton and Tauranga if viewed from a residence perspective, but only Hamilton if viewed from a work perspective (to the nearest 100 people). While not large, the agglomeration effects tend to encourage more living and working in the same zone, except in the case of Auckland; thereby providing a modest offset to the direct effects of better inter-zonal connectivity.

Table 7.11 Scenario 3: Changes in employment by residence and work zone ('000)

		Work zone				
		Auckland	Waikato	Hamilton	Tauranga	Total
Residential zone	Auckland	6.2	0.1	0.1	0.1	6.5
	Waikato	0.2	0.0	0.2	0.0	0.4
	Hamilton	0.1	0.0	0.3	0.0	0.4
	Tauranga	0.1	0.0	0.0	0.2	0.4
	Total	6.6	0.1	0.6	0.3	7.7

The macroeconomic effects are shown in table 7.5. There is a small gain in regional GDP, simply reflecting the size of the agglomeration shock. All of this is manifested in higher exports responding to lower production costs. Accordingly the balance of trade deteriorates by a smaller \$560m compared with \$633m in scenario 2, implying higher household savings. Table 7.12 shows the macroeconomic changes in nominal dollars in the form of an abbreviated input-output table for the entire region. Note that most of the numbers are negative because of the decline in the price level – caused by the decline in the price of transport services. It will be seen that the change in nominal GDP, whether measured from the expenditure side or the income side is -\$2,448m.

Table 7.12 Scenario 3: Changes in macroeconomic aggregates for AHT region (\$m)

	Industries	Households	Exports	Total
Other goods		\$593	-\$39	\$554
Transport: commute		-\$,1666		-\$1,666
Transport: margins		-\$1,212		-\$1,212
Rent		-\$125		-\$125
Imports		\$521		\$521
Labour income	-\$1,411			
Rent income	-\$1,037			
Total	-\$2448	-\$1,888	-\$39	-\$2,448

To summarise, the direct effects of changes in travel time on consumer utility are much more significant than the indirect effects that operate via agglomeration benefits. That is, the gains from a spatial reallocation of economic activity outweigh those from greater population density – at least for this particular case study.[45] Other transport initiatives, notably those more focused on intra-zone travel may well produce a different mix of effects.

Given the dominance of the spatial allocation effect, the elasticity of location choice (see equation 5.7 in chapter 5) could be an important parameter. Thus we look at this in the next scenario.

[45] Hensher et al (2012) found a similar relative mix of effects for a proposed rail link in Australia.

7.5 Sensitivity test: scenario 2a

We arbitrarily double the elasticity for the number of households choosing an r-w option with respect to the utility associated with that option and re-run the SCGE model. Other assumptions and inputs are as in scenario 2.

As might be expected, greater responsiveness to changes in location-specific attributes leads to more people changing where they live and where they work. Thus utility is enhanced. See table 7.13 compared with table 7.6 and table 7.13 compared with table 7.7.

More interesting perhaps is the relative effect between 'with and without' changes in commuting and migration – namely a three-fold increase moving between tables 7.11 and 7.13, compared with a two-fold increase moving between tables 7.6 and 7.7. That is, the aggregate gain from the spatial redistribution of residential and business location is now more than twice as large as the gains from access to lower freight costs. More responsiveness to relative changes in wages rates, land prices and commuting costs, will enhance any welfare gains that accrue from a positive productivity shock.

Table 7.13 Scenario 2a: Changes in utility excluding commuting and migration by residence and work zone

		Work zone				
		Auckland	**Waikato**	**Hamilton**	**Tauranga**	**Total**
Residential zone	Auckland	0.4%	2.3%	6.0%	8.8%	1.2%
	Waikato	2.1%	0.1%	0.4%	4.1%	0.8%
	Hamilton	4.2%	0.3%	0.3%	5.4%	1.1%
	Tauranga	7.7%	3.3%	6.6%	0.3%	1.8%
	Total	1.1%	0.7%	1.2%	1.7%	1.2%

Table 7.14 Scenario 2: Changes in utility including commuting and migration by residence and work zone

		Work zone				
		Auckland	**Waikato**	**Hamilton**	**Tauranga**	**Total**
Residential zone	Auckland	1.4%	8.0%	20.5%	30.0%	4.1%
	Waikato	7.2%	0.4%	1.2%	13.8%	2.7%
	Hamilton	14.3%	1.1%	0.9%	18.4%	3.7%
	Tauranga	26.0%	11.2%	22.6%	0.9%	6.1%
	Total	3.9%	2.5%	4.2%	5.9%	4.0%

This responsiveness may also be seen in table 7.15 which shows the changes in employment by r-w combination. Compared with scenario 2 (table 7.8) there is smaller absolute gain to Auckland, with all other zones gaining more. Put simply, the more mobile people are, the more improvements in inter-zonal connectivity will encourage people out of Auckland – hardly surprising. Nevertheless, because of its sheer size, Auckland still sees the largest absolute change in employment/population.

Table 7.15 Scenario 2: Changes in employment by residence and work zone ('000)

		Work zone				
		Auckland	Waikato	Hamilton	Tauranga	Total
Residential zone	Auckland	5.6	0.1	0.2	0.1	6.0
	Waikato	0.3	0.1	0.1	0.0	0.5
	Hamilton	0.2	0.0	0.5	0.0	0.7
	Tauranga	0.1	0.0	0.0	0.4	0.5
	Total	6.2	0.3	0.8	0.5	7.7

Of course the productive capacity of the economy is unchanged from that in scenario 2 (as the transport shock is the same), so the change in GDP is also the same, but the composition of the change is different. See table 7.16.

Limited land supply disproportionately pushes up property prices in 'desirable' locations. While the household sector receives all rent, the household utility function limits the degree to which 'consumption of land' can be substituted in favour of consuming other goods and services, leading to more saving than occurs with a lower location elasticity. The flip side of lower domestic absorption is that net trade is relatively stronger – the balance of trade deteriorates by only $377m, compared with $633m in scenario 2.

By assumption industrial land rents rise by the same proportions as residential land rents, reducing export competitiveness. Wage rates add further pressure.

Table 7.16 Macroeconomic results

	Scenario 2	Scenario 2a
Private consumption	1.7	1.3
Exports	-0.8	-1.7
Imports	3.4	0.9
GDP	0.9	0.9

In summary, more spatial reallocation of economic activity certainly raises consumer utility, but for any given change in GDP there is not necessarily a corresponding increase in household consumption of goods and services. Some of the gain in income goes into higher saving and higher rent.

7.6 Summary

For this particular case study, which involves various improvements in connectivity across the AHT region, the increase in aggregate utility that follows from a spatial reallocation of where people live and work is greater than the direct productivity effect on GDP of lower travel times, provided there is some flexibility in the supply of land and/or labour. Consumers, as assumed within the model, derive no utility from commuting or freight margins but do have to pay for those services. Thus reductions in travel costs (times) liberate resources for use in utility-raising pursuits.

The spatial reallocation effect also exceeds the agglomeration effect from greater effective population density. This balance may change for improvements in intra-zone, as opposed to inter-zone, travel.

Viewed from the perspective of residential location, zones that benefit from the spatial redistribution of economic activity may not accord entirely with the zones in which agglomeration effects occur, although for this particular case study the differences are minor. There is a small gain to Waikato at the expense of Hamilton.

The model also shows some unexpected effects with regard to the distribution of changes in GDP between net trade and domestic absorption, with implications for saving. At this stage it is difficult to know whether this is an idiosyncrasy of the model – perhaps its lack of investment dynamics, a feature of the specific case study, or a more generally applicable insight that improvements in connectivity really can shift resources between the household sector and the export sector.

Overall the results support the proposition that improvements in connectivity can lead to gains in consumer welfare from a spatial redistribution of where people live and work; gains that might not be fully captured in standard cost-benefit analysis. Hence SCGE modelling could be a useful addition to Transport Agency's tool box for evaluating major improvements in the transport network.

In this case, the following GDP improvements were also identified.

- An increase in GDP of 0.2% (table 7.5, scenario 1) results from the re-directed resources that are freed due to the transport improvement. This figure is expected to be similar to that derived within a standard transport CBA (excluding WEBs), except that the CBA will also include welfare gains resulting from increased leisure time. This gain is expected to be a permanent shift in the level of annual GDP.
- A further 0.1% GDP increase during a period of an exogenously imposed (that is, not an output of the model) 1% pa labour market growth (table 7.5, scenario 2, after deduction of the above 0.2% and the 0.6% scale effect of increased labour). This is a dynamic productivity gain that will not be picked up within a standard CBA. It results from improved allocation of work and residence locations. This gain is expected to be a permanent shift in the level of annual GDP, and is likely to be repeated under a persistent labour growth scenario.
- A further 0.1% GDP increase due to the productivity enhancing effects of agglomeration and connectivity. Some of the effect will be measured within the agglomeration add-on to the standard CBA appraisal.
- The combined 0.4% GDP improvement is equivalent to around $380 million (in 2010 real terms) per annum or $5.2 billion in present value over 30 years at a real 6% pa discount rate.

Furthermore, the SCGE model shows:

- Under a scenario of growing labour force over the combined regions, the road improvements are likely to lead to relatively higher population and workforce growth rate in Auckland and relatively lower growth in the other zones (table 7.4).

In all cases the improvement in household utility is greater than the improvement in GDP, the result of people being able to better match their residential location, work location and consumption to their preferences. These are gains from greater allocative efficiency; gains that occur even when there is no change in the total level of resources (land and labour) available to the economy.

8 Discussion and implementation

This chapter discusses the results of the two models, including an interpretation of how the results will differ from a traditional transport CBA analysis[46]. Some observations are also made about how these models might be incorporated into a Transport Agency analysis.

8.1 User and non-user benefits

The SCGE model shows how user benefits are likely to manifest. A transport CBA for the hypothetical transport improvements in the case study was not undertaken but it would be expected to show the welfare benefits to *road users* in the transport CBA model is of the same magnitude as the welfare benefits to *households* in the SCGE model, namely a 0.2% increase in the annual level of welfare (table 7.3), putting aside for a moment the time taken for this level adjustment to eventuate. Note this figure incorporates welfare gains due, first, to reduced travel times related to unchanged road usage, leading to both lower travel and freight costs, and, second, to people changing their work and resident location, and thus road usage. An important distinction between the transport CBA and SCGE model, though, is that the number of people living in any one zone and the number of people working in any one zone is not fixed in the SCGE model but is in the fixed land use transport CBA.

Note the dynamics in the two models, even in a relatively static scenario, do differ so the results are unlikely to be exactly the same. Consider that a travel use scenario will exist for 'before' and 'after' the transport intervention. The transport CBA will use the 'before' scenario as the counterfactual. A series of travel demand curves are assumed to exist for the series of roads. With no change in any travel demand, the transport CBA is likely to show a similar 0.1% welfare benefit to road users as the rigid SCGE scenario 1 (table 7.2). However, even under a fixed land use assumption, the demand for individual roads will change in the 'after' scenario (although not the total number of people in each residence or origin zone and each work or destination zone as these are fixed). Demand for some roads will increase while demand for others will decrease. The net welfare change in the transport CBA is likely to move closer to the 0.2% result of the unconstrained scenario 1 run (table 7.3), although it is likely to be less due to the transport CBA constraint of fixed populations and workforces per zone. Alternatively it is possible to relax the transport CBA fixed land use assumption and derive an 'observed' demand curve, whereby the rule-of-half calculation is expected to provide an estimate of user benefits similar to the 0.2% SCGE result.

From this perspective, one fundamental difference between the two models is due to assumptions made when deriving the land use totals within each zone.

However, the differences do not end there. The scenario 2 run of the SCGE model shows how the dynamics can change over time, as other factors also change. Although the 1% labour supply increase assumption of scenario 2 is exogenous and arbitrary, the scenario illustrates the challenge with forecasting travel demands. In the transport CBA, such a population increase is handled as forecasts for a new set of travel demand curves at a future date (with typically demand extrapolated between dates). Behind these travel demand forecasts are a set of population and employment forecasts for individual zones, defining a new set of 'fixed land use' assumptions. It is generally unclear when using future demand curves whether the counterfactual used in the transport CBA analysis is the 'before' or 'after' travel demand curve for each road implied by the SCGE model. That is, planners may forecast people will live and work in locations without explicitly considering whether that is indeed dependent on the road investment under

[46] The traditional transport CBA in mind is as per the Transport Agency EEM, including agglomeration benefits.

examination. The SCGE analysis shows the gain in welfare to households is 2%, assuming a 1% labour supply increase (table 7.10); this is a gain of around 1% per person. It is possible the transport CBA analysis, using the 'after' demand curves, delivers a benefit equivalent to 1% per person should the forecast base case travel demands reflect the 'fixed land use' of the 'after' scenario. The base case in this situation would reflect the land use that ultimately may derive from the interactions considered within the SCGE model but there would also be some congestion – as the road(s) had not actually been improved at that stage. The transport CBA, run on expected actual drive times and not the speed limits used in the SCGE model[47], will pick up a relatively large user benefit as this congestion is relieved, plus the change in travel time initially studied in the SCGE model; potentially producing a similar 1% per person total benefit.

Of course, the base case land use assumptions may also vary from those implied by the SCGE 'after' scenario, in which case the two models will produce different results. That is, once we move into future scenarios, the chances are now much greater that the two models will produce different results, simply due to the assumptions around land use and hence travel demand (and not due to externalities at this stage). It could be that transport CBA benefits for a future date exceed those of the SCGE model, if the land use forecasts implied greater separation of residence and work locations than derived in the SCGE model, or vice versa. The main point is both models are trying to forecast future activity within a dynamic environment. Neither can be assured of producing the forecast that eventually matches reality.

That both models are making different assumptions about what might happen between now and the future period of analysis becomes more evident when considering the activity measures derived by the SCGE model for this case study.

Putting aside now any potential difference in the underlying land use assumptions and hence different estimates of welfare effects, the SCGE model goes beyond the expected household welfare gains to show the expected macroeconomic effects. Accompanying the 1% labour force growth (approximately 7,000 people) and resulting 2% welfare gain (scenario 2), the activity effects expected include 0.9% higher GDP, 1.7% higher consumption and a decline in the external trade balance. In per capita terms, GDP decreases by around 0.1%. This result illustrates welfare gains do not necessarily translate one-to-one into GDP or employment gains. Also, returning to the issue of assumptions implicit in any forecast, this GDP result highlights two assumptions in the SCGE model: first, GDP increases only proportionally to the labour share (see Cobb-Douglas function in equation 5.1); and, by assumption, capital does not increase in scenario 2 (capital is subsumed within 'land', see section 5.6.5). More people and improved transportation also require more capital to be able to realise the full potential of the transport intervention. If capital were allowed to increase in scenario 2 then the expected GDP increase would be positive.

More generally any constraint on roads, land, labour or capital will affect the result of any investment. In the SCGE scenario 2, capital was constrained. In the transport CBA analysis, the use of land is typically constrained and it is not clear what other constraints are incorporated in the forecasts that underlie the transport CBA base case travel demands, as any underlying assumptions will be contextual. And of course, in other cases, the lack of road investment may act as the constraint.

The key point of relevance to interpreting SCGE results relative to transport CBA results when it comes to future scenarios is the assumptions implicit in the travel demand forecasts can be significantly different, and may require considerable effort to align.

[47] Although the SCGE model could be constructed using actual travel times but in this case it was not

8.2 Externalities

One factor missing from the GDP outcome above is the productivity effect that results from improved accessibility (ie intra-urban) and connectivity (ie inter-urban). This SCGE model is not designed to estimate these effects. Incorporation of these dynamics into the model may be possible with further model development but the first step was to produce a SCGE model that would capture inter-zonal movements of people and freight. For now the GVA model provides an estimate of the productivity effect, shown in this case to be a 0.1% increase in the level of annual GDP as a result of the travel time savings reported in table 6.1. Again putting aside the period of transition for now, adding this shock to the SCGE model (scenario 3) increases the total GDP effect to 1.0% (table 7.5), or near zero in per capita terms. That is, the combined effect of direct travel savings and the indirect effect of accessibility and connectivity externalities under a scenario of combined reduced travel time and 1% increased labour supply is an increase of welfare benefits for households of 2.0% (table 7.10) and a GDP effect of 1.0% (table 7.9), or in per capita terms, +1.0% welfare and no change to GDP.

In this case, there was little further gain in welfare due to the allocative effects of the implied higher income arising from the higher productivity. A more sophisticated SCGE model might capture such extra benefits but they are likely to be orders of magnitude less than the initial productivity shock of 0.1%, and hence were not part of this research project.

The model also does not capture any externalities that might result from extra exporting activity and potentially the accompanying FDI. Nonetheless, the changing external trade balances described in scenarios 1 to 3 show trade effects can be substantial. There are benefits from external trade that will not be picked up in any transport CBA but which contribute to welfare gains in the SCGE. In this case study, the income effect on imports was dominant and there is a resulting higher trade deficit forecast as a result of the road improvements. Not explored in the study was where thresholds existed amongst parameters and other inputs that switch the effect towards higher exporting activity. This is one suggested area for further research.

Elaborating further on this topic, research suggests higher exporting and FDI can trigger the type of virtuous endogenous growth described by NEG. The research literature does not point to any particular channel of influence but connectivity to overseas markets, via ports, is likely to be a supportive factor. Again this connection is imprecisely researched but inclusion of port connectivity has been used in US economic appraisals and the statistical significance of a similar measure in the GVA project developed in this project also suggests some importance. To be more precise, this project has not been able to clearly define and measure a productivity externality related to improved port access but, equally, it has not been able to disprove that such a connection exists. At this stage, an airport connectivity variable helps explain differences in New Zealand productivity amongst many sectors although it is possible this measure is capturing a broad advantage of proximity to a large city (where airports exist). This is further reason to explore further export/FDI effects within SCGE models, including for investment proposals beyond the AHT region.

One avenue suggested within the literature for externalities is via specialisation of industries (ie independent of any agglomeration of activity that might also occur). The models employed here have not been able to test for this effect, partly because the causal link between transport costs and specialisation is not clear. The GVA model did allow a test which confirmed specialisation does correlate with higher productivity in regions amongst the non-specialist sector. From a modelling perspective, this suggests a useful innovation for the SCGE model would be to include equations that allow imperfect competition, specialisation and spillover effects. From a regional policy perspective, it suggests emphasis be put on facilitating growth around local specialist industries.

8.3 Spatial effects

The key advantage of the SCGE model developed is its ability to model spatial responses to changes in transport costs. The now-existing model makes a significant contribution in this field.

Recall travel enters this model through two channels: via a freight cost component of goods delivery; and via a cost of commuting between a residence and workplace. In turn, the model takes heed of the current work locations and residence locations to infer a value to specific locations. Thus, for example, the prevalence of population in Auckland implies both a strong earnings value and a strong amenity value.

The transport 'shock' to the system lowered the cost of commuting between Auckland and other places, albeit Hamilton and Tauranga are beyond the typical commuting range, and lowered the cost of freight between all three major centres. The resulting percentage changes in residence-work combinations is slightly deceptive since the actual level of commuting between the major centres is low. More telling, as shown in table 7.8, is the greater appeal of the cities (Auckland, Hamilton and Tauranga) under a reduced Waikato/Bay of Plenty travel cost scenario, both for residence and work, and in particular the appeal of Auckland. In modelling terms, if we lower the cost of travel then the inherent – but unspecified – appeal of the cities takes effect at the margin. Note this occurs in spite of an implied higher land/housing cost in the cities.

Importantly, inclusion of higher productivity throughout the region, as in scenario 3, saw some reduction in the shift towards Auckland. From a wider regional development perspective, this points towards the importance of promoting productivity gains in those regions that are away from the major centre(s). Implicit in the results of these models, improving connectivity to international airports does improve regional productivity but, sometimes more than negating this effect, it also increases the value in centralising activities. Regional policy makers would do well to understand this dynamic.

An area not explored deeper in this project, but possibly leading to the overstatement of the appeal of Auckland in the SCGE model, is the relationship between increased population, employment and the cost of land. It is worthy of further research to understand the thresholds around land supply and housing costs that would shift the appeal at the margin away from the cities. This is especially pertinent given the rising relative price of housing in Auckland in recent years.[48]

Research also suggests that there is a two-way effect to changing travel and land costs. The model at present is not disaggregated sufficiently to differentiate those rent-sensitive industry sectors that might move towards the periphery apart from the high-value sectors that put higher value in proximity. This, again, is a field for further development.

Before finishing this discussion of spatial effects, it is important to recall that the 'shifts' implied by the SCGE model are not so much a re-location of current people but a bias at the margin in the pattern of growth rates.

8.4 Period of transition

The GVA and SCGE models take observed measures of economic activity at a particular point of time and an assumed set of relationships, albeit confirmed statistically, to infer a fixed relationship between an input variable (say, travel costs) and an output variable (say, GDP), albeit via many intermediate relationships. These fixed relationships are then assumed to apply to any changes in the input variables.

[48] Scenario 2a did explore the effect of changing the choice elasticity

That is, decrease an input such as travel costs and the economy will adjust to arrive at higher level of GDP that 'fits' with the assumed relationships within the economy.

However, these models make no statement about how long this transition from a 'before' state to an 'after' state will take. Research suggests this could take years and even decades. And in the meantime, further 'shocks' will occur and these too will transition through the economy. From this perspective, the economy is an evolving and emerging series of transition states.

This viewpoint has two implications for project appraisal. First, it is difficult to be precise about a future base case counterfactual, let alone about the marginal effect of any intervention. For small projects, the intervention effects are likely to be largely independent of the underlying base case and so an estimate of marginal effects is not biased. But for large projects, there can be an interplay between future pathways. This, potentially, creates bias around any appraisal. Second, an uncertain transition period both complicates how to transition the one-off level effect into an economic appraisal and, post hoc, complicates how to attribute any project intervention to observed changes.

In this case study, no assumption has been made about the transition period to a higher level of welfare and activity happens. The 0.2% (of direct benefits) is likely to materialise quite quickly in the economy (probably within five years), but the remainder of the growth may take a longer depending on planning and land use regulations and how quickly people can change jobs and work locations. The reallocation of resources (GE effects) between industries and sectors (households versus exports for example) may take a long time to feed through. As for agglomeration effects, little is known about how long they take to materialise.

8.5 Implementation

The results from building and testing the GVA and SCGE models show further information of significance to a major transport project can be gained, at little relative cost when compared with the costs (and benefits) of major infrastructure investment. This is not to say GVA and SCGE analysis is always worthwhile.

The further information includes:

- alternative growth scenarios to consider against those employed within a transport CBA analysis
- additional benefits that are unlikely to be measured within a transport CBA analysis, including in particular welfare benefits resulting from improved allocative efficiency, especially for large projects
- descriptions of the economic activity responses to expect, including GDP and employment effects
- the spatial reallocation and distribution of effects
- and, potentially, thresholds above and below which important desired outcomes might eventuate, and under what conditions.

Potentially it is possible a SCGE model could be built to explore market distortions. The current model does not do that.

However, the research project also confirms the primacy of the transport CBA analysis: given the many uncertainties that exist, it is of considerable value to be able to examine a transport project in terms of probable transport outcomes; plus the transport CBA clearly identifies a marginal cost to be offset against marginal benefits. The interplay present in SCGE models leads to a lack of transparency around transport effects and marginal costs while the GVA model is only a partial representation of outcomes.

Thus a GVA and SCGE model combination are seen as complementary to a transport CBA, rather than providing a replacement analytical method.

Upgrading the existing pilot SCGE model to something more robust, relevant and better anchored to actual data should be possible for relatively little marginal cost for major transport projects in the AHT area. Elsewhere, a customised regional variation of the AHT SCGE model would be required, at greater expense. At present, the SCGE model is not general enough to be used for widespread analysis of projects, as in the US.

Going forward, there appear to be two pathways.

1 One would be to amend and apply the SCGE model as required for large projects so as to improve understanding of the economic dynamics to be expected in general and in particular use it to:

   a validate benefits derived from traffic modelling and CBA by providing an alternative estimate of welfare benefits at future points in time

   b prioritise projects above a minimum BCR against other national objectives (eg export and/or GDP growth)

   c prioritise projects above a minimum BCR against other regional objectives.

2 Another use of the SCGE model is to use it more generally for pre-traffic modelling analysis – this would require substantial development to generalise the current model.

Besides extra SCGE modelling as required under (1) and (2), integration of model results in a multi-criteria setting as implied in (b) and (c) would require the setting of thresholds and consideration of integration into the current Transport Agency prioritisation system. This project has not attempted to estimate such thresholds.

9 Conclusions

9.1 Overview

We have assessed the literature on the economic benefits of greater connectivity, looking at the mechanisms by which connectivity affects the economy, but focusing especially on the extent to which traditional CBA models used to analyse transport investments do not capture connectivity effects.

The first benefit of better connectivity is lower travel times and lower travel costs, and this is potentially fully captured in a CBA. However, the change in economic activity, and hence travel demand, can be difficult to predict. Furthermore, as a direct consequence of lower travel times, better connectivity may also do the following:

1. Generate agglomeration and connectivity benefits (essentially raising industry productivity) through better matching between firms, and between firms and households, by raising the effective population/business density of a location or region and/or the concentration of industry or skills.
2. Enhance industry competitiveness (reduce imperfect competition) by mitigating the effect of distance, which can be a barrier to entry – this could also generate greater efficiency through economies of scale and specialisation, although that could worsen competition.
3. Improve the allocative efficiency of the economy as resources shift between industries to accord with relative prices and consumers' marginal rates of substitution.
4. Raise total employment through higher participation rates (though this may just represent a transfer of employment between locations, not a net national gain).
5. Expand the size of the economy's capital stock.

The above five effects are not usually (and not easily) captured in CBA models. Thus in this report we have pursued two other types of models:

1. A GVA model that is intended to capture the manifestation of agglomeration and connectivity effects – item 1 above.
2. A SCGE model that is intended to simulate where, spatially, the changes in GVA occur. It can also be used to explore items 4–5 above, and item 3 to a more limited extent. The model is currently not designed to simulate reductions in imperfect competition (item 2), but the better connectivity between firms and households (in 1) does allow household utility to increase by having greater access to goods from neighbouring locations through lower freight costs.

9.2 Research findings

The GVA model investigated a number of measures of connectivity to identify possible productivity effects in over more than 50 industries. It found statistically significant effects across a range of industries with respect to effective people mass (based on GTC) and/or connection to airports.

The GVA study confirmed that productivity effects varied by industry, in this case concentrated amongst the manufacturing, consumer services, business services and community services sectors. These showed in the case study as a benefit that, unsurprisingly, showed as a relatively small percentage but was a large number in magnitude. The study was not able to find a rigorous theoretical connection between access to airports and productivity but approximately half the productivity gain estimated in the case study was the result of better access to airports. It is possible this effect was due to proximity in general to large cities but, whatever the causal mechanism, there is a relationship with airports that was found to be statistically significant.

The major innovation in the project was the SCGE model. The SCGE model is populated with, and calibrated to, eight spatial zones: AHT, a rural Waikato zone, two sea ports, one airport and a notional port to capture exports to, and imports from the rest of New Zealand carried by land transport. Households and industries exist in the first four zones, and can move between them, and labour can commute between these zones. The other four zones represent only alternative sources of goods for households and alternative export options for industries.

For a case study we investigated hypothetical (but not unknown) changes to the road network connecting Auckland, Waikato, Hamilton and Tauranga, involving various reductions in travel time, such as 12% less between Auckland and Tauranga, and 16% less between Auckland and Hamilton. Five key results emerge from the models.

1. Excluding any agglomeration effects or changes in total factor supplies, regional GDP (equivalent to GVA) increases by 0.2%. This is simply the direct effect of the productivity increase associated with the shorter travel times. The result would be similar to a standard transport CBA, except the CBA will also include welfare gains resulting from increased leisure time.
2. An (assumed) increase in the regional labour supply of 1% adds a further 0.7% to GDP. This is more than the share of labour in GDP, which is 0.6%. The additional 0.1% is the gain from an improved allocation of work and residence locations. It would not be captured within a standard CBA.
3. Adding in the productivity increase estimated within the GVA agglomeration model adds another 0.1% to GDP. This is the pure connectivity effect; it also is not captured in standard CBA, although Transport Agency's more sophisticated evaluation framework can partially capture it.
4. The combined 0.4% lift in GDP is equivalent to around $380 million (in 2010 real terms) per annum or $5.2 billion in present value over 30 years at a real 6% pa discount rate.
5. In all cases (examined here) increases in consumer utility exceed increases in GDP. This occurs primarily because resources used for commuting in the model contribute to GDP, but do not contribute to utility.

The results suggest, perhaps trivially, that if resources are fixed we will not see the benefits a spatial reallocation of economic activity (where people live and work) can deliver. Not trivial though is that the effect represents an additional 50% to what a traditional CBA would produce, or an additional 33% if that CBA includes agglomeration effects.

One should not, however, interpret the reallocation as necessarily implying existing households and industries move location. While some of this would certainly occur, most of the spatial effect comes via alternative growth paths. That is, without an improvement to the road network, new households and firms would locate in some spatial configuration as the economy grows, but with the improvement the spatial configuration develops along a different path. For example, a firm that might otherwise look at locating in Hamilton might decide that with a new road it can instead better service its markets from Auckland and so locate there instead of Hamilton. Hamilton does not actually lose a firm; it just does not get a firm that it otherwise might have.

9.3 Caveats

The results from our case study require considerable caution:

- The case study is hypothetical and has not been fully evaluated within a standard CBA.
- The agglomeration effects are estimated within a GVA model that employs GDP that has, in turn, been estimated by industry by region.
- The SCGE model, although its database is anchored in the national accounts, contains even more estimated data and parameter values.

Furthermore, while the relative size of the spatial and agglomeration effects is quite large, the case study involved substantial changes to connectivity between significant population centres and ports (picking up connectivity between the region of interest and the rest of the world). These WEBs, especially the spatial effects, would not be expected (or perhaps more accurately, not measurable) for small infrastructure projects in isolated regions. Projects need to be at least of the scale of the Roads of National Significance, if not larger and be somewhat of a 'game changer.' The Oresund bridge between Copenhagen and Malmo is an ideal example. Irrespective of scale, if one cannot tell a plausible story of how wider economic effects may occur for a given infrastructure project, sophisticated modelling is not justified.

In the right circumstances, the results above support the general proposition that improvements in connectivity can generate gains in consumer welfare from a spatial redistribution of where people live and work; gains that might not be fully captured in standard CBA. Hence SCGE modelling would in principle be a useful addition to Transport Agency's tool box for evaluating major improvements in the transport network.

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Appendix A: Notes on economic growth, urban form and transport

The following sections draw heavily, but not exclusively from Redding and Turner (2015) and Desmet and Henderson (2015), two chapters within the 2015 *Handbook of regional and urban economics*.

A1 Transportation

Redding and Turner (2015) provide the following stylised facts about transportation. Detail not drawn from this report has been explicitly referenced.

Transportation is a major economic activity (p1).

- Transport capital expenditure can be high (eg the recent 5,846km Indian Golden Quadrilateral highway connecting Mumbai, Delhi, Kolkata and Chennai cost over US$9 billion.[49]).
- Transportation activity each year is a high share of GDP (3% in US 1990).
- The average household expenditure on transportation over 35 countries was 14.6% of total expenditure during 2005–2009.

Transport costs can be high (p4):

- A typical US transport cost is in the order of 5% of goods value and up to 20% of for lumber (in New Zealand, the cost of internal transport cost for logs from Rodney to Marsden point can be almost 30% of the freight-on-board value of export logs.[50]).
- Plus there are unpriced externalities such as pollution, crashes, congestion, noise.

Transport costs have decreased (p4):

- Rail freight costs dropped sharply between 1890 and 2000.
- US rail and trucking costs have continued to decline from 1960 to 1998.
- More so for air, road and rail than shipping.
- McCann (2009a): The transport-movement costs have fallen by some 95% over the last century (Glaeser and Kohlhase 2004), and telecommunications costs have also fallen by a similar order of magnitude over just the last 35 years (OECD 2008b).
- But in contrast, the spatial transactions costs associated with high knowledge, high value-added, non-routine and non-standardised activities have actually increased over recent years. This is because of the increasing importance of timeliness, speed, variety, customisation, and service-quality, in all high knowledge intensive forms of production and service delivery.

Not all trade travels by the cheapest mode (p6):

- There is large movement by truck where freight charges are higher than rail and sea.

Time in transit is also costly (p6):

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[49] https://en.wikipedia.org/wiki/Golden_Quadrilateral

[50] Source: AT 2011 Transportations Assessment of forest routes for Makarau and Puhoi. Accessed from https://at.govt.nz/about-us/reports-publications/other-at-reports/

- For example, a five-day rail shipment of US$200,000 electrical products costing US$700 freight charge would also tie up capital for five days at, say, US$130 interest or 18% of the freight charge; this percentage will be 15 times higher for computer equipment but 0.1 times lower for general manufactures.
- The 17-country 2005–2009 average round commute trip of 40 minutes would equate to 7.5% of a 40-hour week plus commute time, or 3.5% if commute time is value at half the average wage, as is typically assumed.
- A reported 26-country average household travel time of 73 minutes/day equates to 8% of labour value if weighted at half the average wage, or 2.4-4.8% of GDP if these calculations were applied to the US.

A2 Urban form

It is widely acknowledged that productivity within cities is generally higher than elsewhere and this productivity can result from urbanisation (higher density and variety in general) and localisation (higher co-location of firms within an industry). The dynamic nature of the agglomeration effect is highlighted by Duranton (2015) when referring to the 'process of creative destruction in cities'. Information is important, with Crescenzi and Gagliardi (2015) describing cities as centres of knowledge generation and absorption. Champion et al (2013) refer to cities as human-capital escalators.

Desmet and Henderson (2015) provide the following stylised facts about cities. Detail not drawn from this report has been explicitly referenced.

The world is moving towards more urbanisation:

- Cities have been growing in population size, the median worldwide city doubling between 1960 and 2000 (Henderson and Wang 2007).
- Between 1950 and 2009 the world's urban population moved from under 30% to over 50% of total population.
- McCann (2009): 'there is overwhelming evidence that economic growth and globalisation over the last two decades has favoured larger urban centres in almost every country (Brakman and van Marrewijk 2008; World Bank 2009b). Over recent decades, cities dominated by a diverse range of knowledge-sectors have tended to perform better than cities that are highly specialized (Glaeser et al 1992; Combes 2000) and cities with a highly diversified range of knowledge-sectors also tend to be bigger than the highly specialised cities (Henderson and Thisse 2004)'.

Explanations for continued city growth centre on one or both of two effects relating to the scale economies–diseconomies trade-off:

- Scale economies are increasing, due to growth of human capital.
- Scale diseconomies are dissipating, due to technological progress such as transit systems, cars and highways and/or due to improved management of the urban environment.
- McCann (2009): 'The evidence therefore suggests that there are major advantages associated with industrial clustering and agglomeration for high knowledge-intensive and high value-added activities, and that the geographical concentration of these types of activities is becoming ever more important'.
- McCann (2009): 'The world's most productive cities (OECD 2006) are also the world's most globally connected cities in terms of the scale and variety of their corporate and transport networks (McCann 2008; 2009a; McCann and Acs 2009). As such, the cities that perform the best in the current era of

globalisation are those cities that are located in an area of increasing economic integration and that are also highly globally connected'.

City size distributions tend to be stable over time and ranking of cities within a country also tends to be stable.

- There is Zipf's Law often quoted that, when applied to cities, holds that a city's size is exponentially related to its rank within the country, eg 4th rank city will have approximately 25% of the largest city population, although this is not universal.
- Henderson and Wang (2007) show a similar relationship of world city size distribution in 1960 and 2000, eg the group of cities that were, say, twice as large as the average-sized city had a similar proportion of people in both 1960 and 2000 (although this need not be the same cities in each year).
- Eaton and Eckstein (1997) show ranking of French and Japanese cities by size has been remarkably stable over 100 years.
- Reasons for persistent large cities include durable capital (Henderson and Venables 2009) and/or embedded information (Rauch 1993).

Within stable rankings, there are different relationships between population growth rates and population levels.

- US population growth rates 1990–2000 were highest (15%/decade) amongst areas with population density of 100-500 people per square km, averaging 5–6% elsewhere (Holmes and Lee 2010).
- Dobbs et al (2011) predict 577 cities with populations of between 150,000 and 10 million will contribute more than half of global growth to 2025, gaining share from today's megacities.

Migrants (domestic and international) are generally skilled and might move to large cities with the speculative aim of higher income whereas migrants to second-order cities tend to go to specific jobs.

- Champion et al (2013) infers from a study into UK second-order cities that people move to these cities only after securing a job (see in section 2.4.2 of this report the low people inflow from abroad to Hamilton and Tauranga relative to Auckland).
- Overman and Bosquet (2015) find 52% of British workers without formal qualifications work where they were born but only 31% of workers with degrees have stayed put.

In spite of persistent size rankings, cities experience significant industry and functional churn.

- Duranton (2007) shows employment shares changing for industries within US and French cities between 1977 and 1997.
- Henderson (2015) reports that 'over 1963–92, the dominant U.S. cities in computers, aircraft, instruments, and electronic components all changed'.
- Duranton and Puga (2005) show US cities below 250,000 have more industry specialisation than larger cities, as measured by the Krugman Gini coefficient, implying a diversification as population increases.

The development path of a city can vary.

- Many cities, such as Liverpool, expanded rapidly due to industrialisation.
- However this type of industrial-led urbanisation can be delayed in an open economy with high agricultural productivity (Matsuyama 1992).
- It can be influenced by comparative advantage.

- However countries, such as those within Africa in recent years, may urbanise without strong industrialisation.

Industry tends to go through a cycle of specialisation and concentration near the innovation centre to dispersion to outer suburbs and then hinterlands (Henderson 2015).

- Korean cities showed increasing specialisation from 1983 to 1993.
- Likewise Chinese cities 1995–2008.
- Manufacturing employment in Seoul as a proportion of manufacturing in its surrounding region Kyongghi declined from 76% in 1970, to 45% in 1983 and to 30% in 1993, indicative of industry moving to nearby areas.
- Manufacturing employment in the hinterlands of South Korea as a proportion of national manufacturing employment increased from 26% in 1983 to 42% in 1993, indicative of the second-stage shift from the three main metropolitan areas Seoul, Pusan and Taegu.
- Desmet and Fafchamps (2005) show, for US counties 1970–2000, that having 1% more manufacturing employment in the county lowered employment growth by 2% pa but raised the growth rate of manufacturing employment 40-50 kms away by 0.1-0.2% pa.

Larger cities are more productive.

- McCann (2009): ‘all of the world’s most productive cities are at least twice the size of Auckland, and most are between three and five times the size of Auckland (OECD 2006)’.

Larger cities enable functional specialisation.

- Duranton and Puga (2005) find larger US cities have moved since 1950 towards management as opposed to production activities while smaller cities have done the opposite. US cities with more than 1.5 million people average more management workers than production workers, whereas production workers increasingly outnumber management workers for smaller cities.
- Fafchamps and Shilpi (2005) show that people nearby a growing urban population narrow the skills they use each day, ie they become more specialised.
- Lovely et al (2002) find when export related information is difficult to obtain, exporter headquarter activity is more highly agglomerated relative to headquarter activity in the domestic-only sector of the same industry. These findings support the idea that the need to acquire information contributes to agglomeration.
- See Davis and Dingel (2013) for US skill intensity and employment-to-population elasticities graphs that show ‘bigger cities are specialized more in higher skill occupations and functions’ and ‘skill intensity also rises with city size’.
- Rosewell and Venables (2013) cite ‘Rauch et al (2013) use highly disaggregated occupational descriptions (12,000 occupations) to establish the fact that US metro areas have become increasingly specialised in interactive tasks’.

The productivity enhancement of agglomeration works through several channels.

- Ciccone and Hall (1996) point to higher final goods production resulting from the availability of a greater variety of intermediate inputs.
- McCann (2009) points to several channels: ‘Agglomeration increases competition via the increased mutual transparency and visibility associated with geographical proximity (Porter 1990). In some cases

it also facilitates the networking and coordination between firms (McCann 2003). Agglomeration provides a nursery role for new enterprises (Duranton and Puga 2001) and agglomeration also reduces risks by improving labour market matching processes. However, the major advantage of agglomeration in the modern world is widely regarded as being about maximising the efficiency and effectiveness of knowledge exchanges (Glaeser 2008) in the production processes of high value-added goods and services in a diverse economic environment (OECD 2006). This is quite different in nature to previous eras when industrial agglomeration in cities was primarily associated with the minimisation of transport costs within highly specialised centres (Glaeser and Kohlhase 2004)'.

- Similar discussions are provided by Brulhart and Sbergami (2009), Glaeser (2010) and the World Bank (2009a).
- Pan et al (2012) points to the role of information flows, showing a model built on information flows rather than relying on specialisation can describe city characteristics such as productivity and innovation, as well as crime and HIV or STDs.
- This model builds on the social networks research of Helsley and Zenou (2014).
- Jackson et al (2015) show higher densities can also lead to contagion effects.

Agglomeration effects reduce sharply with distance.

- Research into agglomeration has also shown the productivity effect can attenuate after 1–10 miles away from concentrations of an industry (Rosenthal and Strange 2003) and some work goes further and suggests that effects may attenuate as the distance between related industries increases (Ellison and Glaeser 1997).
- Rosenthal and Strange (2001) find different geographic scope for different types of agglomeration effects, eg knowledge spillovers tended to be local while labour impacts were more widely experienced.
- Duranton and Overman (2005) find geographic localisation to take place at scale of less than 50km.
- Graham et al (2010) detail how the agglomeration effect attenuates with distance. These results and the implications on an employment measure of effective density are shown in table C.1, with the decay parameters equal, in order as tabled, to the estimates found in the meta study, typically used by Graham and others, and estimates in the 2010 study for the UK manufacturing, construction, combined total, business services and consumer services sectors. Further notes from Graham et al (2010):
  - Suggest theory does not reveal much about the function form of any decay in agglomeration effects by distance (due in part to transport costs) but assumptions can be tested empirically.
  - They do this for the UK and show agglomeration density do attenuate with distance, varying by industry.
  - Mass=$\sum \text{distance}^{-\alpha}$ x employ (note the EEM uses generalised cost to effectively calculate the distance decay).
  - For example, overall UK total industry agglomeration elasticity of 0.044 (ie 10% more mass of people in an area leads to 0.44% higher revenue total factor productivity), with a decay parameter of 1.66 (see appendix C for the effect of the decay parameter on measures of effective density using the parameters found by Graham for four UK industries).

  - Decay tested using measures of effective density at different distances away (2.5, 5, 10, 25, 50, 75km) from a centroid (noting that the inverse density weighting formula is widely used but is ad hoc).
  - Refers to empirical testing using discrete choice random utility models:
    - Meta study of gravity models by Disdier and Head (2008) find average elasticity of trade with respect to distance is -0.9 (ie decrease distance by 1 distance unit and trade will increase by 9%), near to the -1 decay parameter generally assumed by Graham. Similar results for intra-national results are found in the US and Canada.
    - Johanssen et al (2003) show commuting is most sensitive to time for intermediate commutes (within region), as opposed to within municipalities or between regions.
    - Interestingly, distance also appears to affect web site use, Blum and Goldfarb (2006) showing an inverse relationship between sites visited and distance from sites (even when no purchase is involved).
- And also use of kernel regression analysis where a distance decay function is used to reduce spatially continuous variables to a discrete measurement that best fits the data of study. Various studies suggest a best-fit near the -1 decay parameter above.

It is widely believed – and built into many transport appraisals[51] – that agglomeration effects can be created by lowering transport costs and/or times, effectively extending the accessible density of people and businesses available to any one person or business.

The reduced travel time might lead to (a) more commuting (b) more meeting of people, both by chance and appointment and/or (c) more freight movement, all combining to lead to higher productivity. Some of these effects may be due to scale effects resulting from access to larger markets (for any given level of delivery costs and/or time) and some may eventuate simply from more efficient use of inputs, including intermediate goods. Effects may or may not result from subsequent re-location within the urban area. In other words, there are multiple dynamics working to re-inforce a more efficient production system but effects can vary by industry and location.

A3 Transportation and intra-urban activity

Transportation has been one influence that shapes cities. The agglomeration effect can be enhanced within a city, both via urbanisation and localisation effects. The urbanisation effect does not extend to inter-city but localisation effects can, a point to be elaborated further in the next section.

Meanwhile Redding and Turner (2015) provide the following stylised facts about transportation and cities. Detail not drawn from this report has been explicitly referenced.

Transport changes have led to more activity in locations where the transport is located and, furthermore, establish a growth pathway that can extend over many decades.

- In New Zealand and Australia almost all the major cities are on ports which provide the connectivity between foreign and domestic markets or within the domestic economy, while there is the growth of railway based towns, particularly in the US (eg Chicago) which provided the connections between the producing areas in the Midwest and markets to the east.

[51] Note, the EEM approach concentrates on inter-industry linkages. However, it may be that agglomeration is also related to access to the potential workforce, providing opportunities for matching skills to opportunities etc.

- Duranton and Turner (2012) show 10% more interstate kilometres in 1983 implied 1.5% more population in 2004, sufficient effect to explain around two-thirds of variation in population growth observed over this period, ie the metropolitan statistical areas that had above average interstate highway length in 1983 were generally those with higher population growth in the next 21 years.
- Berger and Enflo (2013) infer Swedish railroads established in the 19th century are responsible for a path dependency that has cities connected to the network 62% larger today than similar cities at the time.
- Desmet and Rossi-Hansberg (2013), using a CGE model, show the difference in US city sizes can be explained by a model based on city differences in (a) productivity (b) amenities and (c) congestion costs, with the later dependent on transport infrastructure. Hence transportation enters as a key determinant of city size. They also note, though, the welfare gains from a larger population are relatively modest.
- The post war growth of Frankfurt as the major German airport, even though Berlin airport had been larger pre-war, is suggestive that industry location is not uniquely determined by fundamentals and that transportation infrastructure does matter (Redding et al 2011). However, Davis and Weinstein (2002) provide contrary evidence, showing that Japanese cities re-populated quickly after World War II, implying a fundamental role for city and industry location, beyond any transportation infrastructure.
- Haines and Margo (2008) find rail access to a US county during 1850–1860 raised the share of improved acreage and improved farm wages but reduced farm employment.
- Banerjee et al (2012) find Chinese counties closer to a hypothetical line that approximates new road and rail infrastructure had a higher level of GDP per capita but no difference in GDP per capita growth during 1986–2006. Although Redding and Turner (2015) point to other studies showing that amongst rural Chinese counties it was those closest to a new trunk highway that had lower GDP. This is the opposite of the general result that proximity to transport enhances GDP.
- Ghani et al (2013a, 2013b) find higher productivity and increased new entry amongst large manufacturers in districts within 10km of the Indian Golden Quadrilateral highway, which are not present in districts 10–50km away and not present near other existing highways. Furthermore, the relocation included land-intensive manufacturers moving away from the larger cities. In an earlier study, Datta (2011) also found that initial responses included firms near the highway, excluding those firms in the four nodal cities, reduced their inventories and those nearer the highway were more likely to have switched suppliers.
- Gibbons et al (2012) show employment has increased within wards and firms near recent UK transport improvements between 1997 and 2008. They concluded, ‘we find strong effects from transport improvements on area employment and plant counts. A 10% improvement in accessibility leads to about a 3% increase in the number of businesses and employment, up to 30km from the site of the improvement. The estimates range between zero and 10% according to sector and specification. The employment increases appear to come about through firm entry, rather than increases in the size of existing firms. We do, however, find evidence for increases in labour productivity, output and wages amongst existing firms, although these are not so evident at area level’.

The adjacency effect of transportation also shows in land prices and rents.

- Donaldson and Hornbeck (2013) find US agricultural land rent rose 34% relative to other counties in the same state in the year after rail was provided during 1870–1890.

- Bogart (2009) show UK land rent increases between 1692 and 1798 due to access to turnpikes (ie improved roads with tolls).

Inter-city transportation can lead to decentralisation within cities.

- Baum-Snow (2007) finds central city share of population decreased more between 1950 and 1990 for those US metropolitan areas with more access to interstate highway system.
- Baum-Snow (2015) shows likewise for US highways and cities between 1960 and 2000, with each radial highway displacing 16% of central city working age population but only 6% of central city jobs to the suburbs.[52]
- Baum-Snow et al (2015) find a similar effect in China between 1990 and 2012 but the roading effect was restricted to the number of radials emanating from central cities, with no effect on central population of other transport measures such as kilometres of highways, kilometres of rail, ring road capacity, rail capacity (although some transport measures are linked to some shifting of low weight-to-value manufacturing industries away from the centre).

More highways lead to a re-organisation of industry.

- Duranton et al (2014) show more within-city highway lane kilometres increases the weight of exports (domestic and international, in 2007) but not their value. They infer that highways within cities cause them to specialise in sectors that have high weight to value ratios. This result was not supported in a 2014 Columbian study.

A special case of transportation infrastructure to which we will return in more detail is airports. For now, it is simply noted that airports can lead to specialisation but not necessarily employment growth.

- Sheard (2014) finds US airport size affects employment share of tradeable sector but not overall city employment.

A4 Transportation and the wider economy

While transportation improvements can affect the size, shape and activities of a city, it is also of interest to know the interaction between cities after a transport improvement, whether the improvement is targeted solely at one city or at the linkage between cities. In particular, one challenge to appraisal of transport effects is to determine what changes are simply a re-location of activity and what represents growth in activity, output and ultimately welfare. The above studies already allude to winners and losers from any transport investment. This becomes more obvious when changes beyond one urban boundary are considered, as below.

Bringing centres closer in terms of travel time is likely to increase trade.

- Duranton et al (2014) show a 1% decrease in travel distance corresponds to 1.4% more trade, and an even higher 1.9% increase in weight traded, between 66 US cities in 2007, and infer that reducing pairwise distance by way of highway improvements would have large effects on trade.

Increased trade is likely to increase GDP, with ports potentially providing a significant contribution via any reduction in trade costs.

- Storeygard (2013) used the number of lights visible at night by satellite as a proxy for GDP in 287 sub-Saharan Africa small cities (15 countries) and found that an oil price increase of the magnitude of

[52] These finding may not generalise well given cultural issues in US during this period.

2002–2008 ($25 to $97) induces a 6% income decline amongst cities 465km farther away from port relative to an otherwise identical city.

- Barca et al (2012) states that many highly productive cities in the EU are small to medium-sized cities (around 3 million people) whose dominant competitive advantage is they exhibit high degrees of connectivity.
- These results are consistent with research by Head and Mayer (2011) who showed that market potential can be a powerful driver of increases in national income per capita, where 'market potential' was measured as the share of global expenditure of other countries weighted by a factor that included distance. Thus a country can experience an income increase due to growth in neighbouring countries and/or reduced trade costs between itself and other countries.

Some studies show that increasing transportation within one city does not necessarily affect activity in adjacent cities.

- Duranton and Turner (2012) found no roading effect on employment in US metropolitan areas 150–500km away from the interstate highway stock of a neighbouring area, leading them to conclude interstate roading improvements in one area largely affected driving within that area.
- Henderson (2003) finds that plant productivity is affected by employment activity in a plant's own county but not in neighbouring counties.

Other studies imply or measure a displacement of activity between cities.

- The studies mentioned in the previous section (eg Duranton and Turner (2012); Berger and Enflo (2013)) that show higher population growth adjacent to transportation links also show, by implication, population growth slower away from transportation links.
- A more direct measure of displacement is the Chandra and Thompson (2000) study that shows 1969–1993 earnings were 6–8% higher amongst 185 non-metropolitan US counties that received a highway during this period (mainly in finance/insurance/real estate, transport/utilities and retail/services) and 1–3% lower amongst those 391 neighbouring counties that did not receive a highway.
- Moreno and Lopez-Bazo (2007) find negative spill-overs across Spanish regions of transport capital investments.
- Faini, Giannini and Galli (1993) show the transport investment causes rising regional gaps in Italy.

One reason for differing results may be the spatial effect of transport improvements can in theory follow a U-shape pattern. A model suggested by Krugman and Venables (1995) shows with the existence of increasing returns to scale any continuous reduction in transport can reach a threshold whereby the core regions gain due to increasing returns to scale and agglomeration while income in the periphery regions decline, but later the spatial bias shifts to the periphery nations as widening production costs, including possibly congestion, attracts activity back to the periphery.

Whatever the spatial re-location, there is also the issue as to whether society is better or worse for these changes. To determine this requires knowing what the counterfactual would have been without the initial transport investment of study. Included within this net benefit or loss will be a net benefit arising from people re-organising in response to the transport investment – a net benefit presumably because people have freely chosen to re-organise once the transport infrastructure was in place. Measurement of the gains and loss from re-organisation or the overall benefit or loss from the investment have been attempted but the results are by no means definitive.

Studies using CGE models have found transportation to be welfare-enhancing in a cross section of situations, as listed below.

- Allen and Arkolakis (2014) explore the interaction between trade and topography in the make-up of the 3,109 US counties, and infer that removal of the US interstate highway system would decrease US welfare by an estimated 1.1–1.4%. In other words, the welfare gains of the interstate highway system are positive, and exceed the cost of construction (Redding and Turner 2015).
- Donaldson (2010) finds districts in India with access to rail experienced 17% higher agricultural crop real income growth 1870–1930, relative to districts without rail access. Importantly, Donaldson found non-rail districts to have no prior productivity disadvantage so were comfortable inferring a net welfare gain. A key inference from this model and data analysis was that real incomes were increased due to decreased trade costs and increased trade.
- Studies of 2001–2012 (95% completed by 2006) upgrade/expansion of the Indian 'Golden Quadrilateral' highway reveal significant positive effects. Asturias et al (2015) find real income gains but heterogeneous effects.

But more transport is not always better.

- The above-mentioned Chandra and Thompson (2000) study could not reject the hypothesis that aggregate changes in earnings caused by the US highway connection sum to zero across the whole sample of treated and neighbouring counties
- Duranton and Turner (2012), having found a large difference in roading investment prior to 1983 did play a huge role in shaping the relative growth rate of cities thereafter, find a small change (+4.8%) in roading investment in 1983 would not, in general, have been value adding over the next 20 years, ie the net present value would have been negative.

The following sub-sections consider more closely connectivity as it relates to sea and air ports.

A4.1 Sea ports

Distance to market is a key factor with marine freight. Guillemette (2009) reports 'that a 10% increase in distance reduces trade by around 10%, and that this effect has not diminished over the last 30 years', citing Nicoletti and Scarpetta (2003) and OECD (2008b).

The NZ Productivity Commission (2012) cites research that estimates Australia and New Zealand experience a decrease of about 12% GDP per capita relative to the OECD average as a result of distance to market, as opposed to countries like Belgium and The Netherlands that experience a 6% relative gain[53].

Limao and Venables (2001) show onshore costs can also add significantly to the total cost of shipping. In a regression analysis of shipping costs for a 40-foot container from Baltimore to 64 countries, including 29 that were landlocked, own-infrastructure (ie local roads and rail) explained 40% of transport costs for the coastal countries and 60% for the land-locked countries. Note this is not a breakdown of actual costs but a measure of underlying influence.

Importantly, they infer a 10% increase in transport costs reduces trade volumes by approximately 20%.

Further reported:

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[53] They also report a large number of trucking companies operate in New Zealand, with many small regional operators and owner drivers but the largest 2% of operators operate 32% of all vehicles.

- They regress 1990 transport costs of a 40-foot container from Baltimore to 64 countries against infrastructure of each country (average values 1990–95), the infrastructure of the transit country for landlocked countries and distance variables.
- Infrastructure was measured by an index constructed from kilometres of road, kilometres of paved road, kilometres of rail (each per square kilometre of country area), and telephone main lines per person.
- The average transport cost in non-landlocked countries (35 in sample, excluding New Zealand) was found to be US$4,620 and an extra US$3,450 for landlocked countries (29 countries).
- An extra 1,000km by sea adds $190, whereas a similar increase in land distance adds $1,380.
- Own infrastructure explains 40% of predicted transport cost amongst coastal economies; and 36% for landlocked with a further 24% due to transit country infrastructure.
- Also regressed was the cost, insurance and freight component of imported goods against a similar set of variables as above for 103 countries (including New Zealand).
- Distance explained only a relatively small part of the variation in transport costs.
- Moving local infrastructure from the level of the median (Pakistan) to the 25th percentile (US) would be equivalent to 2,358 reduction in distance (cf median distance between countries in 103 countries was 7,555 km; New Zealand was ranked 33rd percentile, Australia 65th).
- Also regressed were import volumes against a similar set of variables as above.
- Combining models, one inference is that a 10% increase in transport costs reduces trade volumes by approximately 20%.

As further evidence of the importance of onshore activities in shipping costs, Shepherd et al (2011) estimate improving multimodal connectivity by 5% would increase APEC exports by 4%. Other results noted:

- The logistics services performance generally has the strongest effect on trade.
- Each day saved is equivalent to a 0.4–1.5% average ad valorem tariff reduction.
- 'The economy-wide impact of improved multimodal connectivity will mostly be realized in the medium to long-run'.
- Their inference results from regressing exports against measures of connectivity including the LSCI (see section 2.3.3 of this report for definition).

Ferrari et al (2011) warn that hinterlands of ports are dynamic, changing as a result of factors such as economic cycles and technological breakthroughs, and a traditional 'distance-decay' perspective does not fit well with the wider use of inland ports today. They show the ability of Italian ports to access various areas affected by competition amongst Italian and other European ports.

Pallis et al (2011) and Ng et al (2014) provide an extensive overview of port papers.

There is a strand of research looking into how ports shape cities and regions. Fujita and Mori (1996) point to cities that started as major ports but continue to grow today in spite of the now minor role of the port. They suggest this is consistent with NEG concepts of endogeneity, agglomeration, increasing returns to scale and transport costs. They tentatively conclude a decentralised industry may be a better organisation but a temporary protection by worsening the transport connection in the core may be required to achieve such an outcome.

In US, connectivity to ports has been included in economic evaluation, with justification due to papers cited such as Shepherd (2011), as mentioned above, and Targa et al (2005) and Berrittella (2010).

- Targa et al (2005) showed positive correlation in 2000 between the number of firms within zip code areas of four counties in Maryland (generally between Baltimore and Washington) and travel times (minutes) to one airport (Dulles). However, the correlation proved negative for two other airports. Also some intermodal terminal facilities were near some of these airports, so some confounding of effects existed. A positive correlation was also found between firm numbers and variables such as miles of roads and number of train transit stations, both expressed per zip code area. In general terms, the study was interpreted as confirmation that business activity was positively associated with transport access but that road, rail and intermodal facilities are complementary (EDR 2013).
- Berrittella (2010) showed in a multi-country study that European regions benefited from investment in intermodal infrastructure, with both imports and GDP increasing.

Reference is also made in Appalachian Regional Commission (2008) to 'Empirical research has established functional relationships between access to international gateways (as measured by driving time) and the total amount of shipments to overseas locations on a port-specific basis'. This research is not explicitly referenced. This line of research has led to the use of a connectivity score for each port to be used in evaluation of transport investments.

A4.2 Air ports

Airports are by their very nature typically located away from city centres and there is often pressure for them to relocate to an even greater distance. This may prevent them from forming useful parts of the economic structure of the city (which tend to be focused round city centre rather than peripheral locations) other than from the activities directly related to them (eg freight and logistics), or from activities which are insensitive to the effects of noise etc associated with airport development.

NERA (2010) notes the following.

1. Distance matters. Virtually all gravity models, for all time periods and for all countries find bilateral trade flows fall as distance increases.
2. Distance matters even for digitally traded goods such as music, games and pornography (Blum and Goldfarb 2006) – for matters to do with information and familiarity.
3. Distance matters more than it used to. In a study of over 100 papers on the subject, Disdier and Head (2008) conclude that the negative impact of distance on trade rose in the middle of the 20th century and has remained persistently high since then. Berthelon and Freund (2008) conclude that this trend has continued, with the elasticity of trade value to distance increasing (in absolute value) by 10% since the mid-1980s.

See McCann and Acs (2011, pp26–27) for a discussion of global connectedness and airports.

Airports may become the city of the future, although this is only one factor that must be weighed against visits also to schools, work and beaches. Kasarda and Lindsay (2011) note the growth of airport cities such as Memphis, Atlanta, Dallas-Fort Worth (all US), Chek Lap Kok (Hong Kong), Dubai, Amsterdam Zuidas, Ekurhuleni (Johannesburg), Songdo (South Korea) and Shuangliu (China). Although Mukkala and Tervo (2013) find in a European study of peripheral regions that the causality arrow went from air traffic to economic development, but the causality direction was the other way around in core cities.

Appendix B: Previous research concerning the case study area

The following sections summarise previous studies that may be of relevance to the AHT case study area.

B1 Upper North Island Strategic Alliance (UNISA) reports and research

Report	Key points
Report to UNISA chief executives. *Opportunities for transport.* September 2011	Strategic opportunities: • Balancing urban and rural economies • Importance of movements within Auckland to wider regions • Understanding role and linkages of ports • Rationalising freight hubs • Align planning
Report to UNISA chief executives. *The value of UNISA to tourism.*	Noted: • Importance of gateways, particularly Auckland International Airport • Support from nine regional tourism organisations in Upper North Island • Collaboration underway already • Different markets exist and work against a common approach • Advantage of air linkages Auckland–Hamilton–Rotorua
Report to UNISA mayors/chairs. *Opportunities to grow the Upper North Island economy.*	Strategic opportunities: • Joint championing of Upper North Island framework • Apply LGNZ/MBIE core cities methodology • Improve interconnection and innovation • Priority sectors Auckland: marine, tourism, food and beverage, high tech, creative, finance, tertiary education. • Priority sectors Waikato: aquaculture, tourism, food production, forestry, bio-packaging, renewable energy. • Priority sectors Hamilton: tourism, ag-bio, agri-tech, dairy research, metals and plastics, creative, tertiary education. • Priority Taupo/Bay of Plenty: marine, shipping, aquaculture, tourism, agriculture, forestry
UNISA report: Port networks Meeting: 8 October 2011.	Recommendations: • Seek agreement on way forward • Engage with the Transport Agency
Bay of Plenty freight logistics strategy 2011	8 actions: • Form Logistics Action Group • Business share and work to find logistics efficiencies

	• Advocate • Ensure health and safety hand in hand with profit • Achieve infrastructure efficiencies and advocate for more • Enable technology • Improve global access and logistic to point that attracts investment • Develop workforce and promote Bay of Plenty as place to be
Bay of Plenty transport futures study. Report to Bay of Plenty Regional Council. November 2010.	Forecast/noted: • Strong commuting growth in Bay of Plenty that 'no amount of investment in road infrastructure could accommodate' • Do minimum not an option • Recommend support efficient freight routes and see opportunity to reduce road freight near Port of Tauranga
How can we meet increasing demand for ports in the Upper North Island? PwC report to UNISA. November 2012.	Noted: • New Zealand appears to be moving to a hub and spoke ports model • Napier to Singapore container freight cost = $1,520 shipping line + $407 Ports of Auckland Ltd (POAL) + $1,529 road to POAL = $3,456, ie inland costs are a high share • Inland ports can reduce rail costs (due to consolidation) • A Ruakura inland port will reinforce Port of Tauranga competitive pressure • Inland ports can be slow to reach capacity • Strong growth in next 30 years but planned developments will provide significant capacity • Discusses options for individual port changes
Upper North Island freight story April 2013	Critical issues: • Strategic road and rail constraints • Delivery of high performance motor vehicle • Utilisation of industrial land • Lack of integrated land use and transport planning • Lack of shared/accurate data • Understand freight supply chain issues for key industries so that they can be reduced • Expand current funding structures

B2 Growth studies

Bay of Plenty growth study 2015:

1. Economic development in the region is being built off a strong platform of collaboration between industry, research and tertiary organisations, Māori/iwi/hapū, and local and central government. Need to jointly commit resources to implement current strategies and proposals.

2 Effective management of water is important.

3 Māori engagement is critical to the region's economic performance.

4 The availability of skilled labour is a constraint on realising industry opportunities because of the changing skills needs of the region's key industries and its ageing population.

5 BOP requires a stronger tertiary education sector presence to provide a broader range of programmes that support fast-growing sectors and to strengthen research linkages with industry.

Bay of Connections economic action plan (2015) focuses on:

- Expand awareness of alternative land use and investment opportunities in agriculture-business
- Fish farming including trout
- Enhance tertiary education
- Improve market access for processed wood products, including more FDI
- Identify and prioritise 10 geothermal-symbiotic industries
- Generally build use of Māori land, including increased horticulture
- Strong tourism growth, especially in Rotorua, Taupo, Tauranga
- Improve water management.

MartinJenkins (2013) on connectivity and infrastructure in *Waikato economic development strategy*:

- 'Proximity to Auckland International Airport provides good access to international air connections, although businesses have indicated that a lack of international connections directly from Waikato can be a constraint on activity. The region has a natural reliance on the Ports of Tauranga and Auckland for exports and imports and there are good transport links to these cities.'
- Major export industries: Dairy product manufacturing; metal and metal product manufacturing; forestry and logging; horticulture and gas supply.
- Highest rates of export growth over 2007–2011: forestry and logging; structural, sheet and fabricated metal product manufacturing; horticulture; basic metal manufacturing and gas supply.
- FDI projects into the region during the 2000s appears to have been relatively low, possibly due to distance to market and investor perceptions of potential constraints.
- By 2031 Waikato is expected to receive more freight than any other region in New Zealand.
- Currently only little commuting between Waikato districts for work or between the region and other regions.
- Has been high residential investments in Thames-Coromandel, and proportionately more non-residential investment in Hamilton.

McIlrath (2013) in the Market Economics report on Waikato growth goals:

- Labour constraints are a very real issue
- Attaining GDP/capita growth around the 2.5% mark is a stretch; it is achievable but will require increases in exports, investment and productivity.

Waikato Economic Strategy Governance Group (2014):

- Major objectives:

- Leverage value from our location and connections as the key servicing hub of the North Island
- Provide a quality education offering which encourages high levels of participation and lifelong learning
- Be New Zealand's premier engineering and primary processing hub
- Be known for excellence in sustainable food production, agri-research and agri-business

- Flagship initiatives:
  - Maintaining and building location advantage, including Auckland/Tauranga connections
  - Growing global industries, especially around primary production, aquaculture, energy and building off Maori and research base
  - Making business easier, including through collaboration
  - Building, attracting and retaining skills and talent
  - Telling the Waikato story.

B3 Ad hoc papers

Gooderham et al (2014):

- Can expect to see high Auckland land prices pushing out unwanted land-uses into the regions
- Changes hard to predict
- Cross boundary issues such as water and transportation
- Land use in vicinity of a metro area will be dynamic
- Most change likely within commuter distance
- Importance in determining change of political environment, technological improvements, environmental change and social perceptions.

McDonald and Smith (2012) New Zealand freight flows model

- Derives 2007–31 projections of tonnes of 13 commodities passing 130 road monitoring points in the Upper North Island plus those travelling through Upper North Island rail corridors.

Ministry of Transport (2014) National freight demand study

This study estimates freight flows deterministically rather than being based on any particular theoretical model, so it does not offer much by way of guidance for modelling connectivity. However, it does provide a rich source of data on inter-regional movement by freight type.

Freight within the region in 2012 was an estimated 99 million tonnes, of which 16m tonnes were transported between the three regions, including large amounts of other manufactures and aggregates (see figure B.3). 4.3m and 1.9m tonnes were moved to Auckland from Waikato and Bay of Plenty respectively. 2.4m and 2.9m were moved from each to Auckland. Movement was net positive from Waikato to Bay of Plenty (2.9m out versus 1.8m tonnes in). 29% of inter-region freight movement was by rail, the rest by road.

Table B.1 Total Upper North Island freight movements 2012 (millions tonnes)

	Northland	Auckland	Waikato	Bay of Plenty	Gisborne	Total (incl other)
Northland	12.0	1.9	0.1	0.9	0.0	16.9
Auckland	0.9	38.3	2.4	2.9	0.1	49.4
Waikato	0.1	4.3	23.8	3.1	0.0	32.1
BOP	0.2	1.9	1.8	20.2	0.1	25.0
Gisborne	0.0	0.1	0.1	0.2	3.2	3.8
Total (incl other)	13.3	48.8	29.0	28.8	4.1	236.0

Source: MoT (2014)

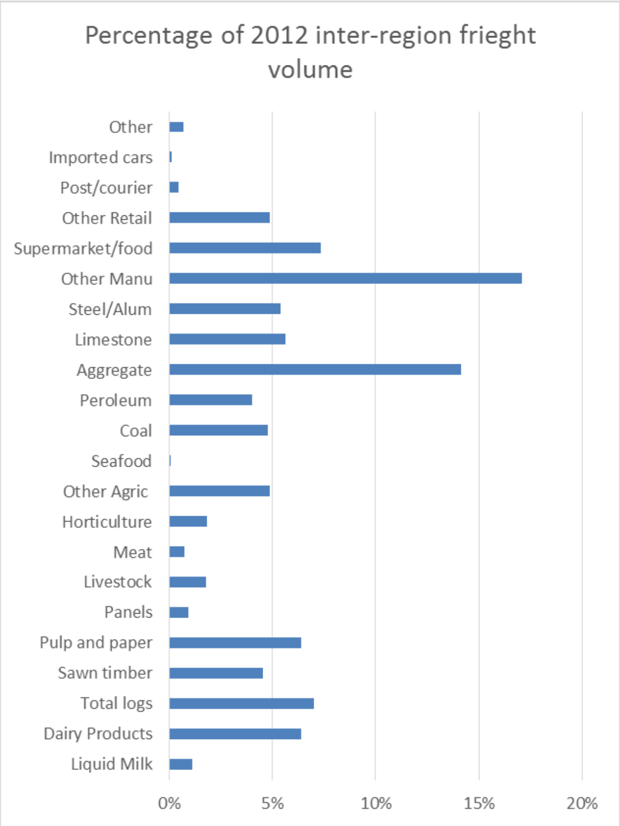


Figure B.1 Industry share of 2012 inter- region freight volume within the case study area

Figures for the national freight patterns are shown in the next two figures.

Figure B.2 Total road freight flows 2012

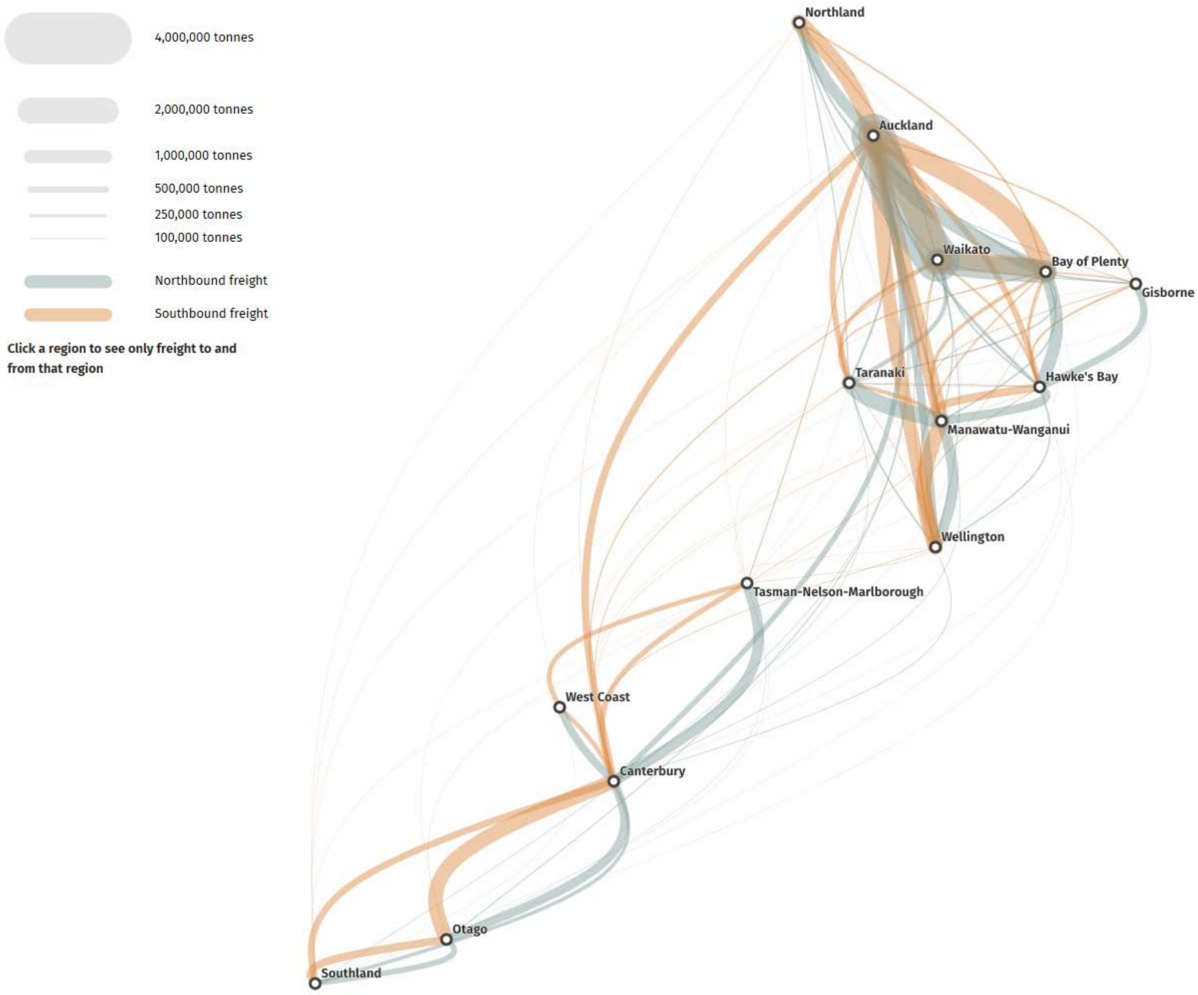
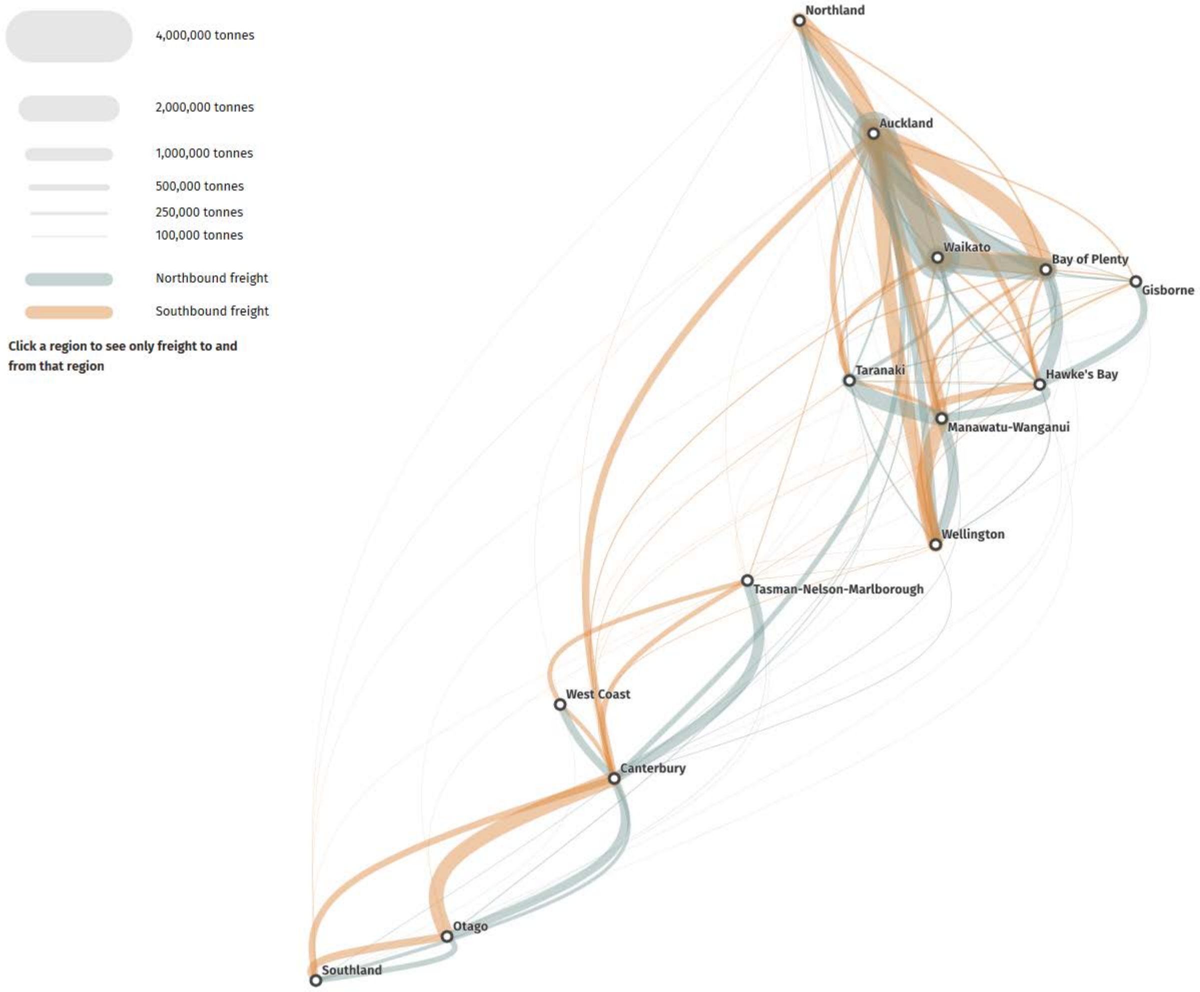


Figure B.3 Total rail freight flows 2012



B4 New Zealand urban research

Covec (2008) summarises NZ agglomeration research.

- Lewis and Stillman (2005) find Auckland and Wellington have the highest levels of productivity in New Zealand.
- Maré (2008) estimates productivity per worker to be 30–50% above the New Zealand average in the Auckland region, with the CBD 120–150% above the national average. In discussing this work, Chen (2012) notes the similarity to London's premium of 41% and the inner London premium of 152%.
- Maré and Timmins (2006) find localisation was the major source of agglomeration effects in Auckland during 1987–2003, with productivity associated with firms that exported, were large and/or had market power.

Grimes et al (2014) research within MBIE's Resilient Urban Futures programme.

- Developed a revealed preference model, including utility affected by consumption of unpriced amenities that attenuates with distance from the core location, and tested on population growth for 56 New Zealand towns 1926–2006.
- Records New Zealand's 10 fastest- and slowest-growing towns 1926–2006. Includes one (Waihi) from Waikato/Bay of Plenty amongst the slowest and eight amongst fastest from Auckland/Waikato/Bay of Plenty (the other two being Whangarei and Levin).
- Also notes collinearity between population levels and variables such as distance to seaport and presence of universities and airports, and hence drops these variables from their model.
- Also drops used instruments such as presence of a meat works or dairy factory in 1920 and straight-line distance to Auckland or Wellington (and more) for potential endogenous variables such as road distances.
- Conclusion: Five dominant factors have impacted positively on urban growth, especially since 1966:
  - local land-use capability
  - sunshine hours
  - human capital
  - population size
  - proximity to Auckland

Grimes (2011) also recommends incorporating complementary projects in a single project analysis where network effects exist.

MBIE and LGNZ core cities project (2012) explored the benefits of establishing an institutional arrangement between major New Zealand cities, akin to that seen in other places such as the UK's Northern Way. A summary of some of their findings follows.

- New Zealand is a highly urbanised country. Over 85% of the population lives in towns and cities.
- The available evidence suggests the cities' economies are relatively economically independent of each other. For example, the six core cities of Auckland, Hamilton, Tauranga, Wellington, Dunedin and Christchurch each have different areas of comparative advantage and economic distinctiveness.
- NZIER found collaboration across city-regions can create benefits for the whole country.
- Developing a stronger network between New Zealand's major cities would provide the country with three potential benefits:
  - an increase in scale
  - improved efficiency
  - a reduction in the economic distance between city-regions.
- The cost of air travel remains relatively high compared with other countries.
- Large, outward-facing global cities with good connectivity drive competitive economies.
- Connectedness can be physical, with a focus on distance, or it can relate to how connected people are via information flows.
- Connectivity is important within a city and the region, but it also has tremendous value between city-regions and with cities in other countries.

- Travel congestion in New Zealand cities remains low by international standards. Congestion levels in Auckland, however, are similar to Sydney and greater Melbourne.
- In many countries, commuting between cities is common (although not evidenced in this report). In New Zealand, however, less than 1% of commuters travel between the three geographically closest core cities of Auckland, Hamilton and Tauranga. Anecdotal evidence suggests this reflects limited employment opportunities and the difficulty of travelling between the cities.
- More workers commute by air from Auckland to the four Wellington cities (Upper Hutt, Lower Hutt, Porirua and Wellington City), than from Auckland to Hamilton and Tauranga combined.

B5 Economic linkages between Auckland, Hamilton, Tauranga

The economic connectivity within the AHT corridor was investigated in a Paling et al (2011) study for MED (now MBIE). The report investigated whether there was evidence for the presence of a 'city-system' between the AHT city regions; in particular, whether the proximity or the connectivity between the three cities has led to higher than expected levels of economic integration, via labour markets, flows of goods and services and knowledge exchange and whether this has contributed to economic growth. In this context a city system was defined as:

> *the sites of dense masses of interrelated economic activities that also typically have high levels of productivity by reason of their jointly-generated agglomeration economies and their innovative potentials* (Scott and Storper 2003)

Paling et al (2011) considered a number of quantitative and qualitative approaches to assessing the linkages between Auckland, Hamilton and Tauranga. These included analyses of data on:

- commuting
- business travel
- migration
- employment structure
- movements of freight

This quantitative analysis was supported by interviews with a range of firms and agencies within the area to identify the strengths of any linkages between the three cities.

These approaches suggested the level of connectivity between the three cities was relatively low and there was little evidence of the emergence of an integrated city system as defined above. In part this reflected the degree of separation between the cities with Tauranga being over 200km away from Auckland and Hamilton–Tauranga and Hamilton–Auckland being in excess of 100km. As a result, flows of commuters and business travellers were limited and the three cities appeared to operate as relatively independent economies but with Auckland as the dominant area of activity, with little evidence that the linkages between them contributed to higher levels of economic activity that would be expected between other provincial cities and Auckland.

The one exception to this was in the movement of freight where there were substantial volumes of manufactured goods moving through the Port of Tauranga to and from the Auckland region. While contributing to the economic activity directly associated with the port, these appeared to have only limited spillover effects in the wider economy of the Bay of Plenty.

A simple regional agglomeration model was developed to assess the effects of a range of notional land use changes and development of the transport network and the results of this are set out in table B.2. These include in scenario 5 an assessment of the possible impact of the government's Economic Growth Agenda (EGA) which assumed a higher proportion of employment in industries with relatively high agglomeration elasticities. The analysis used the approach to the assessment of agglomeration benefits set out in the EEM.

Table B.2 Change in GDP of AHT cities with alternative development scenarios 2041

Scenario	Employment in AHT Cities	Total GDP in 2041 AHT Cities: Total Output ($bill)	Total GDP in 2041 AHT Cities: % of Total in 2041
Current 2009	*583803*	*58.8*	*34%*
Position in 2041			
Base Case Total Employment and Output			
Base Case High Stats NZ growth	1032400	175.1	100%
Scenarios : Change from Base			
Scenario 1 Lower Growth Rate in employment in AHT cities	-131,000	-22.7	-13%
Scenario 2 Relaxation of MULs	-42,000	--13.9	-8%
Scenario 3 Increase of employment of 100,000 in Auckland City	+100,000	+21.7	+12%
Scenario 4 Increase of employment of 100,000 in Hamilton and Tauranga	+100,000	+14.8	+8%
Scenario 5 EGA scenario	0	+1.6	+1%
Scenario 6 Increased **inter**-urban accessibility	0	+0.1	+0%
Scenario 7 Increased **intra**-urban accessibility	0	+0.4	+0%

The results indicated that the level of economic output was sensitive to land use changes, and in particular to the level of activity in Auckland. However, changes in transport connectivity **between** the three cities had a very small impact, an effect that was smaller than improvements in transport accessibility **within** the main urban areas.

The nature of the agglomeration model means the analysis of the transport effects assumed the levels of employment remained unchanged and it was only productivity that increased. However, the analysis of the connectivity effects from alternative sources discussed in the report suggested these effects would be unlikely to have any significant impact on the patterns of land use and employment.

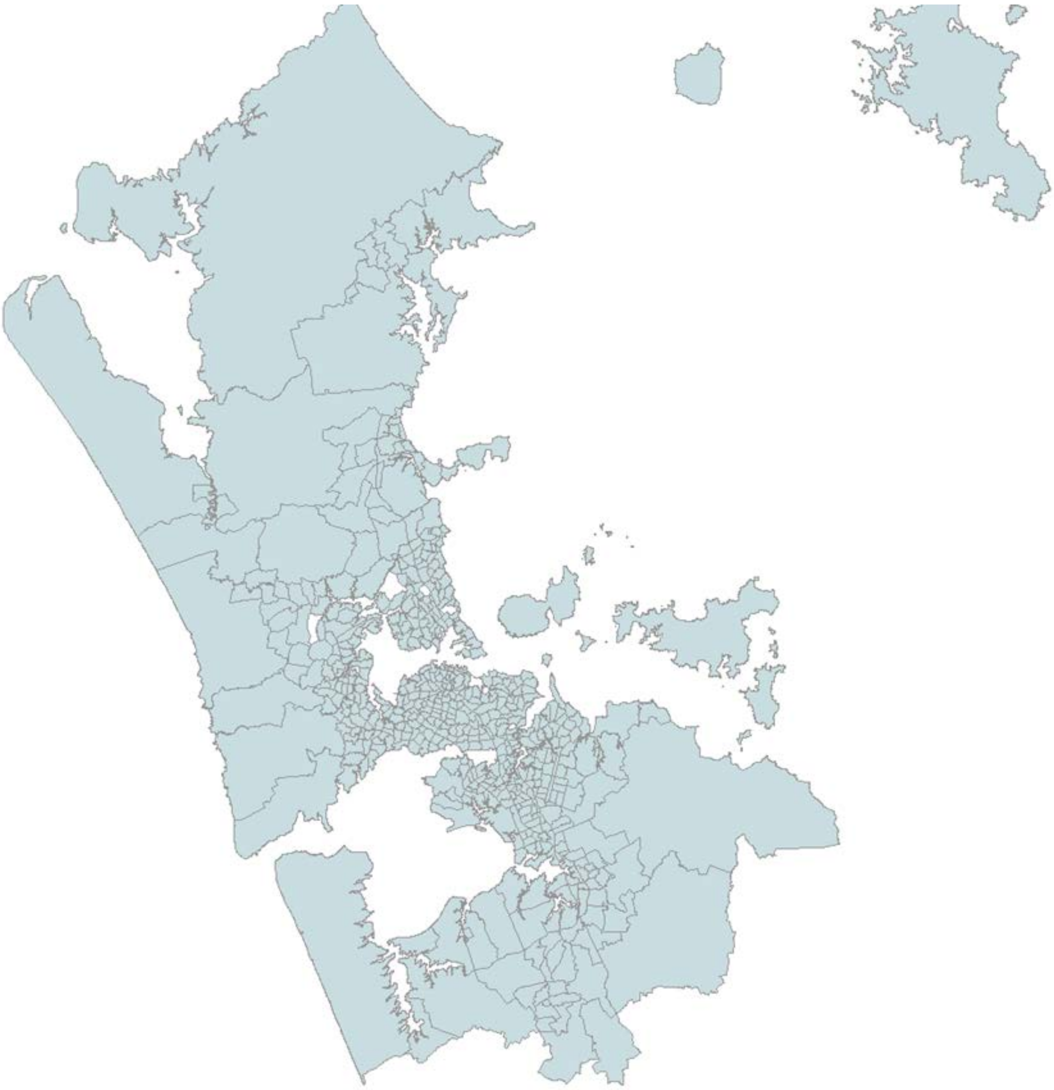
B6 Regional traffic models

Two 'regional' transport models have been developed which cover the AHT corridor, the Auckland regional transport (ART) model, which as its name suggests, covers the Auckland region and the Waikato regional transport model (WRTM) covers the Waikato Region but also extends into South Auckland as far as Manukau and into the Bay of Plenty to include Tauranga and Rotorua.

B6.1 The Auckland regional transport (ART) model

The ART model was originally developed in the 1990s based on data for 1991. It was recalibrated and given a major update in the later 2000's using data from the 2006 census supported by a programme of data collection from traffic counts, surveys of users and journey time surveys at the same time. More recent updates have included the development of a 2013 base. The model includes about 550 zones each of these having defined land use and trip generation and attraction characteristics. The coverage and zoning system for the ART model is set out in figure B.4.

Figure B.4 ART model coverage and zones



The ART model considers both road based and public transport modes. It produces detailed forecasts for three separate time periods through a typical weekday, the AM peak, the interpeak and the PM peak periods. A number of trip purposes are considered for both car and public transport users and heavy vehicles are also considered.

The total economic and population forecasts for the region as a whole are derived externally to the transport modelling process. In addition, while a land use transport interaction (LUTI) model exists, because of the time taken to run this, it is only used sparingly typically in the development of scenarios for particular years which are then assumed to be independent of the particular transport configurations for that year. The LUTI model affects the distribution of population and activity across the region but does not alter the totality of these, which as indicated above are determined externally.

In its typical use therefore, the ART model for a particular year takes a fixed set of trip generations and attractions for each of the zones within the area modelled as set out above. These are largely dependent on the population and employment characteristics assumed for the zones which are determined externally to the transport model and as a result the trip generations and attractions for each zone do not change between alternative transport network scenarios. The characteristics of the transport network then determine how these trips are distributed between the zones. The calibration of the model in 2013 has been used to set out the relationships which underlie the patterns of trip making both in terms of trip generation for each zone and the spatial distribution of these trips across the area considered reflecting the travel conditions on the transport network.

These relationships are then used as the basis for considering the impacts of changes in both the level of trip generation and attraction for the individual zones and the performance of the transport network linking these. The level of interaction between zones is a function of the costs of travel between them subject to the need for the model as a whole to balance and all trips to be allocated. Typically the operation of the model assumes a fixed land use for each year. The changes to the performance of a transport system which might result from a particular intervention and which could be interpreted as its connectivity will change the costs of travel between particular points. In general for car traffic of different purposes this will only alter the distribution of the fixed numbers of trips generated and attracted by each zone (ie the ways in which trip origins and destinations are linked) and their modal split, but would not alter the total number of trips generated either in total or at each location. For freight vehicles the origin-destination patterns of movement are assumed to be fixed and it is only the costs of travel and, if appropriate, the routes used between these fixed trip ends which would change.

The longer distance linkages between the Waikato and Auckland regions are estimated based on a simple factoring up of the observed traffic levels using a growth rate that is determined outside the modelling process. Again changes in the costs of travel between the regions would not result in any increases in economic output although benefits would be estimated if these benefits were generated more efficiently.

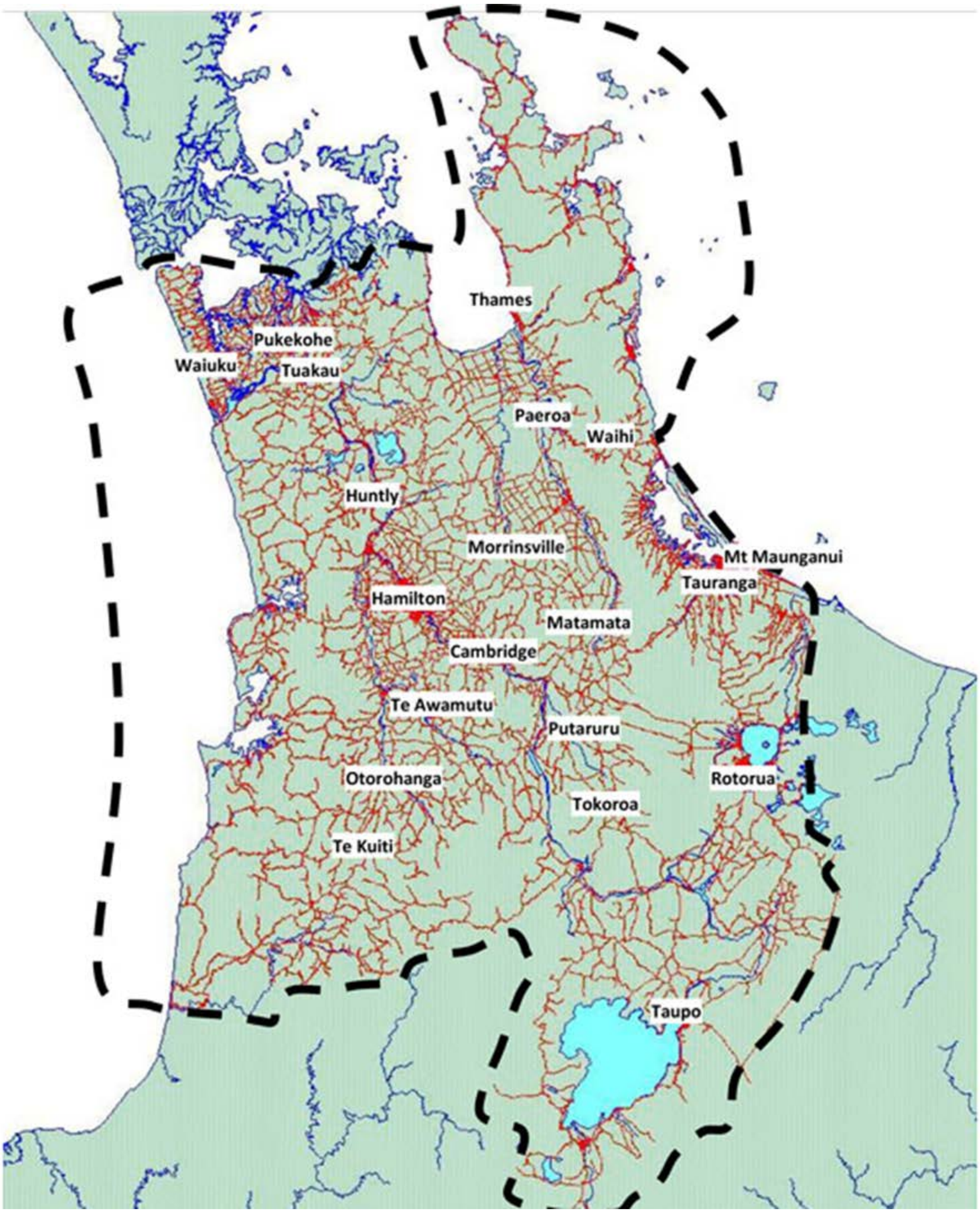
The output of the model is primarily forecasts of the pattern of trip making between the zones for the model, the routes that these flows would use and the costs associated with these movements, which can be broken down into a number of components, including time and distance for highway based modes.

Changes in connectivity as measured by the costs of travel would therefore affect the efficiency with which a fixed level of economic activity is generated, if for example the costs of business travel or freight were reduced, but would not result in any changes in the level of economic activity itself or the value of the output produced. The costs can, however, be used to generate agglomeration benefits which affect the level of productivity of the fixed workforce and also following the procedures in the EEM can be used to generate estimates of the changes in the supply of labour as commuting costs change.

B6.2 Waikato regional transport model (WRTM)

The WRTM provides a similar transport modelling capability for a region centred on the Waikato Region but also including parts of Auckland as far north as Papakura and the western parts of the Bay of Plenty including Tauranga and Rotorua. The model as originally developed in the later 2000s comprised about 900 zones but in 2013 was expanded to about 2,500. The coverage of the model is set out in figure B.5.

Figure B.5 Coverage of the Waikato regional transport model (WRTM)



Because of its structure and inclusion of both parts of southern Auckland and Tauranga as well as the Waikato, the model does allow for changes in the pattern of trip making between these three areas, although again subject to fixed trip generations and attractions for each zone. An increase in trips between Auckland and Tauranga would therefore have to be balanced by a reduction in trips making other journeys.

Unlike the Auckland model the origin-destination pattern of trip making by heavy commercial vehicles is allowed to change in response to changes in the transport network, although again subject to fixed overall trip generations and attractions.

B6.3 Applicability of the regional transport models to connectivity research

The regional transport models for Auckland and Waikato are primarily used to determine future travel patterns and the costs of movement for particular scenarios for the development of the transport network. The models cover both private and public transport and the interactions between these two with, for example, improvements in public transport resulting in reductions in highway congestion as some travellers switch modes in response to the improvements. Costs by both road and public transport would therefore be affected by such an intervention.

Given the assumption of fixed land uses across scenarios for a particular year in the models, changes in connectivity as measured by the costs of travel would affect the efficiency with which a fixed level of economic activity is generated, if for example the costs of business travel or freight were reduced, and this would be measured as part of the standard transport economic benefits from the proposed change. However, the models would not estimate any changes in the level of economic activity itself or the value of the output produced, but simply look at the associated costs. The Waikato model with its broader coverage would also produce estimates of changes in longer distance trip making but again subject to fixed trip ends and by implication fixed levels of economic output.

However, although the models assume fixed levels of economic activity, the changes in the costs of travel which they generate can form the inputs to assessments of changes in the level of economic activity. Using the standard approaches set out in the EEM they can be used to estimate potential agglomeration benefits which affect the level of productivity of the fixed workforce and which can be incorporated in a standard cost-benefit appraisal. Following the procedures set out in the EEM, changes in costs can also be used to generate estimates of the changes in the supply of labour and the size of the workforce. As commuting costs change the supply of labour is also assumed to change although typically this effect is only small.

The costs of travel would also form an input to a GVA or SCGE type model, which also potentially measure the changes in economic output that would result from an improved transport system.

In summary therefore while the transport models themselves do not directly measure the effects of improved connectivity on economic output, they do provide the building blocks which would assist in this assessment.

B6.4 Regional long-term land transport demand model

Stephenson (2015) has recently built a regional transport forecasting model for the Transport Agency. This is comprehensive model that simulates and projects the demand for land transport at a regional origin-destination level. Demand is split into household demand and industry demand for freight.

Household demand for a travel good is related to household type, age, income, the price of travel, population density, the rate of unemployment and mean travel speed. There is a two-stage approach with demand for the number of journeys determined separately from the length of journeys. There is another layer for determining mode choice.

Regional population is endogenously determined by births, deaths and regional migration. A vector auto regression model is used to capture the bi-directional causation between migration and regional GDE per capita.

Demand for freight is modelled by industry specific ratios of freight demand per unit of output (attached to a gravity model GDP) to pick up the spatial dimension, augmented with spatial autocorrelation to capture freight activity between contiguous regions. Identification of three industries (primary, secondary and tertiary) seems to be sufficient. Trade tonnage at ports and airports is also an explanatory variable, although it has little power – a result also found by Byett et al (2015).

As to suitability for this project, the model does not focus on connectivity and does not endogenously determine land use (as land is not a variable in the model other than to measure density and distance). However, the regional migration routines could potentially be useful.

B6.5 Systems model of Waikato/Bay of Plenty traffic

Infometrics (2014) developed a systems model to forecast the volume of traffic at representative telemetry sites in the AHT triangle (but not in the cities themselves), covering most of the Waikato region, plus some of the Auckland and Bay of Plenty regions.

Traffic flows (AADT) are measured at each of the 11 telemetry sites shown in the stylised map below and listed in table B.3. The variable of interest is 'all vehicles' (as recorded by Transport Agency), rather than heavy vehicles.

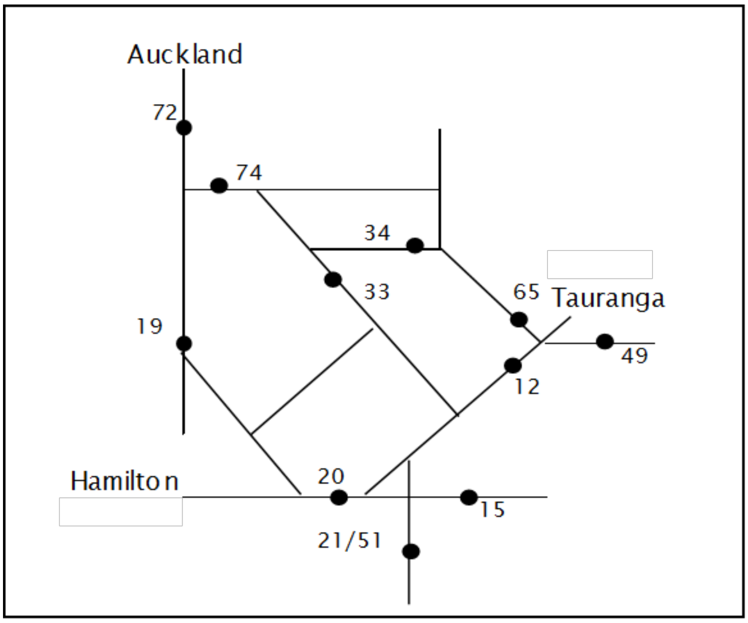


Figure B.6 Systems model site schematic

Table B.3 Telemetry sites

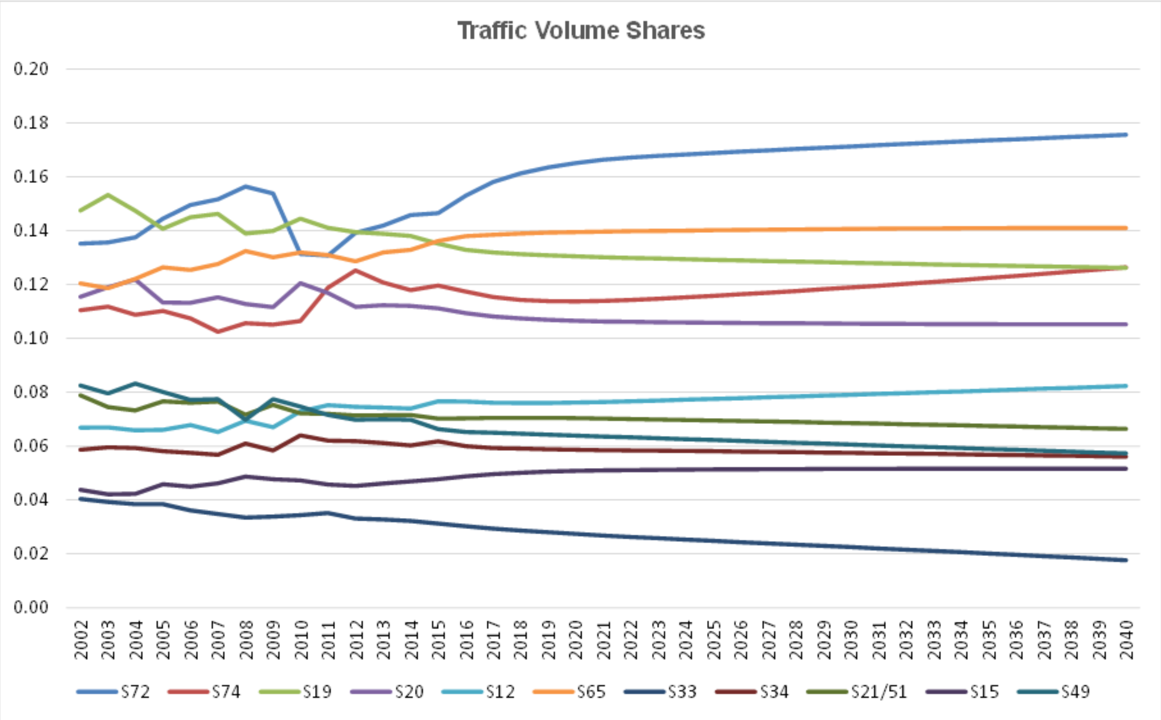
No.	Location
S72	BOMBAY
S74	MAUNGATAWHIRI – west of Grahams Brg
S19	TAUPIRI – north of Gordonton Rd
S20	KARAPIRO
S12	KAIMAI – 100m past Boulder Brg (Kaukumoutiti Stream)
S65	TE PUNA – west of Snodgrass

No.	Location
S33	KAIHERE
S34	WAIHI – east of Samson Rd West
S21/51	LICHFIELD – south of Baldwin Rd and TOKOROA – (WIM site)
S15	TARUKENGA – 4.7km west of Dalbeth Rd
S49	TE PUKE – (WIM site), OHINEPANEA – (13) west of Rogers Rd, (14) south of Maungarangi Rd Paengaroa

A two-stage model was adopted, estimated from quarterly traffic count data from 2002:1 to 2013:1. In the first stage total traffic volume across all sites (V) is expressed as a simple function of total gross domestic product (Y) in the three regions. In the second stage the share of traffic at each site(s) is expressed as a function of the share of traffic at every other site, plus the total volume of traffic (from the first stage), plus employment (Z) in each of nine selected industries in the three regions, plus their own lagged share of traffic.

A default set of projections of GDP and employment (for nine industries and three regions) up to 2017 was applied, giving rise to the traffic share projections below. Growth was projected to be greatest at site 72, at Bombay just south of Auckland. Site 65 west of Tauranga also shows strong growth. In contrast the share of traffic declines at site 19, north of Hamilton, and site 33, Kaihere, continues the downward historical trend.

Figure B.7 Traffic volume share projections



Regarding suitability for this project, the spatial disaggregation is good, but the model lacks any links between transport demand and travel time, the cost of travel and choice of location.

Appendix C: Decay parameters and agglomeration effects

Graham et al (2010) tested UK total factor productivity versus 'effective mass' data to find the average decay factor (α)[54] in the formula Effective mass=$\sum$distance$^{-\alpha}$ x employment. Their decay estimate of 1.66 implies a mass of 100,000 employees, who are 100km away, has the equivalent effect on productivity as only 48 people within 1km (see table C.1). Whereas attributing those same 100,000 people a decay factor of 1.00 implies an effect equivalent to 1,000 people nearby (see table C.1). That is, current practice in the EEM may be overstating the externality influence of people 100km away from the centre being measured[55]. Rice et al (2006) reach a similar conclusion that density effects attenuate, inferring they cease to exist beyond approximately 80 minutes travel time.

Table C.1 Effect of different decay parameters on measured mass of effect over various distances

		Decay parameters						
Distance away (km)		**0.9**	**1.00**	**1.12**	**1.56**	**1.66**	**1.75**	**1.82**
		Meta	**Assumed**	**Manu**	**Constr**	**UK ave**	**Busi ser**	**Cons ser**
		Weighting applied on employment that is 'x' km away						
	1	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	10	12.6%	10.0%	7.6%	2.8%	2.2%	1.8%	1.5%
	50	3.0%	2.0%	1.3%	0.2%	0.2%	0.1%	0.1%
	100	1.6%	1.0%	0.6%	0.1%	0.0%	0.0%	0.0%
eg AK- HAM	**127**	1.3%	0.8%	0.4%	0.1%	0.0%	0.0%	0.0%
eg AK- TAU	**200**	0.8%	0.5%	0.3%	0.0%	0.0%	0.0%	0.0%
		Number of people effectively contributing to productivity (with 100,000 at each place)						
	1	100,000	100,000	100,000	100,000	100,000	100,000	100,000
	10	12,589	10,000	7,586	2,754	2,188	1,778	1,514
	50	2,958	2,000	1,251	224	151	106	81
	100	1,585	1,000	575	76	48	32	23
eg AK- HAM	**127**	1,278	787	440	52	32	21	15
eg AK- TAU	**200**	849	500	265	26	15	9	6

The following paragraphs show the results from considering a range of decay exponents from 0.8 to 1.8 within this project.

The effect of these decay exponents on the proportion of people added to the effective mass variable is shown in the figure below.

For a decay exponent of 1, as implicit in calculations of the previous section, people within $1 GTC of the (widened) area centroid will be fully counted whereas people $24.5 away will be only given 0.041 weight

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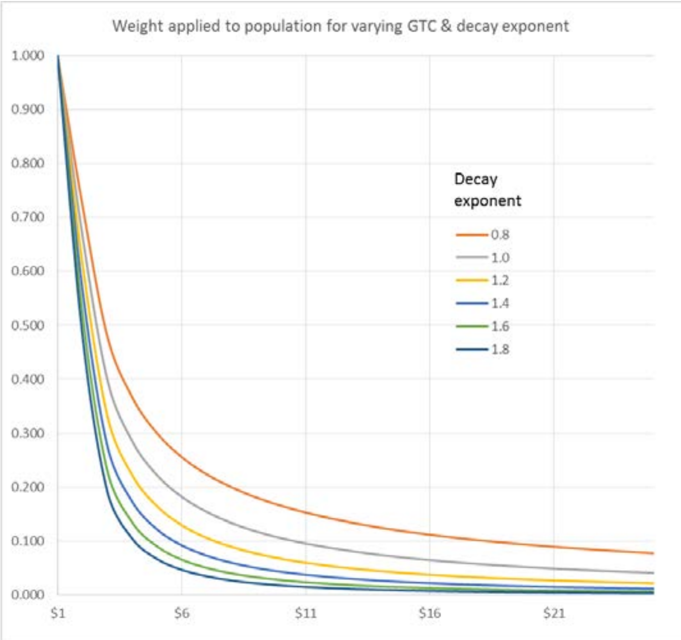
[54] not the same as scale economy index above

[55] It is also possible that it may be under-stating the effect but the magnitude of the current parameters suggests otherwise

(ie 1 divided by 24.5). In effect 100 people who are $24.5 travel cost away will be treated as if they were only 4.1 people.

Applying a decay parameter can amplify this distance effect. Applying a decay exponent of 1.8, as suggested by UK research for the business service sector, would reduce these 100 people to effectively 0.3 people, or at the other extreme of exponents considered, it would increase the effective number to 7.7 people if a decay exponent of 0.8 were applied.

Figure C.1 Weight applied to population for varying GTC and decay exponent

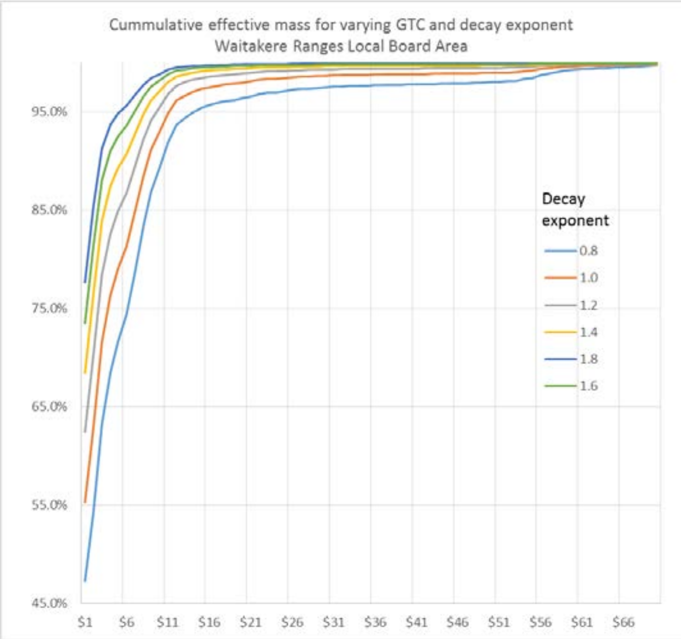


How this affects the effective mass variable in each territory or area depends on the distribution of people around the centroid. Two examples are shown below in table C.2 and figures C.2 and C.3. For the Waitakere Ranges Local Board Area, there are 374,462 people of working age within $5 GTC in 2013. Applying a different decay parameter simply tends to scale the effective number of nearby people.

Table C.2 Measures of effective mass (i.e. working age people), including decay exponents from0.8 to 1.8

	Within 40min	Within $5 GTC	0.8	1.0	1.2	1.4	1.6	1.8
Waitakere Ranges Local Board Area	873,709	374,462	373,565	319,772	283,747	258,944	241,436	228,790
Waikato District	146,089	13,840	98,453	56,635	34,949	23,513	17,368	13,992

Figure C.2 Breakdown of AGTC for Waitakere Ranges



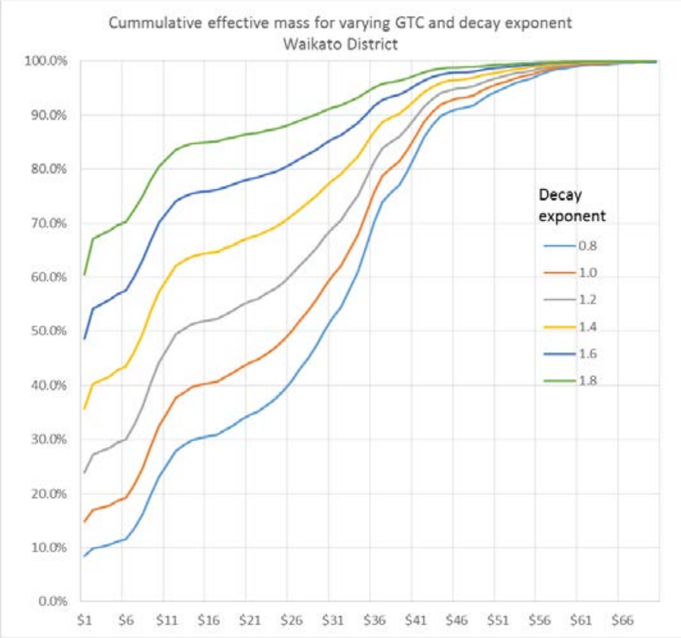
Conversely the Waikato district has only 13,840 working age people within $5 GTC but 146,089 within a 40-minute drive[56]. The effect of increasing the decay parameter here is to put less emphasis on those people beyond a $16 GTC (see figure C.3 below). In practical terms, less emphasis is put on Waikato people's accessibility to South Auckland and Hamilton[57].

The key points here are that the higher decay parameters reduce the number of effective nearby people and the effect differs depending on the spatial distribution of people in the surrounding area.

[56] The Waikato District centroid is near Huntly

[57] As an example, Papakura Local Area Board contained 30,900 working age people in 2013 and could be reached at a GTC of approximately $23, implying 1,343 people would be added to the effective density measure for Waikato if the decay exponent was 1.0 and 109 if 1.8. Likewise the numbers for Hamilton City are 101,000 people at an approximate GTC $11 adding 1,348 (1.0) to 9,182 (1.0).

Figure C.3 Breakdown of AGTC for Waikato



The choice of decay parameter is next explored empirically.

Again focusing on the two sectors detailed above, the agglomeration elasticity declined for both sectors for both 2001 and 2013 data as the decay exponent increased, as set out in table C.3. Again, though, each estimate shared overlapping 95% confidence intervals and hence are not statistically different.

The best fit, as measured by R^2, in all four cases was the smallest decay component of 0.8, which has the effect of putting more emphasis on more distance populations. However, the goodness of fit improvement is small.

Table C.3 Agglomeration elasticities based on GTC- weighted working age population with various decay exponents – 2001 data

Industry sector	2001 decay=0.8 <run 12a>	2001 decay=1.0 <run 12>	2001 decay=1.2 <run 12b>	2001 decay=1.4 <run 12c>	2001 decay=1.6 <run 12d>	2001 decay=1.6 <run 12e>
Wholesale trade	0.131	0.119	0.108	0.097	0.086	0.078
SE	0.020	0.020	0.020	0.021	0.021	0.021
R2	0.9962	0.9961	0.9959	0.9958	0.9956	0.9955
Professional, scientific and technical services	0.073	0.064	0.057	0.050	0.044	0.039
SE	0.012	0.012	0.012	0.012	0.012	0.012
R2	0.9968	0.9967	0.9966	0.9965	0.9964	0.9964

Table C.4 Agglomeration elasticities based on GTC- weighted working age population with various decay exponents – 2013 data

Industry sector	2013 decay=0.8 <run 13a>	2013 decay=1.0 <run 13>	2013 decay=1.2 <run 13b>	2013 decay=1.4 <run 13c>	2013 decay=1.6 <run 13d>	2013 decay=1.6 <run 13e>
Wholesale trade	**0.100**	**0.092**	**0.084**	**0.076**	**0.069**	**0.062**
SE	0.022	0.022	0.021	0.020	0.019	0.018
R2	0.9952	0.9952	0.9952	0.9952	0.9951	0.9951
Professional, scientific and technical services	**0.059**	**0.051**	**0.045**	**0.039**	**0.034**	**0.030**
SE	0.012	0.013	0.012	0.011	0.011	0.011
R2	0.9966	0.9966	0.9965	0.9965	0.9964	0.9964

The statistical conclusion reached is there is no discernible difference between the six decay parameters in terms of their fit with observed GDP.

Appendix D: Projects in the AHT area

Projects that broadly match the time and distance saving of the case study.

Table D.1 Transport Agency projects around the Waikato and Kaimai areas

Section	Location	km	Completed before 2015
SH1 Waikato Expressway			
Pokeno	Bombay–Mercer	12	YES
Mercer	Mercer–Hampton Downs	11	YES
Longswamp*	Hampton Downs–Te Kauwhata	6	NO
Rangiriri*	Te Kauwhata–Ohinewai	5	NO
Ohinewai	Ohinewai bypass	7	YES
Huntly*	Ohinewai–Taupiri	15	NO
Ngaruawahia	Taupiri–Horotiu	12	YES
Te Rapa	Horotiu–Rotokauri	7	YES
Hamilton*	Lake Road–Tamahere	22	NO
Tamahere*	Tamahere bypass	2	NO
Cambridge*	Tamahere–Cambridge south	16	NO
SH29 Kaimai Connection			
Kaimai	SH24/SH29 intersection – Old Kaimai Road	3.5	SPECULATIVE ONLY BY RESEARCH TEAM

* These sections are expected to provide an approximate 24-minute travel time saving at off-peak times

Appendix E: Background regional statistics

E1 Population

The fastest population growth recorded between the 2006 and 2013 Census were in Upper Harbour and Waitemata, both within Auckland and evidence of both population sprawl and intensification in Auckland. Fastest growth in Waikato Region was Waikato District, Hamilton City and Waipa District, ie between Auckland and Hamilton but also around Hamilton itself. In the Bay of Plenty Region, growth was fastest in Tauranga City, with population declines to the south.

Table E.1 Usually resident population count and change at time of census

Regional council area, territorial authority area or Auckland local board area	Population count		Change 2006–2013	
	2006	2013	Number	Average annual change (%)
Auckland Region	1,304,961	1,415,550	110,589	1.2
Rodney Local Board Area	49,359	54,879	5,520	1.5
Hibiscus and Bays Local Board Area	81,858	89,832	7,974	1.3
Upper Harbour Local Board Area	42,873	53,670	10,797	3.3
Kaipatiki Local Board Area	79,131	82,494	3,363	0.6
Devonport-Takapuna Local Board Area	52,653	55,470	2,817	0.7
Henderson-Massey Local Board Area	98,787	107,685	8,898	1.2
Waitakere Ranges Local Board Area	45,498	48,396	2,898	0.9
Great Barrier Local Board Area	894	939	45	0.7
Waiheke Local Board Area	7,797	8,340	543	1.0
Waitemata Local Board Area	62,928	77,136	14,208	3.0
Whau Local Board Area	69,171	72,594	3,423	0.7
Albert-Eden Local Board Area	90,978	94,695	3,717	0.6
Puketapapa Local Board Area	50,805	52,938	2,133	0.6
Orakei Local Board Area	74,520	79,536	5,016	0.9
Maungakiekie-Tamaki Local Board Area	66,375	70,005	3,630	0.8
Howick Local Board Area	113,505	127,125	13,620	1.6
Mangere-Otahuhu Local Board Area	68,151	70,959	2,808	0.6
Otara-Papatoetoe Local Board Area	72,324	75,660	3,336	0.6
Manurewa Local Board Area	77,190	82,242	5,052	0.9

Regional council area, territorial authority area or Auckland local board area	Population count		Change 2006–2013	
	2006	2013	Number	Average annual change (%)
Papakura Local Board Area	41,559	45,633	4,074	1.3
Franklin Local Board Area	58,602	65,322	6,720	1.6
Waikato Region	380,823	403,638	22,815	0.8
Thames-Coromandel District	25,938	26,178	240	0.1
Hauraki District	17,856	17,811	-45	0.0
Waikato District	57,585	63,378	5,793	1.4
Matamata-Piako District	30,483	31,536	1,053	0.5
Hamilton City	129,588	141,615	12,027	1.3
Waipa District	42,501	46,668	4,167	1.3
Otorohanga District	9,078	9,141	63	0.1
South Waikato District	22,644	22,071	-573	-0.4
Waitomo District	9,438	8,907	-531	-0.8
Taupo District	32,418	32,907	489	0.2
Bay of Plenty Region	257,379	267,741	10,362	0.6
Western Bay of Plenty District	41,826	43,692	1,866	0.6
Tauranga City	103,881	114,789	10,908	1.4
Rotorua District	65,898	65,280	-618	-0.1
Whakatane District	33,300	32,691	-609	-0.3
Kawerau District	6,924	6,363	-561	-1.2
Opotiki District	8,976	8,436	-540	-0.9
Total New Zealand	4,027,947	4,242,048	214,101	0.7

Source: Statistics New Zealand

E.2 Migration

Statistics NZ record that migration into the Auckland region from other New Zealand regions is highest from Waikato and Bay of Plenty (relative to their populations).

Table E.2 Regional migration

40. People moving between regions, 2008–2013, movements as a percentage of the population of the source region

TO

Regional Council Area of Usual Residence (2013)

FROM: Usual Residence Five Years ago (2008)	Northland Region	Auckland Region	Waikato Region	Bay of Plenty Region	Gisborne Region	Hawke's Bay Region	Taranaki Region	Manawatu-Wanganui Region	Wellington Region	Tasman Region	Nelson Region	Marlborough Region	West Coast Region	Canterbury Region	Otago Region	Southland Region	Outflows (2008–2013) (%)	Net internal migration (2008–2013) (N)
Northland		5.9%	2%	0.9%	0.1%	0.3%	0.3%	0.5%	0.7%	0.1%	0.1%	0.1%	0%	0.8%	0.5%	0.1%	12.5%	315
Auckland	0.8%		1.5%	0.7%	0.1%	0.2%	0.2%	0.3%	0.7%	0%	0.1%	0.1%	0%	0.6%	0.4%	0.1%	5.8%	-4,662
Waikato	0.6%	3.7%		2.5%	0.2%	0.5%	0.4%	0.8%	1%	0.1%	0.1%	0.1%	0.1%	0.7%	0.4%	0.2%	11.2%	6,102
Bay of Plenty	0.4%	3.1%	4%		0.3%	0.5%	0.3%	0.7%	1.1%	0.1%	0.1%	0.1%	0.1%	0.8%	0.5%	0.2%	12.2%	2,007
Gisborne	0.4%	2.4%	2.1%	2.1%		1.8%	0.3%	1.1%	2%	0.1%	0.1%	0.1%	0%	0.8%	0.5%	0.2%	13.9%	-735
Hawke's Bay	0.2%	1.9%	1.4%	0.9%	0.5%		0.3%	1.6%	2.4%	0.1%	0.1%	0.1%	0%	0.9%	0.5%	0.1%	11.1%	-1,191
Taranaki	0.3%	1.9%	1.6%	0.7%	0%	0.3%		1.8%	1.8%	0.1%	0.1%	0.1%	0.1%	0.7%	0.5%	0.1%	10.1%	-237
Manawatū-Wanganui	0.3%	1.9%	1.8%	1%	0.2%	1.2%	0.9%		3.1%	0.1%	0.1%	0.2%	0.1%	1.2%	0.5%	0.2%	12.7%	-1,878
Wellington	0.2%	2.5%	0.7%	0.7%	0.1%	0.6%	0.3%	1.6%		0.2%	0.2%	0.2%	0%	1.1%	0.7%	0.1%	9.3%	498
Tasman	0.2%	1%	0.5%	0.7%	0.1%	0.2%	0.1%	0.4%	1.6%		6.6%	0.7%	0.8%	3.2%	1.1%	0.4%	17.6%	1,317
Nelson	0.2%	1.8%	0.6%	0.5%	0.1%	0.2%	0.2%	0.4%	2.7%	7.8%		1.2%	0.9%	3.6%	1.2%	0.4%	21.5%	66
Marlborough	0.2%	1.8%	0.7%	0.7%	0.1%	0.4%	0.2%	0.9%	2.2%	1.1%	1.5%		0.5%	5.4%	1.3%	0.4%	17.4%	-714
West Coast	0.2%	0.7%	0.7%	0.3%	0.1%	0.2%	0.2%	0.4%	0.8%	1.4%	1.3%	0.8%		7.3%	1.5%	0.6%	16.7%	-312
Canterbury	0.2%	2%	0.6%	0.4%	0%	0.2%	0.1%	0.4%	1.1%	0.4%	0.4%	0.4%	0.4%		1.7%	0.5%	8.9%	-4,065
Otago	0.2%	2.3%	0.6%	0.5%	0.1%	0.2%	0.2%	0.4%	1.8%	0.2%	0.3%	0.2%	0.2%	4%		1.6%	12.9%	4,701
Southland	0.2%	0.7%	0.6%	0.4%	0.1%	0.2%	0.2%	0.3%	0.5%	0.2%	0.2%	0.2%	0.2%	3.2%	4.7%		11.7%	-1,212

Note: Colour tone indicate the percentage of people moving out to another region from 2008 to 2013 as a percentage of residents (aged 15 and above) in the source region. Darker tones indicate higher outflows in percentage terms

Source: Statistics New Zealand

In terms of number of people, the regional inflow to Auckland is well below the inflow of people from abroad (Paling et al (2011) report 133,000 Auckland residents in 2006 had lived abroad in 2001 versus 55,000 who had lived elsewhere in New Zealand). Also the inflow of people into Hamilton and Tauranga in 2001–2006 was mostly from other regions of New Zealand, with the inflow from abroad only 22% of the total inflow.

Table E.3 Migration patterns between Auckland Metro, Hamilton and Tauranga 2001–2006, residents over 15 in 2006 (Source: Paling et al 2011)

Place of residence in 2006	Place of residence in 2001					
	Auckland	Hamilton	Tauranga	Other NZ	Overseas	Total 2006
Auckland Metro	614,181	3,549	2,073	49,323	133,467	802,593
Hamilton	2,859	61,881	1,140	16,809	10,521	93,210
Tauranga	3,675	1,503	51,615	13,704	5,985	76,482

E3 Skills and income

The average income level of people and the employment levels within skilled occupations are higher in Auckland, as shown below.

Figure E.1 Skilled occupations versus skilled people in New Zealand regions (Source: MBIE 2014 REAR)

E4 Sea port activity

The Port of Tauranga handled around a quarter of New Zealand's exports but only 13% of New Zealand's imports in 2010, by value. Ports of Auckland handled the majority of imports by value but handled only marginally more imports than Tauranga by volume.

Table E.4 Sea freight imports and exports by port – percentage of New Zealand totals: 2010 (Source: NZ Productivity Commission 2012)

Port	Imports (by value)	Imports (by weight)	Exports (by value)	Exports (by weight)
Northport (Whangarei)	14.3%	31.3%	1.3%	6.5%
Auckland	51.4%	21.1%	24.5%	9.1%
Tauranga	12.5%	19.3%	24.6%	27.3%
Taharoa	0.0%	0.0%	0.1%	2.8%

E5 GDP and employment

Table E.5 GDP per filled jobs ($000, 2010 prices) and percentage of GDP by industry grouping

Region, territory, local board	ALL	Primary	Manufacturing	Utilities	Construction	Consumer services	Business services	Government	Community services	Primary	Manufacturing	Utilities	Construction	Consumer services	Business services	Government	Community services
Auckland Region	**98.5**	**43.0**	**107.5**	**269.6**	**68.8**	**79.7**	**111.2**	**78.2**	**61.9**	**0.5%**	**11.2%**	**1.4%**	**5.0%**	**24.8%**	**27.6%**	**3.1%**	**13.8%**
Rodney Local Board Area	89.2	48.5	156.2	123.2	60.9	61.0	127.0	70.8	64.5	8.2%	17.3%	1.2%	10.4%	15.0%	17.1%	1.0%	17.2%
Hibiscus and Bays Local Board Area	86.0	106.9	95.0	123.8	70.6	56.4	132.5	66.8	62.4	2.0%	8.0%	0.2%	12.5%	18.4%	21.6%	3.3%	21.3%
Upper Harbour Local Board Area	91.2	34.3	94.4	118.8	69.1	79.8	91.3	87.6	61.2	0.3%	9.9%	0.5%	7.1%	30.2%	22.0%	5.5%	11.9%
Kaipatiki Local Board Area	85.7	29.4	85.2	125.0	58.7	69.7	110.0	84.5	61.8	0.1%	12.1%	0.0%	7.4%	30.7%	19.5%	1.2%	16.3%
Devonport-Takapuna Local Board Area	96.5	25.0	88.0	336.4	58.3	79.5	125.4	77.4	61.7	0.0%	1.8%	0.1%	2.8%	19.0%	32.4%	10.9%	20.2%
Henderson-Massey Local Board Area	86.4	27.0	99.8	121.2	71.4	64.4	106.8	70.1	62.3	0.2%	19.4%	0.5%	6.0%	20.9%	14.4%	4.5%	21.4%
Waitakere Ranges Local Board Area	86.9	22.7	84.0	124.2	59.4	65.4	145.1	84.4	62.5	0.9%	6.0%	0.7%	10.3%	16.4%	25.6%	1.4%	26.0%
Great Barrier Local Board Area	79.6		66.7		88.5	52.7	121.4	56.3	62.0	0.0%	0.9%	0.0%	10.7%	27.4%	23.7%	4.2%	20.5%
Waiheke Local Board Area	90.7	28.8	270.6	120.0	56.9	54.4	180.1	59.5	62.6	3.8%	11.0%	0.7%	5.3%	22.2%	27.5%	1.8%	15.1%
Waitemata Local Board Area	111.1	170.4	90.4	393.6	64.4	92.7	112.7	75.2	62.3	0.2%	1.4%	1.7%	1.5%	23.7%	47.1%	2.3%	9.5%
Whau Local Board Area	94.6	23.5	99.3	120.8	65.4	73.3	118.7	86.7	61.2	0.2%	26.2%	0.7%	6.5%	22.3%	16.4%	1.5%	13.6%

Region, territory, local board	ALL	Primary	Manufacturing	Utilities	Construction	Consumer services	Business services	Government	Community services	Primary	Manufacturing	Utilities	Construction	Consumer services	Business services	Government	Community services
Albert-Eden Local Board Area	90.5	28.0	78.0	416.7	57.8	65.3	126.8	85.9	61.5	0.0%	3.2%	0.1%	3.4%	19.2%	33.4%	1.9%	26.2%
Puketapapa Local Board Area	82.3	57.1	75.9		66.2	71.1	98.0	59.1	62.2	0.1%	9.6%	0.0%	5.4%	27.8%	17.4%	2.2%	24.9%
Orakei Local Board Area	87.3	107.1	87.4	120.0	57.9	62.1	113.8	87.0	62.5	0.1%	6.4%	0.1%	4.1%	18.1%	30.3%	2.2%	26.1%
Maungakiekie-Tamaki Local Board Area	105.1	28.9	119.5	362.9	77.4	81.4	102.2	83.2	62.2	0.1%	17.9%	3.3%	8.4%	27.8%	20.5%	2.6%	6.8%
Howick Local Board Area	96.0	31.1	102.0	124.7	69.9	75.5	107.0	87.7	61.6	0.1%	22.2%	1.6%	6.1%	26.1%	18.5%	1.1%	11.7%
Mangere-Otahuhu Local Board Area	103.8	26.0	100.1	116.8	75.8	96.5	101.9	85.0	60.1	0.1%	12.3%	0.6%	2.8%	47.5%	11.4%	4.4%	8.3%
Otara-Papatoetoe Local Board Area	91.8	46.1	139.3	315.4	76.3	73.8	89.3	72.7	61.2	0.4%	18.0%	0.8%	3.5%	19.0%	16.2%	6.4%	23.1%
Manurewa Local Board Area	96.1	54.0	100.1	135.1	80.8	84.2	114.8	87.3	61.0	0.1%	23.5%	0.6%	7.7%	23.6%	10.9%	3.0%	17.9%
Papakura Local Board Area	95.8	28.2	118.9	115.6	75.5	65.5	130.7	79.8	61.3	0.2%	24.5%	0.3%	11.1%	20.2%	13.6%	4.3%	13.1%
Franklin Local Board Area	90.9	33.0	140.6	452.5	62.0	62.3	113.4	61.7	64.0	5.3%	20.1%	4.6%	8.3%	14.8%	17.8%	2.0%	14.5%
Waikato Region	**94.5**	**137.4**	**100.1**	**461.9**	**68.2**	**53.2**	**96.3**	**76.5**	**54.4**	**18.5%**	**11.3%**	**5.1%**	**6.0%**	**13.4%**	**15.0%**	**3.0%**	**14.4%**
Thames-Coromandel District	82.4	105.9	106.3	134.5	60.5	45.4	131.2	64.3	54.9	11.2%	11.4%	0.8%	8.6%	17.9%	18.0%	2.3%	15.6%
Hauraki District	118.3	225.2	105.3	138.1	66.4	51.2	106.4	72.6	54.9	42.4%	6.8%	0.4%	4.6%	8.7%	11.0%	2.2%	11.9%
Waikato District	120.8	155.7	96.1	426.9	61.2	53.6	103.7	77.2	53.9	41.1%	6.8%	8.6%	4.6%	6.5%	9.6%	3.2%	7.7%
Matamata-Piako District	101.6	115.6	105.0	139.6	75.5	56.0	117.9	67.7	54.1	26.6%	21.8%	0.4%	6.3%	11.2%	12.1%	1.2%	7.6%

Region, territory, local board	ALL	Primary	Manufacturing	Utilities	Construction	Consumer services	Business services	Government	Community services	Primary	Manufacturing	Utilities	Construction	Consumer services	Business services	Government	Community services
Hamilton City	83.5	97.9	101.6	499.6	73.0	56.3	82.5	77.6	54.6	1.1%	12.0%	5.6%	6.9%	17.3%	18.7%	3.7%	20.8%
Waipa District	89.8	103.6	93.4	397.5	61.2	53.9	104.8	68.7	54.0	20.5%	11.1%	2.7%	5.7%	14.6%	17.7%	1.5%	12.7%
Otorohanga District	107.5	121.7	88.8	129.4	56.4	54.8	128.0	89.5	52.5	41.2%	5.4%	0.9%	3.1%	8.1%	13.8%	9.3%	5.8%
South Waikato District	102.5	138.7	107.0	371.2	59.4	50.0	134.2	72.2	52.8	33.1%	16.2%	2.0%	3.8%	8.6%	7.9%	1.9%	13.6%
Waitomo District	124.5	166.3	98.8	614.9	80.6	48.3	118.8	72.1	56.7	38.0%	13.4%	9.1%	4.9%	6.7%	5.9%	1.7%	8.5%
Taupo District	98.4	137.6	79.4	577.5	67.5	45.0	113.2	77.9	54.6	18.8%	5.2%	12.5%	6.5%	14.1%	15.3%	3.6%	11.1%
Bay of Plenty Region	**76.8**	**78.1**	**87.1**	**360.4**	**63.1**	**55.9**	**82.4**	**73.0**	**44.8**	**10.2%**	**11.0%**	**2.7%**	**6.7%**	**18.7%**	**18.1%**	**3.4%**	**14.8%**
Western Bay of Plenty District	72.8	59.5	87.2	165.8	54.0	58.3	70.0	78.2	43.7	22.3%	11.5%	0.5%	5.7%	12.5%	23.2%	0.8%	8.9%
Tauranga City	74.8	61.0	83.8	234.0	64.3	58.6	86.0	73.3	45.2	2.6%	10.0%	1.4%	8.1%	23.4%	20.2%	3.5%	16.3%
Rotorua District	77.5	113.5	73.6	375.1	64.6	51.1	90.1	76.0	44.6	12.4%	9.9%	3.7%	5.7%	18.6%	14.7%	4.7%	16.1%
Whakatane District	82.1	88.0	103.3	522.7	59.7	54.5	79.8	63.6	44.8	15.6%	8.9%	7.9%	5.0%	14.5%	15.5%	3.4%	15.3%
Kawerau District	109.4	193.8	124.8	590.3	73.6	56.1	127.2	72.3	41.5	4.1%	47.5%	6.0%	6.0%	6.8%	5.7%	2.6%	9.1%
Opotiki District	75.2	80.3	97.3	150.0	79.2	47.3	66.3	73.5	44.4	31.8%	2.7%	0.6%	7.7%	10.8%	15.4%	3.1%	13.5%

Source: Infometrics

Appendix F: Glossary

A40	working age population within a 40-minute drive
A120	working age population within a 40–120-minute drive
AADT	average annual daily traffic
AAIR	access to airport variable used in GVA model
AGTC	working age population nearby, weighted by GTC, a variable used in GVA model
AHT	Auckland, Hamilton, Tauranga (combined area)
ART	Auckland Regional Transport (model)
ASEA	access to seaport variable used in GVA model
BCR	benefit-cost ratio
CBA	cost-benefit analysis
CBD	central business district
CES	constant elasticities of substitution (function)
CGE	computable general equilibrium model
DfT	Department for Transport (UK)
DoT	Department of Transportation (US states)
EDR	Economic Development Research Group Inc
EEM	*Economic evaluation manual* (NZ Transport Agency)
EGA	Economic Growth Agenda (NZ Government)
EIA	economic impact analysis
FDI	foreign direct investment
GDP	gross domestic product
GE	general equilibrium
GIS	geographic information systems
GSP	gross state product
GST	goods and services tax
GTC	generalised travel cost
GVA	gross value added
HS2	company responsible for developing and promoting the UK's new high speed rail network
HPMV	high performance motor vehicle
IATA	International Air Transport Association
IO	input output (table)

LSCI	liner shipping connectivity index
LSE	London School of Economics and Political Science (University of London)
LUTI	land use transport interaction (model)
MBIE	Ministry of Business, Innovation and Employment (NZ)
MoT	Ministry of Transport (NZ)
NEG	new economic geography
NZIER	New Zealand Institute of Economic Research
POAL	Ports of Auckland Limited
PV	present value
PwC	PricewaterhouseCoopers
RAEM	a Netherlands SCGE model
REM	regional economic model
REMI	Regional Economic Models Inc (US)
SACTRA	Standing Advisory Committee for Trunk Road Assessment
SCGE	spatial computable general equilibrium (model)
SERC	Spatial Economics Research Centre (within London School of Economics)
SGEM	an Australian SCGE model
SHRP2	Strategic Highway Research Program 2 (US)
TA	territorial authority (second tier of local government in New Zealand, after regional councils)
TAG	transport analysis guidance (of UK DfT)
Transport Agency	New Zealand Transport Agency
TRB	Transportation Research Board (US)
TREDIS	transport economic development impact system (US)
TRESIS	transport and environment strategy impact simulator (Australia)
UNISA	Upper North Island Strategic Alliance
XVAR	matrix of explanatory variables used in GVA model
WEB	wider economic benefit
WRTM	Waikato regional transport model