Impacts of socio-demographic changes on the New Zealand land transport system

June 2018

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NZ Transport Agency research report 646
Contracted research organisation – Infometrics Consulting Ltd

ISBN 978-1-98-856105-9 (electronic)
ISSN 1173-3764 (electronic)

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Stroombergen, A, M Bealing, I Torshizian and J Poot (2018) Impacts of socio-demographic changes on the New Zealand land transport system. *NZ Transport Agency research report 646.* 81pp.

Infometrics Consulting Ltd was contracted by the NZ Transport Agency in 2016 to carry out this research.

Keywords: demographics, peak car, transport demand, saturation, technology, VKT

An important note for the reader

Acknowledgements

The authors would like to gratefully acknowledge the contribution to this research from the following:

- Members of the Steering Group:
  - Haobo Wang, Ministry of Transport
  - Wayne Heerdegen, NZ Transport Agency
  - Ernie Albuquerque, NZ Transport Agency
  - Thomas Simonson, Local Government New Zealand
  - Kevin Eames, Ministry of Transport
- Michael Cameron of NIDEA at Waikato University for stepping in after the sudden exit of Prof Jacques Poot from the project team.
- Peer reviewers Tim Denne (Covec) and Anthony Byett (ECPE Ltd).
- Jennifer McSaveney from Ministry of Transport for extracting data from the NZHTS

Abbreviations and acronyms

ANOVA	analysis of variance
BAU	business as usual
GFC	global financial crisis
DAPP	dynamic adaptive policy pathways
DfT	Department for Transport (UK)
ERP	estimated resident population
GFC	global financial crisis
ICT	information and communications technology
NZHTS	New Zealand Household Travel Survey
NZIER	New Zealand Institute of Economic Research
PKM	passenger kilometres
PT	public transport
RLTDM	regional land transport demand model
SD	system dynamics
Statistics NZ	Statistics New Zealand
Transport Agency	New Zealand Transport Agency
VK/MT	vehicle kilometres/miles travelled

Contents

Executive summary

Objective

The objective of the research was to gain an insight into how socio-demographic factors in New Zealand affect the demand for personal land travel, especially by private vehicle. Socio-demographic factors in this report include population size and composition, employment and income, although it is impossible to assess the influence of these factors without also considering (if not in detail) other factors such as urbanisation, access to public transport and its quality, new technologies and attitudes to greenhouse gas emissions.

Research areas

We looked primarily at overseas literature on various theories that travel per capita has peaked and/or shifted modes, and at the evidence for and against these theories. Our two main findings were:

1. Evidence of declining travel per capita and changes in the modal mix existed before the global financial crisis (GFC) and before the high oil prices immediately prior to the GFC. Thus one cannot rule out the possibility that changes in travel preferences are occurring within some socio-demographic groups and could be more prominent in the future.
2. A considerable proportion of historical changes in personal travel demand can be accounted for by changes in the age composition of households, income and employment.

Other factors

There are a number of other demand side factors consistent with less travel, such as more concern about global warming and an aging population. There are also a number of supply side factors that could act in the same direction: better public transport and access to it (perhaps also lowering demand for private vehicle use), service industry jobs and more inner city housing. However, not all of these factors are currently moving in the direction of less travel. Even if they do they could be outweighed by rising real incomes (for some age groups) and driverless cars. The effects of other technologies such as telecommuting, social media and online shopping are unclear.

Given the great uncertainties discussed above a scenario approach is advocated when designing transport policy.

Method

To gain more insight into the demand for personal land travel we decomposed New Zealand data on travel by private vehicle, finding that (as internationally) socio-demographic factors can explain most of the changes in such travel between 1998 and 2013. Nevertheless there is a suggestion of a decline in travel propensity leading up to and during the GFC. Rapidly rising oil prices until 2008/09 are probably a contributing factor, along with GFC-induced expectations of low or negative economic growth. Since the GFC the rebound in total travel by private vehicle has been somewhat stronger than changes in socio-demographic factors imply. Overall though there is no support for the hypothesis of a fundamental and sustained reduction in private vehicle travel per capita relative to 1998, conditional on age, employment and (real) income. The same conclusion can be drawn for total private vehicle travel.

Noted trends

The fact that a temporary decline in the (apparent) propensity to travel by private vehicle did occur, albeit in particular economic circumstances, does at least raise the possibility the same phenomenon could occur again and perhaps endure for longer. The circumstances may be different in the future, with, for instance, a marked decline in rural populations or a community-wide heightened concern for the climate change effects of CO_2 emissions from fossil fuels. Acting in the opposing direction are factors such as electric vehicles and autonomous vehicles.

From the perspective of transport infrastructure planning it would clearly be naive to assume (at the present point in time) a significant future decline in the propensity to travel by private vehicle, although it could happen. The above results do not negate the need for a scenario approach to transport planning, but a ‘business as usual’ scenario is still essential.

Model and scenarios

We used a model that was specifically designed to project New Zealand travel demand to explore the effects of socio-demographic factors on private travel by producing a series of demand projections for the next 30 years. The projections were stochastically computed using disaggregated travel demand functions and drawing on probability distributions of historical variation in factors such as population growth, (household) income and employment. The model produced a probability distribution around a central projection of travel demand growth. The greater the historical variation in the factors that determine travel demand, the greater the uncertainty in the distribution of future travel demand.

Outcomes

Most scenarios projected continued growth (1.4% pa to 2050 in the median scenario). Rates of growth did slow, however, and in more urbanised regions private vehicle travel per capita seemed likely to decline. The results confirmed that city densification affects both the amount of travel and the choice of mode, but the interactions between social, demographic and economic factors are complex. The model does not specifically address technological change such as driverless cars or internet shopping, although some of the effects of technology are implicit in the model’s coefficients and probability distributions. However, it is too early to know what effects new technologies may have on travel demand.

Continued research

While the scenario approach is essential to planning future investment in land transport infrastructure, continual monitoring of travel demand is also required. Travel surveys are likely to be the main form of monitoring, but we also suggest a number of non-travel indicators that could be used to assess whether changes in travel behaviour are truly occurring or whether economic factors continue to dominate. Examples include the share of service industry jobs in the economy, total employment, urbanisation and inner city housing and GDP.

Recommended way forward

Finally even if a scenario approach to investment planning is pursued, it is not sufficient to ensure that investment programmes are robust, flexible and minimise the chances of producing stranded assets. An approach known as dynamic adaptive policy pathways (DAPP) is recommended. This is a way of dealing with deep uncertainty in relation to long-lived investments and policy decisions. It is usefully complemented by real options analysis to quantify the value of waiting for more information before undertaking a potentially irreversible investment. For this report we did not develop a DAPP for investment in land transport infrastructure as this was well beyond the scope of the project.

Abstract

We present a discussion about how socio-demographic factors affect the demand for personal land travel. Socio-demographic is a convenient adjective that we use to cover primarily demographic factors, plus their interaction with employment and income. Other factors such as urbanisation and new technologies are also briefly discussed. We look primarily at overseas literature on various theories that per capita demand for travel has peaked and/or shifted modes, and at the evidence for and against these theories. Local literature on this topic is scarce so we decompose New Zealand data on travel by private vehicle, finding that socio-demographic factors can explain most of the changes in private vehicle travel since 1998. We also use a model that was specifically designed to project New Zealand travel demand to explore the effects of socio-demographic factors on private travel. Most scenarios project continued growth. Rates of growth do slow, however, and in some regions private vehicle travel per capita declines. The results demonstrate that interactions between social, demographic and economic factors, and their effects on travel demand, are complex.

1 Introduction

We are interested in the evolution of demand for personal land transport over the next 20–30 years, and the implications this may have for investment in the road network. Commercial travel and freight is outside the scope of this study.

The demand for personal travel is, for given behaviour, fundamentally driven by the size, composition and spatial distribution of the population – demographics. An effective assessment of future travel demand therefore requires a quantification of future population trends that is not going to be 'too far away' from the actual outcomes.

Of course demographic effects are intertwined with economic and technological effects so it is impossible to consider demographic effects in isolation. However, with limited project resources we have to be selective, so in this report we look at the impact of socio-demographic changes on travel demand; emphasising demographics (including urbanisation) and income, but also allowing for interactions with other influences such as technology.

The study has three key parts:

1. A discussion of 'peak car' and related concepts
2. Decomposition of recent changes in travel by private vehicle in New Zealand
3. Exploration of future demand scenarios.

Chapter 2 presents the discussion of peak car, in the context of a review of (mostly international) research on the changing patterns of private travel. Chapter 3 has the decomposition analysis of travel by private vehicle in New Zealand in order to obtain some insight into the extent to which changes in this type of travel are explained by changes in socio-demographic variables.

In chapter 4 alternative scenarios are presented to investigate how future socio-demographic trends might affect the demand for land travel. For this we use the regional land transport demand model (RLTDM) previously developed by the NZ Institute of Economic Research (NZIER) for the NZ Transport Agency (the Transport Agency). Our interest is less in the numbers than in understanding the effects of uncertainty and raising awareness of the possibility of a wide range of scenarios for the future demand for personal travel. The value of a model in this regard is that it can help determine the extent to which different assumptions and trends actually have a significant impact.

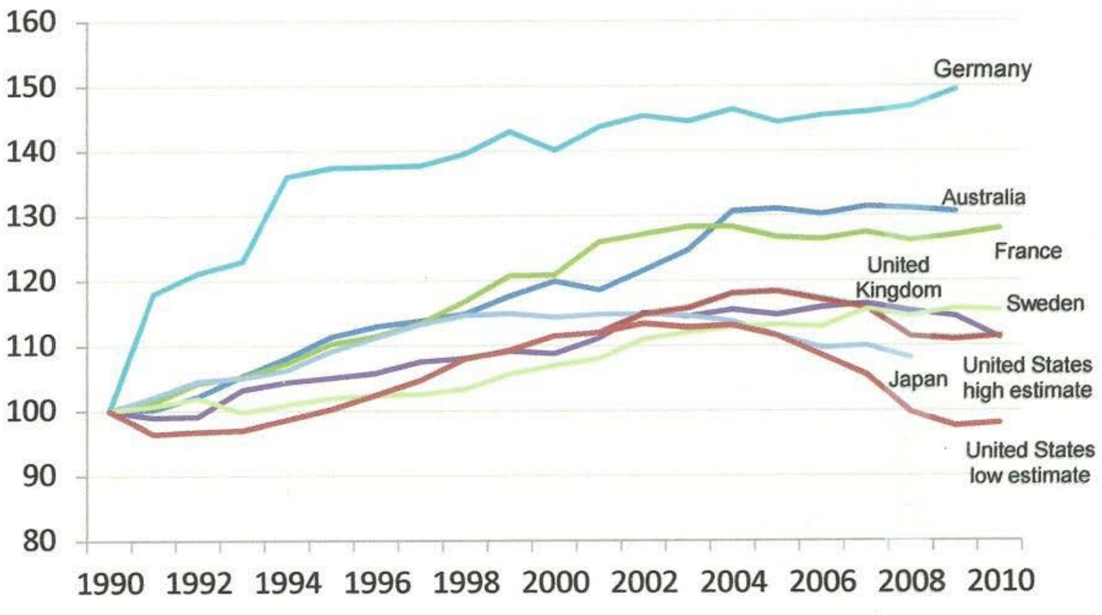
Conclusions and some recommendations are presented in chapter 5.

2 Literature review

2.1 Setting the scene

Goodwin (2012) provides the following graph (figure 2.1) of the changes in passenger kilometres (PKM) by car and light truck in various OECD countries between 1992 and 2010. The general picture is of flattening or declining vehicle kilometres travelled (VKT) since before the global financial crisis (GFC). This follows previous post-war decades of rapid growth characterised by expanding populations, family formation, suburban living and increased car ownership. Figure 2.2 plots similar data for New Zealand and shows much the same profile.

Figure 2.1 Passenger kilometres by private car and light trucks 1990–2009 (index 1990=100)



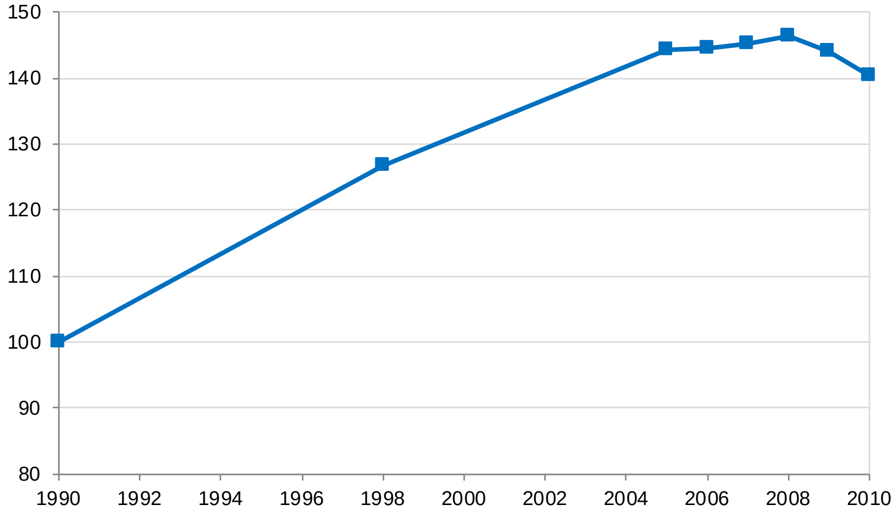
Source: International Transport Forum statistics.

Figures 2.1 and 2.2 illustrate why the Transport Agency and the Ministry of Transport wish to understand how demographic, economic and technological changes affect the demand for personal land travel. If personal travel demand in New Zealand follows the same sort of trajectory as those shown for other countries it could have significant implications for transport investment over the next few decades.

In this chapter we look at what overseas studies have discovered about influences on travel demand. We first put forward the case that the average population has reached – or soon will – a point of car saturation, and then extend the study to show that the evidence for this inference is inconclusive. This is followed by a discussion of the wider factors influencing observed travel demand. We consider total VKT, VKT per capita and mode shifts. While total VKT and mode shift are more relevant to investment in transport infrastructure, the latter is useful for gaining insights into travel behaviour.

We also look at how the findings have influenced the way the demand for travel is forecast, notably using a scenario approach allowing for the possibility that demographic and economic factors affect travel demand in ways that are more complicated than previously thought. Finally we investigate the extent to which New Zealand travel demand aligns with international trends, and suggest ways in which it could be monitored and projected for the purpose of improving investment in transport infrastructure.

Figure 2.2 Distance travelled on road (people aged 5+) (1990=100)



Source: Ministry of Transport (2017). The series is truncated at 2010 to match figure 2.1. See also figure 2.8.

2.2 Travel saturation

2.2.1 Summary

As sections 2.2.2 and 2.2.3 span about 10 pages, we present a summary here.

After half a century of more or less continual growth in car travel per capita to around the year 2000, the trend seems to have levelled out or even declined in numerous OECD countries, particularly since the GFC. Many explanations have been suggested, the main ones including changes in the age composition of the population (more older people who drive less and younger cohorts delaying when they form families and buy cars), more of the population living in cities, increases in the costs of travel by car (fuel, congestion and travel time, parking, licence acquisition, insurance, taxation of company cars), slow growth in income (especially amongst the young), better public transport (PT), diminishing returns to more choice and thus less desire to travel, substitution for travel (video-conferencing, online shopping etc) and concern about the environment – especially greenhouse gas emissions. These factors are not always independent. For example urbanisation and more use of public transport tend to coincide, and it is easier to reduce one's transport emissions when living and working in the same city

Most quantitative research, however, shows that changes in car travel can be explained largely by economic factors (income, employment and costs) and standard demographic factors (population size, composition and less clearly, density). It cannot be concluded that other influences such as information and communications technology (ICT), changing attitudes or delayed family formation are unimportant; rather that any effects are difficult to measure and seem not to be necessary for explaining changes in car travel over the last 20 years or so.

With a recovery in economic growth since the GFC, together with lower oil prices, some rebound in personal car travel seems to be occurring. Nevertheless, high uncertainty about how the various factors listed above might evolve in the future means that transport planning needs to be based on scenario analysis, with stochastic variation in the underlying drivers of demand when possible.

2.2.2 Theory

Graphs such as figures 2.1 and 2.2 are consistent with the idea of car (and associated travel) saturation (although other interpretations are given below), where most people who want to travel somewhere by car can do so.[1] Goodwin (2012), however, stresses that this concept is not new. Forecasts by the Transport and Road Research Laboratory in 1972 projected a levelling off in car ownership in the UK around 2000. It was only about five years too early (Goodwin 2012, p11). A remarkable achievement, although Goodwin sees this less as a comment on forecasting accuracy (as the model may have been flawed with regard to its inputs and/or theoretical structure) as to illustrate that the concept of saturation was around over 40 years ago.

Marchetti (1994) observed that in many countries, over different historical periods and irrespective of mode, travel time (especially for commuting) tends to be confined to a maximum of about one hour per day. Thus cities are roughly 'one hour wide'. In the case of Auckland for example, it takes about an hour to travel by car from Titirangi to Tamaki. This concept is sometimes described as the 'Marchetti wall'.

Puente and Tomer (2008) show that vehicle miles travelled (VMT) began to plateau around 2004 in the USA, and VMT per capita about four years earlier, although they stress there is much variation across states. Use of PT is up, but not by as much as the reduction in car use.

Stanley and Barrett (2010), while dealing primarily with options for improving transport in Australia across a number of measures (fewer emissions, better, social inclusion etc), also show that in state capitals road use by cars has flattened since about 2004 and on a per capita basis has declined since then.

Similarly, Goodwin (2012) cites an Australian paper by Cosgrove et al (2008) which shows a decline in per capita travel in metropolitan areas as a function of mean real per capita income over the period 1950 to 2006.

The reference to metropolitan areas is important as that is our focus here. Almost all the research into travel/car saturation pertains to urban travel, mostly intra-city but also inter-city in relation to commuting. The reasons for this will become apparent.

The concept of a travel time budget (the time made available for travel) is explored in Schafer (2017) who concludes that the projected growth in USA travel demand to 2100 will be primarily due to more use of air transportation. Use of light vehicles is projected to saturate and gradually decline, with the timing depending on factors such as autonomous vehicle penetration which effectively increases the travel time budget. That is, the time spent travelling can be more productive and less stressful, therefore lowering its opportunity cost. If this is true we could expect to see a temporary surge in VKT during the transition period as autonomous vehicles are introduced, before VKT would again start to stabilise.

Agreeing with Schafer, Aparicio (2016) expects faster growth in Europe in air travel than in car travel.

Millard-Ball and Schipper (2011), looking at data for eight industrialised countries, mention the travel time budget in the context of declining travel activity (especially private vehicle use) as other activities raise the opportunity cost of travel. However, they also argue that fuel prices, urban density and transport infrastructure must play some role. As might be expected, the travel time budget scenario is not firmly established. There are other explanations. Goodwin (2012) identifies two other scenarios (although they and the travel time budget theory are not mutually exclusive):

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[1] There will always be some people who desire to travel by car but cannot. They might be physically or mentally impaired for example, or lack financial resources. However, the numbers involved are too small to significantly affect trends in total VKT or average VKT per capita. Of course this does not mean that the issues should be ignored.

1 Interrupted growth: a major effect from the GFC, but also reflecting deeper economic malaise. Higher prices for fuel, parking and driver licences, and higher unemployment (and zero hour contracts) all contribute to less driving and less travel – affecting young people proportionately more. Economic growth since the GFC will have ameliorated some of these obstacles, but Goodwin (2012) does not discuss less obvious pressures such as the costs of education (student loans) and housing, although these are not issues everywhere. Low interest rates have been capitalised into land prices. Together with generally favourable tax treatment for investment in property and easier access to credit by those who already own property also putting upward pressure on prices, it may be that the incomes of Generation Y have not been rising in real terms so there is less disposable income to spend on buying and running private cars.

2 Peak car: a complex set of inter-relationships in which driving propensity is affected by (and affects) social, environmental and technological factors: the growth of cities relative to rural townships, communications technologies (such as car sharing 'applications' and on-line shopping) and their percolation from younger to older age groups, improvements in PT (price, speed, quality, real time information) and access for walking and biking. See for example Fraser and Chester (2016) who discuss peak car in relation to Los Angeles, arguing that congestion is also a contributing factor.

Metz (2013) argues that even though physical access and the range of choice increases roughly with the square of travel time for a given speed (or with the square of speed for a given travel time),[2] choice exhibits diminishing marginal utility. He cites the example of supermarkets; if one already has a choice of three, how much extra utility is gained from being able to access a fourth one by driving slightly further? With diminishing marginal utility of choice, travel will eventually reach saturation as it is difficult to perpetually raise average speeds. There are exceptions such as to access a well-paying job and infrequent long distance travel such as for inter-continental holidays.

One of the interesting implications of this theory is that travel time savings from better roads are ultimately realised in the form of greater access and more choice for more people – which of course is still a gain in welfare.

Expressing car trips as a share of total trips, Metz (2013) shows that car use in London reached a plateau in 1993. Although consistent with the demand-side saturation theory, Metz also cites supply-side factors such as congestion, parking and vehicle operating costs (ie the congestion charge since 2003),[3] as well as the availability of good PT. The latter is complementary to the shift in the structure of the economy towards more service industry jobs and the associated urbanisation of the population.

Another demographic factor is longer life expectancy which allows more time for education and deferred family formation, especially in cities. Whether there are causative effects here or just coincidences is a moot point.

Metz (2013) criticises forecasts produced by the UK National Transport Model as being based entirely on historical relationships. High and low forecasts for the exogenous (and thus endogenous) variables are of little use as they do not even consider the possibility of saturation and peak-car demand. He prefers a scenario approach, which we address in section 2.3. Not dissimilar to Metz, Newman and Kenworthy (2011), looking at travel patterns beyond London, suggest six possible causes of peak car use.

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[2] This assumes radial access from the centre of a circle to any point which of course is a simplification. Thus a square power is likely to be too high in most situations, but better than a linear relationship.

[3] C40 (2011) claims that the charge has reduced traffic levels inside the charging zone by 20%, but Givoni (2010) says that other changes introduced at the same time, such as improved public transport, make it difficult to discern the pure effects of the congestion charge.

1 Hitting the Marchetti wall (as presented above).

2 The growth of PT. The authors claim there is an exponential relationship between car use and PT (as shown in figure 2.3 below, based on cross-section data). This graph indicates that an increase in PT from low levels is associated with a larger reduction in car use – both measured in terms of PKM.

3 The reversal of urban sprawl. Again there may be an exponential relationship as shown in figure 2.4. If a city begins to slowly increase its density, the impact on car use can initially be quite strong before eventually tailing off. Hence density has a multiplier effect on the use of PT and walking/cycling, as well as reducing the length of travel. Reversing urban sprawl would reduce the growth in car use.

Figure 2.3 Car PKM per capita versus public transport PKM per capita

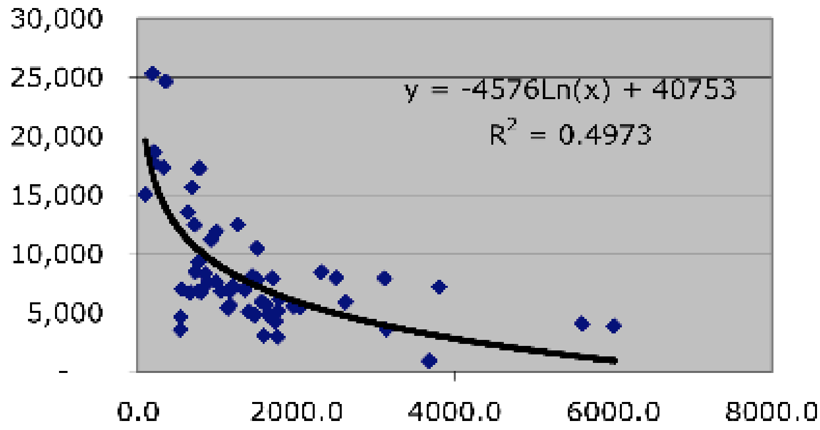
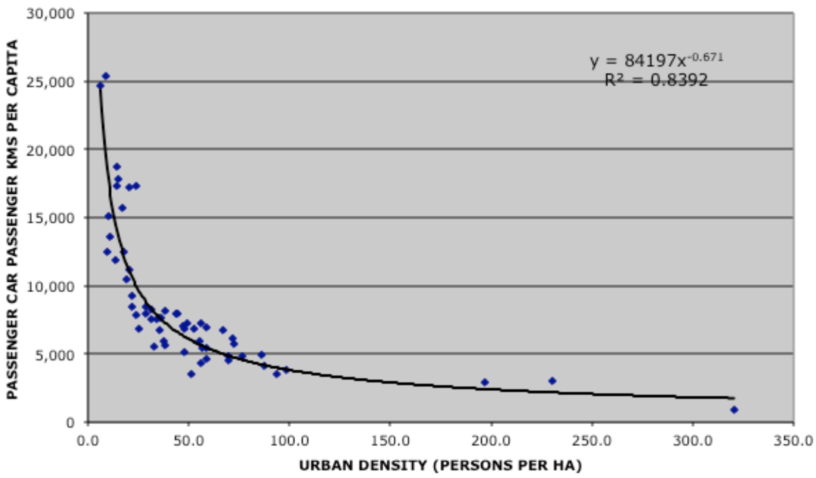


Figure 2.4 Urban density versus private car travel in 58 higher income cities



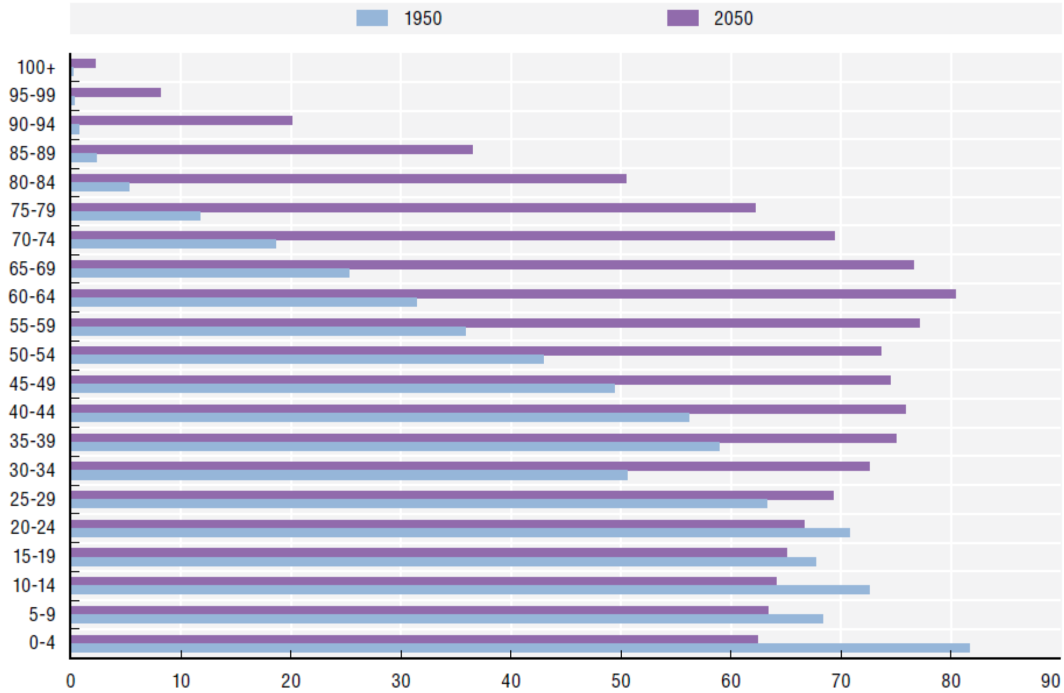
Both graphs could be consistent with the idea that there is a threshold at which PT is simply less costly than private vehicles. Once the volume of people travelling between any two points per time period reaches one (or more) thresholds, the generalised cost of PT (notably time spent waiting and travel time reliability) induces a large scale shift to PT away from private cars?

1 The average age of people (living in cities) in the developed world is increasing and older people tend to drive less, resulting in lower rates of national average car use per capita. However, the age issue is not clear cut. As discussed below older people may be increasing their propensity to travel, albeit not by driving a car. The latter is a cohort effect while the former is an age effect.

2 The growth of a culture of urbanism. Under the 'empty nester' hypothesis older people move from the suburbs to live in the city. It is claimed that this trend has been underway for over a decade and that it is a major contributor to the peak car phenomenon. In other words, urbanisation is a major contributor to peak car, and older people moving to cities and/or to city centres is a major contributor to urbanisation patterns. It is suggested that this is not a fashion, but a structural change based on the opportunities provided by greater urbanism.

3 The rise in fuel prices (noting that the study uses data up to 2008 and that prices peaked just before the GFC).

Figure 2.5 Age structure for Europe + North America + Australia + New Zealand + Japan (millions)



Source: OECD (2008)

Clearly these six factors are not independent. Reactions to fuel prices might include changing one's proximity to work. Less urban sprawl is encouraged by better PT and so on.

In the following section we look in more detail at the evidence for or against the various dimensions of travel saturation.

2.2.3 Evidence

There are many studies on the topic of travel saturation. Davis et al (2012) quote various statistics about driving and travel behaviour, drawing on the following key points to conclude that it is likely, but not certain, that declining travel demand is here to stay.

1 VMT per capita (in the USA) peaked in 2004, before the recession initiated by the GFC. Total miles driven peaked in 2007.

2 Between 2001 and 2009 young people (16–34 year-olds; roughly Generation Y or 'millennials' born 1985–2004) reduced their VMT (number of trips and mean distance), raised their use of PT, biked more and walked more.

3 The prevalence of those without driving licences also increased. This is partly caused by tougher and more expensive graduated licensing laws.

4 The number of vehicles on the road peaked in 2006.

5 Technology provides the means to substitute away from transport or change transport mode. Examples are Skype and Facebook, and smart phone 'apps' that provide real time information about PT and car or bike sharing.

6 More young people than any other age group reported conscious efforts to replace driving with alternatives to transport. One reason given is the desire to minimise negative environmental impacts.

7 Relatively more young people (although also those aged over 60) prefer to live in places that are close to amenities and PT access points.

8 Higher real fuel prices reduce the frequency and distance of car travel.

Davis et al (2012) acknowledge that the economic recession is a factor behind the reduction in VMT by young people, as this group was especially affected by the rise in unemployment, but note that less driving occurred also among young people with jobs and/or those living in high-income households.

As the decline in VKT per capita was evident before the GFC (points 1–4) we can infer that the GFC probably reinforced the trend rather than being the underlying cause. If that hypothesis is true, declining VKT per capita is likely to not only continue for some time, but could be more marked than before the GFC if travel behaviour acquired during the GFC persists, although in the short term a more positive economic outlook could counter this effect.

While one might say it is fortunate new communication technologies have made it easier to reduce the use of private car travel just when its affordability was at a historical low, the differences in attitude by young people to transport and where they wish to live (points 6 and 7 above) do suggest that declining VMT (and especially via driving) per capita is more than a period effect.

Actually, communication technology may not be a substitute for face-to-face contact. More use of online social networking increases the size of social networks, leading to greater travel in aggregate. This generates a complementarity between IT developments and face to face contact (Tillema et al 2010 and The Economist 2012). Thus ICT may induce rather than reduce physical travel. This may also apply to business networking.

Le Vine and Jones (2012), again with data up to but excluding the period of the GFC, stress that London is different from the rest of the UK. Car traffic (but not vehicle ownership) has declined since 1998, caused largely by fewer journeys, not shorter trips. In other places car traffic rose up to 2008. There is little evidence of peak car outside London among those aged over 30, nor among females – at least prior to the GFC. London also has considerably more use of rail, associated with greater patronage rather than longer journeys per passenger.

Separating age effects from cohort effects, Le Vine and Jones (2012) find that for the period 1995 to 2007 very little of the observed aggregate change in car and rail travel in the UK is accounted for by the ongoing changes in the proportions of the population that are in each age group, or that live in different types of location. (Denne and Wright 2016 also found little evidence of a generational difference with regard to New Zealand). Most change in the UK and over that period is attributed to changes in travel behaviour within groups, caused by external factors. Possibilities include:

- shifts in household structure and housing tenure
- much less company car use by men

- less use of cars by migrants (although confounding factors such as location are not controlled for)
- car running costs and congestion
- better PT
- more brown-field development.

Also using UK data, Stokes (2012) documents a pronounced 40% decline in VMT per capita for males aged 17–30 from 1996 to 2010. The rate of decline since the onset of the GFC is not noticeably different from that before the GFC so less affordability seems not to be the main reason. Also the decline in driving by males has not been offset by more driving by females.

The cohort of males in the next age group (31–59) show about half the rate of decline, while the cohort aged 60 and over show an increase in VMT. Cohorts of women in both of these age groups show an increase in VMT. Thus the inference is that irrespective of differences in driving propensity by age at a point in time, the propensity is changing by age over time. Successive cohorts are reducing their VMT. That is, we are seeing cohort effects as well as age effects. (We discuss age and cohort effects below). These age-travel relationships are the same as noted by Le Vine and Jones (2012).

Further supporting evidence cited by Stokes includes:

- Successive snapshots (1988–95, 1995–01, 2002–08) exhibit progressively later access to a car for males. For women the trend is more difficult to discern as it is overwhelmed by greater access at all ages.
- Between 1995–01 and 2002–08 there was a shift in the proportion of people in each age group who call themselves 'main drivers', declining most amongst the 17–23 age group, but increasing almost monotonically from age 31. This is similar for VMT.
- While driving propensity rises with income quintile for males, the propensities are converging as driving by the top three quintiles is declining over time. Interacting income quintile and age strengthens both individual effects. Again for women the age and income effects are much less marked due to a general trend of more driving by women.
- The decline in driving is also most evident among males with jobs, albeit that driving propensity for employed males is still higher than for those without employment. For females the same differences in driving propensity by employment status exist, but in contrast to males there is almost no sign of convergence.
- Deferred couple formation and starting a family is also correlated with less driving. This is analogous to the shift in household structure suggested by Levine and Jones (2012).

The above points are all statistical correlations. Exploring the reasons for the reduction in driving, Stokes (2012) reports that the younger the age group the more prominent is the issue of costs – learning to drive, vehicle purchase, insurance etc, although younger groups still expressed a wish to learn to drive in the future (presumably when they are better able to afford it). Hence as discussed above in the context of the work by Goodwin (2012), affordability is important and is probably influenced by wider economic factors that also delay family formation.

A qualitative study based on 51 interviews of Generation Y people by Hopkins and Stephenson (2015) in New Zealand also lists the costs of car ownership and licensing as a barrier to driving. Other reasons are environmental motivations and access to PT. The authors note that the sample is under-represented by Generation Y with children.

Similarly Delbosc and Currie (2013), based on a survey of 200 young people (Generation Y) in Melbourne find that costs and licence restrictions present significant barriers toward the acquisition of driver licences. The survey could not establish whether this is a short-term delay or whether driving licences might be completely foregone by part of that cohort, but the authors note that providing viable alternatives to private transport may delay the need for young adults to seek a driving licence.

Social Research Associates (2015) use surveys (online and face to face) to investigate travel attitudes, preferences and changes in behaviour of four population subgroups in the UK; younger people, older people, commuters and immigrants. The surveys are not fully random so their main value is in gaining insights about travel behaviour rather than in drawing robust statistical inferences about the whole population. Also while people can express preferences, decisions are made subject to constraints, so observed behaviour does not always align with stated preferences. With these caveats in mind, the main results of the surveys are consistent with the studies discussed above. In particular:

- Young people are very concerned about the cost of driving, widely defined – insurance, licence acquisition, alcohol regulations (lowering the convenience of driving) and so on. Education loans also mean less disposable income. Interestingly, in contrast to Davis et al (2012) and Hopkins and Stephenson (2015), environmental factors do not play a major role in their travel decisions, albeit that the studies relate to different countries.
- Most young people still aspire to own a car but a sizeable minority do not. However preferences are affected by location (urban, rural), access to PT, and life events such as starting a family. Inner city housing is too expensive, but living in the suburbs tends to increase the need for a car.
- Older people cite cheaper (off-peak) PT fares as a reason for travelling more.
- ICT seems to increase the travel time budget (for example being able to work on the train), with real-time information further promoting PT. This is also required for multi-modal journeys which seem to be increasing in popularity. Thus there are both demand and supply effects at work here.
- Migrants travel less than those born in the UK, but the difference diminishes with length of stay.
- London is unusual (as per Le Vine and Jones 2012).

The authors emphasise that the results show substantial differences by socio-economic group, residential location, migrant status and ethnicity (although the latter observations, as is often the case, do not control for the effects of income, employment and so on. This issue is discussed below).

Headicar (2013) stresses the relevance of spatial distribution, especially the rural – urban (notably London) distinction, for understanding peak car. Stokes (2012) also shows that the reductions in driving are strongest in London (supporting Metz 2013 and Le Vine and Jones 2012), where housing affordability is a significant issue and there is a congestion charge. On the other hand it is also an area that is well served by PT, making it easier to avoid driving. Supply affects demand.

In a key study Leard et al (2016), while not denying that changes in driving behaviour do exist and may well become prominent in future, show that demographic and economic factors (notably changes in household income, changes in the number of workers per household and changes in the age of household head – less important) explain most of the change in VMT between 1995 and 2015; the slowdown following the GFC and the subsequent recovery.

Their conclusions are robust to different starting points, different datasets and different model specifications (nonlinear interaction effects and fixed effects).

The increase in the number of workers per household is the dominant explanatory factor after 2010, but the authors caution against assuming causation in this regard because of the possibility of omitted variables such as the number of drivers or the gender of drivers (refer Stokes's (2012) point above). However, omitted variable bias per se does not necessarily compromise causation, rather its estimated strength. The question of causation relates more to simultaneity. Employment status may be as much a function of access to a vehicle as VMT is a function of employment. For New Zealand this question was analysed in Stroombergen and Watt (2003) using two stage least squares, finding that household access to private transport (a car) has a strong effect on determining rates of employment.

Perhaps the key message of Leard at al (2016) is that demographic and economic factors should be thoroughly investigated before reaching for changes in driving habits to explain changes in VMT and VMT per capita. To paraphrase the authors, if VMT is a concave function of income, an increase in the variance of the income distribution, such as caused by an increase in the proportion of low income households (but with no change in the mean), could reduce average VMT. Without allowing for this nonlinear effect, the observed reduction in VMT would look like a change in driving habits.

The decomposition approach used by Leard et al (2016) is applied to New Zealand data in chapter 3.

Supporting Leard et al (2016) and using econometric analysis of aggregate time series data, Stapleton et al (2017) find that changes in the demand for car travel in Great Britain since 1970 can be explained largely by changes in income, changes in the fuel cost of driving (being fuel prices adjusted for changes in engine efficiency) and changes in urbanisation. The income elasticity of car travel is found to be significantly larger than the price elasticity. There is a small effect from changes in the proportion of licensed drivers, but no measurable effect from the diffusion of ICT or changes in income inequality, although the authors caution that data limitations mean these inferences may not be robust. The analysis is based on data that has been normalised with regard to the number of adults so how much of the change in total VKT is attributable to changes in the size of the population is not stated.

Mooney (2017) quotes Brian Taylor (director of the Institute of Transportation Studies at UCLA) who says that when allowing for the later family formation and later house buying of millennials – 'deferred adulthood' – their driving behaviour is not so different from that of previous generations. The drop in VMT during the GFC is attributed to economics, not lifestyle choice.

Similarly for France, Grimal et al (2013) find that the decline in individual car travel can be largely explained by changes in fuel prices, income, GDP and unemployment. There is some saturation in car ownership in high-income locations.

For the Netherlands, Van der Waard et al (2012) find that car travel (driver plus passenger) stabilised around 2005, but they emphasise differences by region, age and gender. There are also fewer trips for leisure and for commuting by younger drivers – in line with more higher-density living. However, the authors find little evidence of saturation in vehicle ownership and driver licence acquisition, but do observe a stabilisation of female participation rates. The contribution of e-commerce, social media etc could not be determined.

Looking at Sweden, Bastian and Börjesson (2014) show that the change in car VKT per adult over 2002 to 2012 can be explained almost purely by economic variables, namely GDP and fuel prices. However, low-income, urban populations have higher car travel elasticities with respect to fuel prices and economic growth. In contrast, high-income, urban populations reveal some degree of saturation in car ownership and in VKT per adult. The authors also emphasise that land use and transport options are important as they affect fuel price elasticities. Also, fuel price elasticities tend to be higher if changes in fuel prices are rapid.[4] As in other countries immigrants own fewer cars and travel less.

Building on their earlier analysis Bastian et al (2016) examine car traffic in six countries (US, France, UK, Sweden, Australia and Germany), again finding that changes in GDP and fuel prices are largely sufficient to explain changes in VKT per capita, albeit with changing elasticities over time. Nonetheless the authors argue that behavioral factors undoubtedly exist. Indeed they may underlie the time-varying elasticities. For example a declining elasticity with respect to GDP per capita was observed in all of the countries, which is consistent with a saturation of car use and car ownership in the highest income segments. Bastian et al argue that such trends for particular socio-economic sub-groups are not inconsistent with aggregate level trends, drawing a metaphorical parallel between the waves and the tide respectively. It is also suggested that behavioral factors may well be induced by the long-term effects of economic incentives and events.

For Germany, Kuhnimhof et al (2016) find that since 2000 car use among young adults (aged 18–29) has declined. Two reasons are posited: an increasing share of young drivers use alternative modes of transport, and gender differences in car travel have largely disappeared. Young men have lower car ownership than previous cohorts and no longer do they drive more than young women. In an earlier study Kuhnimhof et al (2012 obtain similar results for six countries – Germany, France, Great Britain, Japan, Norway and the US.

More generally Kuhminof et al (2016) note diverging travel trends of different socio-demographic groups and speculate that socio-demographic shifts in the population (such as deferred adulthood – delaying marriage and parenthood) and other factors such as the costs of driving and PT accessibility could be important. Like other researchers they wonder whether this cohort will retain its less car-oriented, more multimodal travel behaviour in the future, or if it will eventually adopt the same travel behaviour as past generations.

Litman (of the Victoria Transport Policy Institute, Canada, quoted in Mooney 2017), has found there is a latent demand for neighbourhoods with multiple travel modes and the supply of inner city housing is constrained by policy. In that case a change on the supply side would lead to a change in travel behaviour, namely lower VKT per capita.

The Department for Transport (UK) (DfT) (2015) undertook a comprehensive review (with many good references) of the evidence on road traffic trends and the factors behind them. Their report stresses that the VKT story varies widely by socio-demographic group, location, type of road and type of vehicle:

- Traffic on urban roads shows the least or no growth.
- VKT by vans does not show the slower growth evident in total VKT.
- Car ownership does not show the same slowdown in growth as VKT per capita.
- Lower VKT is primarily due to fewer trips, not to reductions in average distance.
- Trends by gender, age and income are as reported above by Stokes (2012) (who is cited by DfT).
- There is a marked London effect, which is a substantial drop in VKT per capita exceeding that in other cities. It is unclear whether it is a leading indicator.

[4] Infometrics (2014) also found a change effect, rather than a level effect, with regard to the influence of petrol prices, acting via VKT, on road crash fatalities.

The review identified 10 main factors that affect vehicle traffic.

1 GDP, incomes and employment. Confirmed by econometric evidence; a strong historical link that is still positive, but declining in strength. An important consideration here is labour income, which for younger people has not yet attained pre-GFC levels. Accompanying lower rates of employment mean less commuting and less financial ability to own a car.

2 The costs of driving. This is a factor that covers all costs; licence acquisition, vehicle purchase, insurance, fuel etc. it is a more significant issue (again) for younger age groups with lower incomes. There is also an interaction effect in that more efficient vehicles are obtained first by older, higher-income groups, which show the largest decline in VKT per capita.

3 Company car taxation: as analysed by Le Vine and Jones (2012). Changes to how company cars are taxed coincided with the observed decline in driving by middle-aged men in higher-income bands, especially in London. Of course this effect will level out. (Changes to fringe benefit tax in New Zealand could have had a similar effect.)

4 Population growth, population density and urbanisation. As with other studies discussed above more people means more VKT, but there is less driving and less travel in urban areas (even controlling for self-selection bias). The authors suggest that this is not a major factor in declining VKT per capita as movement from rural areas to urban areas is not large. Still, the behaviour of newcomers could affect that of incumbents. With regard to the supply side, (perceived) improvements in PT frequency and reliability assist the decline in metropolitan car use, although the authors note that the increase in PT use is much smaller than drop in car use.

5 Migration. It is observed that migrants travel less by car and tend to live in urban areas. Over time, however (as noted above), their behaviour may change if they assimilate.

6 The impacts of technology. Telecommuting substitutes for physical commuting but the effect is small, while the effect of online shopping is unclear. Likewise for social media, although see Tilemma et al (2010) as discussed above. The effect of autonomous vehicles could be to increase the travel time budget, implying more travel.

7 Household and family formation. Gaining a partner and having a child are associated with a higher likelihood of acquiring a car. So is employment. These changes are occurring later in life for millennials – deferred adulthood. Whether this is a response to economic factors (costs) or social factors (more independence) is not apparent. Indeed even higher female labour force participation could be driven by economic factors or social factors. Whatever the case, the review explains the effect is not large.

8 Attitudes to driving and the environment. All age groups like the flexibility of access to a car even if mostly younger age groups express a desire to drive less. The authors suggest that environmental concerns have not been a major factor in the decline in VKT per person.

9 Market saturation. The review cites Metz (2013) and Goodwin (2012), but observes that car ownership continues to rise and the fall in car use is attributable to a mix of many effects. It seems though that the car ownership saturation theory is being taken too literally. While it is true that more households are acquiring a second car, the real issue is ready access to a car. A second car is more convenient for households. It could also reflect the tendency for young people to leave home later – the deferred adulthood effect again. Of course as discussed in section 2.2, the observed reduction in VKT per capita does not prove the hypothesis.

10 Network effects. The authors relate this mostly to the supply side. Inadequate road capacity leads to congestion that not only increases expected travel time, but also increases the variance of travel time, which can be worse. Other factors include parking scarcity and the presence of bus lanes.

The DfT (2015) report briefly mentions other factors such as shared cars, changing trends in educational participation and land-use policy – notably more brown-field redevelopment for both housing and businesses. The last point was also noted by Le Vine and Jones (2012).

A rather different approach is taken by Tilley (2016). The various factors that affect travel are grouped into three layers, more or less reflecting the time period over which they act:

1 Period effects: mostly macroeconomic factors such as growth and recession, government transport policies, and fuel prices. Tilley notes these factors may also have longer term effects.

2 Mid-structural effects: operating at a moderate rate of change; suburbanisation and its reversal, new transport technology, electronic media and communications, inequity arising from housing market problems and changes in life expectancy.

3 Deep structural effects: occurring at an almost imperceptible rate of change; dispersal of families, delayed childbirth, roles of women in society (dual caring role of the baby boomer generation) expectations of mobility (driving licence or not, long distance travel).

Tilley claims that understanding the simultaneous operation of these three layers is conceptually important to interpreting mobility trends and understanding future mobility. As a framework to assist one's thinking this may be true, but it is not straightforward to operationalise the layers into quantitative analysis.

Reverting to the DfT (2015) review, in summary most of the change in total VKT and VKT per capita is attributed to economic factors: income, employment and the cost of car ownership. Affordability is more of an issue for younger people, but those people are also relatively more 'technology savvy', more prepared to work from home or live closer to work, and generally more concerned with the environmental effects of travel. Nevertheless these findings are not universal. As we have shown above, some researchers have found little emphasis on environmental effects for example. As the DfT (2015) authors say there is not a one size fits all hypothesis to explain the trends.

Nevertheless with the more positive outlook for income and employment, growth in total VKT has resumed and is expected to continue, albeit at a slower rate akin to that before the GFC, due to even slower growth in VKT per capita. In some areas traffic may decline due to the influence of factors such as the age composition of the population, urbanisation, congestion, ICT and better PT. Have the advances in ICT and the provision of PT been a response to travel preferences or is the causation in the reverse direction? Has demand led supply or has supply led demand?

Historically these non-economic factors have had mostly marginal effects, but they will be more dominant if they become entrenched in currently young cohorts. We may then see evolving cohort effects rather than period effects. As Le Vine and Jones (2012) say:

> *Multivariate econometric analysis will be essential to disentangle several of the various explanations for changing relationships, such as cohort effects versus simple time trends, effects arising from changing cost structures, policy effects versus changing attitudes, the effects attributable to the many variables which are correlated with each other, and causality as opposed to correlation.*

To accommodate the uncertainty in its travel demand forecasting the DfT (2015) advocates scenario analysis with the national transport model. Lyons and Goodwin (2014, p2) neatly summarise:

There is no professional consensus backing either the official forecasts or any specific alternative, and a strong implication is that methods of policy formulation and project design should test robustness to a much wider span of feasible futures than is reflected by traditional methods involving rather narrow bands of statistical uncertainty.

2.3 Scenario approach

The vast range of uncertainty about the future of travel demand – how it will be affected by demographic, economic and technological factors, means that (as advocated by Metz 2013 and DfT 2015) a scenario approach is required to understand future pathways for travel demand. This is not a substitute for better analysis, but rather a framework in which the analysis is done. We will return to this in section 4.5. As an illustration of how significantly different scenarios can be, consider four scenarios reported by Le Vine and Jones (2012):

1 Company cars. If company car mileage were to disappear completely (continuing an earlier trend), without any corresponding increase in personal car mileage, total national car mileage per person would be reduced by a further 10%.

2 Gender comparability. If women's car use rises over time to the same levels as men across the age spectrum, this would add 35% to the average national car mileage per person.

3 Generational change. If those currently in their 20s (and younger) maintain their lower mobility characteristics as they age, this would eventually –as the cohorts age – imply a decrease in per-person driving mileage of approximately 20%.

4 Increases in rail market penetration. In 2005/07 18% of Londoners used surface rail, up from 15% in 1995/97. Outside London the corresponding figures are 4% and 7%. If these proportions grew to 20% and 10% respectively, per-person rail mileage would increase by around 40% from its 2005/07 level.

Zmud et al (2014) provide a comprehensive report to assist transport decision makers understand how socio-demographic changes over the next 30–50 years may affect personal travel in the USA.[5] To this end the researchers developed a system dynamics (SD) model (Impacts 2050) to explore four scenarios that differ with regard to economic growth, technology, social attitudes etc, based on eight underlying trends (in the USA). The scenarios are momentum (in essence a business-as-usual scenario), technology triumphs, global chaos and gentle footprint. The eight trends are:

1 Population size and growth

2 Population greying: aging

3 Population browning: proportionately more Hispanics and Asians

4 Changing workforce: older, more female, more diverse

5 Blurring of city and suburb (residences and workplaces in both)

6 Slower household formation

7 Generation C: connected, communicating, computerised, communities

8 Greater environmental concern.

[5] At our client's request we have looked at this report in considerable detail. See also appendix A.

Each of these trends is associated with different impacts on travel demand within metropolitan areas, whether per capita or in total. Of course while one can easily make qualitative statements about the effect of the various trends on travel demand, such as that an aging population implies relatively less demand for work-related travel (offset to some extent by higher labour force participation of older people as pension age eligibility rises), actually estimating how much less entails rather more rigour.

Hence the development of a model (an SD model) that has – indeed requires – quantification of the eight trends and of the relationships between the trends and travel demand. The authors make the point that travel demand models usually emphasise statistical accuracy (exact numerical parameters and functional form) over structural accuracy (correct variables and causal relationships) which, while appropriate for short term forecasts, is not appropriate for longer term scenarios. Historical relationships are less likely to apply. An SD model with its emphasis on the dynamics of stocks, flows and feedbacks suits this context.

The eight trends are too vague and qualitative for modelling. Thus to define the scenarios the research team first defined six key drivers:

1 Population size and growth

2 Geo-demographics of the population

3 Population structure and composition

4 Household based economic activity

5 Cultural and social diversity

6 External factors interlinked with socio-demographics – urban form, technology and infrastructure.

Unfortunately even identification of these drivers is not sufficient for modelling purposes. The model itself has five sectors, but it is not clear how the above six drivers of the scenarios translate to the five model sectors. They are as follows:

1 Demographic: The model has age (six groups), household type (four), acculturation (native born, foreign born with less than 20 years, foreign born with more than 20 years in the USA), ethnicity (four), labour force status (two), household income (three) and residence area type (three). This yields 184 socio-demographic groups. Except for ethnicity and birthplace these variables change over time, trivially in the case of age and according to transition probabilities for the others.

2 Travel behaviour: For every socio-demographic group the model has car ownership (three categories), trips per day (two; work and non-work), mode (four types) and trip distance.

3 Land use: Three types of land (urban, suburban, rural) and four uses (residential, non-residential, developable, protected). Land release rates are largely exogenous, but can be set to react to demand emanating from the demographic and employment sectors.

4 Employment: Three types of land as above and three types of jobs – retail, service and other. Rates of job creation, loss and migration seem to be exogenous. There is no production sector as such to demand labour and thus no explicit allowance for capital-labour substitution.

5 Transportation supply: Three types of land as above and five types of use – freeway, arterial, and other roads, plus rail and non-rail (mostly bus) routes. Changes to capacity are exogenous. Demand for transport space comes from the demographic sector.

The first two sectors are the most important parts of the model. The transition probabilities in the demographic sectors are estimated from the Panel Study of Income Dynamics[6] and census data. The travel behaviour sector is the only sector with empirically estimated relationships using the US National Household Travel Survey (NHTS). More detail on this sector is presented in appendix A.

The model is applied to five metropolitan locations in the USA: Atlanta, Boston, Detroit, Houston and Seattle, although the authors note that some of the county level data had to be estimated using iterative proportional fitting as unit record census data was not available.

The four scenarios are applied to each location. Hence the output of the model is substantial. Confining the results to travel demand, eight indicators are presented in the report. Table 2.1 below is compiled from table 6-7 in the report where results are given in five categories: more than 25% increase, increase of 10–25%, change between -10% and 10%, decrease of 10–25%, and decrease of more than 25%. However, summarising across the five locations means that the changes in some indicators span more than one interval. So in table 2.1 for example, <-25% means a decline of more than 25%.

It would seem to be the case that the lower automobile VMT observed in recent years in the USA (and in other countries) has been projected forward in all scenarios, albeit to varying degrees – again for intra-city travel. (As noted above the decline in inter-city VMT may be stronger due to cheaper air travel). The preponderance of results is clearly towards less travel per person – for both work trips and non-work trips, more car sharing, less car ownership, and thus more use of other modes. However, as discussed above it is not clear exactly what is being assumed or put into the model, such as:

- a permanent shift in tastes away from private car travel, initiated by environmental concerns for example
- technology providing more opportunity to substitute for personal travel – such as working from home
- permanently higher real fuel prices (and low economic growth) that make travel relatively less affordable
- the aging of the population coupled with the observed lower VMT per capita with age. Similarly with regard to non-white ethnicity.

Table 2.1 Selected indicator trajectories 2010–2050

	Momentum (BAU)	Technology triumph	Global crisis	Gentle footprint
Population	>10%	-10% to 25%	-25% to 10%	>10%
Auto VMT per capita	-25% to 10%	-25% to 10%	<-25%	<-25%
% non-car owning	-10% to 25%	-10% to 10%	>25%	>25%
% car sharing	-10% to 10%	-25% to 10%	>25%	>10%
Average car occupancy	-10% to 10%	-10% to 10%	10 to 25%	-10% to 25%
PT mode share	-10% to 25%	-10% to 10%	-10% to 25%	>25%
Walk/bike mode share	-10% to 10%	-10% to 10%	>25%	>25%
Work trips per capita	-25% to -10%	-25% to 10%	<-10%	<-25%
Non-work trips per capita	-10% to 10%	-10% to 10%	<-25%	<-25%

[6] The PSID is panel survey of households that has been running for many decades. See: www.src.isr.umich.edu/projects/panel-study-of-income-dynamics-psid/

Overall, while the four scenarios (and five locations) provide plausible pictures and bounds with regard to the effects of future demographic changes on travel behaviour, they all need an explicit caveat saying something like:

> *... assuming that a particular demographic group (age, work status, household type for example) in 2050 will have the same travel behaviour (vehicle ownership, mode preference etc) as that demographic group had around 2014.*

The scenario modelling approach to understanding future travel demand is a great improvement on merely using high and low growth assumptions for population and GDP, but its usefulness really depends on being able to relate the output from a model to what is being put into it.

2.4 New Zealand focus

2.4.1 VKT history

While in a broad sense we would expect the findings for countries such as the UK, USA and European countries to also apply to New Zealand, we discuss below some New Zealand specific studies.

Abley et al (2008) look at travel demand by purpose of trip and trip mode. They used data from the New Zealand Household Travel Survey (NZHTS) covering the period from 2003 to 2006, but the years are combined to form a single snapshot view. The number of trips and distance per day show the standard approximately inverted U relationship with age. Unsurprisingly the amount of travel is strongly associated with the number of cars to which a household has access and to the size of the household (but possible interaction between these two variables is not explored). The number of trips rises more or less linearly with personal income, but the association changes for different modes: declining with income for bus, U-shaped for walking and no relationship for cycling.

The Ministry of Transport (2009) also discusses the inverted U relationship between age and VKT, peaking when people are in their 40s (and also between age and time spent travelling). Other sections look at reasons for travel, region, mode and crash risk, but there is nothing on whether the age-VKT relationship is changing, nor on economic factors. See also Ministry of Transport (2017).

The Abley et al (2008) report is updated in Milne et al (2011) with four more years of data. Again the emphasis is on trip purpose and mode. This time though the authors have looked at changes over three time periods 2003–06, 2006–08, 2008–10. For Wellington and Christchurch they observe fewer trips per household, but Auckland trips peaked in 2006–08, although the authors note this could be due to sampling error. In other locations there is no consistent trend.

A simple ANOVA model was developed for household trip generation using population age profile, car ownership and household type as potential ‘explanatory’ variables. Age was found to be insignificant. Car ownership has the most explanatory power. As the authors readily acknowledge, more explanatory variables are required. For example, income probably affects car ownership so changes over the sample period could be capturing the effects of the GFC. Also changes in urban density would be likely to affect the demand for travel in metropolitan areas.

Conder (2009) reviews different types of car ownership and related models, and updates a car ownership model for New Zealand using aggregate national time series data. Explanatory variables are GDP per capita, car prices and a time trend. Unfortunately car saturation is assumed *a priori*, but it is responsive to the age composition of the population and economic factors. A cohort model is presented as a theoretically better alternative, but rejected because of data requirements. While the report does not deal specifically with socio-demographics and travel demand, it makes a number of relevant observations:

- Up to 2006 there was an almost monotonic increase in vehicle ownership.
- The number of trips increased at a slower rate than car ownership between 1989 and 1990, and 2003 and 2006. Thus the number of trips per vehicle declined.
- The number of cars per household is related to income and household size.
- There are fewer vehicles per capita in Wellington than in Auckland or Christchurch, suggesting an effect from urban density and PT availability.

Victorio (2011) develops some macro-aggregate transport forecasting models using various combinations of fuel prices, population, GDP, total consumption and employment as explanatory variables. The estimation period is quarterly from 2002 to 2010 inclusive. While the econometrics is more or less valid, the theory behind the specification of the equations is fairly weak. For example total consumption is intended to capture travel for shopping trips, the population variable makes no allowance for the age mix, and including employment could invite simultaneity (as discussed above). In general the results support the hypotheses of fuel prices and population being the main determinants of personal travel, although their influence seems to wane considerably once allowance is made for non-stationarity. It is not always entirely clear which results relate to what models. Unsurprisingly the pure forecasting models (VAR and VEC) are not particularly illuminating from a structural perspective.

A clear exposition of the role of macroeconomic variables is demonstrated in Schiff and Small (2014) in the context of forecasting revenue from fuel excise duty and road user charges, which depends critically on VKT

Frith et al (2012) finds rising VKT per capita among older age groups, still within the context of a cross-sectional inverted U shape between travel and age. Nonetheless the authors estimate that not taking the aging population into account overstates the increase in household travel by around 40% by 2056. However, as most of the data series in the report do not extend beyond 2009 it is not clear to what extent the projections may be affected by the GFC.

Simic and Bartels (2013) emphasise the importance of including factors such as income, employment and vehicle operating costs when developing transport demand models, but unfortunately their report has no analysis of travel behaviour. The report focuses on how to develop econometric models that the Transport Agency could use to estimate the extent to which the relationship between income and passenger vehicle travel has changed over time. Actually building any models was out of scope.

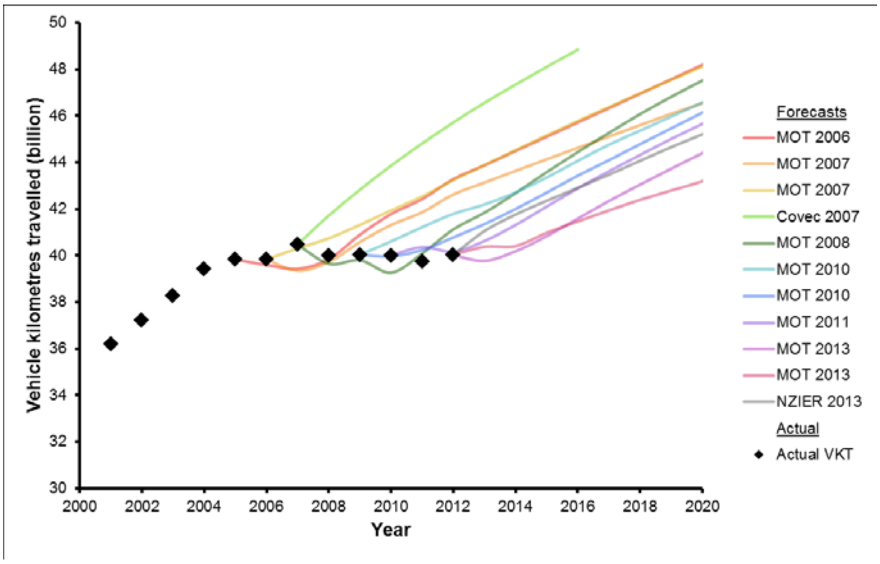
Curran (2014) in a report for the Ministry of Transport looks at many of the factors discussed above, essentially asking whether the decline in VKT per capita (or in total) in New Zealand is structural (the saturation or peak car hypothesis) or a temporary phenomenon induced by the GFC. Like those for the UK, forecasts of VKT for New Zealand keep delaying the upturn after the flattening ostensibly caused first by high fuel prices and then by the GFC (see figure 2.6).[7] Curran notes that between 2004 (the peak in per capita VKT) and 2013, New Zealand‘s GDP per capita increased by about 12%, while VKT per capita fell by about 6%. However, as will be demonstrated in chapter 3, this type of aggregated observation does not do justice to the complexity of the relationship between economic and socio-demographic variables, and VKT.

As per Stokes (2012), there is a relationship with age at a point in time, but it seems to be changing by age over time as well. Similar trends apply to the proportion of people in each age group who hold a

[7] The NZIER projection was derived under assumptions stipulated by MoT and was not NZIER’s preferred projection.

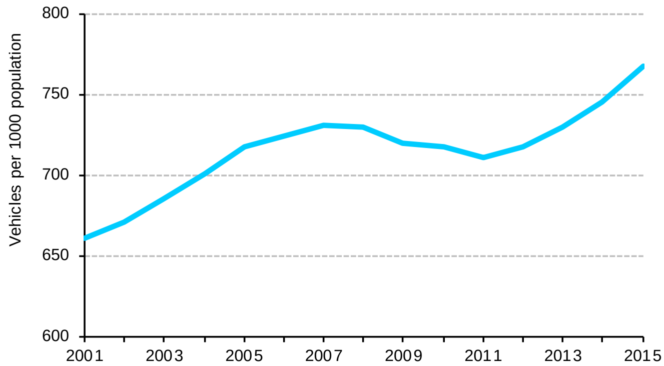
driving licence, although with regard to Stokes's finding, this does not mean that licences will not be sought later.

Figure 2.6 Historical light vehicle VKT forecasts and actual



Curran's analysis does not enable one to distinguish between structural and cyclical effects. It is quite possible, as demonstrated by Leard et al (2016), that economic factors (income, employment and the cost of travel) are very influential and could have nonlinear effects when interacting with age. The latest data (subsequent to Curran 2014) shows strong upturns in light vehicle ownership and total light vehicle travel since 2012 (figures 2.7 and 2.8). After peaking around 2004 there is also an upturn in light vehicle travel per capita (figure 2.9), but the implied amount of travel per light vehicle has continued to decline.[8]

Figure 2.7 Light fleet ownership per 1000 population



[8] In addition, http://transportblog.co.nz/tag/vkt/ has some interesting graphs and www.transport.govt.nz/land/ has summary tables drawn from the NZHTS. It has been suggested that the fall in travel per vehicle might be due to the increasing average age of the vehicle fleet. However, as travel per vehicle is equal to travel per capita, divided by vehicles per capita, this hypothesis would mean that the age of available vehicles determines vehicles per capita or travel per capita. The reverse seems more likely.

Figure 2.8 Total light vehicle travel

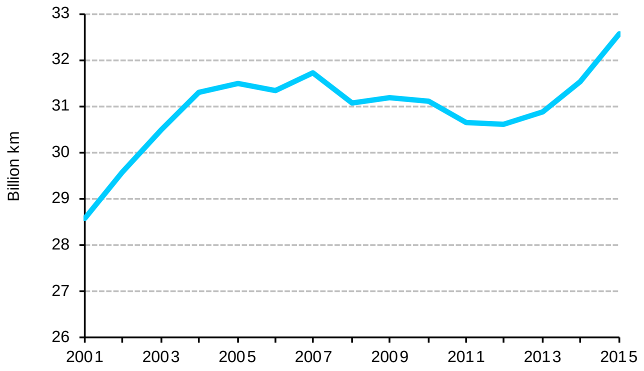
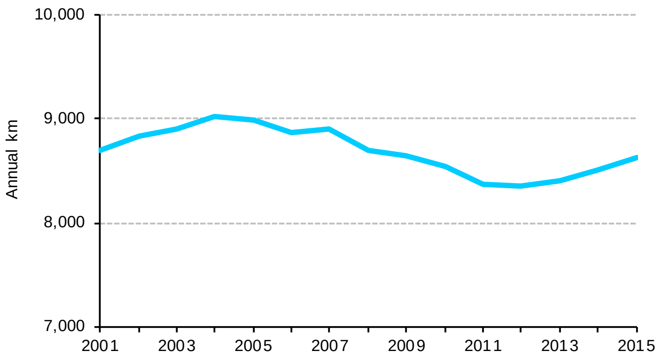


Figure 2.9 Light vehicle travel per capita



Source for figures 2.7–2.9: Ministry of Transport Vehicle Fleet Statistics (www.transport.govt.nz/resources/vehicle-fleet-statistics/#annual). Light vehicles exclude motorcycles.

We might conjecture that in New Zealand with its lack of good PT between cities and towns, that car travel per capita (and ready access to a car) is likely to have some way to go before it peaks, especially with many Roads of National Significance projects coming on stream – a supply side effect.

Sheng (2016) finds a very high value (greater than three) for the elasticity of car ownership with respect to GDP per capita and a stronger demand for cars by younger people (aged 15–24) than by any other age group. Sheng uses the ‘seemingly unrelated least squares’ approach to estimating modal demand, which is a major improvement on single equation techniques that fail to consider the fact that contemporaneous error terms across mode demand equations must be correlated. However, the results (and thus conclusions) are compromised by the simple specification of the equations – in particular no allowance for lags and a poor proxy for vehicle operating costs.[9]

Most of the research reviewed above on the demand for travel does not go very far beyond cross-tabulation, in contrast to statistical or econometric analysis that attempts to distinguish between confounding factors. Indeed Stephenson and Zheng (2013) lament the lack of statistical rigour in New Zealand models of transport demand. In that paper and in Stephenson (2016) they do something about it.

[9] Sheng’s main focus is actually on journeys to work, not aggregate VKT. Using a spatial Durbin model she clearly demonstrates the importance of allowing for urban form (spatial correlation and autocorrelation) in mode choice.

The latter report describes the regional land transport demand model (RLTDM) that we use in chapter 5 to produce projections of travel household demand.

The effects of socio-demographics on the demand for land transport are embedded within the model's estimated equations, so scenarios will reveal the full extent of their effects. Nonetheless it is useful to summarise the main structure of the model and the results gleaned from it.

- Inter-regional migration is based on origin-destination and age-specific migration probabilities.
- The model has relationships between population growth and density, and functional relationships between congestion and costs of travel.
- Personal travel demand is modelled in two stages: journeys per household and distance per journey.
- Regional mode of travel choice is based on conditional logit models of discrete choice.

Analysis of journeys by household and by region shows that:

- Regional sensitivity to the costs of travel reflects a number of underlying factors including population composition and relative incomes.
- People who live alone (often retired people) and sole parent families tend to be more income constrained than most and exhibit greater sensitivity to travel costs than other households.
- In densely populated and urban regions, where average speeds are relatively low, increased speeds have a positive effect on the number of journeys. In contrast, in rural areas where average speeds are relatively high, an increase in speeds reduces the number of journeys, though this may be offset by longer journeys.

Key drivers of changes to travel demand include:

- A 10% increase in the average costs of travel (dollars per km) is associated with a 0.3% reduction in travel demand (VKT, which is the number of journeys multiplied by average distance per journey), though this value varies according to shares of costs in household budgets and over time as costs rise and fall.
- A 10% increase in the percentage of people unemployed yields a 0.1% reduction in travel demand nationally, holding all else constant while controlling for differences in density across regions – impacts are larger in more densely populated regions.
- A 10% increase in population density is associated with a 0.8% increase in travel demand, holding all else constant, but controlling for differences in unemployment and travel speeds across regions – impacts are larger in less densely populated areas
- A 10% increase in travel speed is associated with a 14% increase in travel demand, holding all else constant while controlling for differences in density across regions.

Analysis of mode choice resulted in a finding that when cost increases are confined to one mode consumers find a substitute for that mode, but changes are not large. For example, a 10% increase in the cost of driver travel per dollar of household income causes an average 0.2% reduction in driver trips. Mode substitution is stronger in urban areas such as Auckland and Wellington where population density is higher and PT accessibility is greater.

As noted, in chapter 4 the RLTDM model will be used in a forward-looking capacity to understand the effect of socio-demographic factors on the demand for personal land transport. However, this report makes no comment about the validity of the model.

2.4.2 Indicators

In the absence of a definitive picture of the effect of socio-demographic factors on travel demand in New Zealand, we undertake our own analysis in chapter 3. Before that, however, we broaden the scope of the literature review and look at whether there is other information, apart from direct travel surveys, that might provide some clues about whether changes in VKT (especially car use) per capita are occurring? Even with comprehensive future travel demand scenarios (refer chapter 4), such information could provide clues about whether any particular scenarios are more likely than others.

Consider some aspects of travel/car saturation theory, mentioned by DfT (2015) and others:

1 Longer life expectancy, which allows more time for education and family formation – the deferred adulthood hypothesis

2 More jobs in service industries, including working from home

3 More people living in cities which, coupled with less housing affordability, suggests more apartments and town houses rather than detached houses in suburbs. (This is where a metropolitan, non-metropolitan distinction may be very important. Aggregating Auckland, Wellington, Christchurch, Hamilton, Tauranga and Dunedin, in comparison with the rest of New Zealand could be quite meaningful.)

4 Improving PT

5 Rapidly advancing communications technology

6 Rising generalised cost of private car use

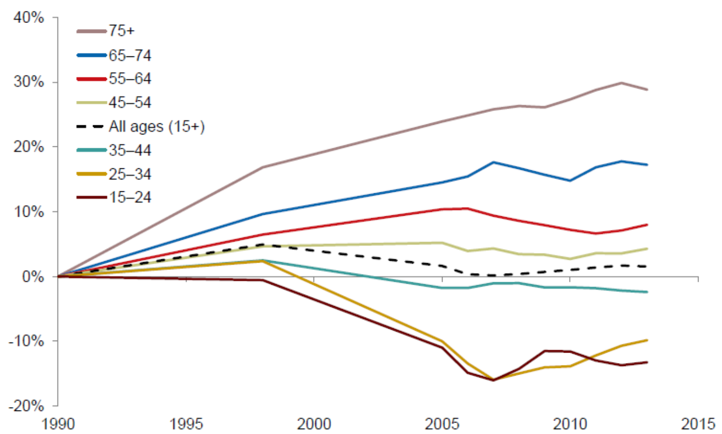
7 Changes in income and employment.

2.4.2.1 Demographics

Increasing life expectancy is well documented, see for example Christensen (2009) for a general discussion, and Statistics NZ (2016b) and Jackson (2011) for information specific to New Zealand. Greater life expectancy may increase total VKT even if average VKT per capita declines – this is the same effect as an increase in population. However, barring major medical advances deferred family formation cannot continue indefinitely, although average family size could continue to reduce for some decades yet.

Allied to this is the decline in driver licensing (discussed above). Denne and Wright (2016) mention the issue, suggesting more difficult tests, urbanisation and PT availability as possible reasons (see figure 2.10). Again though it may just be a deferral.

Figure 2.10 Driver licence possession (change since 1990)

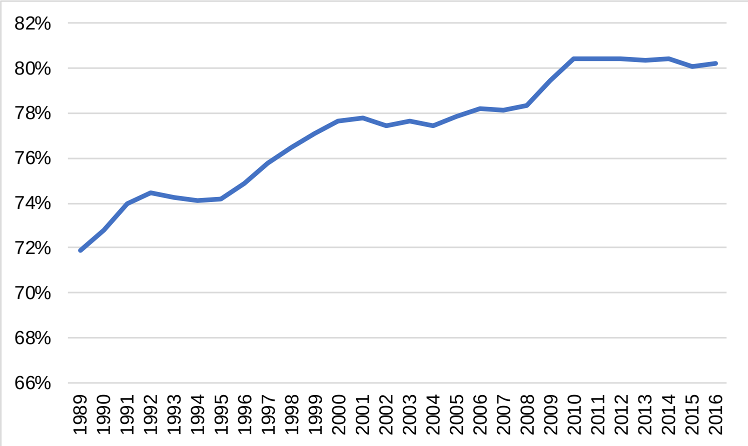


Source: Denne and Wright (2016)

2.4.2.2 Service employment

The share of total (non-agricultural) employment, measured as filled (full or part-time) jobs, accounted for by service industries has risen since at least 1989 (refer figure 2.11).

Figure 2.11 Share of services filled jobs in total non-agricultural filled jobs



Source: Statistics NZ data from Infoshare

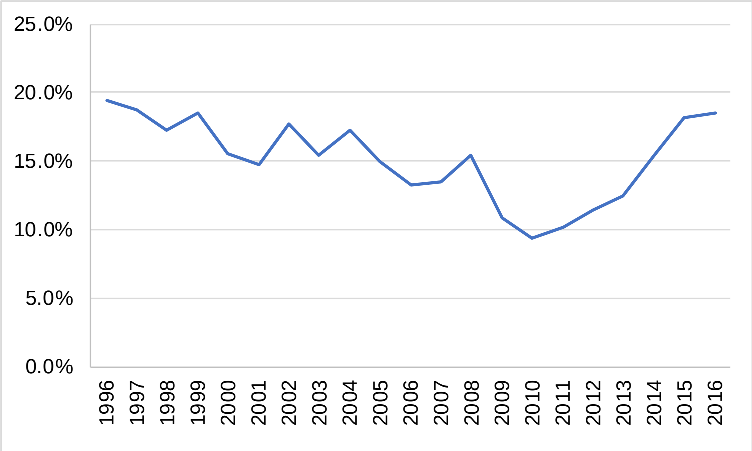
In recent years the share has been stable at around 80% so there may not be much downward pressure on VKT per capita from this angle in the immediate future. Nevertheless, service industries tend to be more labour intensive than manufacturing, and the demand for services (beyond basic services) is income elastic. As societies become richer a large proportion of household expenditure is allocated to services. An aging population may also lead to more employment in the aged-care industry, so again more service industry employment.

Labour substituting technologies such as automation and robotics may further reduce the demand for work related travel and commuting.

2.4.2.3 Housing, urbanisation and land use

With regard to the third point above, figure 2.12 shows the floor area of building consents for new apartments, townhouses and units, as a proportion of floor area for all dwellings, for the last 20 years. Before 2010 there was a bumpy, although clear downward trend. Since 2010 the change has been monotonically upward. Whether this is attributable to the sharp increase in urban land prices over the last five to six years, the cost of travel, or to a change in the type (and location) of housing in which people wish to reside requires further analysis. We can say that the consent data is consistent with less demand for metropolitan travel. On the other hand Donovan and Munro (2013) ascertain that urban form has only a modest impact on transport outcomes.

Figure 2.12 Building consents: ratio of floor area of apartment and flats to floor area of all dwellings



2.4.2.4 Public transport

In (at least) two cities there is increased use of bus lanes, bus priority at traffic lights, more real-time information on bus and train arrival times, and mobile phone applications for bus and rail networks. There is an expanded rail network in Auckland. All cities have Uber. In Wellington and Auckland the share of commuting journeys taken by rail and bus has risen over successive census years – refer figures 2.13 and 2.14.

Figure 2.13 Share of travel to work journeys by PT and active modes, Auckland

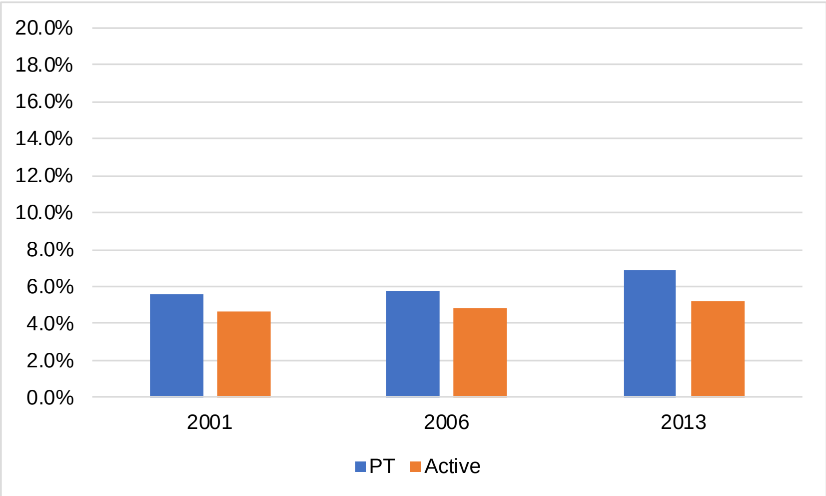
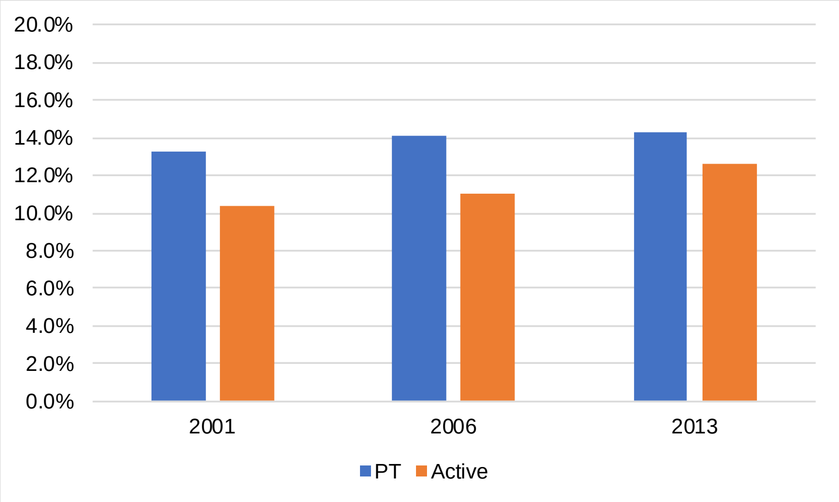


Figure 2.14 Share of travel to work journeys by PT and active modes, Wellington



Source for figures 2.12–2.14: Statistics NZ Census data

These graphs also show a steady, albeit slow increase in the proportion of commuting journeys that are walked or cycled (active mode), reinforcing the notion that more people are living closer to where they work and/or that such modes are more attractive (for reasons such as price and safety) than they were before 2001. Rive et al (2015) predict sustained growth in PT use, especially among Generation Y. Denne and Wright (2016) show that Auckland's PT patronage is well behind other Australasian cities when population density is considered, suggesting considerable scope for PT growth.

With regard to long-distance travel we can probably ignore rail, but part of the reason for slower growth in VKT by car is likely to be the increased availability of cheap domestic air travel. While families would drive between say Auckland and Wellington, couples and individuals might fly (and rent a car at the destination).

2.4.2.5 Communications technology

Communications technology is constantly improving – better audio-visual connections via the internet, faster speeds, virtual reality, virtual private networks and holography. Holographic imagery coupled with voice communication could be the future for some person-to-person communication, reducing the need for both business travel and leisure travel. However, as mentioned above, the widening scope of social networks may imply complementarity (rather than substitutability) between communications technology and face-to-face contact – that is travel. Thus the impact on VKT per capita is unclear.[10]

2.4.2.6 Generalised cost of car use

The DfT (2015) notes a higher generalised cost of car use in the UK. We are not aware of any studies that compare the generalised cost of private car use in New Zealand with that in other countries. Apart from the standard rate of GST the only additional tax on vehicles in New Zealand is the annual registration fee. Private use of a vehicle provided by a company attracts fringe benefit tax, but this is not unique to vehicles. Imports of second-hand vehicles have helped to keep downward pressure on used car prices.

Petrol attracts excise duty (a specific tax), but fuel prices are currently low in real terms. Only two sections of road are tolled. However there are other costs to consider. Congestion is the most obvious, be it paid for in

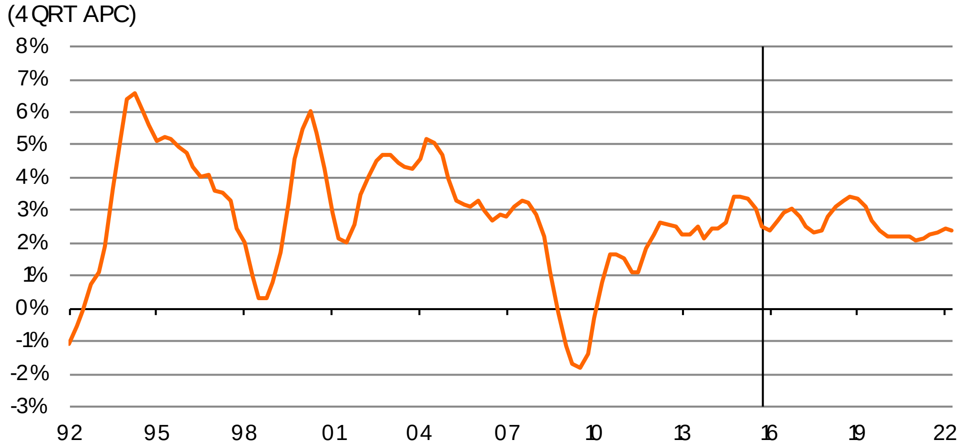
[10] Bowie et al (2017) discuss the effect of the internet on transport demand and look at 'mobility as a service'.

time or in the form of road pricing to substitute for the time cost.[11] Obtaining a driving licence is costly, both in terms of money and time. Inner city parking is becoming scarcer, and speed and alcohol limits tend to drift down. All of these factors raise the effective price of driving a car and travelling in a car.

2.4.2.7 Income

Income is a loose term. It can mean GDP, national income, household income, or even just labour income. As discussed in DfT (2015) the measure used can be important in understanding different aspects of travel behaviour. Nevertheless adopting GDP as a longer run reasonable proxy for all broad measures of income, figure 2.15 shows a strong recovery after the GFC that lies behind the upturn in VKT illustrated in figure 2.8. Solid growth is projected to continue for the next five years. Its effect on VKT may well dominate all other factors.

Figure 2.15 Expenditure GDP



Source: Infometrics' calculations, based on Statistics NZ data

The above variables form part of a wide collection of information that can help to decide whether there is a long-term structural change in (mostly metropolitan) land travel per capita – the amount and the modal mix (away from driving private cars), and whether economic and population growth will nonetheless dominate total VKT.

Of course direct surveys of travel behaviour are indispensable for assessing what is happening at present (or more precisely the recent past). They show trends in different types of travel (such as education versus social interaction) and thus provide insight into changes in travel behaviour, but richer insights can be gained by complementing these surveys with the above indicators (Tilleys 2016, three layers).

As noted above, if less travel and less driving are going to be a feature of the economy, both demand and supply factors need to align. A preference for less driving, (whether because of concern about climate change or impeded by cost) is more difficult to realise without fast internet and good PT. To the extent that supply side effects operate (PT provision for example) it may be possible to influence travel demand rather than passively trying to predict it.

There may also be a positive feedback or hysteresis effect generated by greater consolidation of such preferences. If so, when those who are currently aged under 30 eventually acquire the same employment

[11] See Smith et al (2009) for a disaggregation of travel costs by mode, and for congestion data: www.transport.govt.nz/ourwork/tmif/networkreliability/nr002/

and income levels as their parents (even if at a slightly older age) their current travel patterns will persist to some extent.

Table 2.2 summarises the demand and supply side factors.

Many of the influences listed seem to be heading in a direction consistent with less travel and less private car use – some more than others, but quantitatively they may not dominate. While all the research that we have seen agrees that the GFC-induced recession has clearly affected travel behaviour, it is not clear whether the GFC effect is strictly temporary or reinforcing some pre-GFC trends. Coupled with the theories of a travel time budget and decreasing marginal utility of choice, it seems plausible that a trend reduction in private car use per capita is occurring, especially amongst some socio-demographic groups, albeit masked by cyclical factors. The rate of reduction is not clear, nor its endpoint, but investment in transport infrastructure cannot ignore the possibility.

Table 2.2 Factors affecting demand for and supply of travel

Factors that reduce the demand for (car) travel	Factors that enable the reduction in demand to be realised
(1) Aging population, increased life expectancy and deferred household and family formation, etc	(6) Better PT and access to it, including Uber etc
(2) Environmental issues such as fossil fuels and climate change	(7) Better telecommunications technology
(3) Price signals – generalised cost of travel and of car operation in particular	(8) More service industry jobs
(4) Income (disposable, eg after student loans)	
(5) Preference for inner city, medium density living	(9) Enabling mixed-use land development

There are, however, some developments that could put travel demand back on to a strong upward path, as figure 2.8 seems to be suggesting. The most likely are:

1 An upturn in economic growth leading to much higher real incomes. This is already occurring as shown in figure 2.14. Notwithstanding theories about decreasing VKT per capita there is still a generally positive relationship between income and car ownership, and between car ownership and VKT.

2 The spillover from the Auckland housing market, both north and south of Auckland, leading to new subdivisions with cheaper housing and longer commutes. This is item (9) in reverse.

3 Electric cars – if electric cars substantially lower the total cost, or indeed just the variable cost of personal car use, item (3) is mitigated. If the electricity is generated from renewable sources item (2) is also mitigated.

4 Self-driving vehicles could lead to more travel especially by the elderly who otherwise may not wish (or may not be allowed) to drive themselves. Item (1) is lessened.

The existence of these sorts of counter-trends provides all the more reason for monitoring the indicators discussed above – and of course for scenario analysis. We turn to this in chapter 5, but before that we consider in chapter 4 the demographic projections that will underlie the travel scenarios.

2.5 Summary

None of the New Zealand studies cited above provide a robust disaggregation of how historic changes in socio-demographic factors in New Zealand have affected the demand for personal land transport. We have, however, learnt of some interesting and relevant findings, mostly from overseas research.

1 A considerable proportion of historical changes in personal travel demand can be accounted for by changes in the age composition of households, income and employment. Nonlinear interactions between these variables can capture what other analyses attribute to (exogenous) changes in consumer preferences or behaviour.

2 Historically, travel costs have had a relatively small effect, but more on the mode mix than on the total amount of travel. In some countries the costs of acquiring a driver licence, vehicle insurance, parking and congestion costs are particularly high. Fuel price effects may have been understated.

3 Evidence of declining VKT per capita and changes in the modal mix existed before the GFC and before the high oil prices immediately prior to the GFC. Thus one cannot rule out the possibility that changes in travel preferences are occurring within some socio-demographic groups and could be more prominent in future.

4 There are a number of demand side factors consistent with this such as more concern about the effects of climate change, the rising costs of vehicle ownership and operation, and an aging population. There are also a number of supply side factors that could be acting in the same direction: better PT and access to it, service industry jobs and more inner city housing.

5 However, not all of these factors are moving in the direction of less VKT. Even if they do they could be outweighed by rising real incomes, deferred adulthood reaching its natural limits and driverless cars.

6 It is difficult to separate age effects, period effects and cohort effects when analysing the effect of socio-demographic variables in travel demand.

7 Therefore, to paraphrase Lyons and Goodwin (2014), policy formation and design need to be based on a wider range of feasible futures than just bands of statistical uncertainty. In other words a scenario approach is advocated.

8 The usefulness of scenarios is enhanced by being able to assess if some are more likely than others. Monitoring how factors that affect travel behaviour are evolving over time assists such judgement.

9 New Zealand studies mostly confirm the importance of demographic and economic factors in determining travel demand, for example the quadratic relationship between travel and age, and the strong effect of income on car ownership.

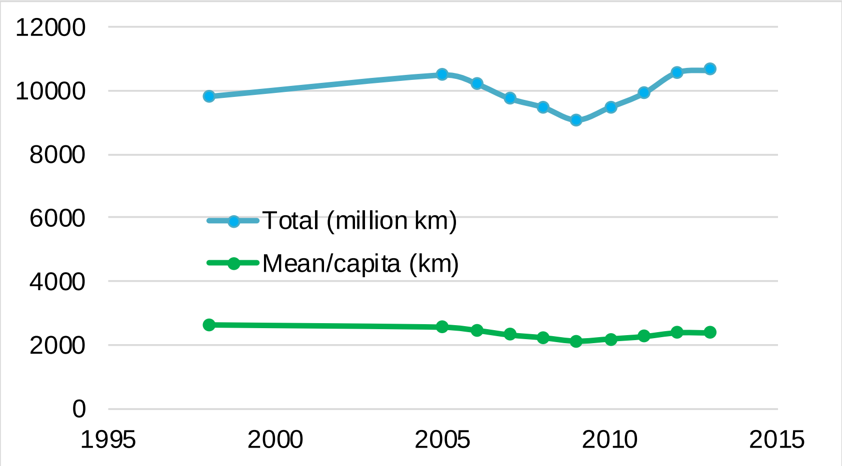
10 Most international authors find that immigrants travel less than nationals, but this may not apply to recent immigrants to New Zealand, many of whom are returning New Zealanders.

11 The most rigorous New Zealand research is by Stephenson (2016) and Stephenson and Zhang (2013) who, while not decomposing past changes in VKT into contributions from socio-demographic (and other) factors, have developed models that enable this type of analysis.

3 A decomposition analysis of private VKT in New Zealand

Our objective in this chapter is to ascertain the extent to which changes in private vehicle travel since 1998, as shown in figure 3.1, can be 'explained' by changes in size of the population, its age structure, changes in employment and changes in income. It turns out that these socio-economic changes can explain most of the observed changes over this period.

Figure 3.1 Total and per capita annual travel by private vehicle



Source: NZHTS

3.1 Data

Data from the NZHTS is available as three-year rolling averages of June years from 2003/04–2005/06 to 2010/11–2013/14. In subsequent text and in the graphs in this chapter these years are referred to simply by their middle year: 2005 to 2013 inclusive. The survey also has data for the June years 1990 and 1998. We use latter, but the former has a small sample and some conceptual differences so is ignored in the meantime.

The data covers average annual distance travelled in light four-wheeled vehicles and motorcycles – drivers (excluding taxi drivers) and passengers. Average annual distance is disaggregated into 90 'cells'; five age groups, nine personal income groups and two employment groups (employed or not employed). More employment groups would be preferable, but we would be limited by sample size issues. For each cell we also have the population count and the sample count.

The five age groups are:

1 0–14 years

2 15–24 years

3 25–44 years

4 45–64 years

5 65+ years

And the nine personal income groups are:

1 No income

2 $1–$15 000

3 $15,001–$20,000

4 $20,001–$30,000

5 $30,001–$40,000

6 $40,001–$50,000

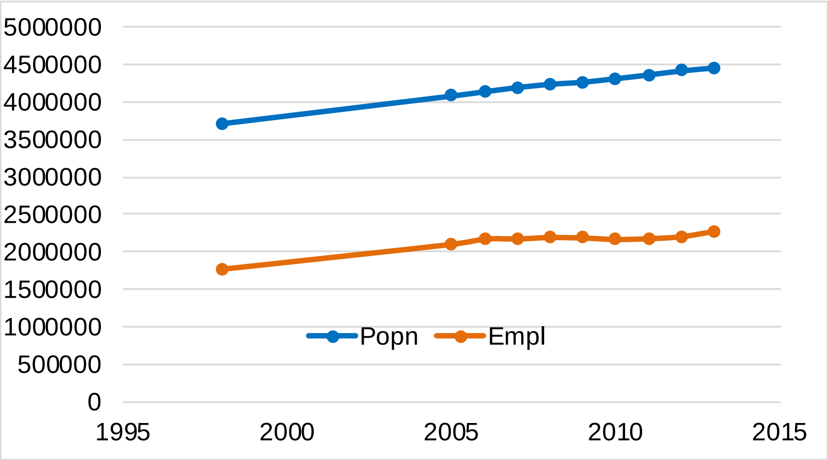
7 $50,001–$70,000

8 $70,000+

9 Unknown/object/missing

Figure 3.2 shows population and employment over the period 1998 to 2013. Other factors equal, we would expect to see the changes in both population and employment to lead to rising private vehicle travel, albeit less of an effect from employment which was fairly flat from 2006 to 2011.

Figure 3.2 Population and employment



Unfortunately the income groups are nominal. Given the data limitations there is no perfect way to convert them into real income groups. Our approach is as follows:

- Taxation records provide data on personal income in bands of $1,000, up to $150,000, from 2001 onwards. From this we can calculate mean income per year for each of the above income bands.
- The means are deflated by the CPI.
- Individuals (and their mean travel) are reallocated to income groups based on their real income.
- Nothing can be done about the unknown/missing group. In such cases Leard et al (2016) imputed real income based on matching households by the number of workers per household, household size, statistical area, race and education. The NZHTS does not have sufficient information for this type of imputation.
- For 1998 we use the 2001 income tax data.

The results below are presented with and without the income adjustment.

Leard et al (2016) use household income rather than personal income, but it seems the former is not easy to derive from the NZHTS. One might argue that household income is better as it is more closely associated with access to a private car than is personal income, but this does depend on the degree of sharing within households.

3.2 Method

The decomposition approach is conceptually straightforward. Essentially it splits an observed change in some aggregate variable such as travel, home ownership or mortality, into changes in the size and composition of the underlying population and changes in the propensity (behaviour that is not explained by the selected variables) per capita in each group that defines the composition. For example a change in aggregate mortality might be split into the change due to changes in the composition of the population by age group, and changes in the rate of mortality per age group. In general the more groups and the more characteristics they capture, the greater the proportion of aggregate change that is explained by compositional effects rather than group-specific propensity effects. With regard to the mortality example, what appears to be a propensity effect might in fact be attributable to a change in the gender or ethnicity composition of the population.

In our case the aggregate variable is travel by private motor vehicle and the group (or cell) contains people identified by age band, income band and employment status. Any changes in aggregate travel that are not explained by changes in the size of the population, its age, income or employment, will appear as propensity changes – in this case as a changes in average travel per age-income-employment group.

Ideally, as in Leard et al (2016), we would estimate equation 3.1 to derive the parameter α, travel propensity per individual, in the base year (t=0), where N is a vector of zeros and ones corresponding to whether or not an individual (i) is a member of a given group, V is a vector of observed travel propensity for the i individuals, and ε is an idiosyncratic error term.

$$V_{i0} = \alpha_o N_{io} + \epsilon_{i0} \quad \text{(Equation 3.1)}$$

The values of α_o could then be applied to the composition of the population in a subsequent year to see how much of the change in travel could be explained by changes in the size and composition the population, leaving any residual to be attributed to changes in ε.

However, without the benefit of unit record data we use a deterministic decomposition approach. In equation 3.2 V is a vector (with 90 rows) of total travel by a group (defined by age, income and employment), N is a vector of the number of people in that group, α is a vector of mean travel per person in that group.

$$V_t = \alpha_t N_t \quad \text{(Equation 3.2)}$$

Expressing changes in V between any year t and some base year t=0 in discrete terms:

$$V_t - V_0 = \alpha_0(N_t - N_0) + (\alpha_t - \alpha_0)N_t \ = \alpha_0 \Delta N + \Delta\alpha N_t \quad \text{(Equation 3.3)}$$

Equation 3.3 decomposes the change in total travel into changes in the number of people in each group and changes in mean travel per group, for given age, income and employment characteristics. In the results below we show how the balance between these two components depends on how many of the three variables (age, income and employment) are actually used.

3.3 Results

Figures 3.3 to 3.6 show the decomposition of total private vehicle travel with different definitions of groups (N in equation 3.3). In figure 3.3 the population groups are defined only by age. Employment and income are ignored, so N is a vector of length five. The results tell us that changes in the size and age structure of the population, denoted as ΔN (blue bars), would on their own have led to increases in total travel relative to 1998, in every year from 2005 to 2013. This is unsurprising as population rose during the period – see figure 3.2. In other words using 1998 travel patterns and scaling up the amount of travel by the change in population in each of the five age groups, could have been expected to lead to an increase in total travel in all years 2005 to 2013. In reality many of those years actually saw reductions in total travel (see figure 3.1), so the implication is that private vehicle travel propensity denoted by Δα (orange bars), conditional on demographics, declined – quite strongly in fact.

In figure 3.4, employment status is brought into the decomposition, so N is now a vector of length 10 (five age groups and two employment types). The results slightly strengthen the previous message. Relative to travel in 1998, the changes in the size and age structure of the population and of employment would have led to more private vehicle travel in every year from 2005 to 2013. That this did not occur again implies a decline in private vehicle travel propensity conditional on demographics and employment, a pattern which accords with the GFC and fuel prices.

Figure 3.3 Decomposition using only age

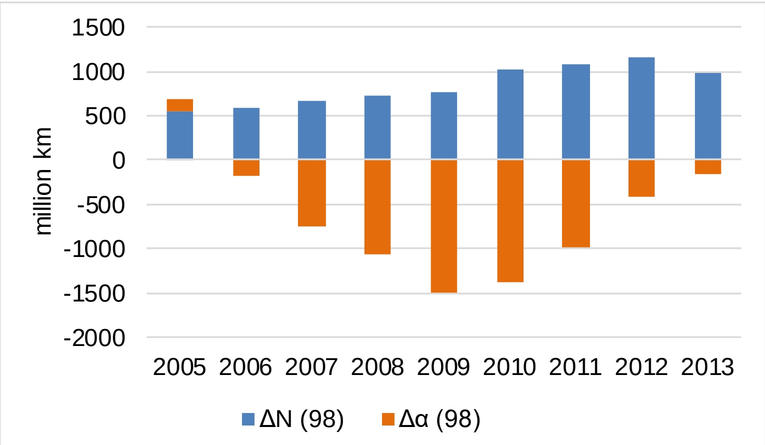


Figure 3.4 Decomposition using age and employment

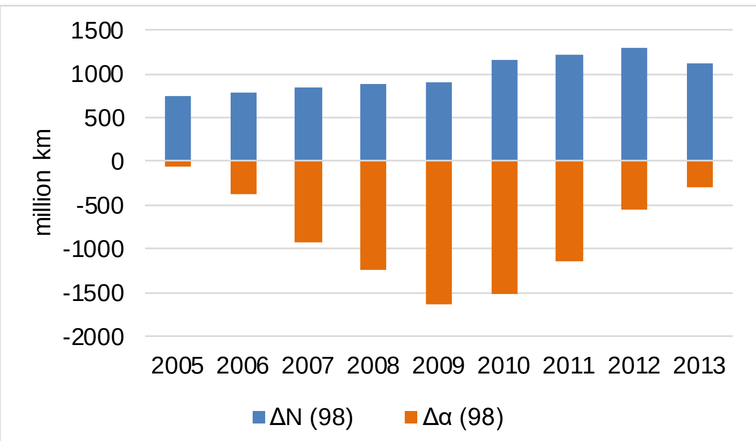


Figure 3.5 has the full decomposition including nominal income; N is now of length 90 (five age groups, two employment types and nine income groups). This shows a marked difference in comparison to the previous results. What appears to be a change in travel behaviour in figures 3.3 and 3.4 can be largely explained by changes in (nominal) income. Accordingly the implied changes in private vehicle travel propensity per capita (in each group) are now much less than when only demographic and employment changes are considered. The compositional effects are directionally consistent with the decline in private vehicle travel during the GFC and with the resumption afterwards. Interestingly the implied changes in travel propensity reinforce the compositional effect in most years. For example, when compositional change implies an increase in private vehicle travel, the implied change in private vehicle travel propensity is also positive.

Note that whichever factor (or factors) one adjusts for first will appear to take the bulk of the population size effect. In figure 3.6 we adjust only for income, excluding age and employment effects (so N is of length 9). The picture tells a similar story to figures 3.3 and 3.4. The rising population ought to have led to more travel, but as this did not occur there is an apparent reduction in travel propensity. In section 3.3.1 we look at the composition of mean travel by private vehicle, but first we look at re-estimating figure 3.5 using real rather than nominal income.

Figure 3.5 Decomposition using age, employment and nominal income

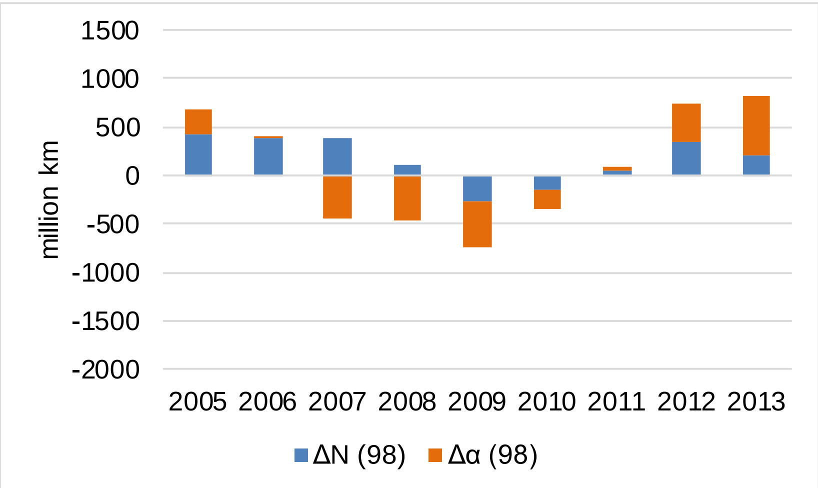


Figure 3.6 Decomposition using only (nominal) income

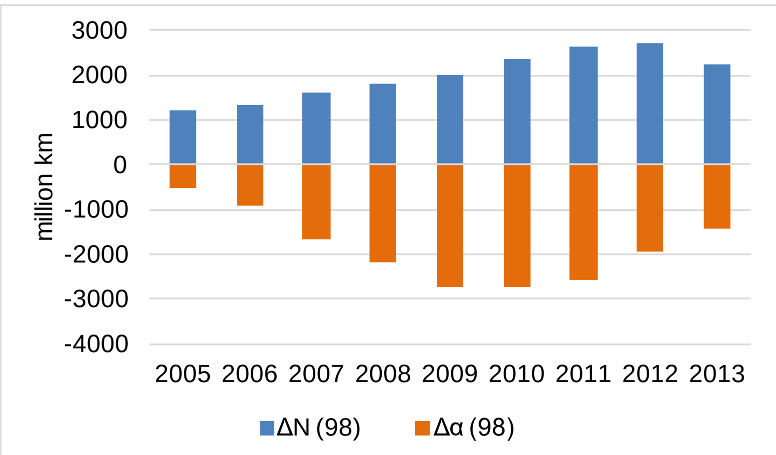


Figure 3.7 replicates figure 3.5, but income is adjusted for inflation since 1998 by the CPI to produce a measure of real income. There are still 90 population groups. The results imply that more private vehicle travel should (given 1998 demographic, employment and real income patterns) have occurred from 2006 to 2008 before the GFC, than actually did occur, implying a decline in travel propensity during that time. This extended from 2009 to 2011. In 2012/13, while compositional changes did suggest an increase in travel, as indeed occurred, they were not quite strong enough, implying a small increase in private vehicle travel propensity – but less than in figure 3.4. Again there is a sort of pro-cyclical propensity effect.

It is possible that allowing for other influences could reduce the implied changes in private vehicle travel propensity. For example the steep rise in oil prices up to 2008/09 may be a factor contributing to the apparent decline in propensity over that period. Other potential explanatory factors might be changes in urbanisation or changes in access to PT. Viewed over the whole period from 1998 to 2013 there is no evidence of a sustained decline in total private vehicle travel, nor in the propensity for such travel.

We should not forget measurement error. As discussed above, the conversion of nominal income to real 1998 income relies on an imperfect match with 2001 tax data, as well as on the assumption that within-group variation in income in the NZHTS data is the same as in the taxation data. In addition we have no way of inflation-adjusting the income of people in the ‘unknown/object/missing’ income group.

Figure 3.7 Decomposition using age, employment and real (1998) income

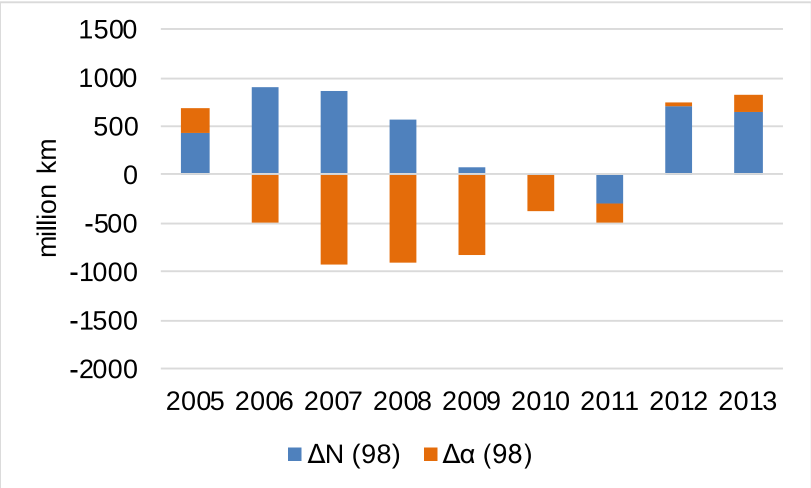


Figure 3.8 is analogous to figure 3.7, but is based on 2005 data, which at least removes the uncertainty around deflation of incomes to 1998. Because travel demand in 2005 was higher than in 1998, changes relative to 2005 seem more negative – most of the bars in figure 3.8 are below zero. Excluding the growth in real incomes that occurred before 2005 means that changes in travel attributed to socio-demographic changes are compressed. In 2009 especially, both components are negative, signifying that while socio-demographic changes ‘predicted’ a decline in travel, the predicted decline was too small. Overall though the message from figure 3.7 that there was a decline in private vehicle travel propensity before and during the GFC remains.

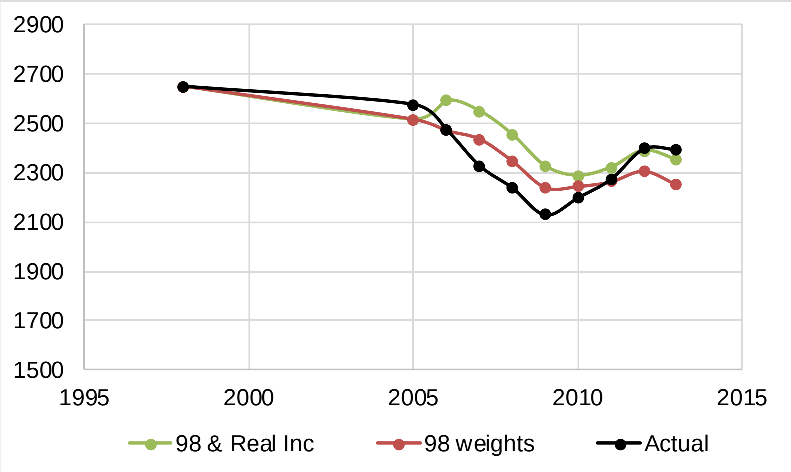
Figure 3.8 Decomposition using age, employment and real (2005) income

The results of the decomposition methodology would very likely be replicated by an econometric approach with unit record data. This would also allow for some additional sophistication such as the possibility that access to a vehicle affects the likelihood of employment (Stroombergen and Watt 2003), so employment status might not be exogenous. It would also be possible to test the robustness of the estimates against the sample size of the groups using weighted least squares, although fortunately there is a 91% correlation between sample size and mean distance travelled.

3.3.1 Mean travel per capita

If we decompose mean rather than total (private vehicle) travel per capita, the effects of population size are removed, leaving purely socio-demographic compositional effects. Figure 3.9 shows actual mean travel per capita, mean travel calculated using current year weights combined with 1998 travel propensity per capita by group, and mean travel calculated using current year weights and real income combined with 1998 travel propensity per group. The story is consistent with the results above.

Figure 3.9 Decomposition of mean per capita private vehicle travel



Without the real income adjustment (red line), changes in the composition of the population and in nominal income would have explained most of the decline in mean travel over the years of the GFC and up to 2010. Since then, however, the recovery in mean travel has been stronger than age and employment changes suggest. With the inflation adjustment to the income bands, implied mean travel still declines sharply during the GFC, although not by as much as without the income adjustment. During the period 2006 to 2010 there is a strong suggestion of a decline in travel propensity, consistent with figure 3.7. Nonetheless the decline in propensity was short-lived as changes in demographics and real income predict mean travel from 2010 very closely.

3.4 Discussion

Between 1998 and 2013 mean travel per capita by private vehicle fell by about 10%, but from starting point to end point this reduction can be entirely explained by socio-demographic changes, particularly changes in real income. On this evidence there is no support for the hypothesis of a fundamental and sustained reduction in private vehicle travel per capita relative to 1998, conditional on age, employment and (real) income. The same conclusion can be drawn with regard to total private vehicle travel.

However, there is a suggestion of a decline in travel propensity leading up to and during the GFC. As discussed in the preceding section though, rising oil prices until 2008/09 were probably a contributing factor. It is possible that the rapid rise in fuel prices had a greater effect on travel demand (particularly by private vehicle) than would have happened if the rise had occurred over a longer period (Bastian and Börjesson 2014). Followed immediately by the GFC, which would have led to expectations of low or negative economic growth (even if the reality turned out to be less severe than expected, at least in New Zealand), an unusually strong reduction in travel demand – stronger than implied by socio-demographic changes – is not implausible. The rebound has also been strong, with private vehicle travel being back to where socio-economic changes predict. There may even be a small degree of over-shooting.

Still the fact that a temporary decline in the (apparent) propensity to travel by private vehicle did occur, albeit in particular economic circumstances, does at least raise the possibility that the same phenomenon could occur again and perhaps endure for longer. The circumstances may be different in future; a marked decline in rural populations or a community-wide heightened concern for the effects of climate change caused (in part) by CO_2 emissions from fossil fuels. Of course as discussed at the end of section 2.4, other factors such as electric vehicles and autonomous vehicles may raise the propensity to travel by private vehicle.

Overall, no single factor explains the observed change in VKT behaviour since 1998. Rather, a combination of socio-economic factors (age, employment, real income, fuel prices) can explain a significant amount of the change. It would be reasonable to expect that an analysis of these and some of the other factors discussed in previous sections would be required to give insights into future travel demand over several decades.

From the perspective of transport infrastructure planning it would clearly be naive to assume (at the present point in time) a significant future decline in the propensity to travel by private vehicle, although it could happen. The above results do not negate the need for a scenario approach to transport planning, but a ‘business as usual’ (BAU) scenario is essential.

In the next chapter we use a scenario approach to seek to understand how socio-demographic factors could affect future travel demand. The scenarios are stochastically computed using disaggregated travel demand functions and drawing on probability distributions of historical variation in factors such as population growth, (household) income and employment – precisely those factors that have been demonstrated above to be important. The model produces a probability distribution around a central projection of travel demand growth. The greater the historical variation in the factors that determine travel demand, the greater the variance – uncertainty – in the distribution of future travel demand.

Nevertheless the stochastic approach could still understate uncertainty as (a) the behaviour of the input variables is not known with certainty, (b) there are multiple input variables and hence the requirement to also model interactions correctly and (c) all relationships are contingent on factors such as technology and/or the long-term creep referred to by Tilley (2016).

The effects of changes in 'exogenous' factors that are not part of the stochastic process, such as fuel prices, can be analysed by running the stochastic method with different input assumptions for the exogenous variables, analogous to the standard deterministic scenario methodology. Hence we expect to be able secure a good understanding of what factors will most likely influence future travel demand.

4 Future travel demand

4.1 Framework

Our interest is in alternative scenarios of personal travel demand. As in Zmud et al (2014) it helps to identify some key themes or drivers that characterise different scenarios. Accordingly, figure 4.1 presents a stylised diagram of eight main factors (combining items (3) and (4) from table 2.3) that affect future VKT and its composition.

Figure 4.1 Schematic of main factors affecting VKT

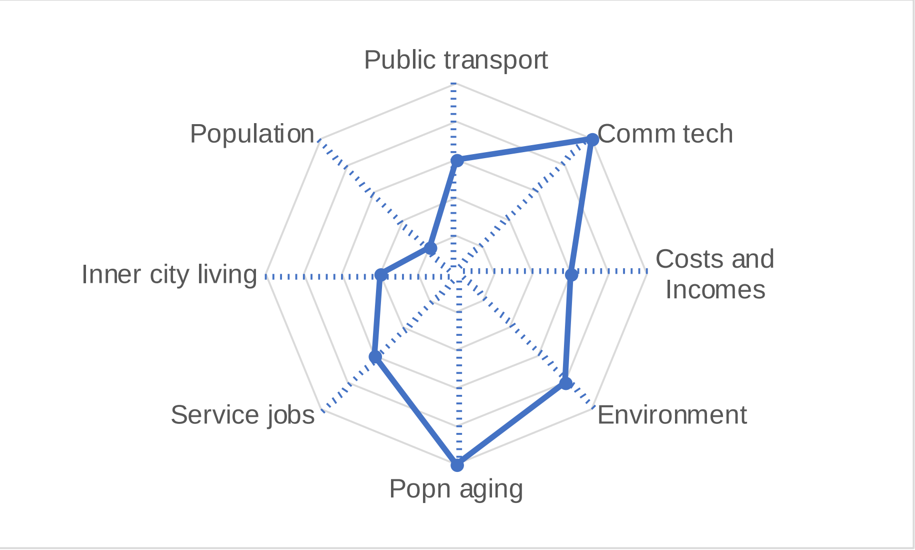


Figure 4.1 is not intended as a rigorous numerical assessment as the axes are not quantitatively comparable. For example a high-low scale for PT quality is not readily comparable with a scale for a tendency to inner city living. Nor is it necessarily the case that communication technology has a higher score than population size. Figure 4.1 is just an illustration.

For the approach to be useful each axis needs to be defined in such a way that the area of the polygon is roughly proportional to some travel-related measure, such as VKT per capita. In that case population size is not really relevant, but its composition would be. Hence the population axis would need to range from a negative effect near the origin to a positive effect heading outwards. Other axes such as that for environmental concern would have to be inverted – a high concern being closer to the origin.

The challenge (again as in Zmud et al 2014) is in converting observations or assumptions about each axis into quantitative – time dimensioned – modelling inputs. We pursue this below.

4.2 Population

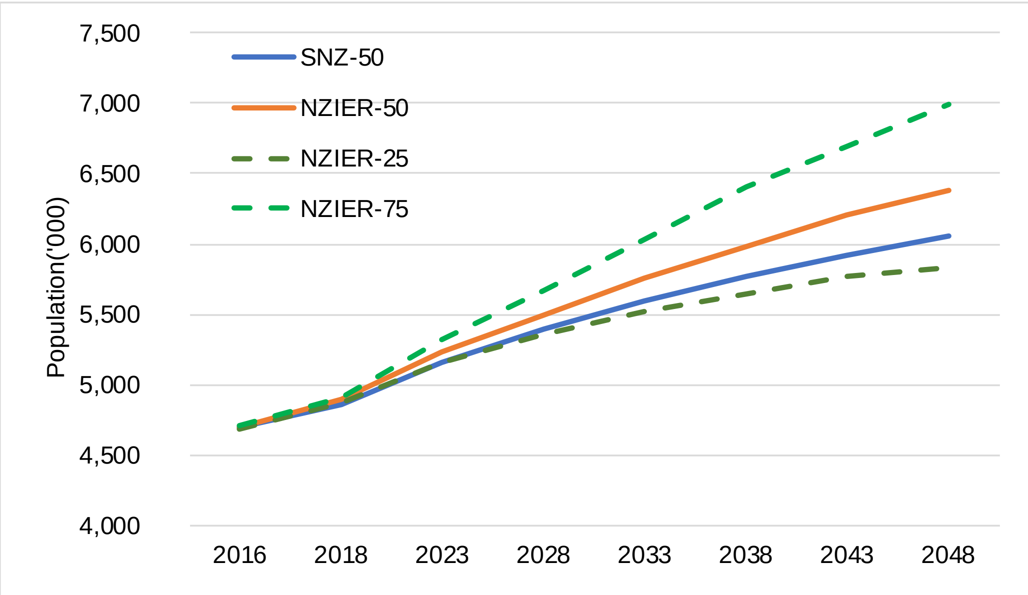
Given the importance of population growth in determining travel demand, as shown in the previous chapter, the project team has looked in some detail at Statistics NZ's population projections and how they are compiled. This is presented in appendix A.

On the whole demographic projections have a relatively good track record, at least at the national level. Unsurprisingly sub-national projections have wider error margins. In the mid-1970s Statistics NZ expected New Zealand's population to be about 4.6 million by June 2016 (based on the medium projection with a 1974 base), which was exactly on the mark. In fact, most population projections since the 1970s expected the 2016 New Zealand population to be around 4 to 4.5 million, which is – given the long time span over which short-term volatility is averaged out – a quite remarkably accurate forecast. The only exceptions are projections published in the first half of the 1980s, which expected much lower growth (leading to an expected 2016 population of between 3.8 and 4 million) due to assumptions that were strongly influenced by declining fertility and high emigration observed in the late 1970s (a period effect).

In recent years Statistics NZ has moved to more use of stochastic or probabilistic projections rather than deterministic projections. The NZIER also uses a stochastic approach to produce demographic projections as a component of the RLTDM. Their base data is from Statistics NZ.

Figure 4.2 shows the NZIER 25th, 50th and 75th percentile projections, and compares them with the Statistics NZ 50th percentile projection. By 2048 the NZIER median projection is 6,377,000 compared with 6,061,000 by Statistics NZ, a difference of about 5%. NZIER's interquartile range is from 5,832,000 to 6,987,000, easily encompassing the Statistics NZ projection between the 25th and 50th percentile projections. Accordingly we can use the RLTDM's population projections as the basis for looking at future travel demand, confident that we will capture sufficient uncertainty in population projections.

Figure 4.2 Population projections – 50th percentile ('000)



4.3 Ministry of Transport travel projections

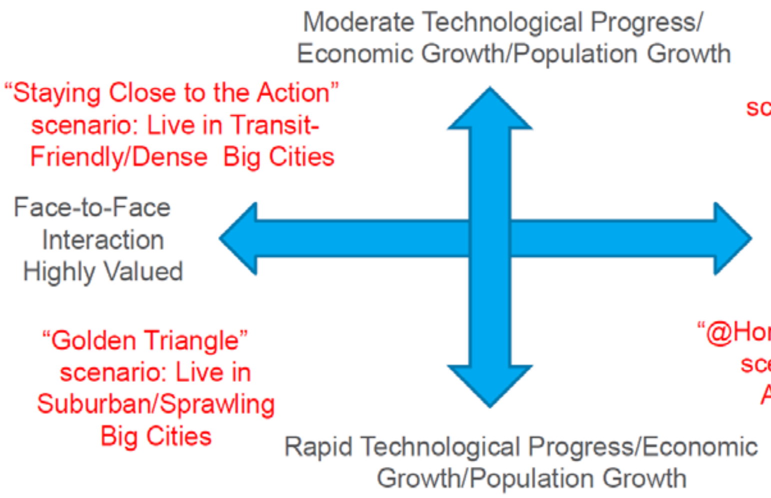
As per the UK DfT, recent forecasting by the Ministry of Transport has moved away from an approach based on high and low projections of population and economic growth to one based on scenarios. The Ministry's BAU scenario, however, follows the traditional approach using only demographic and economic inputs. Noting that VKT relates to all travel, not just light vehicle travel, the BAU shows rising VKT and an increasing number of trips by self-driving private vehicles right through until the end of the projection period in 2042/43. Four other scenarios are added. These are developed from the four quadrants generated by two axes, see figure 4.3 (a sort of condensed version of figure 4.1):

1 The x-axis relates to travel substitution, ranging from low (emphasis on face-to-face contact) to high (ready switch to digital communications). It seems to deal primarily with the demand side. The demand for vehicles is a function of household type and income, and travel is distinguished by mode,

distance, duration, purpose, time of day and day of week. Thus there is considerable flexibility for the user to alter travel demand relationships.

2 The y-axis second axis relates essentially to overall economic growth, picking up effects such as size of the population, the relative cost of energy and the rate of technological progress.

Figure 4.3 Four scenarios



Source: Samuelson (2016)

All four alternative scenarios still depict monotonically rising total VKT, but at different rates. The number of trips per capita declines in some scenarios. There is more use of taxis and vehicle sharing, largely substituting away from self-driving or from being a passenger in a private car. This is particularly evident in the high growth scenarios.

The Ministry of Transport is currently extending this work as part of the Transport Outlook project so further discussion on the scenario results would be premature. Overall though the model is a significant advance on the usual forecasting models. For plausible changes in assumptions the model can demonstrate the sensitivity of demand projections to those assumptions.

4.4 Regional land travel demand model

4.4.1 National projections

The RLTDM developed by NZIER is a sophisticated model for forecasting the demand for land transport and analysing alternative scenarios, see Stephenson (2016). The model is used to illustrate (a) the uncertainty inherent in any VKT projections and (b) the reasonable likelihood that peak VKT is probably still some years away.

Like the population projections, light vehicle travel demand is also projected using a stochastic methodology. This approach means the RLTDM can produce results that are consistent with a wide range of deterministic scenarios, if the latter are seen from the perspective of historical variability.

In figure 4.4 we present the projections at the 5th, 25th, 50th, 75th and 95th percentiles. Table 4.1 shows the actual values in five-year increments from 2015 to 2050.

Figure 4.4 VKT projections

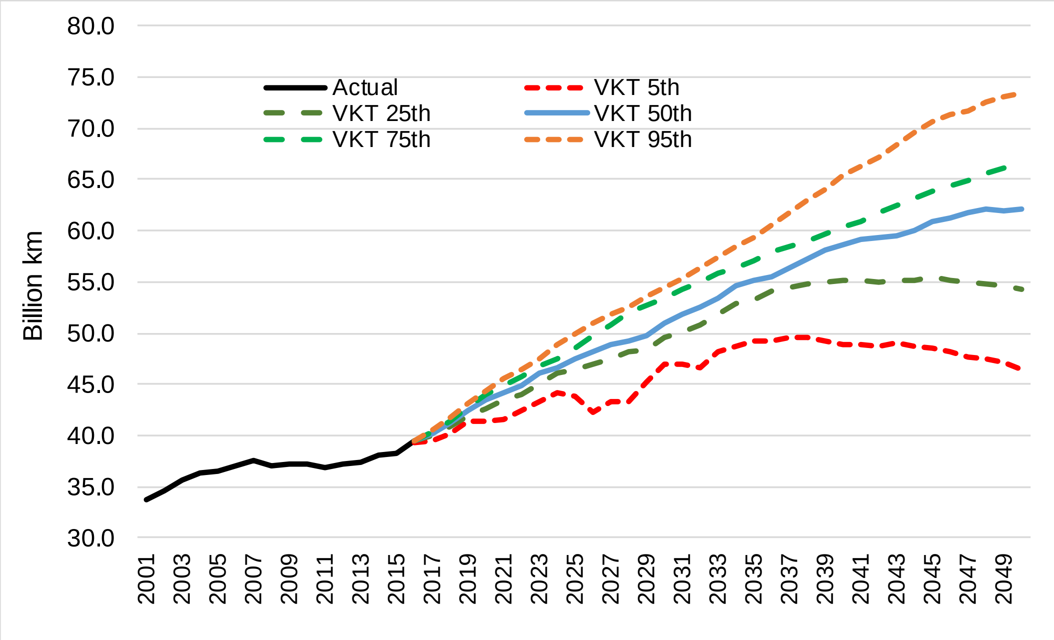


Table 4.1 VKT demand projections (billion km)

Percentile	2020	2025	2030	2035	2040	2045	2050
5	41.464	43.813	47.001	49.197	48.913	48.607	46.495
25	42.672	46.448	49.534	53.227	55.152	55.405	54.306
50	43.419	47.411	50.926	55.112	58.693	60.817	62.112
75	43.919	48.512	53.471	57.105	60.431	63.823	66.884
95	44.285	49.865	54.385	59.311	65.413	70.548	73.435

All projections show a rise in total VKT except for the 5th percentile which shows a decline after 2035. The 90% uncertainty interval (5th to 95th percentile) in 2050 is 26.9 billion km, or from about 25% below the median to 18% above the median. For the narrower interquartile range centred on the median projection, the growth rate is approximately 1.4% pa ± 0.3% pa, on the base year value of 38.2 billion km in 2015.

4.4.2 Regional projections

Figure 4.5 shows 50th percentile projections for the 12 regions in the RLTDM. Travel demand rises monotonically in all regions except Auckland where it peaks around 2040 and then falls. There are also differences in slope, with Otago VKT growing fastest at 2.1% pa (2015 to 2050) and Auckland the slowest at 0.8% pa. Wellington VKT is the second slowest growing at 1.2% pa.

These differences are clearer in figure 4.6 which shows the regional composition of VKT in 2015 and 2050. Auckland, Wellington and Northland (just), experience declining shares. For Auckland and Wellington there is a density effect, but for Northland the reason is primarily relatively low economic growth.

Figure 4.5 Regional VKT projections, 50th percentile

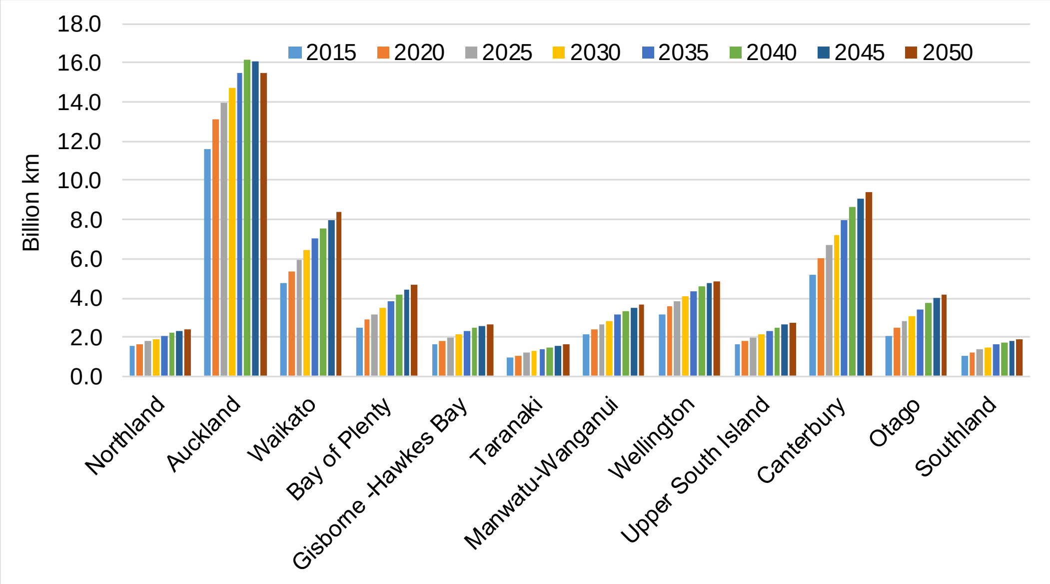


Figure 4.6 Regional VKT shares 2015 and 2050

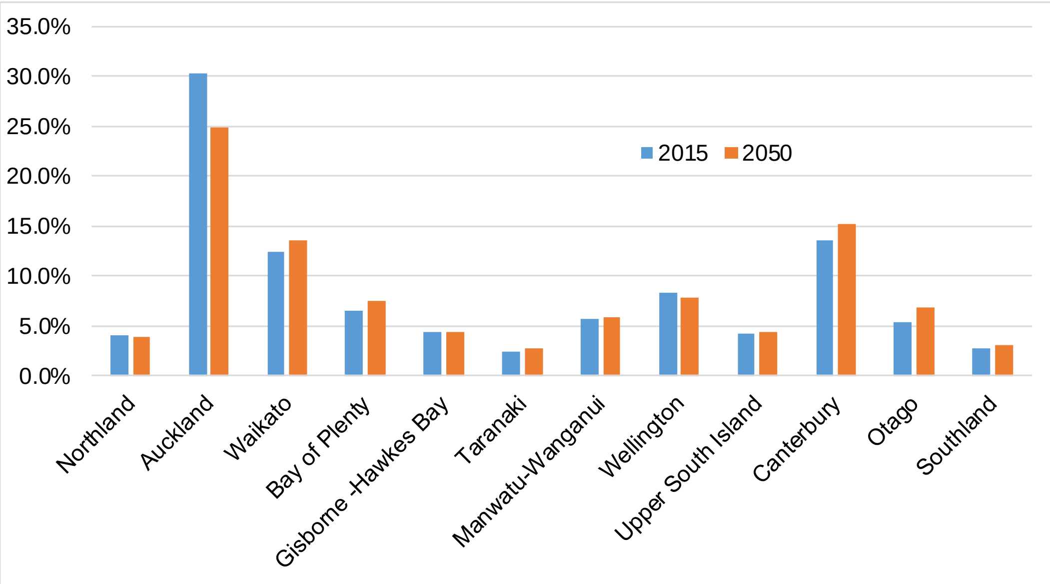
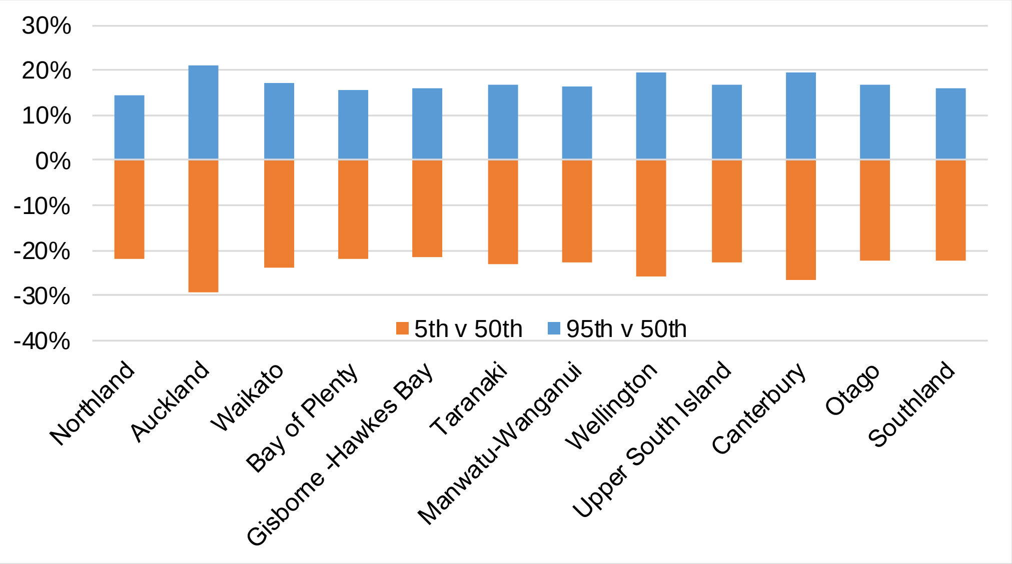


Figure 4.7 shows the 5th and 95th percentile values as percentages of the median in 2050. Broadly speaking the 5th percentile values are around 25% below the medians while the 95th percentile values are about 18% above the medians. The largest uncertainty ranges occur in the three main urban regions.

Figure 4.7 Regional VKT at 5th and 95th percentiles relative to median in 2050

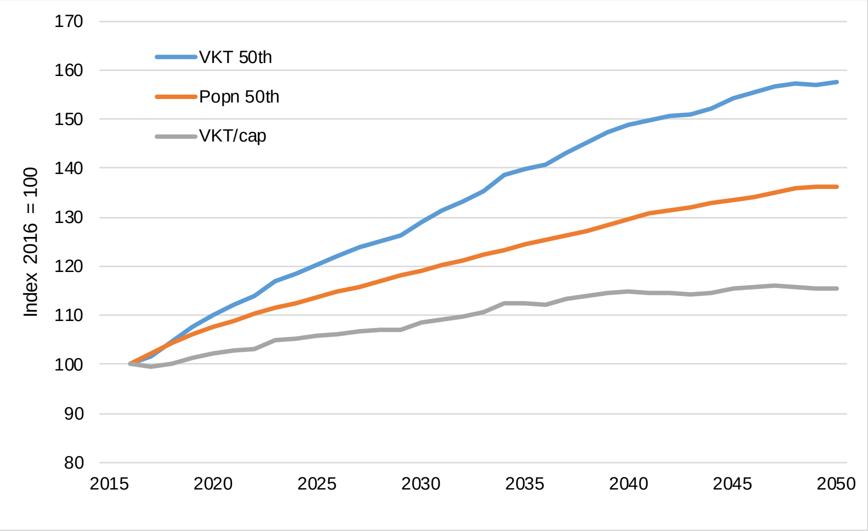


4.4.3 Saturation

Do the projections depict any sign of travel saturation per capita? Population uncertainty is only one component of travel demand uncertainty. The latter also includes uncertainty in other factors such as incomes and employment. Thus the median VKT projection does not necessarily embed the median population projection. Nevertheless if all components of travel demand, including population, are set at their median projections, the result is likely to be close to the median travel demand projection.

In figure 4.8 VKT per capita is calculated using the median projections for both the population and total VKT. It trends upwards (though not monotonically) until around 2040 to 2045 from when it remains largely flat.

Figure 4.8 Growth in VKT and VKT per capita



It is clear from figure 4.9 that the levelling-off of national VKT is caused largely by the marked reduction in VKT per capita in Auckland, which starts around 2040 and which by 2050 is 9% lower than in 2015.

Thus the combined effects of all the variables that impact on travel demand are clearly nonlinear. That is, the system is nonlinear. Wellington shows a similar, albeit more muted trend with little growth in VKT per capita from around 2040. All other regions exhibit strong growth in VKT per capita over the projection horizon. As shown in figure 4.10, urban density is one factor that contributes to the nonlinearity of the system.

Figure 4.9 Growth in VKT per capita by region

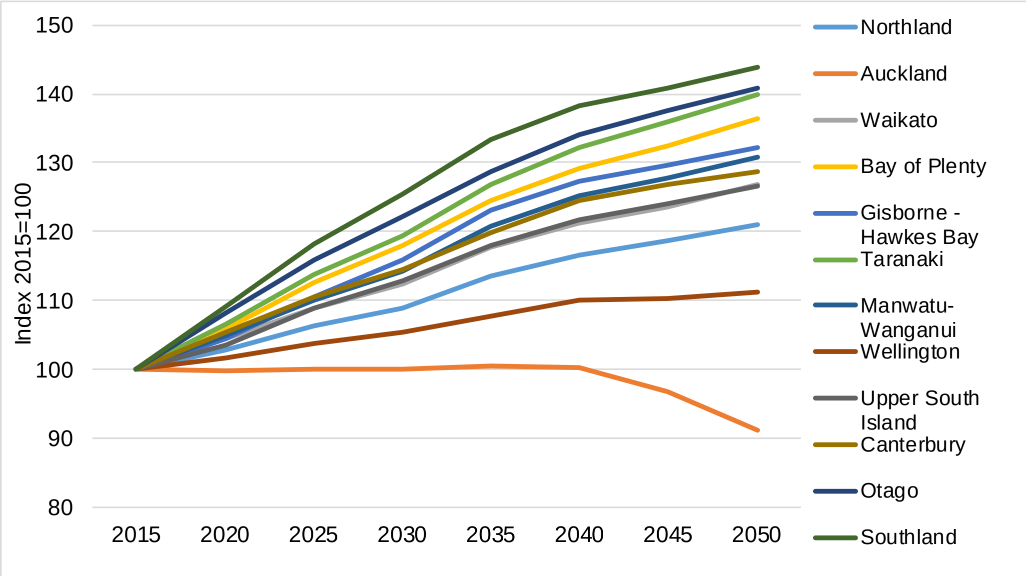
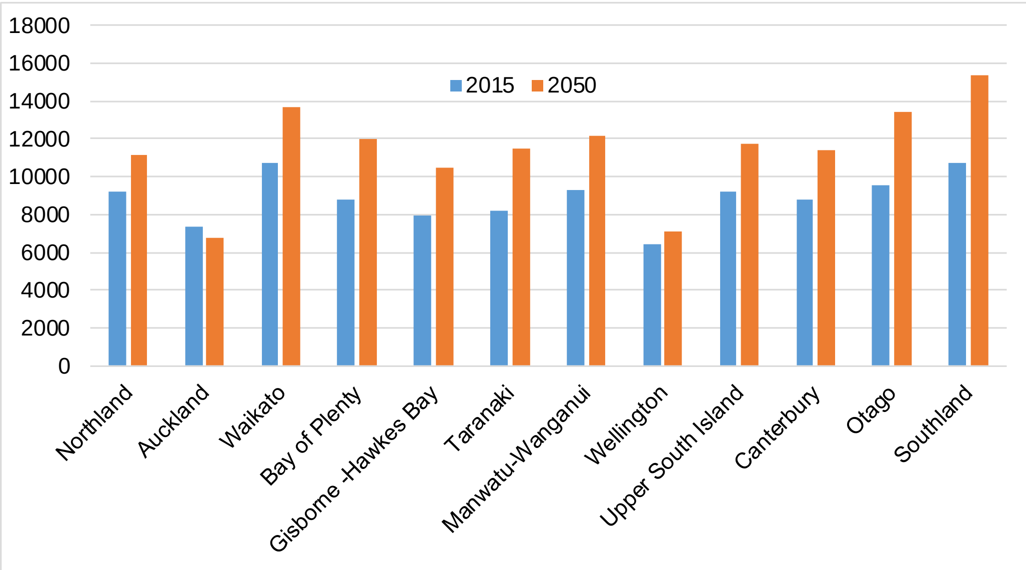


Figure 4.10 VKT per capita by region 2015 and 2050



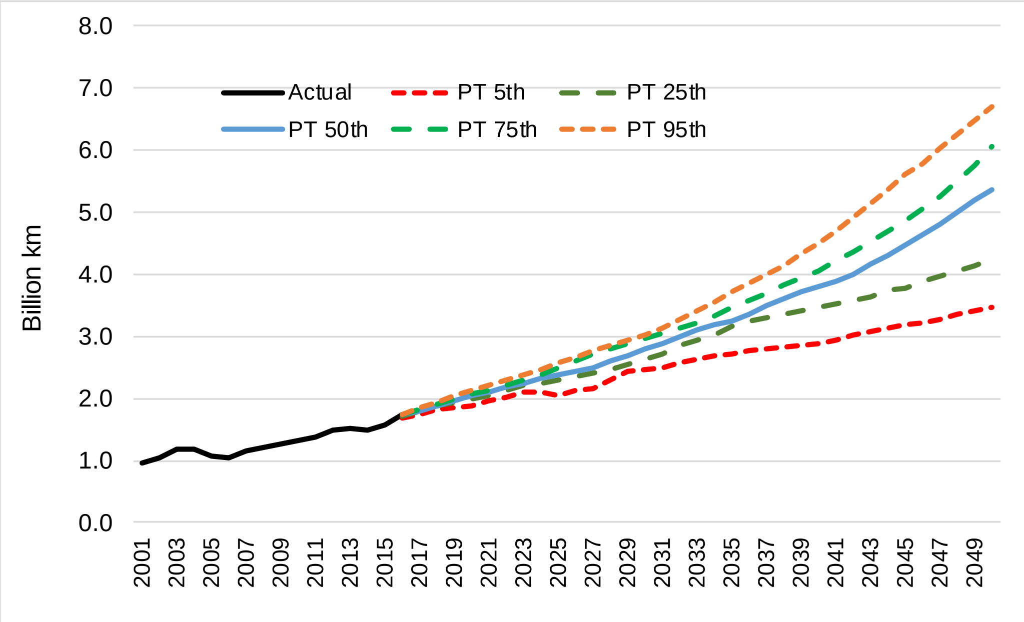
Wellington had the lowest and Auckland the second lowest VKT per capita in 2015, at 6,400 km pa and 7,400 km pa respectively. By 2050 these averages are 7,100 km pa and 6,700 km pa respectively. Their paths cross between 2045 and 2050. The highest VKT per capita in 2015 occurred in Waikato and Southland, both around 10,700 km pa. By 2050 Southland is projected to be well ahead with 15,400 km pa. We look at urban density further in section 4.4.4.

4.4.3.1 Public transport

The RLTDM also includes PT, with stochastic projections in vintiles. Figure 4.11 shows the projections for travel on PT at the 5th, 25th, 50th, 75th and 95th percentiles. It is analogous to figure 4.4 for VKT.

In contrast to VKT none of the projections show any sign of reaching a plateau. Indeed all but the 5th percentile projection steepen in slope compared with the historical growth between 2001 and 2015. The median growth rate is 3.1% pa from 2015, with the interquartile range spanning 2.5% pa to 3.4% pa.

Figure 4.11 PT projections



4.4.4 Alternative scenarios

Notwithstanding the range of outcomes in the stochastic projections from the RLTDM, we are interested in the sensitivity of travel demand projections to other scenarios.

The RLTDM stochastic projections incorporate uncertainty in the following variables:

- population size and age structure
- household income
- regional labour force and regional employment
- number of households per region
- GDP/GNP
- net migration
- vehicle fleet age for private (and commercial) vehicles

Referring back to figure 4.1, there are eight axes that capture the main factors that influence travel demand. The stochastic projections above incorporate a number of them: population size and aging, income, urbanisation (picked up to some extent through region and density) and PT. The other factors in figure 4.1 are communications technology, environmental awareness and service industry employment. These factors have no direct counterparts in the model and so the results are implicitly contingent on them behaving as before; their historical influence on VKT being captured in the estimation of the model's parameters.

Discussion with the Steering Group led to a decision to explore the following scenarios:

1 Household incomes fixed at 2015 levels. This involves fixing a variable that is normally stochastic.

2 Oil price unchanged from 2015. This involves changing an exogenous assumption.

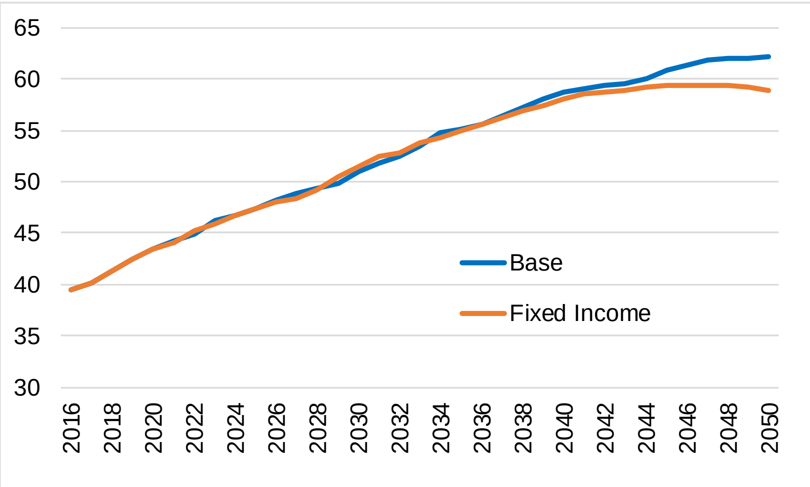
3 A change in urban density in Auckland and Wellington.

4.4.5 Fixed incomes

In the RLDTM, household incomes follow projected GDP with some adjustment for life-cycle stages. Income is a component in the projections for travel demand and for vehicle ownership. Travel demand is much more sensitive to changes in prices than to changes in income. The price and income elasticities in the RLTDM are -0.08 and 0.01 respectively. This implies that changes in income will take much longer to have a noticeable effect than responses to prices.

Figure 4.12 compares the median projections for total VKT for the base case (as in figure 4.4) and with average household incomes fixed at 2015 levels. Total household income still rises because of population growth. Visually there is little divergence until around 2040, increasing after 2045. By 2050 total VKT is about 5% (three billion kilometres) below the base case 50th percentile, but the increment in VKT between 2015 and 2050 is smaller by 14% and the level of VKT is clearly heading on a downward trajectory. However, VKT is still above the lower quartile of the base case scenarios displayed in figure 4.4.

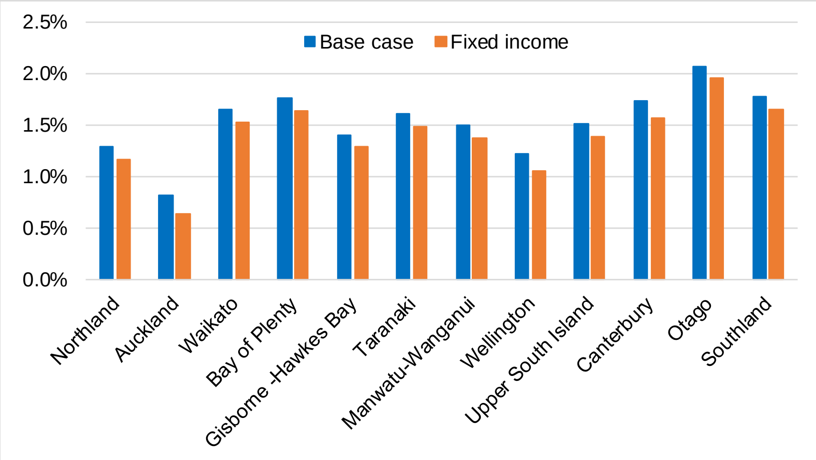
Figure 4.12 VKT, fixed income vs base case, 50th percentile



The result may seem at odds with historical effects as analysed in chapter 3. However, the period 2005–2013 saw quite dramatic changes in real income, including negative changes and a sharp increase in the cost of travel before the GFC. In contrast, in the above scenario there are no negative real income changes, just a change from about 1.5% pa growth to no growth, which lowers the rate of growth in VKT from 1.34% pa to 1.19% pa (50th percentiles). This is entirely consistent with the change in income.

As shown in figure 4.13 growth in VKT declines in all regions, though it is proportionally greatest in Auckland where the growth rate is only 0.6% pa compared with 0.8% pa in the base case (50th percentiles). Wellington too sees a relatively greater fall, in contrast to Otago and Southland. Thus the relatively lower dependence of denser urban areas on private vehicle travel is evident.

Figure 4.13 VKT growth rates, fixed income vs base case, 50th percentile



4.4.6 Fixed oil price

In the base case the oil price rises over time according to the following equation:

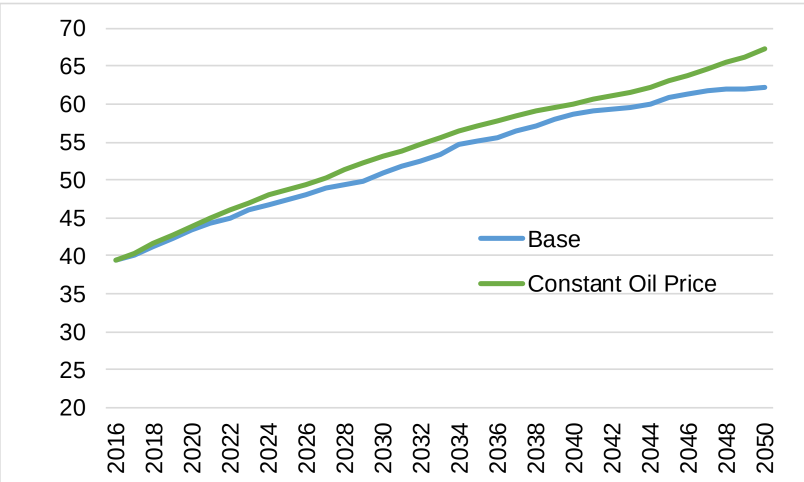
$$Price = price(-1) + [(price\_lr - price(-1))/price\_smooth] \quad \text{(Equation 4.1)}$$

The long run price is *price_lr* and the actual price trends smoothly towards it over 30 years (*price.smooth* is 30). In the base it is assumed that over 30 years the nominal oil price will move towards $US300 per barrel which is broadly consistent with the International Energy Agency (nd) for the long run.

Figures 4.14 and 4.15 illustrate the effect of holding the oil price constant at the 2015 value. Note that excise taxes and other surcharges are the always the same, and constitute a significant proportion of the price of fuel at the pump. Hence a given percentage change in the oil price leads to a rather smaller percentage change in the fuel price facing the consumer.

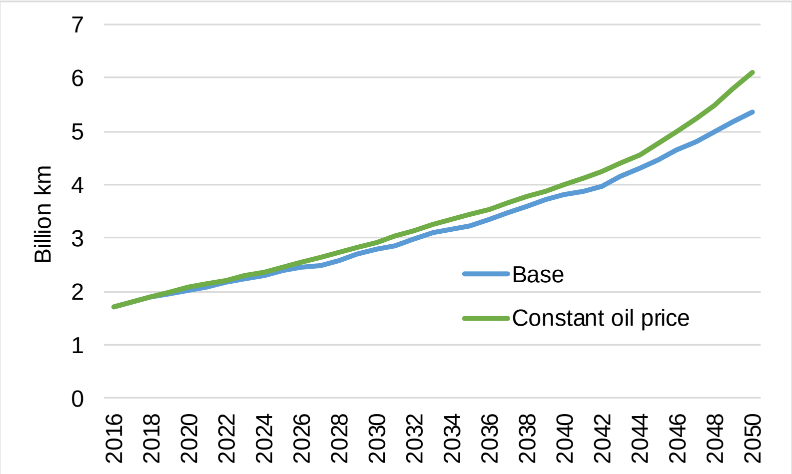
The effect on VKT is noticeable sooner than the effect of changing income. By the end of the period in 2050 the difference in VKT at the 50th percentile is 5 billion km, or 8.2% above the base case 50th percentile. This is just outside the upper quartile of the base case scenarios.

Figure 4.14 VKT, Fixed oil price v base case, 50th percentile



PT also sees an increase in demand, The difference at the 50th percentile by 2050 is 700 million km or 13.4% above the base case 50th percentile. Thus we infer that although public and private transport are generally thought of as substitutes, the positive income effect of lower fuel prices is enough to benefit both modes.

Figure 4.15 PT, fixed oil price vs base case, 50th percentile



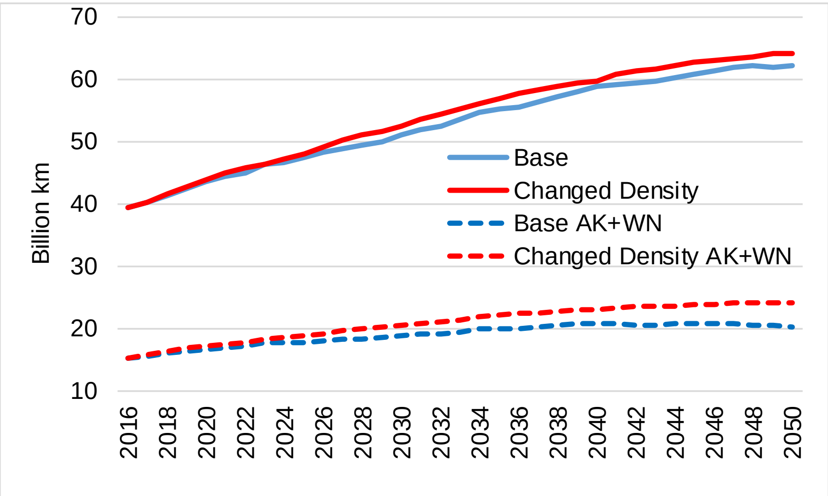
4.4.7 Urban density

As an additional sensitivity test we increase the population density of the Auckland and Wellington regions by 10%, over and above what occurs endogenously in the base case. Population is held constant overall so density in other regions decreases.

We expect to see an increase in PT use and active modes in Auckland and Wellington and alongside that, an increase in VKT in the regions that experience a corresponding decline in density. The effects on VKT at the 50th percentile are shown in figure 4.16, along with the base case results.

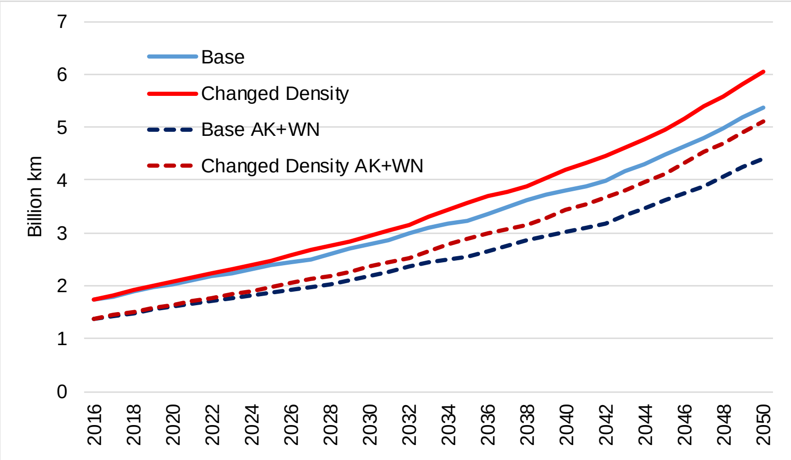
At the national level, there is an increase in demand for travel by private vehicle; two billion km, or 3.2% by 2050, which is still well inside the inter-quartile range of the base case. Interestingly, however, the increase in VKT is dominated by Auckland (AK) and Wellington (WN) where by 2050 it is 18.3% above the base case, implying that total VKT declines in other regions by 4.1%.

Figure 4.16 VKT, greater density vs base case, 50th percentile



As illustrated in figure 4.17 national demand for PT increases by much more (proportionately) than VKT; namely 12.4% which puts PT demand approximately on the 75th percentile of the base case. Again the increase is dominated by Auckland and Wellington where PT demand rises by 16.2%, implying a reduction in PT demand in other regions of 4.8%.

Figure 4.17 PT, greater density vs base case, 50th percentile



Outside Auckland and Wellington where population density declines, there is an increase in both personal VKT per capita and PT per capita, and a small shift in favour of personal VKT. The same is true in Auckland and Wellington where one might have expected to see a relative shift in favour of PT. (We obtain similar results if we simulate the increase in density by reducing the developable land in Auckland and Wellington by 10%). That this does not happen reflects a complex collection of influences.

Auckland and Wellington have relatively high rates of employment and relatively high incomes. When their populations are exogenously increased the extra people (the 10%) are statistically identical to the base case populations and therefore take on their social, economic and travel characteristics. So even if the pure effect of greater density in Auckland and Wellington would be to lower personal VKT, *ceteris paribus*; if the additional people simultaneously experience higher income and higher rates of employment – which are associated with more vehicle use – their total VKT could rise.

In a general sense the results illustrate that 'pure' changes in density are somewhat of an artifice, seldom occurring in isolation. People move to cities at least partly because of the prospect of better jobs and higher incomes, or in response to employment shocks (see Mare et al 2009; Blanchard et al 1992). Furthermore, the tendency for people to self-select into areas where they can use their preferred mode of travel (Melia et al 2011) is also not captured by an exogenous change in density.

Nor is the whole range of spatial factors that affect the choice of residential location. This issue is researched by Torshizian (2017) who studies the role of spatial factors in Aucklanders' choice of living environment, taking into account the endogeneity of spatial factors with respect to individuals' backgrounds. After accounting for a wide range of related factors the results indicate that: (a) a higher level of population density in one's own neighbourhood lowers residential satisfaction, and (b) locating next to a denser area raises one's residential satisfaction.

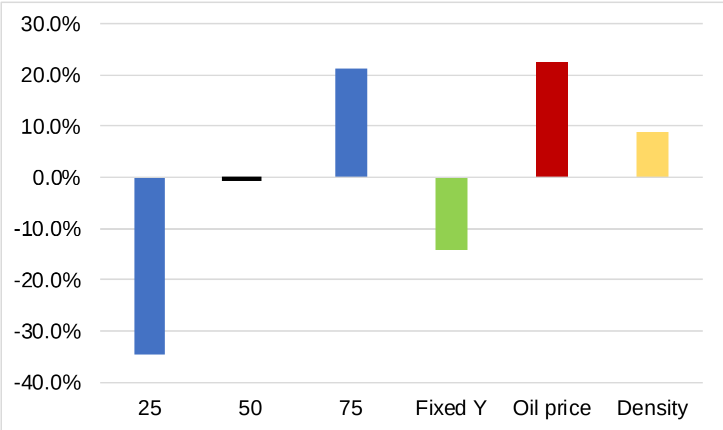
Overall, a travel demand scenario based on an assumed change in population density is likely to be simplistic and quite probably misleading, compared with the effects of an endogenous change in density.

The results also exemplify the danger of using deterministic scenarios, as opposed to stochastic scenarios to inform transport planning. Although truly exogenous (to New Zealand) events such as changes in oil prices are reasonably tractable in terms of their effects on travel demand, the effects of endogenous variables such as migration and choices about where to live and work are far too complicated to be treated as stand-alone sensitivity tests. Demographic, social and economic factors can be inseparable, hence the need for sophisticated models.

4.4.8 Discussion

Figure 4.18 shows the percentage difference in the increment in VKT from 2016 to 2050 between the base case median, the medians for each of the above alternative scenarios, and the base case 25th and 75th percentiles.

Figure 4.18 Relative increase in VKT 2016 to 2050



Historical variation in the effect of demographic factors (population size, age structure and household formation) and economic factors (GDP, employment and household income) on VKT are captured in the base scenarios. At the lower quartile the increment in VKT is lower by 34.5%, and at the upper quartile it is higher by 21.2% relative to the median.

Stripping out the effect of an increase in household income lowers the increment in median VKT by 14.2%, equivalent to about 41% of the stochastic variation in VKT between the 25th and 50th percentiles caused by economic and demographic factors combined.

A constant oil price, which is in effect another economic factor albeit not in the stochastic group, raises the increment in VKT by 22.6%. This is equivalent to 107% of the stochastic variation in VKT between the 50th and 75th percentiles.

The 10% lift in density in Auckland and Wellington which increases the increment in median VKT by 8.8%, is equivalent to about 42% of the stochastic variation in VKT between the 50th and 75th percentiles. We can think of this as being a demographic factor that acts in addition to the stochastic demographic factors.

It is impossible to decompose future VKT growth into discrete causative factors as there is too much uncertainty about how VKT might evolve and to what level. The best we can say is that of the roughly ±28% interquartile range in VKT growth between 2016 and 2050 that could be expected on the basis of historical variation in demographic and economic factors, the split between demographic factors and economic factors is probably around 50/50 – insofar as they are separable. The oil price, however, could have an equally large effect, while changes in urban density (in Auckland and Wellington could lift or lower the projected 2016 to 2050 increment in VKT by ±9% of the median or ±30% of the inter-quartile range.

This last point about urban density and the various regional results provided above raises the question of whether predicting national VKT (as opposed to regional or local VKT) is actually of much use. One possible reason is that the revenue of the National Land Transport Fund is determined at least in part by national VKT. Another reason is that it helps to build up understanding around some of the trip generation and distribution assumptions that are used in regional (or city-wide) travel models.

Even at the regional level, however, projections are still rather aggregated. Travel demand is primarily of interest at the programme or project level, where the issue is travel between two (or more) points at particular times of the day. Disaggregating to this level still requires a scenario approach, but takes us into the area of investment appraisal. We touch on this in the next section.

4.5 From scenarios to infrastructure investment

While a scenario approach coupled with continual monitoring of the types of indicators listed in table 2.2 is essential to good transport planning, it is not sufficient to ensure that investment programmes are efficient and robust as uncertainty does not go away once a programme has begun.

A majority of scenarios run 'today' might point to the likely need for a new road, but there is still a risk that the new road could turn out to be an under-utilised (or even a stranded) asset. That would be a waste of resources, but not constructing it can also be expensive in terms of higher congestion costs. Either way there is a risk. If a flexible investment strategy is adopted – perhaps building a road with fewer lanes but with provision for more – rather than simply making a single (irreversible) investment at the start of a planning period it may be possible to reduce overall costs. A flexible strategy involves implementing an on-going monitoring regime in which the trigger to act might be an agreed percentage change in mean travel time in the number of days that travel time exceeds a pre-set duration.

For example the above picture of a possible eventual decline in VKT per capita in Auckland and perhaps Wellington after 2040 implies that planning around PT should consider such a scenario, requiring:

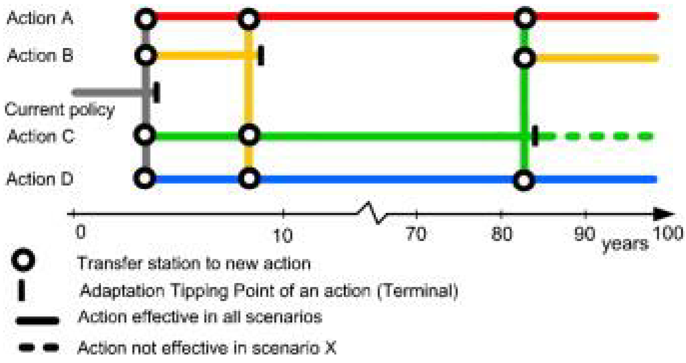
- a better understanding of the pathways that would generate this type of scenario (the 5th percentile VKT results in figure 4.4).
- monitoring the indicators that are consistent with such a pathway evolving.

An approach known as DAPP provides an appropriate flexible framework for decision-making concerning long-lived investments and policy decisions in an uncertain and changing environment (Haasnoot et al 2013).[12] An illustration is given in figure 4.19.

Here there are four possible actions that characterise numerous pathways. The pathways relate to different combinations of investment and planning activities; what sort of infrastructure should be built and when? Do some actions have use-by dates (the initial portion of the yellow action in the diagram)? Is it possible or cost effective to move to a different pathway (such as from green to blue)? Under what circumstance? Will some investments be redundant under particular scenarios? Are there investment programmes that can be adapted to deal with dynamic external circumstances?

[12] See also www.deepuncertainty.org/

Figure 4.19 Example of a dynamic adaptive policy pathway



Source: Haasnoot et al (2013)

Flexibility can be evaluated with real options analysis to quantify the value of waiting for more information before undertaking a potentially irreversible investment (see Byett et al 2017 and Lyons and Davidson 2016 in relation to transport investment, and Infometrics and PS Consulting 2015 in relation to flood protection).

For this report we do not develop a DAPP for investment in land transport infrastructure as this is well beyond the scope of the project.

5 Conclusions and recommendations

5.1 Conclusions

The objective of the research has been to gain insight into how socio-demographic factors affect the demand for personal land travel. Socio-demographic factors in this report include population size and composition, employment and income. Other factors such as urbanisation, access to PT and new technologies have also been considered, albeit in less depth.

We looked primarily at overseas literature on various theories that total travel and/or travel per capita has peaked and/or shifted modes, and at the evidence for and against these theories. Our main findings are:

- Evidence of declining travel per capita and changes in the modal mix existed before the GFC and before the high oil prices immediately prior to the GFC. Thus one cannot rule out the possibility that changes in travel preferences are occurring within some socio-demographic groups and could be more prominent in future.
- Nevertheless a considerable proportion of historical changes in personal travel demand can be accounted for by changes in the age composition of households, income and employment.
- There are a number of other demand side factors consistent with less travel, such as more concern about global warming, and rising costs of vehicle ownership. There are also a number of supply side factors that could act in the same direction, such as better PT and access to it.
- However, not all of these factors are moving in the direction of less travel. Even when they do they could be outweighed by rising real incomes and driverless cars. The effects of other technologies such as telecommuting, social media and online shopping are still unclear.
- Given the great uncertainties discussed above a scenario approach is advocated when designing transport policy.

Our decomposition of New Zealand data on travel by private vehicle revealed that changes in population size, age structure, employment and income can explain most of the changes in such travel between 1998 and 2013. There is, however, some evidence that travel propensity declined in the years leading up to and during the GFC. Rapidly rising oil prices until 2008/09 are probably a contributing factor, along with GFC-induced expectations of low or negative income growth. The growth in travel by private vehicle since the GFC has been somewhat stronger than changes in socio-demographic factors imply.

Overall there is no support for the hypothesis of a fundamental and sustained reduction in private vehicle travel per capita relative to 1998, conditional on age, employment and real income. The same conclusion can be drawn with regard to total private vehicle travel.

Of course this does not mean the future will be the same as the past. To this end we used a model that was specifically designed to project New Zealand travel demand, to explore the effects of socio-demographic factors on private travel. Projections are stochastically computed using disaggregated travel demand functions and drawing on probability distributions of historical variation in the factors of interest; population growth, (household) income and employment.

- All projections show a rise in total VKT except for the 5th percentile which shows a decline after 2035. The 90% confidence interval in 2050 ranges from about 25% below the median to 18% above.
- At the 50th percentile private VKT rises monotonically in all regions except Auckland where it peaks around 2040 and then falls. Both Auckland and Wellington experience declining shares of total VKT.

- Private VKT per capita at the 50th percentile trends upwards (though not monotonically) until around 2040 to 45 from when it remains largely flat.

  In contrast to VKT none of the projections for PT show any sign of reaching a plateau. The median growth rate is 3.1% pa from 2015, with the interquartile range spanning 2.5% pa to 3.4% pa.

Three additional stochastic scenarios were examined: fixing real household income, no change in oil prices and greater urban density in Auckland and Wellington.

- Holding real income constant reduces VKT growth, but it is still within the probability distribution of the base case scenarios, suggesting these scenarios already capture the effects of plausible changes in income growth.
- The results with a fixed oil price are also within the probability distribution of the base case scenarios.
- The same can be said with respect to 10% higher population density in Auckland and Wellington.
- As best we can determine, and bearing in mind the complex inter-relationships between demographic and economic changes, these two sources of change seem likely to generate roughly equal contributions to VKT growth between 2016 and 2050.

5.2 Recommendations

Recommendations for further research depend largely on the Ministry of Transport's and the Transport Agency's priorities. With that caveat in mind, we see three areas that merit more investigation:

1. The decomposition in chapter 3 could be enhanced by using an econometric approach, but this would require unit record data from the NZHTS. (We understand this is possible).
2. While the scenario approach is essential to planning future investment in land transport infrastructure, this does not necessarily help decide which scenarios are most likely to eventuate. Decisions cannot wait forever. Monitoring other (non-transport) indicators of travel demand could assist in this regard, but they need to be further analysed for their causative (as opposed to just statistical) effects.
3. The scenarios we examined are weak with respect to the effects of new technology such as ride sharing 'apps', driverless cars and internet shopping. This area deserves more attention.
4. Even if a scenario approach to investment planning is pursued, there is still the question of how the best investment pathway response to different levels and patterns of transport demand should be decided. Investment programmes need to be robust, flexible and minimise the chances of producing stranded assets. An approach known as DAPP is recommended, complemented by real options analysis.

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Appendix A: Travel behaviour in the model by Zmud et al

The travel behaviour sector in the model by Zmud et al (2014) is summarised below.

A1 Car ownership

- The car ownership model shows the ‘car share’ propensity declining with age up to 60–74 but reversing to peak at age 75+.
- The ‘no car’ propensity is roughly quadratic (inverted U shape) with age, with a minor peak at age 30–44, reversing to produce a higher peak at age 75+.
- Single people with children are more likely not to own a car or car share, but the reverse applies for couples with children.
- Non-white people are less likely to own a car, as are people with low income (the strongest variable in the model) and those not working. (Refer to the box in section A4).
- People living in urban locations are also less likely to own a car. Likewise for new (less than 20 years in USA) immigrants.

A2 Trip rate

- The coefficients are generally less significant than in the car ownership models
- Work trips: roughly quadratic in age, with a flat peak over a wide age range 30–59.
- Non-work trip: increase with age, peaking at age 60–74.
- Non-white people undertake fewer work and non-work trips. Similarly for those with lower income and rural residents.
- Having children increases the number of non-work trips, but reduces the number of work trips. For immigrants the situation is reversed.

A3 Mode choice for work trip

- Also unsurprising, not owning a car has the strongest effect on the choice of mode.
- Walking or biking declines with age after age 30–44 and workers under 30 are more likely to be car passengers than older workers. Age effects for PT are weak.
- Low income workers are more likely to car-share than higher income workers, but less likely to walk/bike or use PT. The same pattern applies to workers in rural areas, those in couple households and single people with children, but the opposite applies to couples with children and people who live in urban areas.
- With regard to ethnicity, non-white workers are more likely to car-share and to use PT, but less likely to bike/walk.

A4 Mode choice for non-work trip

- Once again not owning a car has the strongest effect on the choice of mode.
- The age groups 16–29 and 75+ are most likely to be car passengers and the former is also the most likely to use PT for non-work trips. Walking and biking decline monotonically from age group 16–29. For children under 15 almost 80% of trips are as a car passenger.
- Other variables tend to have same directional effects as for work trips, although one difference is that high income people are relatively more likely than those on lower incomes to use all three non-driver models – car passenger, PT or walk/bike.
- Higher fuel prices also increase the probability of using all three non-driver modes.

Attribution

One has to be careful when ascribing differences in travel demand to ethnicity. In the New Zealand context the Transport Domain Plan lists the relationship between transport and Māori as a priority 'knowledge need'. While observed Māori travel behaviour may not be the same as that for the wider population (a parallel picture to Zmud et al's), it is certainly not clear that observed differences can be attributed solely or even largely to ethnicity. As with many other social indicators, allowing for the effects of factors such as age, income, employment and location can probably explain a significant proportion of what appears to be an ethnicity effect.

The table below shows the profile for access to motor vehicles for Māori and for the whole population. The mean number of vehicles is about 1.7 for Māori and 1.9 for the wider population. This is not a large difference which would likely become even smaller if adjusted for factors such as income.

Access to motor vehicles

	Māori	NZ population
None	10	5
One	35	30
Two	38	43
Three or more	18	22

Source: Statistics NZ 2013 Census

If there is a residual ethnicity effect it raises the question of what ethnicity is actually measuring and whether it is constant over time. Clearly one cannot technically change one's ethnicity, but what that variable might be picking up in a travel demand equation is not necessarily clear nor time-invariant. Is there an inherent aversion to travel or driving that is pervasive amongst (for example) Māori and diminishes with decreasing identification with Māoritanga? That seems most unlikely.

While the Transport Domain Plan is right to prioritise obtaining more knowledge about the relationship between transport and Māori, any policy recommendations that result from such research must be based on a very careful analysis of exactly what effects being Māori (or some other ethnicity) have on travel behaviour.

Murdock et al (2015), projecting travel demand in the USA, show that while population growth will lead to an increase in demand for all transportation modes, demographic changes will lead to fewer drivers, fewer VMT, and greater demand for PT in 2060 than what would occur if minority ethnic groups changed their travel behaviour to match that of non-Hispanic whites in 2010 – which they will probably do to at least some extent. This would have a significant impact.

Note that ethnicity is different from the (new) immigrant issue. If immigrants come from countries with extensive PT systems they will expect it in New Zealand as well. So this may generate the growth in PT use, particularly in Auckland.

A5 Trip distance

- Trip distance models are not estimated for walk/bike trips. For the other three modes (driver, car passenger and PT) the strongest determinant of trip distance is whether the trip is for work or not – the former being longer, especially for drivers.
- Excluding children, trip distance tends to decline with age across all modes. Trip distance is also shorter for those without a car or with shared car access.
- Higher income groups travel longer distances than lower income groups, as do recent immigrants. (DfT (2015) noted that migrants travel less – trip frequency and distance effects – than nationals).
- Rural trips are longer than urban trips.

As might be expected when estimating the various components of travel behaviour with single equation techniques and few joint-effect variables, some of the coefficients are not intuitive or are even counter-intuitive. For example the effect of fuel prices on the share of trips allocated to PT is negative. There are probably omitted variable effects acting here, such as congestion and the income effects of changes in fuel prices. Generally speaking, however, the directions of the effects in the model are as theoretically expected.

One is cognisant of the point noted above that, for long-term scenarios, model structure is more important than precise statistical relationships. Within the overall flavour of a given scenario a few rogue coefficients may not matter much and probably would not lead to unreliable model results, unless one wishes to focus particularly on (say) the effects of fuel prices on travel demand. The bigger danger though is that one might not know when a model result is awry.

In fact this concern raises an even more important one, namely that as far as we can determine the estimated relationships do not distinguish between age effects and cohort effects (and cannot allow for period effects). See table A.1. For example the car ownership model shows that the 16–29 age group is more likely to share a car than the 30–44 age group, but we cannot be certain that the former group will continue to share cars as they age. That is, when they are aged 30–44 they may or may not have the same car ownership propensity as people aged 30–44 at the time of the study.

The same argument applies to trip rates, mode choice and trip lengths. This is extremely germane to the question of the future demand for travel.

Table A.1 Age, cohort and period effects

	Cohort effects	Period effects
Cross section data	Not controlled for	May be unique
Longitudinal data	May be unique	Not controlled for unless have data on successive cohorts

It is possible that the way the model is run for the different scenarios takes into account the age-cohort challenge, but almost no information is provided on which model levers are adjusted and how to run the various scenarios. In the report table 5.4 of key assumptions does provides broad qualitative guidance and the report suggests that more information is available in the model execution files.

Appendix B: Population projections

B1 Background

An effective assessment of future travel demand requires a quantification of future population trends that is not going to be 'too far away' from the actual outcomes. However, acceptable inaccuracy or desirable accuracy are both context-specific and subjective terms. Generally speaking, the more disaggregated or specific the population that is to be forecast, the greater the uncertainty surrounding the determinants of that population and, hence, the greater is the inaccuracy that should be considered acceptable.

B1.1 Projections versus forecasts

Historically, a distinction has been made between population projections and population forecasts. This distinction can be rather artificial: projections and forecasts are both based on formal mathematical and statistical models that yield intervals of possible outcomes in which the midpoint may be considered the most likely outcome[13]. The characteristics of projection and forecasting models may nonetheless differ fundamentally. Compare for example the standard cohort component method of projections with ARIMA time series models to generate forecasts.

Projections can be interpreted as scenario-based forecasts, with all projections sharing the same model but differing in assumptions (scenarios). If the assumptions are varied within plausible bounds, the range of population projections provides reasonable bounds on uncertainty. This varying of assumptions can be done manually (yielding deterministic projections) or model parameters may be drawn many times from a distribution (yielding stochastic or probabilistic projections – discussed later in this appendix).

In the case of forecasting, the same result is achieved by calculating probabilistic bounds around a given forecast (referred to as a statistically derived prediction interval) or by calculating a range of forecasts resulting from varying of the model assumptions (often referred to as sensitivity analysis).

In both cases we end up with a range of possible outcomes, combined with an assessment of which outcomes are more or less likely. In practice, a common distinction between projecting and forecasting is that projections are often used to generate long-term forecasts (up to a century), while statistical forecasting techniques are typically used for predicting future outcomes in the short term (one month to a year) to medium term (one to ten years).

B1.2 Forecasting the total New Zealand population – the track record

Comparing demographic projections with other long-range forecasting, demographic projections have a relatively good track record, at least at the national level. An example will be useful here. In the mid-1970s Statistics New Zealand expected the NZ population to be about 4.6 million by June 2016 (based on the medium projection with 1974-base), which was exactly on the mark.[14] In fact, most population projections since the 1970s expected the 2016 New Zealand population to be around 4 to 4.5 million, which is – given the long time span – a quite remarkably accurate forecast. The only exceptions are projections published in the first half of the 1980s, which expected much lower growth (leading to an expected 2016 population of between 3.8 and 4 million) due to assumptions that were strongly influenced by declining fertility and high emigration observed in the late 1970s (a period effect).

[13] See, eg Keilman (1997)

[14] See figure 7.1 (p45) of Statistics NZ (2016a).

Not everyone agrees that the Statistics NZ population projections have performed reasonably well in forecasting the national population. In 2014 NIZER argued that population predictions needed to be improved because Statistics NZ 'under-predicted our population growth – big time' (Lees and Stephenson 2014, p1). However, this strong critique of Statistics NZ projections was based on very selective use of past projections. To make their point, they picked the worst performing set of projections of all projections done since then. In any case, even with this worst performing projection, the actual population one to two decades ahead (ie between 1992 and 2002) was within the low and high bounds of the 1982-base Statistics NZ projections. On the other hand, the 1982 base projection under-predicted the 2014 population by 625,000 people, ie it missed 14% of the actual population. NZIER does make the valid point that such inaccuracy of long-range population forecasts could lead to wrong decisions (even if made using the latest forecasts available at that time) regarding spending on long-lived infrastructure or other long-range issues (such as superannuation, health expenditures and the environment).

A key question is therefore to what extent methodologies can be improved to yield more accurate long-range demographic predictions (so that investment decisions on transport infrastructure can be more robust). NZIER argues that in the current environment of data abundance and near-unlimited computational capacity a much wider range of data should be informing projections. Additionally, subjective prior beliefs can be incorporated by means of Bayesian techniques. Statistics NZ has in fact been responsive to such criticism. Probabilistic (stochastic) methods are now used to model population uncertainty more explicitly, at least at the national level, following pioneering work by Wilson (2004) and Dunstan (2011). Probabilistic projections are not yet used for official population projections in New Zealand at the regional level, but Statistics NZ is developing Bayesian methods to estimate and project subnational populations (Bryant et al 2016), which incorporate multiple data sources (Bryant and Graham 2013). Exploratory work has also been done by Cameron and Poot (2011). Their methodology is discussed below.

B1.3 Forecasting population versus other socio-economic trends

Even though the best population projection methods will from time to time yield inaccurate predictions, the forecasting accuracy in most other areas of long-range forecasting is significantly worse,[15] although in recent years the situation has improved among certain types of forecasters (referred to as 'superforecasters'), who are willing to base forecasts on large volumes and a wide range of very different types of information, as well as a willingness to adapt predictions continually as new data become available. The caveat remains, however, that such improvements are most effective for short-range forecasting and achieving accuracy in long-term predictions remains fiendishly hard.

Once again, demographic trends are – at least at a very aggregate level such as national or global – relatively more easy to predict than economic, social or technological trends. Demographic change has considerable persistence. For example, given low and relatively predictable rates of mortality until people reach old age, the New Zealand population aged 20-80 in 2037 is already alive and known (aged 0–60) today – except for the effects of international migration. While migration can be very volatile, it is concentrated among young individuals and families. International migration's contribution to population change has on average been relatively small although the last few years are a notable exception. Of course, relatively greater variability over time and between areas in fertility, mortality and migration (internal and international) at the sub-national level reduces the forecasting accuracy at that level.

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[15] Indeed, Tetlock and Gardner (2015) note that, historically, the average expert has been 'roughly as accurate as a dart-throwing chimpanzee'.

One potential criticism of most population projections, including those by Statistics NZ, is that population projections are often used to calculate economic and social outcomes (such as potential GDP, with given assumptions regarding productivity trends by age and sex; or demand for residential building), but feedback effects (changed socio-economic conditions affecting fertility, mortality and migration) are rarely incorporated. For example, given assumptions about the extent to which the Auckland housing market can respond to the projected growth in the number of households, any mismatch between demographic demand and physical supply will lead to house price changes and household crowding. In turn this could affect household formation, fertility, migration and mortality (the latter in terms of crowding affecting health). There are several reasons why such feedback are usually not taken into account.

Firsy, models of the impact of economic conditions on demographic processes are rather imprecise, given that there are many social, cultural and institutional influences as well (see eg the model by Poot and Siegers ((2000)) of long-run economic trends affecting fertility in New Zealand).

Second, incorporating such feedback loops could lead to nonlinear reinforcement of trends which ultimately yields population projections that our outside reasonable bounds. The classic example of this is the so-called Club of Rome report (Meadows et al 1972), which predicted potential Malthusian collapse of the world population in the early 21st century under scenarios that did not incorporate new natural resources and rapid technological change.[16]

Thus, system dynamics models of a country or region usually have a demographic module included that projects the population with the best available data, but that does not allow labour markets, incomes, land use and travel to impact on fertility, mortality or migration. A New Zealand example is the Waikato Integrated Scenario Explorer (WISE, see Rutledge et al 2008).

B1.4 How accurate are New Zealand population estimates?

When assessing the accuracy of population projections, it has to be kept in mind that population is not an unambiguous concept. In countries with population registration systems, the total population is usually defined as those who are registered (the de jure population). This is unlikely to be equal to the actual number of people within the country’s border at any given point in time (the de facto population): it excludes visitors, unregistered residents and it includes registered residents temporarily abroad or those who migrated but did not deregister. New Zealand, like eg Australia and the United Kingdom, does not currently have a population registration system although the integrated data infrastructure system under continuing development may eventually yield data equivalent to a population register. Instead, the core population concept in New Zealand is the estimated resident population (ERP) which is an estimate of the population stock at a point in time, excluding visitors, but including those who are temporarily absent.

At present, the census provides the most reliable information to yield ERP data and the census therefore also informs the base population for projections.[17] However, the census is an imperfect measure of the resident or total population because of undercount. The net undercount of the total population on census night in 2013 was estimated to have been 2.4%. The census undercount has increased over recent decades, because it has become harder to enumerate young people living independently or people living

[16] In defence of such system dynamics models one ought to point to their strong and positive influence in developing policies for environmental protection and sustainable development.

[17] While there will be a census in 2018, the future of the census is uncertain given that census-like information may be obtainable beyond 2020 from administrative data and surveys (see www.stats.govt.nz/Census/census-transformation-nz/census-transformation-papers.aspx)

in unconventional settings.[18] Additionally, the census is held only once every five years (and seven years between 2006 and 2013), which creates additional uncertainty in intercensal years. Finally, the census is held in March while the base year ERP (and subsequent projected populations) refers to the population on 30 June, so that errors in estimating actual population change between the census and the census-year ERP affects the quality of the ERP and the projections.

All official national population projections produced using a stochastic approach (in 2012, 2014 and 2016) have assumed uncertainty in the base ERP. If there is uncertainty in ERP estimates that will have a permanent impact on projections. It is therefore important to make the June 2013 ERP as accurate as possible. To do so requires combining data from the (latest) 2013 census, the 2013 Post Enumeration Survey (PES), data from international arrival and departure cards, and data from births and deaths registrations. Past ERP series (based on previous censuses) may be adjusted if the 2013-census-informed ERP cannot be reconciled with the fundamental demographic stock-flow equation that current population equals past population plus births minus deaths plus inward migration minus outward migration.

Knowing that the information used to estimate ERPs is not perfect, Bryant et al (2016) model the uncertainty by a Monte Carlo simulation approach (a methodology that also underpins probabilistic projections – discussed further below). Basically, they run 1,000 simulations of population changes in which the parameters are varied plausibly each time by random drawing or by Bayesian techniques). This yields a range (interval) of ERPs for the total population and for sub-populations defined by age, sex, ethnicity (Māori and total) and region. After disregarding the top 2.5% of the estimates and the bottom 2.5% of estimates, they define relative uncertainty as the half-width of the remaining interval divided by the median.

This method shows that at the national level relative uncertainty in ERP is less than 1% except at the oldest ages (85+). However, ERP is relatively more uncertain for smaller regional councils and for young Māori. In such cases, the relative uncertainty in the ERP may exceed 5% percent.

B2 Projections

B2.1 National and regional projections

As discussed, Statistics New Zealand regularly produces population projections, with national level projections being augmented since 2012 by using stochastic methods as well as the standard cohort method. For the latest Statistics NZ subnational (regional) population projections which are not stochastic,[19] the National Institute of Demographic and Economic Analysis (NIDEA, at Waikato University) has determined uncertainty margins around the projected trajectories by region and time horizon. Figure B.1 illustrates the projections for total New Zealand, but data for 16 regions is also available. Table B.1 provides the medium projections by region.

Unsurprisingly, uncertainty increases with the projection horizon and is generally inversely related to population scale. That is, one can say something more precise about Auckland's population in 30 years' time than about West Coast's population. Here the uncertainty index is defined as the difference between the high and low values divided by the medium value.

[18] The census undercount has been derived from the PES. The net census undercount of 103,800 (2.4%) was the result from an estimated 135,500 people having being missed, which was partially offset by 31,700 people who were counted more than once. By comparison, the first PES in 1996 suggested an estimated undercount of 1.2% in 1996.

[19] http://nzdotstat.stats.govt.nz/wbos/Index.aspx?DataSetCode=TABLECODE7542

The Auckland region is both the largest and the fastest growing, expanding at 1.2% pa from 2016 to 2043, well above the national average of 0.7% pa. Population declines are projected for three regions (under this scenario): Gisborne, Manawatu-Wanganui and Southland. Of course these regions also have high uncertainty indices, but Canterbury has the highest index, a consequence of population volatility following the Canterbury earthquakes.

Figure B.1 New Zealand population projections with uncertainty margins

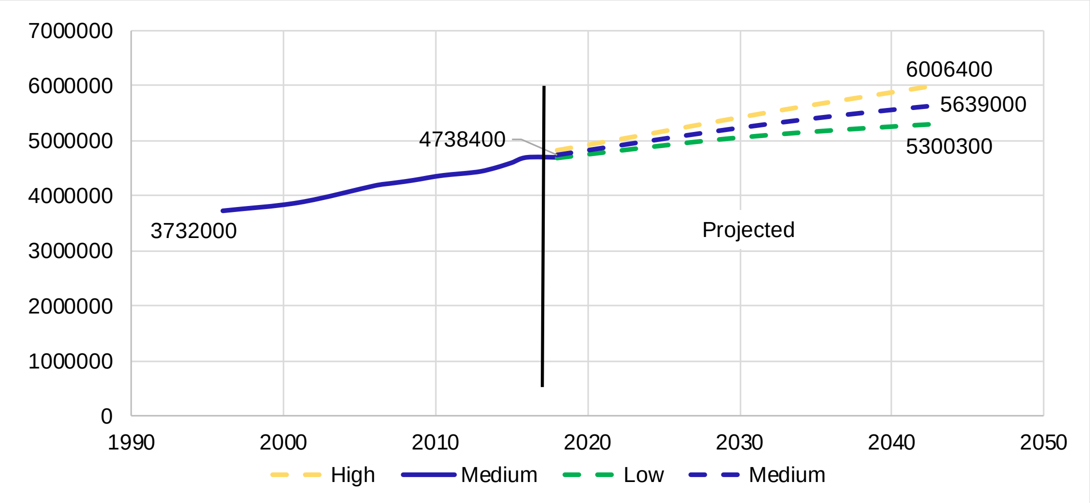


Table B.1 Regional population projections

Region	Population in 2043	Growth (%pa) from 2016	Uncertainty index (2043)
Auckland region	2,229,300	1.20%	18.1
Bay of Plenty region	328,700	0.42%	29.5
Canterbury region	729,200	0.73%	34.1
Gisborne region	47,600	-0.02%	30.9
Hawke's Bay region	164,000	0.06%	29.3
Manawatu-Wanganui region	234,700	-0.03%	30.3
Marlborough region	46,700	0.10%	28.7
Nelson region	55,900	0.37%	29.5
Northland region	182,900	0.24%	28.2
Otago region	239,800	0.33%	26.9
Southland region	96,800	-0.05%	30.4
Taranaki region	130,200	0.41%	29.3
Tasman region	54,000	0.27%	30.0
Waikato region	517,400	0.52%	25.9
Wellington region	548,400	0.31%	27.2
West Coast region	33,200	0.08%	32.5
Total New Zealand	5,638,800	0.68%	12.5

B2.2 Age projections

Population projections by four broad age groups have recently been updated by Statistics NZ, this time using a stochastic method (discussed below). The graphs below present projections at the 10th, 25th, 50th (median), 75th and 90th percentiles. (Note that the first two observations in each graph are only two years apart). Of course this means that we can also produce such figures for the total population (but not by region). There are some interesting differences across the groups:

- The 0–14 group has virtually no growth after 2033. At the 10th and 25th percentiles growth is negative from around 2023. Only the 90th percentile shows continual growth and even that is very low by 2048.
- The 15–39 age group shows a decline from 2028, but most scenarios show a recovery by 2038.
- The 65+ group has the smallest uncertainty margins and is forecast to grow very strongly in all scenarios.

The interquartile range for the total population in 2043 is 520,000, while between the 10th and 90th percentiles the range is 1,000,000. The high-low difference in figure B.1 for 2043 is 700,000. Thus we infer that the traditional high-low deterministic scenarios probably span at best 70% of the output from a stochastic process.

Figure B.2 Population projections for age group 0–14

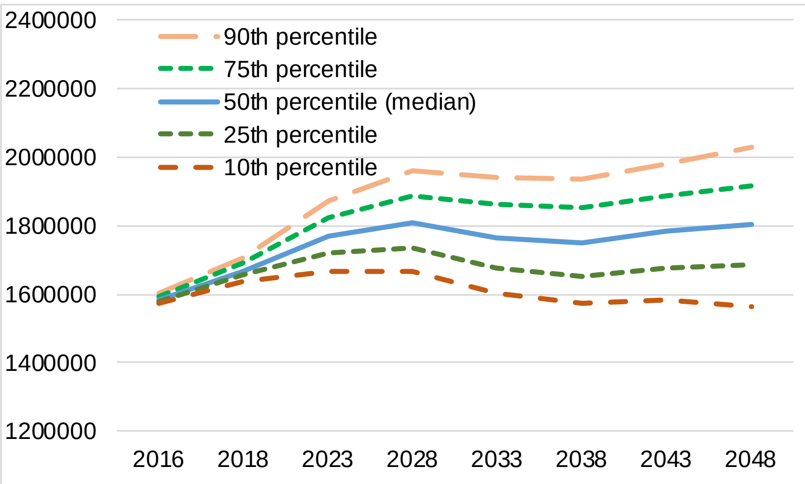


Figure B.3 Population projections for age group 15–39

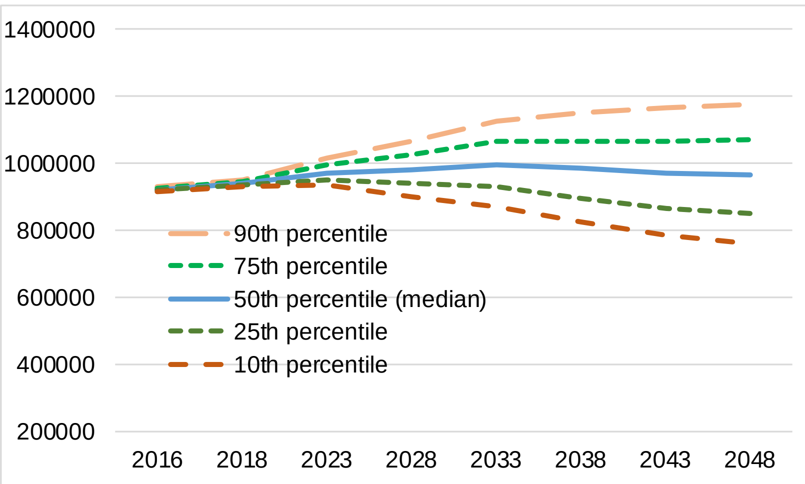


Figure B.4 Population projections for age group 40–64

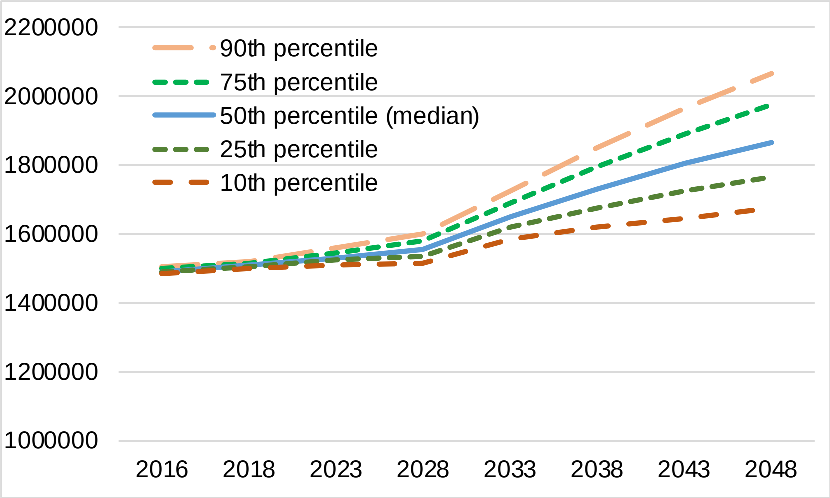


Figure B.5 Population projections for age group 65 and over

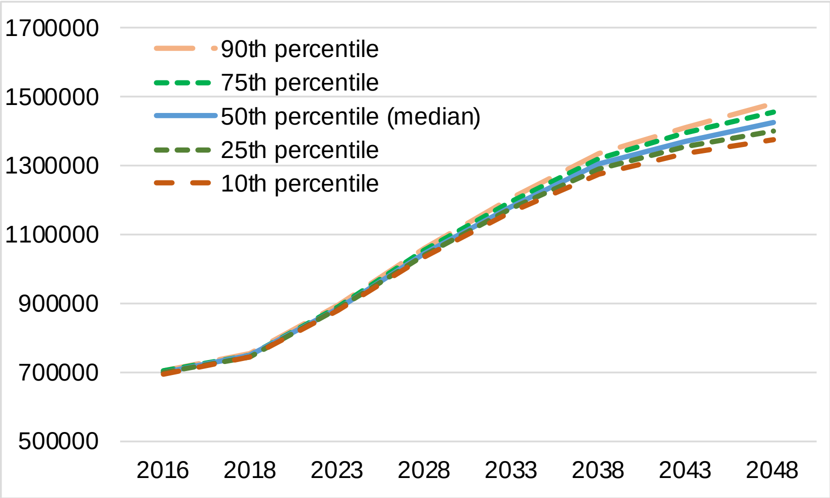
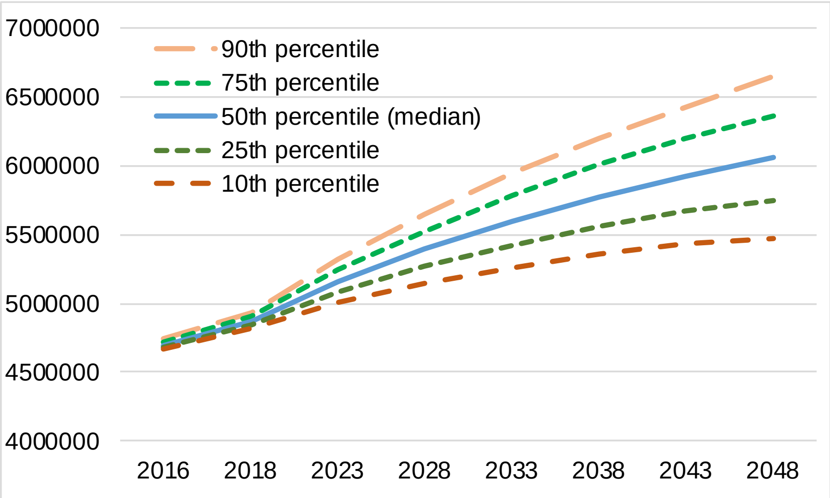


Figure B.6 Population projections for total age groups



B2.3 Household projections

As with regional population projections, Statistics NZ's household projections are not compiled using a stochastic process. Thus we have calculated uncertainty bands analogous to those for the regional projections. Three types of household are projected; single person, family and other multi-person households. Projections go only to 2038.

The household projections and associated indices of uncertainty are based on the low, medium and high variants of the national family and household projections produced by Statistics NZ. The low variant assumes low fertility, high mortality, and low migration; the medium variant assumes medium fertility, medium mortality, and medium migration; and the high variant assumes high fertility, low mortality, and high migration. There are also 'A' scenarios and 'B' scenarios for each variant. Under the latter it is assumed that living arrangement type rates (LATRs) will change linearly between 2013 and 2038. Under the 'A' scenarios it is assumed that LATRs remain constant at 2013 levels. The medium-B variant is Statistics NZ's preferred scenario.

We note there is a disconnect between the census data on household numbers (by type) and the projected household numbers (by type).Statistics New Zealand's family and household projections begin with an estimate of the number of families and households in June 2013, as the census counts are an under-estimate of true number. This is because there are families and households temporarily absent from their usual residence, but are elsewhere in New Zealand on census night. In these cases the people may be counted, but 'wholly absent' families and household will not be counted. Also there are families and households temporarily overseas on census night. Cameron and Cochrane (2016) discuss this further.

Figures B.7–B.10 show the uncertainty bands for the 'B' scenarios. The 2013 figure are estimates, as described above. The medium B scenario projects growth of 1.06% pa ± 0.11% pa from 2013 to 2038. This is faster than the rate of population growth. Underlying this is the 1.58% pa growth in single person households. In contrast the number of family households is projected to grow at 0.92% pa and the number of other multi-person households at only 0.11% pa. This is also the smallest group and so unsurprisingly has larger uncertainty margins.

From the regional projections we infer that the dominance of Auckland and other urban areas will reduce (or in some scenarios reverse) the rate of increase in travel, especially private vehicle travel per capita, owing to the urbanisation effect. The travel implications of the different growth rates for different household types are unclear, as factors such as income and employment are also relevant. However, these factors are automatically incorporated in the RLTDM model's travel projections, presented in chapter 4.

Figure B.7 Projections of total number of households

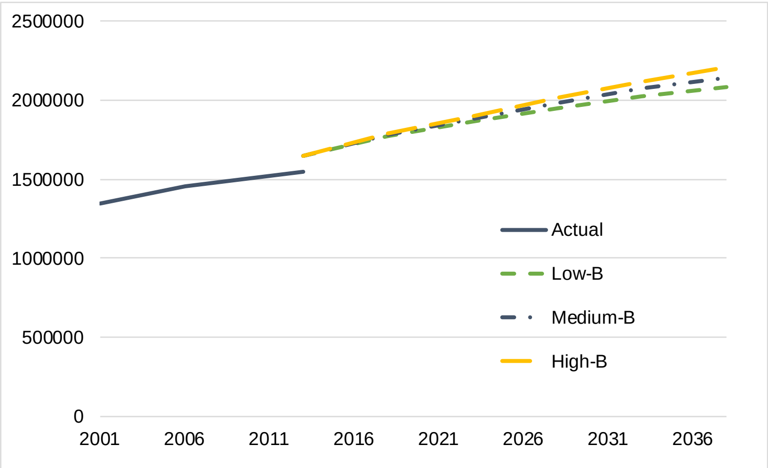


Figure B.8 Projections of number of one-person households

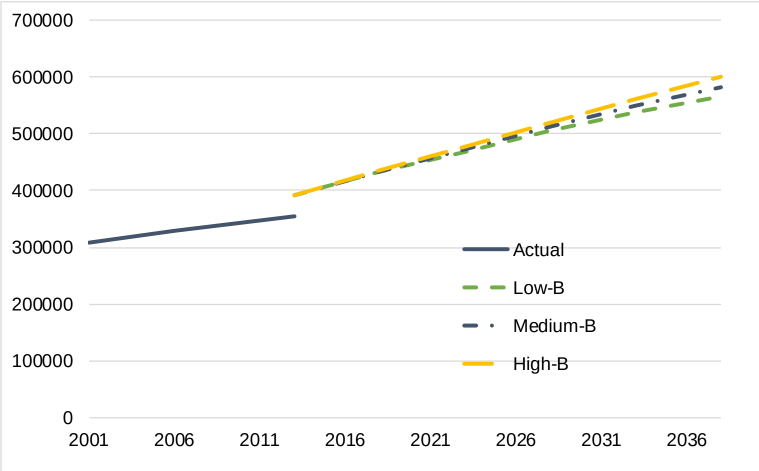


Figure B.9 Projections of number of family households

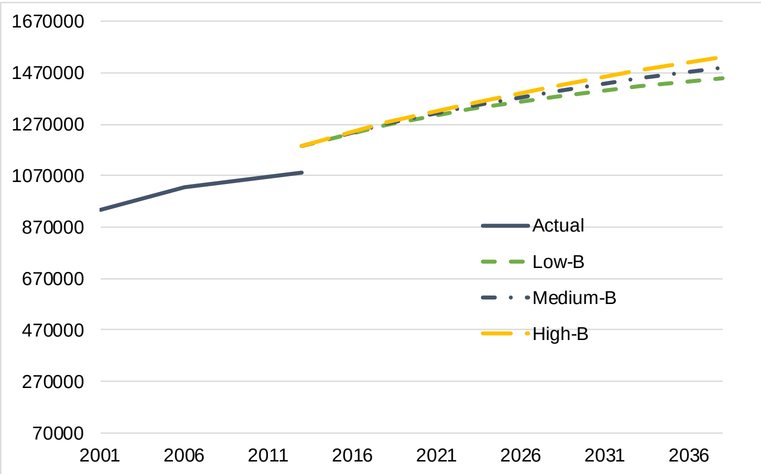
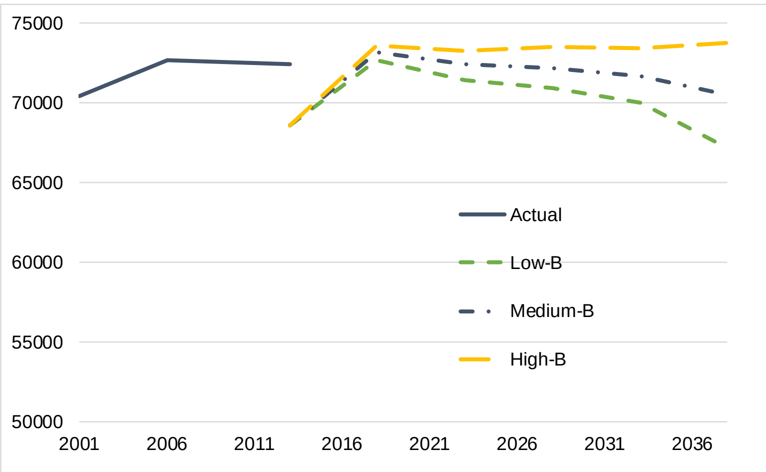


Figure B.10 Projections of other multi-person households



B3 Stochastic uncertainty margins

Cameron and Poot (2011) show that the standard deterministic cohort method for producing population projections tends to yield conservative projections – overestimating slow-growing populations and under-estimating fast-growing ones. Instability of international migration is cited as a key reason for this. Although it is cyclical its amplitude and periodicity are highly variable. In response Cameron and Poot (2011) describe a stochastic method for producing population projections, and apply it to sub-regions within the Waikato.

The standard cohort method uses alternative scenarios to capture different assumptions about three main variables: fertility, mortality and net migration. Little is known about the relative likelihood of different scenarios.

In contrast under the stochastic method fertility and mortality are modelled by age and gender specific rates, and for net migration these rates are also area specific. Stochasticity is introduced by applying scaling factors to these rates, drawn from probability distributions based on historical data. The starting point is Statistics NZ's deterministic 'medium' series for fertility and mortality, and census data for migration.

The scaling factors are fixed over the projection period. In principle they could vary over time, but autocorrelation would likely need to be considered. Similarly there is no allowance for covariance between variables, but with good data this could be changed. Deterministic scenarios are often presented in ways that may appear to assume correlation between variables, for example high fertility and low mortality in one scenario.

With 10,000 draws, the results obtained for the Waikato sub-regions show that the Statistics NZ 'medium' projections based on conventional cohort methodology are outside the interquartile ranges (but within 95% intervals) of the stochastic projections. Cameron and Poot (2011) interpret this as limiting the usefulness of discrete 'medium' type scenarios beyond the short term. The results also show that the projection bands are widest for smaller areas with relatively little population change.

The authors advocate applying the stochastic cohort method to all regions and sub-regions (local authorities) in New Zealand, but caution that this would be a large exercise. They would also prefer to use gross, rather than net migration flows for both international and national migration, suggesting that the latter could be simulated using the gravity model approach – see Omoniyi et al (2016).