Social and distributional impacts of time and space-based road pricing

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An important note for the reader

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Abbreviations and acronyms

AM	AM peak period
ARPES	Auckland Road Pricing Evaluation Study
ARPS	Auckland Road Pricing Study
ATAP	Auckland Transport Alignment Project
CBD	central business district
EB	employment based
EEM	*Economic evaluation manual*
FATF	Funding Auckland's Transport Future
GC	generalised cost
HBE	home-based education
HBO	home-based other
HBSH	home-based shopping
HBW	home-based work
HBW	home-based work
HH	household
IP	Inter-peak period
min	minute
MSM	macro strategic model
NZ	New Zealand
OP	off-peak period
PM	PM peak period
PT	public transport
RFC	relative financial cost
SNZ	Statistics New Zealand
SP	school peak period
Transport Agency	NZ Transport Agency

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Executive summary

Road pricing is a potential method for managing travel demand, funding transport infrastructure, and/or abating other consequences associated with road travel. While time- and space-based road pricing is not in widespread use in New Zealand, growing concerns about congestion make it an increasingly attractive option.

Road pricing can improve the efficiency of the transport system and deliver overall social benefits. However, it will result in increases to the financial cost of travel for many users, which may be difficult for some people to bear or avoid. It is therefore important to understand how costs and benefits are distributed between different individuals or groups in society.

In this report, we outline a general framework that can be used to analyse the social and distributional impacts of road pricing in the New Zealand context and trial it on two hypothetical case studies of road pricing schemes in New Zealand cities. The research sought to:

- Draw on relevant literature and practitioner interviews to understand the likely social and distributional impacts of time and space-based road pricing.
- Develop an assessment framework to identify populations that might be affected by road pricing and to analyse the degree by which they would be affected.
- Apply the framework to two case studies of hypothetical road pricing schemes to demonstrate that it is feasible to implement and to assist in understanding the potential social and distributional impacts.
- Briefly comment on the potential policy implications of the research findings, including implications for mitigating any perceived adverse social and distributional impacts.

A general framework for assessing social and distributional impacts

We identified three general principles that should guide assessment of social and distributional impacts. To test these principles, we applied them to two case studies of hypothetical road pricing schemes in New Zealand cities.

1 Road pricing will have different impacts on specific households (or individuals). If it is not possible to measure outcomes at the household (or individual) level, then analysis should group households based on characteristics that affect their:

  a exposure to the impacts of pricing – relevant characteristics include location, household composition, employment status, and car ownership

  b ability to bear the financial costs of pricing – household income, or disposable income, is a particularly relevant characteristic

  c ability to respond to pricing, eg by changing their transport behaviours – this will reflect location and travel needs.

2 When considering the distributional impacts of road pricing, it is important to consider multiple ways in which impacts may be distributed:

  a vertical distribution of impacts, or impacts on households with different abilities to pay or mitigate the costs

  b horizontal distribution of impacts, or impacts on similar households that live in different places and which therefore may be exposed to a different degree.

3 Road pricing will have both financial and non-financial impacts on households. Multiple impact measures are therefore needed to capture different categories of impacts, and to address the possibility that households will incur a mix of costs and benefits. We suggest a package of measures that capture impacts on the financial cost of travel (relative to income), impacts on household travel times and generalised costs of travel and impacts on accessibility to employment.

Wellington cordon charge case study

Our first case study consists of a qualitative analysis of a cordon charging scheme for Wellington. This consists of a high-level analysis of potential social and distributional impacts based on readily-accessible Census data to demonstrate how this framework can be implemented without transport modelling or highly detailed analysis of demographic data. We analysed a $5 per day charge for vehicles entering (or passing through) inner-city Wellington during weekdays. This analysis only considered the effects of a toll, and did not assess the impacts of any redistribution of toll revenues.

This analysis highlights the benefits of a qualitative approach for providing insight into potential social and distributional effects without requiring costly modelling. However, there are limits to this approach, including difficulty in looking at combinations of household characteristic such as combined income and household composition. This limited our ability to draw highly detailed conclusions about impacts. In addition, the method we used to identify trips travelling across a single cordon may not be applicable for other pricing structures (eg distance-based pricing) or for transport networks with more alternative routes than Wellington. This could be addressed by using transport model outputs to establish a base trip matrix to identify potential transport impacts.

Notwithstanding those caveats, this case study identifies some potential social and distributional impacts of a Wellington cordon charge. Because this scheme principally affects CBD-bound commuters, it is more likely to affect high-income households relative to low-income households. However, people driving across the cordon between north and south areas are likely to have lower incomes and face more limited alternatives for switching modes to avoid the toll. It may be possible to mitigate some of these impacts by improving the speed of public transport journeys and reducing waiting times for journeys that must transfer in the CBD, or by making complementary changes to the structure or level of public transport fares.

Due to its design, the cordon scheme may have smaller impacts (in dollar terms) on households that make few commuting trips, including one-parent households and families that make more school or retail trips. We therefore tentatively suggest that it may therefore be less important to consider mitigation targeted towards these household types.

Auckland distance-based, time-varying road pricing case study

Our second case study consists of a quantitative analysis of the impacts of a distance-based, time-varying road pricing scheme that would apply to the entire Auckland road network. It draws on detailed data from a travel demand model, census and Household Travel Surveys to create a robust and quantitative evaluation of the social and distributional impacts of road pricing. We analysed the road pricing scenario defined in the Auckland Transport Alignment Project, which would target the highest prices to the most congested locations and where travel alternatives were most likely to be available. Off-peak charges would be lower than peak charges. Once again, this analysis only considered the effects of a toll, and did not assess the impacts of any redistribution of toll revenues.

This case study demonstrates it is possible to analyse the social and distributional impacts of a hypothetical road pricing scheme in quantitative terms by analysing transport model outputs and relating them to demographic data on households in different locations. However, this analysis does require custom data from Statistics New Zealand and from the Household Travel Survey, and the creation of algorithms for analysing transport model outputs and linking them to demographic data.

While this approach is more data intensive than the qualitative method used for the Wellington case study, it offers several important advantages. Because it uses strategic transport model outputs, it provides a more detailed picture of the transport impacts of road pricing, including some options for mitigating financial costs by changing travel behaviour. The use of detailed location-specific demographic data enables these impacts to be allocated among different groups of households and between similar households in different locations. The ability to 'cross-tabulate' impacts by household location, income and composition enhances our ability to identify specific areas where there may be a need to mitigate perceived adverse impacts.

This analysis suggests that the impacts of this hypothetical road pricing scheme are likely to be widely distributed throughout Auckland. Most types of households would experience increases in the financial costs of travel, offset to varying degrees by benefits related to faster or more reliable travel, or improved accessibility. The estimated scale of these financial impacts is on the order of 1% of household income, which is in line with previous studies and is roughly comparable to the estimated social cost of traffic congestion in Auckland. Under this particular set of prices, the generalised cost of travel is expected to rise for all household groups and income groups. This indicates that, in this hypothetical example, toll prices may be set at a level that exceeds many households' willingness to pay for the resulting reductions in average travel times. However, there may be additional benefits related to improved travel time reliability and the optimisation of trip departure times that are not captured by the strategic transport model used in this assessment.

Lower-income households are likely to experience the largest financial impacts relative to their incomes. This principally reflects variations in household incomes, rather than variations in the financial costs of the scheme. Similarly, households with children, especially single-parent families, are likely to experience larger financial impacts relative to their incomes than other household types. This reflects the fact that children contribute to household travel – they need to be transported to school and activities, and they induce retail trips – without contributing to household incomes. Similarly, the magnitude of impacts on households varies significantly by location.

This analysis suggests that multiple policy responses may be needed to mitigate any perceived negative social and distributional impacts of this road pricing scheme. Responses may not be limited to transport investment and transport pricing options but could also consider broader options around tax and benefit policy or even education and labour market policy. In saying this, we note that how road pricing revenue is spent or redistributed can have a significant impact in the overall social and distributional impacts of the scheme.

For example, it may be possible to address perceived horizontal equity issues by using road pricing revenue to invest in new transport infrastructure or services, eg by providing more transport choices to people in locations where the toll has a relatively high impact. However, this would not necessarily address the impacts experienced by one-parent households and two-parent households with children, as these households are distributed throughout the city and face relatively large financial impacts due to their household structure and trip-making pattern rather than their location. An alternative approach, such as targeted changes to tax and transfer policies for families with children, may be more successful in mitigating these impacts.

Conclusions and recommendations

The social and distributional impacts of road pricings are multi-dimensional. As a result, no single measure will tell the whole story, and it is important to consider both the aggregate effects and the effects on individuals and households. The framework outlined in this report attempts to bring together several impact measures and several categories of households that may be affected differently in a relatively accessible way. Trial applications of this framework to two case studies highlight how this framework can be implemented using either a qualitative approach that does not rely on modelling, or a quantitative approach that employs modelling and more in-depth analysis. Either approach can provide useful insight into the social and distributional impacts of road pricing.

We note that information on the social and distributional impacts of road pricing will have several different uses. It may be used to design a road pricing scheme that balances perceived adverse effects, to develop mitigation responses to the scheme's impacts, or to communicate the impacts of road pricing to stakeholders or the public at large. It is therefore appropriate to begin any analysis by identifying what the information will be used to do.

We outline several recommendations for transport evaluation. The first is to incorporate this framework into the NZ Transport Agency's *Economic evaluation manual* (EEM). At present, the EEM's appendix A17 contains one page of brief guidance on evaluating the equity impacts of transport projects. While this guidance is conceptually consistent with the framework we have outlined, it does not provide a concrete illustration of how these principles can be put into practice and as a result it is seldom applied to transport evaluation. We therefore suggest replacing or supplementing the existing guidance with the material in this report.

A second recommendation, when evaluating the social and distributional impacts of road pricing, is to carefully consider how the design of transport models may affect their ability to capture the key behavioural responses to price changes. In the literature review and practitioner interviews, we noted some shortcomings associated with the use of strategic transport models to evaluate some impacts, including improvements in travel time reliability and retiming of trips to take advantage of 'dynamic' gains from road pricing, trip chaining to avoid multiple tolls, and land use/location responses to road pricing. We identify, but do not recommend, several potential modelling approaches that may assist in addressing some of these issues.

Abstract

This report outlines a general framework that can be used to analyse the social and distributional impacts of road pricing in the New Zealand context and applies it to two hypothetical case studies of road pricing schemes in New Zealand cities. This framework attempts to bring together multiple dimensions of social and distributional impacts in a relatively accessible way to describe relevant impacts on households and individuals and communicate them to policy-makers and the public in a way that can inform the design of pricing schemes and mitigation measures.

1 Introduction

1.1 Motivation

The NZ Transport Agency (the Transport Agency) commissioned MRCagney to undertake research into the social and distributional impacts of time and space-based road pricing.

A large body of economic research identifies road pricing as a way to efficiently manage travel demands and optimise allocation of scarce road capacity; levy transport charges to fund transport improvements; and/or abate negative consequences of road travel, especially in cities afflicted by traffic congestion. At the same time, recent technological developments in mobile communications technology are improving the ease with which road pricing can be implemented. Yet despite its apparent benefits, relatively few places have implemented road pricing. Why?

Based on this research and our professional experience, we suggest the answer to this question is (to a significant degree) related to the social and distributional impacts of road pricing. That is, while road pricing proposals can improve the efficiency of the transport system by managing transport demands to improve the allocation of scarce road capacity, the impacts are not universally positive for all individuals or groups. Rather, the costs and benefits of road pricing may fall on different people, and some people may experience disproportionate impacts relative to their ability to pay tolls or change their behaviour to avoid them. In this context, it is perhaps not surprising that many people are sceptical of road pricing proposals, and that the most common cause of the opposition relates to the perceived 'fairness' of the proposals.[1]

In this research, we sought to understand the social and distributional impacts of road pricing in the New Zealand context and outline a general framework that could be used to evaluate concerns related to 'fairness' and identify potential options for mitigating social and distributional impacts. While road pricing is not currently used in New Zealand, central government and Auckland Council are currently investigating potential applications through 'The Congestion Question' project (formerly the Auckland Smarter Transport Pricing Project), which aims to determine if road pricing is an appropriate mechanism to reduce or manage congestion in Auckland. One of the goals of this research was therefore to inform The Congestion Question project by providing insight into the social and distributional impacts of road pricing. However, we did not intend to evaluate options being considered by The Congestion Question project, and nor did we analyse how revenues should be spent or redistributed.

This research sought to:

- Draw on relevant literature and practitioner interviews to understand the likely social and distributional impacts of time and space-based road pricing.
- Develop an assessment framework to identify populations that might be affected by road pricing and to analyse the degree to which they would be affected.
- Implement this framework to two case studies of hypothetical road pricing schemes to assist in understanding the potential social and distributional impacts of road pricing in the New Zealand context.
- Briefly comment on the potential policy implications of the research findings.

[1] In saying this, we note that public perceptions of road pricing schemes often rise after implementation, which suggests that fear of the unknown also plays a role (CEDR 2009).

1.2 Structure of this report

The following sections of this report are structured as follows:

- Chapter 2 reviews relevant literature and identifies key issues that are relevant for the development of a framework for assessing social and distributional impacts.
- Chapter 3 summarises the results of interviews that we undertook with a range of practitioners, to understand what they viewed as the most pertinent issues for our research.
- Chapter 4 presents principles and outlines a general assessment framework for evaluating the social and distributional impacts of road pricing.
- Chapter 5 applies this framework in a qualitative case study of a hypothetical cordon pricing scheme in Wellington, which illustrates how these principles can be used to evaluate social and distributional impacts even without detailed transport model outputs or in-depth analysis of demographic data.
- Chapter 6 applies this framework to a quantitative case study of a hypothetical distance-based, time-varying road pricing scheme for Auckland, illustrating how the framework can be put into practice using transport model outputs and demographic data.
- Chapter 7 concludes by discussing some key findings from this research and identifying recommendations for policy and evaluation practice.

In the process, we also comment on how road pricing schemes may be designed so as to mitigate their potential social and distributional impacts. However, we did not assess the overall merits of alternative road pricing schemes, as they were outside the scope of the research.

2 Literature review

In this chapter, we review the literature on road pricing with a focus on findings that are relevant to social and distributional impacts. The following sections are structured as follows:

- Section 2.1 briefly reviews the role of road pricing.
- Section 2.2 discusses the sources of efficiency gains from road pricing.
- Section 2.3 considers how we define 'equity/fairness' when analysing road pricing proposals.
- Section 2.4 discusses the potential impacts of road pricing schemes on users.
- Section 2.5 reviews approaches to assessing user impacts.
- Section 2.6 summarises our findings.

In completing this review, we drew on the results of both academic research as well as professional reports.

2.1 The role of road pricing

A large body of research identifies a potential role for road pricing in managing travel demands to optimise use of scarce road capacity, abating the negative consequences of road travel, and charging transport users to fund improvements to the transport system. These roles are particularly relevant in cities afflicted by traffic congestion. In this sub-section we consider these potential roles for road pricing and note how they interact.

First, road pricing is often viewed as an efficient way to manage travel demands. Under this line of thinking, road pricing is a corrective ('Pigouvian') tax that internalises the external costs of congestion to individual road users. The tax is set to account for external costs of travel, such as congestion and crashes, and to achieve a more socially efficient level of demand (Treasury 2015). The economic theory behind using road pricing to manage travel demands and abate the negative externalities of road travel is articulated in Ecola and Light (2009):

> *... individuals who drive on congested roads create costs for others. By entering a congested highway, one's vehicle takes up space, slows the speed of upstream traffic, emits pollution, increases the probability of vehicle collisions, and increases noise levels for other motorists and nearby residents and businesses. Because these costs are imposed on others without compensating them, motorists are unlikely to incorporate these impacts into their decision making process. Congestion pricing seeks to remedy this by imposing a charge that reflects the monetized value of the externalities associated with driving.*[2] *This encourages motorists to behave in ways that more closely reflect the interests of others in society. Specifically, congestion pricing discourages drivers from taking vehicle trips during the most crowded times of day if those trips could be made at other times, on other modes, or on other routes or forgone entirely.*

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[2] Note: This statement reflects the views of the referenced study's authors. We acknowledge that in a perfect world this would be the case; however, in most real-world situations, the true monetised value is moderated by political processes. Likewise, it is difficult to estimate monetary values for some externalities, which may make it difficult to respond to them via a price mechanism.

Second, road pricing can be a way of charging transport users to fund the provision of transport infrastructure and services. We emphasise that a user charge is not a tax per se; rather it is a fee for supplying goods or services. To the extent that user charges reflect the costs of providing transport infrastructure and services ('cost reflexivity'), then people can determine what they wish to consume and pay for. By improving the cost reflexivity of transport user charges, road pricing can help to ensure (in the long run) users' willingness to pay for travel is greater than or equal to the costs of catering for that travel.[3] This is especially relevant to congested urban areas, where the marginal costs of increasing the supply of transport infrastructure and services, for example to accommodate peak period demands, tends to increase rapidly as cities develop and grow in size (Treasury 2015). In such settings, road pricing can help to reflect the social costs of supplying transport to users, thereby improving the quality of the price signals between supply and demand.

Third, road pricing can be implemented to raise revenue, with funds used for other, indirectly related, or even unrelated purposes (Tax Working Group 2010). Indirectly related purposes may include funding public transport or cycling infrastructure, while an unrelated purpose could include using road pricing to fund education, arts, or some other public goods. What circumstances might warrant using road pricing revenue for unrelated purposes? One argument advanced in the literature is that road pricing revenues may be used to reduce other distortionary taxes, such as taxes on labour income (see, for example, Parry and Bento (2001)). This line of research emphasises that taxes on labour income are distortionary because they reduce the returns to labour and suppress employment. When road pricing tolls are paid for by commuters, then they can further reduce returns to labour. Using an economic model, Parry and Bento (2001) found that using road pricing revenues to reduce taxes on labour income had the effect of doubling the efficiency benefits of the road pricing scheme. In this context, road pricing revenues may help reduce undesirable distortions elsewhere in the economy.

It is rare for a scheme to be implemented only for one reason. The three potential roles of road pricing interact and to some degree conflict with each other. For instance, if road pricing is intended primarily as a corrective tax instrument to manage excess road congestion, rather than as a means of raising additional revenue, it may be appropriate to set tolls at a level that raises relatively little revenue. While outside the scope of this report, we suggest there is a pressing need to reach agreement on how road pricing revenues might be used, so researchers and practitioners can provide a full account of the social and distributional impacts of road pricing. And although the rest of this report focuses on understanding only the direct impacts of road pricing, we urge readers to bear in mind that this represents only one side of the road pricing 'coin'; the use of revenues is at least as important to distributional impacts.

2.2 Efficiency gains from road pricing

To set the scene, we now briefly describe how road pricing can improve efficiency. Understanding the sources of these efficiency gains provides insight both into *why* road pricing is being considered by many jurisdictions, and also *how* road pricing may affect individuals differently.

[3] In the short run, transport users will make daily decisions in light of their previous decisions about major investments such as purchasing a home, buying a car, or investing in skills that are relevant to a specific industry. They may therefore choose not to respond to price changes immediately. This may influence the magnitude and distribution of benefits and costs in the short run versus in the long run. Below, we discuss some studies that have attempted to estimate the short-run and long-run effects of road pricing.

Congestion describes how the quality of service deteriorates with the intensity of use. While congestion can, in principle, arise for many facilities, the term is most commonly used to refer to road networks.[4] In the case of road networks, beyond a certain quantity of demand each additional vehicle at road links and at intersections causes the speed of traffic to decline substantially, imposing large delays on other users. In economic terms, congestion implies the marginal social cost exceeds the average private cost faced by those users. In the absence of road pricing, users do not bear the full cost of their decision to drive, so road networks experience excessive demands and reduced performance due to congestion'. This is the economic intuition behind road pricing.

More formally, road pricing seeks to correct for congestion externalities. In doing so, two potential sources of efficiency gains are identified in the literature (see for example, Small et al (2007) for a review):

- Deadweight losses – static 'link' models of congestion use classical Pigouvian reasoning to show that road pricing can reduce the deadweight losses that arise from excess demand and the congestion externalities that result.
- Monetisation of delays – dynamic 'bottleneck' models of congestion follow Vickrey (1969) and observe that road pricing monetises delays and incentivises drivers to adjust departure times (Arnott et al 1994; Börjesson and Kristoffersson 2014; van den Berg and Verhoef 2011).

The efficiency gains associated with deadweight losses and monetisation of delays arise from distinct microeconomic channels; the first reflects a *static efficiency* associated with internalising an external cost whereas the second reflects a *dynamic efficiency* associated with monetisation of delays and changes in departure times. Both have implications for the social and distributional impacts of road pricing schemes.

First, we consider the efficiency gains that follow from reduced deadweight losses and lower demand. It seems logical to assume this demand reduction occurs when people with the lowest willingness to pay are priced off the roads. Willingness to pay, moreover, seems likely to be determined by the value that one places on the travel-time savings and trip reliability that result from road pricing schemes. If individuals' willingness to pay for travel time savings is strongly and positively correlated with income, then the effects of road pricing in the static model may be regressive, as pricing will tend to discourage low-income people from travelling.

Small et al (2005) note in an investigation of the distribution of drivers' preferences for travel time and reliability:

> *motorists exhibit... substantial heterogeneity in those values. We suggest that road pricing policies designed to cater to such varying preferences can improve efficiency and reduce the disparity of welfare impacts compared with recent pricing experiments.*

Second, we consider efficiency gains that follow from monetisation of delays and departure time adjustment in the context of queuing and delays at bottlenecks in the transport network. It seems plausible to suggest that the 'winners' in this setting are those with more flexible lifestyles, where flexibility is a general rubric that captures changes to the days, times, and locations that one travels. However, individuals with the most flexible lifestyles may not necessarily have higher incomes or willingness to pay for travel time savings. In general, the distributional impacts of these efficiency gains are less clear-cut.

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[4] Other transport facilities are also congestible, albeit in different ways. For example, public transport vehicles can become crowded (ie all seats full, people standing in the aisles), which reduces comfort for users and may introduce small delays in boarding and alighting but does not affect travel speed.

Real-world road pricing schemes are likely to generate efficiency gains from both sources. Moreover, real-world settings are significantly more complex, so straightforward answers are generally elusive. Nevertheless, it is useful to keep these two sources of efficiency gains in mind when evaluating material presented in subsequent sections. In these sections, we focus on efficiency gains flowing from reduced deadweight losses, which are more readily modelled by existing strategic transport models. Strategic transport models are limited in their ability to model efficiency gains arising from changes to departure times, meaning they may underestimate efficiency gains or overestimate costs to some users. Where road pricing schemes cause changes in departure times, then their distributional impacts may be quite different. We return to this issue in section 2.6.

Under the static model of traffic congestion, and in the absence of mechanisms to return revenue to users, the only clear 'winners' from road pricing schemes are those with a relatively high willingness to pay for travel time savings. Everyone else – to varying degrees – 'loses', including all those who are priced off the road as well as most who continue to drive. In such a modelling setting, and without yet saying anything about how road pricing revenues are applied, road pricing proposals may struggle to gain democratic support. Consequently, the use of revenues can be important for mitigating distributional impacts and shaping public perceptions about the 'fairness' of road pricing.

2.3 Thinking about equity and fairness

The introduction of any pricing scheme for publicly provided goods and services will inevitably be met by concerns, real or perceived, regarding equity and fairness. Whereas efficiency describes the total benefits and costs of a policy, equity considers the relative distribution of those benefits and costs between individuals and social groups. Additionally, the degree to which impacts are felt by individuals or social groups is a signification consideration regarding equity. In the presence of congestion, the use of road pricing to allocate scarce road resources is likely to be efficient, while also creating winners and losers. This leads to the question: What distribution of winners and losers is acceptable?

Such questions are of critical importance to political economy and, as such, are likely to determine the relative viability of road pricing proposals. Major policy interventions, such as road pricing, often walk a tightrope between efficiency and equity. A recent review of road pricing schemes noted that an on-going concern in nearly all implemented schemes related to those who pay, those who do not pay, and those who benefit (D'Artagnan Consulting 2018). In theory, efficiency gains could be used to compensate losers, although this is difficult to do, and rarely done in practice.

Definitions of equity and fairness are contested and multifaceted (Ecola and Light 2009). To some, it is fair that motorists pay for the costs they impose upon society, which may be achieved via road pricing. Conversely, others contend that road pricing may place an unfair burden on disadvantaged members of society. To highlight the multi-faceted nature of equity, we adapt the following thought-experiment from Eliasson and Mattsson (2006):

> *You commute daily by car. On the way, you have to cross a bridge across a river. One day, the bridge closes for repairs for a long time. Another bridge is available further downstream, but the detour takes an additional 20 min. During the time it takes to repair the bridge, the road authority has arranged with a ferry that can take cars over the river.*
>
> *Some people complain that it is unfair that the authority charges a price for the ferry tickets. When offering the ferry for free, it turns out that there is not room on the ferry for everyone who wants to use it. The authority now considers four different methods to choose who gets to travel with the ferry:*

- *Price: Charge those who want to travel, and set the price so the ferry is just filled.*
- *Queue: Those who arrive first to the jetty and stand in line get to go with the ferry.*
- *Need: Those who want to travel with the ferry have to show some evidence to support their need. The authority then provides ferry passes based on their judgement of greatest need.*
- *Lottery: Tickets are allocated randomly, so that everybody has an equal chance of winning.*

The above four allocation mechanisms all make implicit assumptions around what can be considered a fair and equitable distribution of scarce resources. 'Queue' is effectively how access to the road network is currently managed, whereas 'price' is how it would be managed in the presence of road pricing. While useful for highlighting alternative mechanisms that may be considered fair, this thought experiment is a simplification to the extent that it presents the alternative methods as being mutually exclusive. In real-world applications, road pricing schemes can of course combine both the 'price' and the 'need' methods. In such a scheme, vulnerable individuals, such as low-income households, would presumably receive discounts.

In this report, we draw a distinction between what we refer to as 'equity standards' and 'equity indicators'. The former describes the social value of different distributions of benefits and costs across the population and represents what economists might call a social welfare function. Economists typically assume that government policies seek to deliver the distribution of resources that maximises total welfare given society's underlying preferences. However, there are many potential equity standards that may be accepted by different people in different contexts. By contrast, equity indicators refer to quantifiable or qualitative *measures* of the social and distributional impacts of policies. They serve a descriptive, rather than normative, function – they seek to describe and summarise impacts, rather than identifying whether they are 'good' or 'bad'. Our research is focused on indicators, rather than standards, as the question of what is an appropriate equity standard for society to aspire to requires broader social and political input.

In earlier sections, we indicated that – in this study – the primary role of road pricing was to act as a corrective tax for managing travel demands at an efficient level, rather than to raise revenue. In this context, the public finance literature provides additional insight into notions of equity and fairness that are relevant to road pricing. Issues of equity were considered, for example, by The Tax Working Group (2010) that was tasked with evaluating potential changes to New Zealand's tax system, which advanced the following concept of equity and fairness:

> *Equity and fairness: The tax system should be fair. The burden of taxes differs across individuals and businesses depending on which bases and rates are adopted. Assessment of both vertical equity (the relative position of those on different income levels or in different circumstances) and horizontal equity (the consistent treatment of those at similar income levels, or similar circumstances) is important. The timeframe is also important, including how equity compares over peoples' life-times.*

Synthesising the different strands in the public finance literature, we suggest the following four measures of equity are most relevant to investigations of the equity impacts of road pricing (adapted from Bills and Walker 2017):

- Vertical equity – taxpayers with greater ability to pay should pay more tax, where ability is typically measured by an individual's income or wealth, noting that other personal circumstances will also influence ability to pay.
- Horizontal equity – taxpayers with equal amounts of income (or assets) should pay the same amount of tax.

- Intergenerational equity – there is alignment in the degree to which the incidence of benefits and costs fall on different generations of taxpayers.
- Market equity – taxpayers that receive a greater proportion of the benefits should contribute a greater proportion of the costs.

We note that these measures are not necessarily mutually exclusive; it is possible, for example, to devise taxes that are equitable in both the vertical and horizontal sense.

In this report, we follow Levinson (2010)'s observation that 'no single equity measure is appropriate to use, and different measures lead to different policy conclusions' and consider multiple definitions of equity. In particular, we consider both vertical and horizontal equity when measuring and reporting social and distributional impacts. While intergenerational, and market equity are also relevant, they tend to be much broader policy questions than those that arise from a specific road pricing scheme.

Using a vertical equity lens, we focus on understanding how road pricing affects groups or individuals who are able to bear those costs. In the simplest terms, this project seeks to understand how the 'winners' and 'losers' from road pricing relate to people's existing socioeconomic status. We believe this definition of equity is likely to be most relevant to stakeholders. The horizontal equity lens allows us to examine how people of similar circumstances, but different locations may be affected by road pricing.

In doing so, we must keep our own subjective preferences about equity and fairness in mind when analysing social and distributional impacts. Ultimately, the selection of equity standards and equity measures is a question best answered by political representatives working in conjunction with technical experts and in consultation with the community (Thomopoulos et al 2009). While we believe that the measures recommended this report relate to broadly-accepted concepts of equity and fairness, there is likely to be value in testing this framework with the public.

2.4 Understanding the impacts of road pricing

One message emerging from the literature is that the impacts of road pricing are primarily defined by existing travel patterns. That is, before assessing (complex) behavioural response to road pricing, significant insight into potential impacts can be gained by understanding how people currently travel.

For instance, the financial impact of a per-kilometre road pricing charge is likely to align with the total distance households presently drive at peak times. If wealthier households drive disproportionately further at peak times, then the distributional impacts of the road pricing scheme are likely to be vertically equitable, and vice versa. Impacts are largely determined by existing travel demands because (1) the monetary costs of transport are only one component of the total cost and (2) the demand for transport is typically inelastic, with elasticities less than -1.0. For these reasons, one can expect that most people will sustain their existing transport and land use choices patterns, even after road pricing is implemented.

In saying that, people can and will make behavioural responses because of road pricing, and these responses may affect the overall distribution of benefits and costs. The reason is that people's ability to respond to road pricing, for example by changing to public transport, may be positively correlated with other socio-economic indicators, such as income. If the ability to respond to road pricing is inequitably distributed, then behavioural responses to the road pricing scheme may exacerbate existing socioeconomic inequities and vice versa. This highlights the importance to base analysis on data on people's *actual* socioeconomic circumstances and transport options to understand the joint impact of both factors.[5]

Behavioural responses to road pricing can be categorised in terms of whether they represent a change in (1) transport or (2) location. (NB: Changes in land use are a consequence of changes in location; hence we tend to refer to the latter as the primary choice.) Impacts are summarised in table 2.1 and discussed in the following sub-sections. In principle, we expect both transport and location responses to *mitigate* the costs of road pricing for individual users, acknowledging that some individuals will not be able to adjust their transport choice or location.

If users choose to adapt their behaviour, then we expect the adaptation to be less costly than paying the toll and continuing to travel as before. Hence, the value of the tolls paid provides something of an upper bound on the relative costs incurred by users who adjust their behaviour, which in turn bounds the compensation that they might reasonably expect to receive.

Table 2.1 User responses to road pricing

Type of response	User response	Impacts on users
Do nothing	Do nothing: same mode, same route, and pay associated toll	Financial cost: users pay the full value of the toll Time: users experience faster travel times (insofar as others switch) Other: N/A
Transport response	Change route: same mode, different route, and pay associated toll	Financial cost: users pay the lower toll and thus avoids some financial costs Time: users may experience slower travel times (depending upon network-wide responses) Other: N/A
	Change mode: so as to reduce (in the case of car-pooling) or avoid the toll	Financial cost: for users switching to public transport, financial costs may include fares; for users switching to carpooling would have lower costs, for users switching to walking or cycling cost would be zero Time: users may experience slower travel times Other: users may experience other disbenefits, eg from less convenient journeys
	Change travel-times: so as to travel at times when tolls are lower	Financial cost: users pay the lower toll and thus avoids some financial costs Time: users may also benefit from faster travel times in off-peak periods Other: users may experience disbenefits from not being able to travel at their preferred time
	Avoid making trips: whether by removing trips entirely or linking them with other trips	Financial cost: users avoid tolls by not travelling. There may be some offsetting financial costs, eg for home delivery of goods Time: users avoid travel time Other: users may experience non-monetary disbenefits from avoiding trips, such as a loss of consumer choice from avoiding shopping trips
Location response	Change destinations: to locations that are	Financial cost: users avoid tolls (or pay lower tolls) but may incur some financial costs of switching, eg by accepting lower wages in a different

[5] A corollary, which we explore later in the report, is that it may be most effective to mitigate some adverse social and distributional effects 'at the source', eg through tax and transfer policy, education opportunities, or labour market policy, rather than trying to mitigate them via the transport system.

Type of response	User response	Impacts on users
	subject to a lower toll	work location Time: users may also experience faster travel times due to shorter journey distances Other: users may experience non-monetary disbenefits from switching to different destinations, eg a loss of consumer choice from shopping at smaller retail destinations
	Change origin: to locations that are subject to a lower toll.	Financial cost: users avoid tolls (or pay lower tolls) but may incur some financial costs of switching, eg by paying higher rents to live in a more convenient location Time: users may also experience faster travel times due to shorter journey distances Other: users may experience non-monetary disbenefits from switching to different origin, eg a loss of amenity from living in a less attractive location closer to destinations or loss of important community linkages

Source: Adapted from Salomon and Mokhtarian (1997)

In the following two sub-sections, we summarise evidence on transport and location responses respectively. The literature on which this commentary is based is summarised in appendix A. To finish this section, we review the literature on approaches to measuring the welfare of people affected by road pricing.

2.4.1 Transport responses

We reviewed published papers that assessed the impact of road pricing on transport behaviours, as summarised in appendix A1. These papers include modelling/forecasting efforts and empirical analyses of the outcomes of schemes that have been put into practice. Most studies focused on cordon charges or charges applied to individual road links (eg toll bridges or high occupancy toll lanes), as these are the most common road pricing schemes that have been implemented to date. There have also been some attempts to evaluate the overall welfare impacts of specific road pricing schemes, including a lively debate over whether the London congestion charge has delivered net benefits or disbenefits (Eliasson 2009).[6]

Studies tended to focus on distinct types of responses. The most common response identified in the literature is changes to transport mode, generally from car to public transport.[7] There is also evidence for changes to departure time, as predicted in concept by the bottleneck model. Some studies also find evidence of changes to route choice, depending on the scheme design. A common finding, however, is that most car commuters will continue to drive in, at around the same time, even after the implementation of road pricing. In other words, most car users do not significantly alter their travel patterns in response to road pricing. There are several possible explanations for the muted effect of road pricing, specifically:

- People are constrained from changing transport behaviours by the limited availability or practicality of alternatives.

[6] Prud'homme and Bocarejo (2005) contend that the London congestion charge has caused net social disbenefits, while other studies that adopt different assumptions about the value of travel time savings or the area of analysis find evidence of net social benefits.

[7] Some studies also investigated carpooling, but none placed a great emphasis on walking or cycling.

- People perceive that the benefits of road pricing – in the form of reduced travel times and improved reliability – exceed the increased monetary price of travelling.
- Habits are hard to break, meaning that people may choose not to change behaviours even if there are benefits to doing so, at least not in the short run.

All three explanations are likely to be relevant, and they all tend to support the notion that the demand for transport is generally inelastic. However, some behavioural responses may not be immediate and could take time due to the nature of the choices involved.

Several studies investigate the influence of socio-economic variables, including income, gender, age and household structure, on people's responses to road pricing (eg Bonsall and Kelly 2005, Eliasson and Mattsson 2006). While it is difficult to generalise from studies carried out in different contexts, there do appear to be meaningful differences in how people respond to pricing. That is, individual and group-level heterogeneity is important. This observation is a relatively consistent finding from the literature on road pricing and transport modelling in general.

Three transport responses – namely switching routes, time periods and modes – may help minimise the effect of the toll to individuals, while also having implications for the design of the scheme itself. The degree to which these responses manifest in response to road pricing will depend upon both the setting and the design of the scheme. For example, a flat all-day cordon toll, such as used in London, would not serve to encourage changes in the time of travel, even if it may encourage mode shift.

The fourth type of transport response is perhaps one of the most interesting: In response to road pricing, people may avoid making some trips. Trip suppression may manifest due to income effects, changes in trip-linking behaviour, and/or the substitution of alternative delivery methods, such as online shopping coupled with home delivery. Further research on the degree to which these different mechanisms are evident in the New Zealand context is likely to be useful. We expect people's ability to make changes in trip-linking and/or choose alternative delivery methods to be positively correlated with income, as it relies on access to internet-enabled computers or phones and may be complementary with flexible work arrangements. If so, then this would tend to enhance the ability of high-income households to mitigate the effects of road pricing. However, this correlation may decline over time as more households gain access to these technologies.

2.4.2 Location responses

We also reviewed published papers that assessed the impact of road pricing on location choices, as summarised in appendix A2. In the medium to long term, people and firms may well change their locations to take advantage of the impacts of the toll.[8] Most of the papers we reviewed were focused on modelling or forecasting the impact of road pricing on land use, rather than analysing what has happened in response to existing pricing schemes. Ecola and Light (2009) comment that little work exists on the long-term locational and land use impacts of road pricing, because – with the notable exception of Singapore – most schemes have not been operating long enough for the effects on location choice to be analysed.

When reviewing papers, we were primarily interested in the following two questions:

[8] We note that changes in location choice happen in advance of and independently from changes in land use, although the latter can complement the former. For example, a road pricing scheme may directly influence where people and firms choose to locate, which subsequently indirectly impacts on where land use development occurs.

- Does accounting for location/land use responses to road pricing have large welfare implications other than the transport responses, such as impacts on property values in different locations?
- How is road pricing predicted to affect urban form, in terms of the distribution of land uses throughout the city?

With regards to the first question, there is some evidence that the short run location/land use response to road pricing may be different to the long run response, although the literature on this issue is not particularly broad or settled. We identified two studies that report larger welfare gains from road pricing when accounting for location and land use effects (Anas and Xu 1999; Safirova et al 2006). The latter study is particularly interesting: It models welfare gains for households with varying incomes and allows for redistribution of revenue and finds that the equity impacts of road pricing differ significantly when land use responses are considered. A further interesting finding is that the toll required to maximise traffic flow is higher when land use responses are taken into account. This suggests people may move closer to their destinations, which may be in relatively congested areas, in response. New Zealand has some of the highest rates of residential mobility in the OECD, along with relatively flexible labour markets. This implies the impacts of road pricing on a location may well be larger in New Zealand than in other jurisdictions, and would seem to be worthy of further research.

With regards to the second question, we find a consensus that road pricing *will* affect urban form, but no agreement about the direction of effects (see Levine and Garb (2002)).[9] Studies that have modelled the effects of road pricing using 'monocentric' models (in which all commuters travel to a single employment destination) tend to find pricing increases density and reduces the spatial extent of the city. In contrast, studies that have modelled a 'polycentric' urban form deliver more mixed results, with some suggesting the city will disperse more and some suggesting it will concentrate. Anas and Xu (1999) and Brinkman (2016) posit two offsetting effects on urban form, which could in principle lead to net concentration or dispersal: (1) Some low productivity businesses will tend to disperse from central locations, which are now more expensive to access, so as to be closer to workers and customers; and (2) some residents will concentrate near employment centres and amenities to reduce commuting and travel costs. Of course, different pricing schemes may have different impacts on urban form. For instance, cordon charges create incentives to move both inside and outside the boundary.

On this basis, we suggest there is sufficient evidence and reason to expect a location/land use response to road pricing[10], and that this response is likely to have implications both for the efficiency and distribution of benefits and costs associated with the scheme. New Zealand's housing and labour markets are – by international standards – relatively flexible, especially compared to Europe. Relatively low search frictions in New Zealand's housing and labour markets may well increase the impacts of road pricing on travel demands in the medium to long run and have implications for welfare and implementation.

2.4.3 Dynamics of the response

In addition to the nature of the transport and location response to road pricing is another interesting question, that is, how does the travel demand response to road pricing change over time? And what are the implications for the dynamics of the welfare effects of road pricing?

[9] This potentially poses a challenge to attempts to use road pricing to influence urban form, although we acknowledge this could be a relevant goal for policymakers.

[10] We acknowledge that fixed assets such as housing and economic activity centres generally have a long useful life. As such, decisions relative to location are likely to occur slowly over a long period of time.

Eliasson (2009) observes that the effects of road pricing on travel demands could be smaller *or* larger in the long run. Adapting from Eliasson (2009), we distinguish between 'amplification' and 'rebound' effects:

- Amplification effects – in the long run, individual people and firms may be able to make more significant and enduring changes in response to the toll, eg they can change home/work location and reduce car ownership, which amplify the reduction in travel demands. There is some evidence, for example, that search frictions in housing and labour markets may stymie people's ability to respond quickly to road pricing initiatives. Over time, however, some people may adjust home and work arrangements to suit. Meanwhile, innovative technologies and services may emerge to further mitigate the effects of road pricing. The fact most travel demand elasticities tend to increase over time tends to support the argument for net positive amplification effects.
- Rebound effects – on the other hand, behavioural and/or wider economic adjustments may cause travel demands to rebound in the long run. Potential explanations might include:
  - *acclimatisation*, in which people adjust to the psychological effect of the toll and gradually resume their former transport patterns
  - *induced demand*, in which previously suppressed trips, presumably with high values of time, emerge on now-less-congested road networks
  - *general equilibrium effects,* in which the economic benefits of road pricing eventually lead to increased levels of economic activity, and hence higher travel demands.

Experience in Stockholm suggests the initial drop may be slightly overstated, perhaps due to people's sensitivity to new price signals, which subsequently dissipates as people acclimatise to tolls. In general, however, the initial reduction in travel demands appears to have largely been sustained. Whether this indicates amplification and rebound effects are insignificant, or that they balance each other out, is unknown. The net result, however, is that the magnitude of the travel demand response is relatively stable.

While the impacts of road pricing on travel demands are generally sustained over time, the impacts on welfare may follow a different trajectory. Notably, over time we expect people to be able to adjust their transport and location choices to mitigate the effects of road pricing. For example, people may choose to live closer to where they work, own fewer vehicles, and/or make greater use of alternatives. While financially motivated, these decisions may well catalyse wider changes in transport and land use outcomes, which in turn have implications for welfare. For example, if people make medium to long-term decisions that reduce their demand for vehicle travel and increase their demand for non-car modes, then this may have external benefits and costs. And of course, these benefits and costs may not be equally distributed across the population.

For this reason, we draw a distinction not just between the dynamics of the response in terms of transport vis-à-vis location, but also a distinction between the dynamics of the impacts on travel demands vis-à-vis welfare. Notwithstanding these distinctions, we cannot say much on their trajectories and detailed assessments will require further research. On the balance of evidence, however, we consider it likely that the dynamics of the response to road pricing tends to amplify the effects of the scheme on travel demands and welfare. Short to medium-term analyses may therefore not provide precise estimates of the long run implications of road pricing for economic efficiency, or distribution of impacts.

2.4.4 Measuring impacts

Later sections will consider how to measure the impacts of road pricing. In this section, we present some preliminary findings from the literature.

When measuring the impacts of road pricing, researchers generally acknowledge the importance of accounting for monetary and non-monetary effects. Failing to account for the latter tends to underestimate the benefits of road pricing, as users will bear financial costs while benefiting from faster and more reliable journey times.

Accounting for non-monetary benefits, however, requires making additional assumptions about their relative value to people. Somewhat understandably, different individuals place different values on these non-monetary benefits. Karlström and Franklin (2009) note:

> *by making the assumption of a constant [willingness to pay for travel time savings], among the rich we may be underestimating the relative value of travel time savings compared to the burden of tolls paid, and among the poor we may be overestimating the same.*

On average, it seems likely that people with higher incomes will place a higher value on non-monetary effects, such as faster and more reliable journey times. Ecola and Light (2009) present evidence that people with higher incomes are more likely to use high-occupancy toll lanes in the USA, for example. This may reflect the fact that the marginal utility of income is not constant, but instead is likely to decline with income. The effect is that tolls tend to have larger welfare impacts on people with low incomes. However, willingness to pay for faster or more reliable travel times is not exclusively correlated with income, as people of all incomes frequently face time constraints, eg when travelling between jobs.

Different studies have responded to these issues in a variety of ways. The studies we reviewed tended to use one of two basic approaches to measuring welfare impacts, in terms of consumer surplus, for individuals:

- *Resource cost approaches*, where monetary and non-monetary costs of travel are calculated for individual trips and then aggregated, with a rule-of-half adjustment for behavioural responses.
- *Utility approaches*, which use direct measures of consumer surplus from random utility models or 'compensating variations' (see, for example, Geurs et al (2010) and Bureau and Glachant (2008)).

Most strategic transport models adopt a resource cost approach to modelling the impacts of road pricing. The underlying assumption, which we formalise in later sections, is that individuals' overall travel demands are determined by the mix of trip purposes they must undertake, and that they choose the combination of modes, routes and time periods that minimises the travel costs they incur in the process. Under this assumption, the imposition of a toll simply serves to increase the costs of some modes and routes compared with others, resulting in some demand shifting to lower cost options while still completing trips for various purposes. In contrast, activity-based models adopt the utility approach whereby individuals are assumed to maximise the value of their total daily activities, some of which are enabled by transport. In this framework, the addition of a toll may be to make some activities unviable and/or cause complex changes in the scheduling and linking of trips undertaken across the day, based on their relative importance.

A final issue identified in the literature relates to the aggregation of impacts. Some studies, such as Fridstrøm et al (2000) and Karlström and Franklin (2009), report an aggregate measure, such as the change in the Gini coefficient of disposable income, which is a summary measure of the degree to which income is distributed equally or unequally between individuals. However, summary measures like the Gini coefficient may not clearly distinguish impacts on people with very low incomes, or enable reporting of impacts for other at-risk groups. For this reason, it is more common to report results in a partially aggregated form, such as by quintile of household income.

2.5 Previous studies of road pricing

Based on the preceding discussion, we can already conclude that the distributional effects of road pricing are complex and context dependent. While local context and design decisions – rather than theory – will determine the distributional impacts of the scheme, we see value in understanding how user impacts have been assessed elsewhere. In the following sub-sections, we review international and local assessments, before finishing with a discussion of different approaches to the measurement of welfare.

2.5.1 International studies

We reviewed a representative selection of published papers on the equity impacts of road pricing. These papers primarily focused on quantitative analysis of equity or distributional impacts, rather than qualitative assessment of effects. They are summarised in appendix A3.

Our first observation is that the literature tends to focus on different aggregations of people. Ecola and Light (2009) note:

> *The economics literature tends to group people based on their income or where they live and work, whereas the planning literature tends to look at the broader category of those who may be in some way disadvantaged with respect to transportation (e.g., because of disability, age, gender, or language ability). Particularly important with respect to congestion pricing is where people live—because of the way in which congestion pricing is implemented, some neighborhoods may bear a far greater burden than others. So, an equity assessment that considers only income may reach a different conclusion if the basis for the assessment is the neighborhood.*

Most studies we reviewed fell into the first category, that is, they used economic approaches to focus on how impacts varied for people or households with different income levels, and who live/work in different places. Some studies, however, focused on other types of disadvantage that may relate to equity. Bonsall and Kelly (2005) propose a 'sociological' approach that focuses on people who may be at risk of social exclusion or who face constraints on transport choices. They identify the following groups as relevant:

- people with low incomes
- people with disabilities
- elderly people
- women (eg due to security fears when using other modes)
- ethnic minority groups (if language/cultural barriers make use of other modes difficult)
- people without access to public transport.

Studies came to varying conclusions about whether road pricing increased or decreased equity for people on different incomes, relative to a scenario without road pricing. Eliasson and Mattsson (2006) summarise by observing 'It is difficult to come to clear-cut conclusions about the distributional effects of congestion pricing. Rather we have to carry out equity analyses for specific congestion pricing schemes and specific cities'. We intuitively concur with this assessment, given the complexity of the existing situation and potential responses.

The direction of equity impacts appears to depend upon the following factors:

- location/land use outcomes – the location of high and low income (or other at-risk people) households with respect to employment and educational opportunities
- scheme design – the distinction between cordon and distance-based schemes, potential concessions, and interaction with location/land use outcomes
- revenue management – particularly how revenue is subsequently used, for example to fund transport investment, reductions in other charges/taxes such as fuel taxes or income taxes, or direct monetary transfers
- transport system – especially the supply of non-car transport options.

We emphasise the importance of revenue management, including the use of road pricing as an alternative to other taxes or charges. Some studies have found that road pricing results in lower net costs or higher net benefits for people on lower incomes. Typically, this reflects the fact that revenue redistribution is included in the assessment, usually through some progressive form of redistribution, or when road pricing is compared with other revenue-raising options. As higher-income households tend to travel more, they tend to pay more in tolls especially when levied on a per kilometre basis, which means there may be a net financial gain for lower-income households once redistribution is accounted for. If revenue redistribution is not included in scheme assessment, lower-income households tend to be more likely to experience higher net costs, relative to income, than higher-income households.

Studies also varied in terms of how they modelled the equity impacts of road pricing. Some studies employed theoretical models to understand the direction of equity effects (Arnott et al 1994), while several others were based on outputs from conventional transport models (Fridstrøm et al 2000; Safirova et al 2006). In subsequent sections, we will consider both approaches in more detail in the Auckland context.

The most common approach in the literature was the estimation of a custom econometric model (typically a random utility/logit model) using microdata from travel surveys. Once estimated, such models allow for the testing of counter-factual scenarios to simulate welfare impacts on individuals in the sample. The reason for the popularity of these models is two-fold. First, the models have consistent theoretical foundations with regards to people's preferences for different outcomes, which enable them to be directly linked to estimations of consumer surplus and welfare. Second, the models are granular, in the sense that their structure can efficiently accommodate heterogeneity between users. As Eliasson and Mattsson (2006) note:

> *... it is virtually impossible in a large-scale model to account for all cross- correlations between variables such as income, gender, car ownership, occupational status, family situation etc. Usually, each of these variables is specified for each geographic zone, but it would be unfeasible to specify the simultaneous distribution of all variables for each geographic zone. Thus, it is necessary to choose between good geographic resolution and a good representation of the simultaneous distribution of socioeconomic variables. For most applications, good geographic resolution is a more important consideration, as it will other-wise be difficult to calculate, for example, link flows with any accuracy. But when the main focus is to study distributional effects, this is no longer true: it is then more important to account for socioeconomic cross-correlations, such as high-income households having greater car ownership than other households.*

This comment is worth keeping in mind when considering how to assess distributional impacts in Auckland and, in particular, the potential limitations of strategic transport models.

Some studies also considered the actual impacts of road pricing schemes that have been implemented, often focusing on user perceptions of pricing schemes. For instance, Odeck and Brathen (2002) surveyed users of Norway's long-standing toll network to assess their attitudes towards tolling, while research conducted by CEDR (2009) found acceptability of road pricing typically increased after it was implemented.

2.5.2 Auckland studies

Prior to this study, there have been three previous attempts to evaluate the equity impacts of road pricing in the Auckland context. These include:

- The 2006 Auckland Road Pricing Evaluation Study (ARPES) undertaken by the Ministry of Transport (2006)
- The 2008 Auckland Road Pricing Study (ARPS) undertaken by Market Economics (2008)
- The 2014 Funding Auckland's Transport Future (FATF) undertaken by Market Economics (2014a, b).

Both ARPES and ARPS were led by the Ministry of Transport, whereas FATF was initiated by Auckland Council. In the following sections we briefly review the methodology, underlying assumptions and key findings of these.

2.5.2.1 Auckland Road Pricing Evaluation Study (2006)

ARPES evaluated five schemes: a single cordon charge, a double cordon charge, an area charge, a motorway ('strategic network') toll and a parking levy. Schemes were developed and assessed only to an indicative level.

The ARPES summary published on the Ministry of Transport's website contains no detailed information on the distributional impacts on individuals or households.[11] However, it does report on an analysis of the share of households and trips that may be affected by different charging schemes, as summarised in table 2.2.

Table 2.2 ARPES analysis of the impacts of road pricing on households and trips

Scheme	% of households affected [a]	% of total trips affected is paid	% of total trips where charge
Single cordon	13% – 21%	9%	7%
Double cordon	17% – 29%	12%	8%
Area	19% – 32%	14%	7%
Strategic network	13% – 21%	10%	8%
Parking levy	8% – 13%	6%	2%

Note:

[a] The percentage of affected households is given in a range as it was not possible to estimate exactly the number of trips per household

The share of households affected varies significantly across the schemes, with area and double cordon charges affecting the greatest share of households. While the ARPES summary does not discuss this further, it is also likely that different types of households will be affected by different charging schemes.

2.5.2.2 Auckland Road Pricing Study (2008)

ARPS subsequently provided a more detailed assessment of (1) an area charging scheme that applied to the city centre and inner isthmus areas, including the motorway corridors through this area and (2) a cordon charge designed mainly to raise revenue, rather than improve transport network performance.

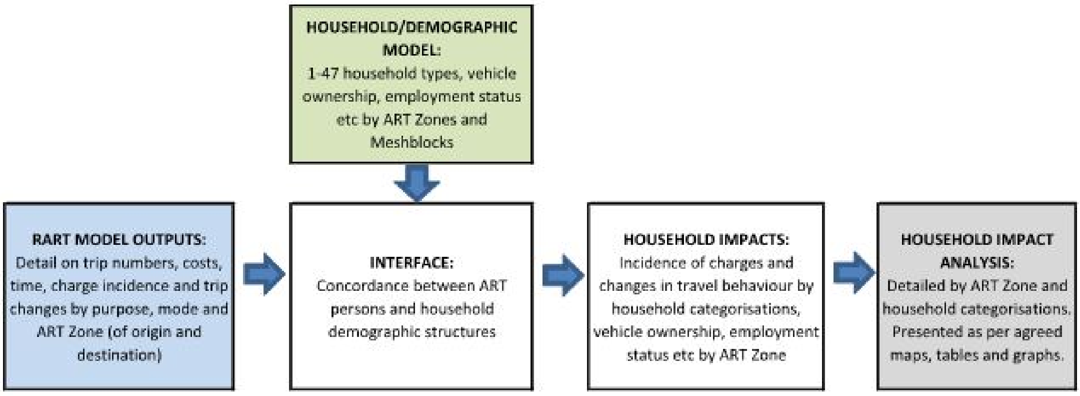
[11] www.transport.govt.nz/land/auckland/the-congestion-question/previous-ministry-of-transport-studies/

The 2008 study contained more in-depth analysis of impacts on traffic speeds; the ability of users to respond to charges (eg by using public transport to substitute for car travel to the charging area); impacts on households (including distributional and geographic impacts); economic impacts (including impacts on freight users); and environmental and land use implications. Technical reports are available on the Ministry of Transport's website.[12]

Consistent with the 2006 study, ARPS found that an area charging scheme directly affects 19–32% of households, who would either incur the charge or change behaviour to avoid it. Approximately 30–40% of these households are expected to incur the charge, while the remaining households are expected to either change mode or change the number of trips they undertake. Changes to time of departure or land use were not assessed.

The characteristics of affected households were identified using a methodology developed by Market Economics (2008). This methodology, which is summarised in figure 2.1, matches outputs from the Auckland Regional Transport model (designated as RART in the diagram) at the zone level with information on household composition, vehicle ownership, and employment status from the 2001 Census (designated as the household/demographic model in the diagram).

Figure 2.1 Market Economics' (2008) methodology for identifying affected household types



This methodology combines transport model outputs with information on household/demographic structure to identify the households that are most (or least) affected by road pricing. Estimates of out-of-pocket costs and broader welfare impacts, such as generalised costs of travel, are based on the transport model. Welfare impacts from avoided trips are estimated using a rule of half approximation of consumer surplus. As noted in the review of the literature, this approach may under-estimate the regressivity of schemes because it does not account for variations in the value of travel time savings and the marginal utility of income for people with different incomes.

Market Economics' (2008) approach categorises households into 47 groups based on the following characteristics:

- *Household composition*: single person living alone; couple; two parent family, one parent family, multi-family, and non-family households
- *Age of household head*: grouped into varying age bands
- *Quantile of household income;* grouped into five income bands within each category.

[12] www.transport.govt.nz/land/auckland/the-congestion-question/previous-ministry-of-transport-studies/

One advantage of this approach is that it allows for a granular analysis of impacts on individual types of households. On the other hand, this approach has several drawbacks when analysing equity impacts. First, it is unclear whether these results could be aggregated up into an overall statistic for the equity impacts of road pricing, such as a Gini index. Second, these results focus on income and household structure and may not be suitable for capturing other aspects of disadvantage or social exclusion that may be relevant. In addition to assessing the impact of road pricing on households, the 2008 study also included interviews with focus groups including people from groups and areas that are most likely to be affected by road pricing.

Finally, the 2008 study considered economic impacts, including impacts on businesses, through a survey of businesses. As part of this, road freight companies and businesses in general were surveyed on their willingness to pay $6 for different percentage reductions in travel time.

2.5.2.3 Funding Auckland's Transport Future Study (2014)

The FATF study was initiated by Auckland Council to investigate alternative options for raising additional revenue to fund transport infrastructure in Auckland. It considered three options: (1) raising rates and fuel taxes, (2) introducing a flat per-kilometre charge on the city's motorways and (3) introducing a variable motorway charge that was higher at peak times. Unlike previous studies, FATF did assume that additional revenues would be spent on increasing transport network capacity. The reported equity impacts therefore reflect the impact of both road pricing *and* additional transport expenditure.

Market Economics (2014a) assessed the impacts on households using a similar methodology as for the 2008 study. Once again, they estimated financial impacts on households by combining transport model outputs at the zone level with forward projections of household composition and incomes based on census data. Unlike the 2008 study, this study focused on financial impacts alone, rather than general changes in welfare from monetary and non-monetary costs.[13] No consideration was given to costs of avoided trips. This is generally a narrower concept of distributional impacts than is used in most of the international literature.

Results generally showed that the schemes involving motorway charges would have low impacts on most households, with added costs of less than 1% of after-tax household income for 86–89% of households. Market Economics also reported further analysis of impacts on vulnerable households, which it defined as low-income households (bottom 20% of income within each category) with or without children.[14] These households were found to pay less than the average Auckland household in dollar terms. However, they make up a disproportionate share of the households that experience very high impacts relative to incomes.

Market Economics' quantitative analysis was supported by qualitative research into the responses of 26 vulnerable households, which were defined as low-income households. The key finding from this research is that these households would not be able to absorb congestion charges (or fuel tax/rates increases), and as a result would have to make changes to lifestyle or travel patterns to mitigate costs. In the short run, this would serve to increase financial stress on households. In the long run, these households would consider changing home locations, reducing to one car, or increasing reliance on public transport.

[13] Changes in public transport and car travel time were assessed using transport modelling but results were not incorporated into the analysis of impacts on households.

[14] It is unclear how these categories were defined. We note that they do not directly address other types of disadvantage identified in the literature, although there is likely to be some correlation.

In a companion study, Market Economics (2014b) implemented a similar analysis for impacts on businesses. This matched transport model outputs for business-related trip purposes at the zone level with information on the location of different types of businesses. Businesses were grouped into four broad categories depending on their use of the transport system: transport companies (such as road transport and courier companies), businesses that are heavily reliant on transport, regardless of mode, to function (including retail and household services), businesses that rely on the road network to carry out activities (including construction, rental and hiring, and household repairs), and other economic sectors that are mainly affected in an indirect way.

Results showed that motorway tolling is expected to lead to net benefits for businesses, as the monetary value of travel time savings generally exceeds the cost of tolls. This is intuitive given that people travelling with freight or making other work-related journeys are likely to have a higher willingness to pay for travel time savings than people travelling for non-work purposes. Positive impacts were found to be largest for firms that provide mobile services to households, construction firms and transport firms. In contrast, the retail sector may be negatively affected if people forego some shopping trips.

2.6 Challenges for modelling responses to road pricing

Many evaluations of road pricing are based on outputs from strategic transport models. This includes previous studies of road pricing in Auckland (summarised in section 2.5.2) and the second case study in this report (section 6). Strategic transport models are widely available and commonly used to assess the impacts of major transport projects. However, our review of the international literature review and our brief discussion of Auckland's macro strategic model (MSM) in section 6.2.1 suggest that strategic transport models have several important limitations for modelling some aspects of the behavioural response to road pricing, and identifying how specific at-risk individuals may be affected by road pricing.

While developing or applying new transport models is outside the scope of this report, we briefly discuss some potential alternative methods for modelling the social and distributional impacts of road pricing. These include activity-based models, models that endogenise location choices, models of how people choose their departure time in bottleneck congestion models, models of travel time reliability, and targeted analysis to identify individual-level impacts, including impacts on specific at-risk individuals that may not be possible to accurately identify using census demographic data.

2.6.1 Activity-based models

Among the behavioural responses that are typically not fully accounted for by strategic transport models are changes in departure times and avoidance of trips. These two responses are transport-related behaviours that most strategic transport models do not currently consider, but which could do with some significant extensions.

In the literature, considerable attention is being paid to activity-based models, which may be relevant to efforts to model the social and distributional impacts of road pricing. In the US, the Transportation Research Board produced a primer to activity-based models, which are described as follows (Castiglione et al 2015, p7):

> *... activity-based models incorporate some significant advances over 4-step trip-based models, such as the explicit representation of realistic constraints of time and space and the linkages among activities and travel, for an individual person as well as across multiple persons in a household. These linkages enable them to more realistically represent the effect of travel conditions on activity and travel choices. Activity-based models also have the ability*

to incorporate the influence of very detailed person-level and household-level attributes and the ability to produce detailed information across a broader set of performance metrics. These capabilities are possible because activity-based models work at a disaggregate person-level rather than a more aggregate zone-level like most trip-based models.

Activity based models seek to model an individual's travel demands across an entire day and, in doing so, serve to relax the following two issues that are common to trip-based strategic transport models:

- Independence of trips – standard strategic transport models do not recognise that the modes, locations and timing of travel made by the same individual are inter-related. In addition, the models lack information on how individuals coordinate with other household members, such as partners and children, to determine the overall demand for travel. In conventional strategic transport models, trips are assumed to be independent, rather than inter-related.
- Aggregation of households – standard strategic transport models assume that all members of a certain household type share the same transport preferences. This means that all households of the same type that are living in the same zone exhibit the same travel demands. Aggregating individuals reduces the underlying diversity of preferences in the population and tends to introduce biases with regards to how a population responds to transport policies.

According to the TRB, activity-based models seek to '... provide a more intuitive, consistent, and behaviourally realistic representation of travel than trip-based models'. They do this in three ways:

1 Modelling individual travel demands

2 Allowing for inter-related decision making across time, households and locations, which leads to improved modelling of tours

3 Using more detailed information on factors that explain travel demands.

Activity based models can, in principle, be integrated with existing strategic transport models as they employ a similar random-utility modelling framework. The key difference lies in the trip generation step, where activity-based models use different approaches to trip-based models. In terms of the deployment of activity-based models, we understand they are under development in Australia and have been applied in the US. In the latter, one of the primary applications was to evaluate road pricing options, on which the TRB comments as follows (p15):

Activity-based models have been used in both New York and San Francisco to evaluate congestion pricing options. In New York, an activity-based model was used to evaluate scenarios in which tolls were imposed for vehicles traveling to certain portions of Manhattan. In San Francisco, an activity-based model was used to evaluate area-based and cordon-based pricing scenarios. The activity-based models provided the ability to represent how different travelers respond differently to alternatives, and to provide a consistent representation of how the different alternatives impact the timing, destinations, modes, and even the generation of tours and trips. Because the models explicitly represent individual persons and households, the models could be used to evaluate a variety of alternative schemes, including discounts offered to different groups to address equity concerns.

One of the primary downsides of activity-based models is that they can impose significant data collection requirements and involve significant work in the initial stages. And, like existing strategic transport models, these models can only be used to answer questions that are within their range of calibration and validation. Consequently, any attempt to use these models would have to pay close attention to model development and calibration.

2.6.2 Endogenising location choice

In the medium to long run, we expect road pricing will affect the relative attractiveness of certain locations for certain people compared with the current situation. Some locations will become more attractive and vice versa, so households and firms are incentivised to change locations over time.

Regardless of whether conventional strategic transport models or activity-based models are used, various methods existing for endogenising location choice in response to transport outcomes. To date, little documentation exists to suggest that such methods are systematically applied in the New Zealand context. While land use transport interaction models are a well-known and established approach, we are unsure of their microeconomic foundations and/or the robustness of parameters. Recent research in spatial economics has also developed new techniques, such as spatial general equilibrium sorting models, which explain the distribution of people and firms across space in response to policy-relevant amenities and attributes, such as transport infrastructure. Regardless of the models that are used, efforts to understand the effects of transport outcomes on location very much sit on the frontier of theoretical and applied research.

The general premise of all models, however, is that *location choice* is affected by *transport outcomes*.[15] That is, the latter tend to impact on the former. One way to conceive of this is to consider an individual who is seeking to maximise their utility by choosing where to live and work. In doing so, they consider the attractiveness of the two locations, for example prevailing rents, wages and access to schools, while avoiding costs of travelling between the two. Formally this problem can be stated as follows:

Equation 2.1 Economic model of utility maximising behaviour with endogenous location choice

$$\max_{i,j} U_{ij} = \delta_i + \gamma_j - C(m,r;\ i,j) \qquad \text{(Equation 2.1)}$$

Where;

- U_{ij} denotes total utility, or strength of preference, associated with living and working in i and j
- δ_i and γ_j denotes the utility the individual derives from living and working in i and j respectively
- $C(m,r;\ i,j)$ is a transport cost function, which depends on modes m and routes r, conditional on living and working in i and j. The perceived costs of travel $C(\cdot)$ will depend on transport outcomes between locations i and j.

As with activity-based models, location choice models can be placed in a random utility framework and estimated using multinomial logit and/or nested logit models. In doing so, practitioners can identify parameters in the cost function $C(\cdot)$ through which transport outcomes, such as monetary costs and travel-time, affect the relative attractiveness of locations. In this way, these models can predict the number of people who live and work in each location. By extension, the models can predict how the distribution of the population is affected by changes in transport outcomes. Parameters in the transport cost function $C(\cdot)$ effectively represent elasticities of the demand for locations with respect to changes in transport outcomes.

In terms of how these findings might be incorporated into strategic transport models, one option is simply to iterate over the land use inputs in response to changes in transport outcomes. This would function by:

1 Specifying initial values for the distribution of households and jobs

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[15] We note that this is likely true in the long term, if one assumes that land use development is always working towards equilibrium with the transport system. In reality, individual land use decisions are continuously being made within an area. Sometimes these changes are in reaction to the transport system and sometimes they are done for other reasons.

2 Modelling future transport outcomes, eg travel-times and monetary costs

3 Using the changes in transport outcomes, and parameters estimated for the transport cost function, to adjust the distribution of households and jobs

4 Repeating from step 2 until convergence.

Areas that become relatively more accessible due to transportation investments, for example, may be expected to attract more households and jobs, and vice versa. Of course, this is only one possible approach to endogenising location choice within strategic transport models. Further research is required.

2.6.3 Modelling dynamic efficiencies in bottleneck congestion models

As noted in section 2.2, road pricing may lead to both static and dynamic efficiency gains, but strategic transport models typically only model impacts arising in a static setting. This is likely to under-state the benefits of road pricing, and potentially over-state distributional impacts.

The ‘bottleneck’ model of congestion can be used to analyse the dynamic impacts of road pricing. This model, which is described in Small (2015), considers how people trade off scheduling costs (the difference between desired and actual arrival time) and travel time costs (time spent waiting in queues) when travelling through a bottleneck in the transport network that only allows a fixed number of vehicles through.

This model implies that time-varying road pricing would completely eliminate travel time costs, while having no effect on scheduling costs. When users vary in terms of the value they place on travel time savings or reduced schedule delay, additional gains may arise from changing the order of arrivals at the destination (Small et al 2007). In this setting, it is in principle possible for time-varying road pricing to provide net benefits for many or all travellers.

Although bottleneck models are in common use in the transport economics literature, they are not tractable for network-wide modelling. As a result, we suggest these models could be used to obtain theoretical insight into how the impacts of road pricing may be distributed between people who place a different value on travel time, in order to supplement analysis based on strategic transport models. We also note that insights from the bottleneck model can be combined with stated preference surveys to understand how individuals may choose to change their departure time, as demonstrated by Saleh and Farrell (2005).

2.6.4 Modelling travel time reliability

Strategic transport models typically estimate impacts on average travel times, but do not model variability in travel times, which may have a significant additional impact on transport users. As a result, the impact of road pricing on travel time reliability may represent an additional source of efficiency that is not captured by existing modelling frameworks.

Hyder Consulting (2007) outlines a procedure to produce post-model estimates of travel time reliability benefits for users. This procedure can estimate the first-order impacts on reliability but does not capture second-order effects on trip distribution, mode choice or assignment. Brennand (2011) investigates how travel time reliability can be incorporated into traffic modelling to estimate trip assignment, but does not analyse impacts on mode choice or trip distribution in the context of a strategic transport model.

This represents a potentially important area for further investigation and methodological development, including better understanding what value users place on reduced travel time variability.

2.6.5 Modelling impacts on at-risk individuals

A key lesson of the Auckland case study is that it is difficult to 'cross-tabulate' a large number of household or personal characteristics at a detailed geographical level. This is due to Statistics New Zealand's rules about suppressing information that potentially enables individuals to be identified. However, this limits our ability to analyse impacts for small groups of people who may be at risk of experiencing disproportionate impacts from road pricing. This includes, for instance, people with disabilities, who may face distinct transport challenges and options.[16]

At minimum, it is important to engage directly with affected individuals or groups that represent them in order to understand the specific issues they face. However, in some situations, bespoke analysis and modelling techniques may also be used to better understand and quantify potential impacts. For instance, stated preference surveys, in which selected people are asked how they might respond to road pricing options, can be used to develop models that estimate the impacts of alternative pricing schemes on financial costs and overall welfare. This approach was employed in several papers in the literature, eg Arentze et al (2004); Saleh and Farrell (2005); Washbrook et al (2006).

A key question that many of these analyses can seek to answer is the level of monetary compensation that may be required for at-risk groups that face specific transport challenges. This is especially important where these households and individuals make commute trips, for which road pricing will impose additional financial costs. Similarly, the design of targeted discounts inroad pricing schemes may focus on specific types of households and individuals that are likely to bear disproportionate impacts.

This type of analysis may be potentially relevant for assessing impacts at the individual level. However, these benefits must be weighed up against the cost of undertaking custom data collection and analysis. If it is not possible to undertake such an analysis, it will be especially important to identify and engage with people who may be disproportionately affected due to their personal circumstances and who may not be accurately captured by data used to implement the general framework we outline in this report.

2.7 Summary of findings

Based on our review of the literature we summarise our findings as follows:

1. What is the role of road pricing? Research finds that pricing can help to (1) manage travel demands; (2) levy road user charges; and/or (3) raise revenue. In this study, we assume road pricing is primarily designed to manage travel demands. Adopting road pricing for this purpose, however, will have implications for road user charging and government revenues, more broadly.
2. How does road pricing lead to economic benefits? Road pricing improves economic efficiency in two key ways: first, there are static efficiency gains that follow from reducing the external costs of vehicle travel and, second, there are dynamic efficiency gains with monetising delays and incentivising changes in departure times. In terms of distributional impacts, we can expect that efficiencies associated with reduced demand will primarily impact on road users with low willingness to pay for travel time savings. In contrast, efficiencies arising from changes in departure times will primarily affect people with more flexible schedules.
3. What can the revenues from road pricing be used for? Research suggests the use of revenue has critical implications for the efficiency and equity of the overall road pricing scheme. Internationally,

[16] Disability status may be correlated with other indicators, such as income or household structure. However, these are unlikely to be a useful proxy measure.

road pricing revenues are commonly used to fund transport infrastructure and services. As many users will not benefit from this investment, however, it seems unlikely to mitigate distributional concerns, even if it is politically attractive. Other potential uses of revenue include (1) direct monetary transfers, (2) reductions in other transport user charges, such as vehicle registration and/or fuel excise duty, and (3) reductions in other distortionary taxes, such as taxes on labour income. Although the use of revenues lies outside the scope of this study, we caution that they are critical for assessing the overall distributional impacts of road pricing schemes, and therefore warrant further research.

4 What definition of equity and fairness do we adopt in this study? Research suggests equity is multi-faceted, and that several measures are typically required to assess the impacts of road pricing schemes. We distinguish between equity standards and equity measures. The former considers the acceptability of a given distribution of benefits and costs, and is a political rather than a technical question, whereas the latter simply measures the distribution of benefits and costs. Regardless of what standards and measures are adopted, we suggest they are clearly established before embarking on scheme design and appraisal. We focus our research primarily on vertical equity, which considers impacts on people who are able to bear the financial costs associated with road pricing.

5 How will people respond to road pricing? Even with road pricing, we expect that most people will continue to drive as (1) the monetary costs of tolls will make up only a small proportion of total transport costs and (2) the demand for vehicle travel is generally relatively inelastic. That said, road pricing will affect both monetary and non-monetary transport costs, and some people will change their behaviour as a result. Some of these behavioural responses are modelled in strategic transport models, whereas others are not. People's ability to respond to road pricing may be correlated with their socioeconomic status, and hence have implications for distributional impacts.

6 Why are implementation timelines important? People's ability to respond to road pricing may change with time. Hence, implementation timelines, and specifically the availability of information in advance of implementation, may have implications for distributional impacts. If more notice is given in advance of implementation, people will be better placed to take steps to mitigate the effects of the scheme in advance. In other words, implementation timelines are not merely an issue of process, but rather are likely to have implications for overall socioeconomic impacts. While search frictions may slow the speed at which people can change their location, New Zealand has – by international standards – relatively flexible housing and labour markets.

7 What can we learn from previous assessments of road pricing? Previous studies highlight the merits of adopting both an economic and a planning approach to assessing distributional impacts. The former considers impacts across the population, whereas the latter considers impacts on specific vulnerable groups. While the distributional impacts of road pricing are complex, they are largely driven by (1) location/land use patterns, (2) scheme design, (3) revenue management and (4) transport outcomes. Research highlights the merits of combining outputs from strategic transport models, which seek to minimise transport costs, with individual activity-based models, which seek to maximise utility. However, there is also a need to consider alternative modelling approaches that may better capture various behavioural responses. Previous studies in the Auckland context provide a useful basis for further research into road pricing schemes, even if we consider there is a need to go much further in some respects.

Armed with this background information, we can now proceed to the next section, in which we present the results of our interviews with practitioners who are active in the field.

3 Practitioner interviews

In this section, we discuss the results of interviews with practitioners undertaken as part of this project. The interviews were motivated by the recognition that there are often sizable gaps between published research and best practice on road pricing. In this context, engaging widely with active practitioners provides additional insight into contemporary developments that are not widely understood or documented.

We sought out interviewees with a range of backgrounds in the hopes of generating diverse feedback. Our interviewees included the following people, who we thank for their time and feedback:

- Professor David Levinson, Professor of Transport Engineering, The University of Sydney
- Professor Graham Currie, Professor of Transport Engineering, Monash University
- Professor Erik Verhoef, Professor of Spatial Economics, Vrije Universiteit Amsterdam
- Scott Wilson, Principal Consultant, D'Artagnan Consulting
- Kate Zielke, Senior Transport Planner, North Central Texas Council of Governments
- Nathan Drozd, Senior Transport Planner, North Central Texas Council of Governments

While common topics were discussed in each interview, the questions and conversations varied greatly by practitioner based on the current focus of their activities. The following sections discuss our conversations in four areas: (1) equity considerations, (2) impacts, (3) generating support and (4) summary of findings. It is difficult to discuss these topics in isolation due to the high degree of inter-relation between them.

3.1 Equity considerations

In all the practitioner interviews, definitions of equity emerged as a central consideration of social and distributional impacts. Consistent with the findings of the literature review, it was widely recognised that there are many definitions of equity and different people can define 'fairness' in different ways.

Several people noted it is difficult to talk about equity in the context of social and distributional impacts without knowing precisely what the scheme would entail. This is because the types of equity issues that arise would be varied based on the design of the scheme. For example, a scheme that charges only during periods of congestion on a primary network has different equity implications than say an all-day cordon charge. One practitioner noted equity issues can occur at any point in a scheme, not just following implementation, so early and ongoing monitoring of impacts is essential.

One interesting perspective focused not on inequity and equity, but instead 'winners' and 'losers'. Central to this discussion was that there will always be those that benefit – the winners, and those that suffer – the losers. Interpreting this as an equity impact, however, is a fallacy, because it implies that the status quo is fair. The status quo simply represents a baseline of inequity, which may in fact also be inherently inequitable by many definitions. Interventions may shift the winners and losers, bring equality, or maintain the status quo. It was noted that identifying the winners and losers early in any process, and working to mitigate impacts on those losers that are considered to not be winning from the status quo was likely to be critical for the success of a scheme.

One practitioner noted a distinct difference between equality and equity, or outcomes versus opportunity. Equality means everyone gets the same outcome, whereas equity is concerned with providing all individuals with the opportunity to have an equal outcome. That is, a different degree of intervention may be required to achieve an equitable outcome. This begs the question: which is more important in the context of road pricing? Notions of equality and equity are of course of interest regarding potential mitigation measures.

There was a fair amount of discussion about identifying populations for impact assessment. For example, in the United States, federal legislation requires an assessment of impacts on minority or low-income populations before any investment decision is made. Impacts on other groups beyond those prescribed in legislation are not widely considered. Income appeared to be the primary classification method, but several practitioners noted there are other options including spatially (eg urban/rural or along transport corridors), or by life decision (eg commute method, car ownership). This resulted in further discussions about identifying at-risk groups. Generally, at-risk populations were thought to be those with low incomes or limited transport alternatives, which may be the result of age, ability, or other life circumstance. However, as one practitioner noted 'your most affected groups may be those that fall outside traditional definitions of 'at-risk''.

3.2 Social and distributional impacts

Social and distributional impacts were discussed with the interviewees, and the commentary ranged from high-level concepts to specific measures.

Beginning with high-level concepts, one practitioner noted that impacts are not necessarily negative and preferred to categorise impacts in terms of benefits and burdens, with one person's benefit being another person's burden, and vice versa. The interviewees noted they had come to this notion in hindsight. After developing an impacts assessment protocol, they realised they had spent so much time focusing on impacts in a negative connotation that they missed an opportunity to highlight benefits. Shifting the conversation to benefits and burdens provides a holistic assessment.

As part of a holistic assessment, multiple interviewees commented that it was extremely difficult to talk about impacts without knowing how the revenue generated from the project would be used. As noted in the literature review, the use of revenues defines the total benefits and costs of a scheme. While there are challenges to revenue recycling, harkening back to ideas of fairness, equity, winners and losers, the use of these funds can alter whether the scheme is progressive or regressive (real or perceived). Likewise, the purpose of the scheme is also important regarding project revenues. If the scheme was developed from a congestion management point of view, several practitioners noted that investing the funds into alternative transport seemed logical. Whereas, if it was developed as a revenue generating scheme, it may be perceived as more equitable to invest the funds back into the road network. Regardless of the type of scheme, how revenues are used is of critical importance to understanding the social and distributional impacts.

While generally out of scope for this project, mitigation opportunities were discussed in relation to impacts. Discounts were consistently identified as a viable mitigation measure. However, several practitioners noted these should be offered to a limited group of people and for a limited time. A scheme's effectiveness can be undermined by discounts. For example, if the scheme is developed as a congestion relief measure, offering discounts may not induce behavioural responses and simply exacerbate congestion. Likewise, discounts introduce opportunities for fraud, and the more discounts offered, the greater the risk.

Looking more specifically at measuring impacts travel demand model outputs were typically used. However, it was noted this is a less than ideal tool, as these models have not been developed for this type of analysis, and they were seen as a fall-back option rather than a preferred method. One practitioner noted they tend to use travel demand model outputs in practice, but assessing impacts is generally not a desk-top exercise. They believed that meaningful impact assessment required a more hands on approach in terms of outreach, surveying and interviewing. Conversely, another researcher noted surveying was a dubious approach to assessing impacts because it was difficult to identify the result of the scheme versus other factors (eg economic cycles, personal choices). Further to that, another practitioner noted there is a definite need for quantitative science around disadvantage; impact assessment would be very much a part of this.

Because travel demand model outputs tend to be the default measures, practitioners noted they evaluated impact related to travel times, vehicle trips, speeds and job accessibility within a given time. It was noted these analyses could be expanded, but data integration paired with limitations of existing models was a challenge. The London scheme was recognised as an exemplary example of impact assessment and monitoring.

3.3 Generating support

While we recognise it is not within the scope of this project to build support for a road pricing scheme, there are aspects of this that directly relate to our research. The interviewees noted that road pricing schemes require broad support to gain traction. Lack of acceptance around schemes is often positioned around issues of equity and fairness, which was important for our research.

For a scheme to be fair, one practitioner noted it was important that users perceive they are receiving a benefit from paying tolls. Schemes developed as a revenue generating tool often fail to advance due to some people's perception that road pricing is an 'unfair' way to raise the needed revenue. However, schemes developed to manage congestion tend to gain more acceptance, as there a rational nexus between road pricing and the problem of congestion.

The type of scheme itself can have perceptions of fairness. One example given was around cordon schemes. These are often viewed as being unfair because there is not a strong connection between the price you pay and the problem you cause. For example, a short trip in a cordon pays the same as a trip that traverses the entire cordon. Whereas, distance based tolling is perceived to be equitable because you pay based on what you 'use'.

Messaging plays a critical role in the development and delivery of successful road pricing schemes. Communication is vital to delivering a scheme and guiding the message is important. As discussed earlier, any road pricing scheme will generate winners and losers, and as one interviewee noted, it is best to identify them before they identify themselves. Demonstrating benefits and burdens to a range of audiences – both technical and layman – is important. Therefore, the implications for this project are that the framework needs to be robust and technically sound; however, the results need to be put forward in the simplest terms for the public to understand. Practitioners noted that using clear and concise forms of communication were best, and recommended maps, charts and measures like a Gini coefficient to communicate results.

As previously mentioned, one interviewee noted that as they developed their assessment of road pricing they spent so much time focusing on the impacts they generally neglected the benefits. Since the road pricing system they evaluated has been implemented there has been wide public support because of the realisation of benefits in terms of time savings, travel time reliability and high-quality facilities. They felt they had missed an opportunity to communicate this element of the project. It was assumed the road pricing would have negative effects, because people do not like to pay for things that were once free. In reality, the negative effects have been marginal, but the benefits have been meaningful.

Furthermore, to gain support, mitigation approaches should be identified and communicated with affected groups. Failure to do so can negatively impact outcomes. For that reason, providing information on these is of critical importance. Communication is important and should be at the forefront of any scheme. A critical piece of this communication is impacts on affected populations and, importantly, benefits to users.

3.4 Summary of findings

While our interview candidates had a range of backgrounds and worked in different areas of practice, some common themes emerged.

First, we note there was consistent feedback regarding ambiguity around the definition of equity, and consequently the choice of measures of social and distributional impacts. All the interviewees commented there are many ways to define equity, and the definition itself is critical to understanding impacts. Because impacts change with each definition of equity, explicitly defining our use of the term and acknowledging the limitations of the definition will be important for the credibility of an assessment framework.

Second, the practitioners noted it is somewhat challenging to talk about social and distributional impacts without having some knowledge about how generated revenues would be used. Uses of revenue are consequential for understanding impacts.

Third, limitations to existing assessment techniques were noted by several interviewees. However, the options on what was necessary to overcome these limitations were varied. For the purposes of this research, it is important to acknowledge limitations and challenges with existing analysis tools. Therefore, we seek to develop a high-level assessment framework that stands on its own, but can be supported with existing data sets from the travel demand models and the census. As these modelling tools and data are improved, then the quality of insight provided by the framework will naturally also improve.

Fourth, the practitioners stated that garnering public support was key to successfully delivering a scheme. For a scheme to be accepted it had to be perceived to be fair. Therefore, defining equity, identifying winners and losers, understanding benefits and burdens, and clearly communicating this information early and often is highly important.

Lastly, we note that practitioner interviews confirmed what has been evident through the initial phases of this project, namely:

- The impacts of road pricing are very complex, and may be difficult to model.
- The assessment framework needs to address this complexity, while being simple to communicate.

4 A general framework for assessing social and distributional impacts of road pricing

This section outlines a general framework for assessing the social and distributional impacts of road pricing. This framework is conceptual in nature and can be applied in various contexts, using different data sources and with different levels of detail.

This framework comprises two key elements, following on the literature review (chapter 2) and discussions with practitioners (chapter 3):

- First, it outlines three general principles for evaluating the social and distributional impacts of road pricing.
- Second, it outlines two general principles for reporting and interpreting the results of evaluation.

The following section discusses how this framework can be implemented in the specific context of an evaluation of alternative options for Auckland road pricing. This demonstrates the framework is practical to apply and highlights some specific challenges for implementation.

4.1 Principles for evaluating impacts

There are three general principles that should be applied when evaluating the social and distributional impacts of road pricing, or other transport interventions.

First, road pricing will have different impacts on specific households (or individuals). If it is not possible to measure outcomes at the household (or individual) level, then analysis should group households based on characteristics that affect their:

- exposure to the impacts of pricing
- ability to bear the financial costs of pricing
- ability to respond to pricing, eg by changing their transport behaviours.

Second, when considering the distributional impacts of road pricing, it is important to consider multiple ways in which impacts may be distributed:

- vertical distribution of impacts, or impacts on households with different abilities to pay or mitigate the costs
- horizontal distribution of impacts, or impacts on similar households that live in different places and which therefore may be exposed to a different degree.

Third, road pricing will have both financial and non-financial impacts on households. Multiple impact measures are therefore needed to capture different categories of impacts, and to address the possibility that households will incur a mix of costs and benefits.

These general principles are defined further in the following sub-sections.

4.1.1 Accounting for differing impacts on households

Household characteristics affect households' exposure to the impacts of pricing, their ability to bear financial costs and their ability to respond to pricing to mitigate costs. To understand the social and distributional impacts of road pricing, it is therefore necessary to account for characteristics that may influence these factors. Where it is not possible to analyse impacts at a household or individual level, household characteristics can be used to group the impacts for analysis.

Some relevant characteristics are measurable, while others are difficult to measure. For example, household income is an easy-to-measure characteristic that affects households' ability to bear the costs of road pricing without financial stress. As a result, many studies of the distributional impacts of road pricing use income to categorise households.

Household income is not the only variable that may affect the likelihood of financial stress. For instance, households with high debt levels from student loans, mortgages or other personal or business debt are also less likely to be able to bear the costs of road pricing. However, debt levels may be harder to measure and hence this information may not be available. Likewise, high-income households may face higher income tax rates, resulting in less of a difference in after-tax income.

A further issue is that household characteristics often overlap with each other. For instance, in Auckland, low-income households are disproportionately concentrated in west and south Auckland, often in areas with lower availability of transport choices. This may exacerbate impacts on low-income households by reducing their ability to change transport behaviours to mitigate financial costs.

In this case, considering one characteristic (income) without considering the other (location) may underestimate the impacts on some groups. Consequently, analysing the social and distributional impacts of road pricing requires analysing the joint impact of multiple household characteristics.

Table 4.1 summarises three household characteristics that should be taken into account when assessing the social and distributional impacts of congestion pricing. These factors are primary drivers of differences in impacts experienced by households, and they are generally feasible to measure based on readily-available data (ie without conducting custom surveys or data collection).

Table 4.1 Three primary household characteristics that relate to the impact of road pricing

Characteristic	Suggested approach to categorising households	Rationale for using this variable
Home location	Choice of categorisation should depend on the spatial characteristics of the place in question. Some potential approaches could include: • categorising at a highly disaggregated level, eg census area units or transport model zones • grouping areas together at a ward/local board level or broad area of the city (eg west Auckland, north Auckland) • grouping areas together based on existing levels of transport accessibility or transport choice	Home location affects households' exposure to the impacts of pricing and the options available to respond to pricing by changing behaviours. On the one hand, location influences existing patterns of household travel behaviour, including the transport modes that are available to use and the distances people must travel to work, education, retail or other destinations. This may, in turn, affect their exposure to road pricing. On the other hand, location influences the availability of transport mode choices and hence households' ability to respond to pricing.
Household composition	Statistics New Zealand's household composition classification should be used. This categorisation can be aggregated further to group together similar types of households. In some cases, an alternative method of classifying household composition may be preferred, eg to align with the format of outputs from transport models or custom groupings used in travel surveys.	Household composition affects households' exposure to the impacts of pricing as it influences their travel behaviour. Household composition includes factors such as: • family structure, including whether households consist of related or unrelated people and whether they include children, or adults only • household size, eg single people living alone, couples without children or multiple flatmates.

Characteristic	Suggested approach to categorising households	Rationale for using this variable
		Household composition may affect travel in several ways. Larger households tend to make more journeys, which may increase their exposure to pricing. Furthermore, different households make different types of trips at different times, eg households without children will not make trips to drop children at school.
Household income	Households can be categorised into 'bands' based on whether they have high, intermediate or low-income levels. The number of income bands may vary based on the local context and availability of data. As household size and composition varies, it is desirable to adjust for this by measuring equivalised household income. This ensures a 'like for like' comparison between households of different size. Statistics New Zealand uses Jensen equivalised household income, which is calculated by dividing household income by household size and adjusting for the number of children in the household. If data is available, disposable (after-tax) income is preferred to gross household income as it better measures the amount of money available to households.	Income affects households' ability to bear the financial costs of pricing. In general, households with higher incomes will have more ability to pay tolls. They may also place a higher value on travel time savings, as there tends to be a positive relationship between income and value of travel time. Income can also indirectly affect households' travel behaviour and hence their exposure to the impacts of pricing. For instance, lower-income households are less likely to own a car and are thus less likely to travel by car in the first place. In the 2013 Census, 23% of households with income under $30,000 did not have access to a motor vehicle, compared with less than 1% of households with an income over $100,000.

It may be feasible and desirable to include additional household characteristics in cases where:

- Richer data on household characteristics is available, and there are no restrictions on accessing or publishing that data. As discussed further in chapter 1, Statistics New Zealand's confidentiality rules may limit analysts' ability to 'cross-tabulate' a large number of variables.
- The additional variables provide additional information on households' exposure to road pricing, their ability to bear financial costs, or their ability to respond by changing behaviour. Adding 'extraneous' variables is undesirable as it increases the complexity of analysis without increasing its precision.

Some additional variables that may provide additional information to understand the social and distributional impacts of congestion pricing include:

- Employment status of household members: This affects households' exposure to the impacts of pricing as employed people may travel at different times or to different locations. Employment is also likely to be positively correlated with income, which may offset the impacts of additional exposure.
- Household car ownership: This affects households' exposure to the impacts of pricing as households that do not own cars are likely to make fewer trips that will require them to pay tolls.
- Age of household members: This may affect households' exposure to the impacts of pricing, as people of different ages may have different travel behaviours, as well as their ability to respond to pricing by changing their behaviour. Note that these effects are partly captured by measuring household composition (eg households with children) and employment status (as older people are more likely to be retired).

- Gender or ethnicity of household members: In some cases, these may affect people's ability to respond to pricing by changing behaviours, as they may affect the perceived safety of using different transport modes.
- Disability status of household members: This may influence households' exposure to the impacts of pricing and their ability to respond to pricing by changing behaviour. People with disabilities may face difficulties using some transport modes, eg walking or cycling to work.

4.1.2 Accounting for vertical and horizontal distributional impacts

It is important to measure and report on both the vertical and horizontal distribution of impacts. Following the literature review, these are alternative ways to think about the equity impacts of public policies. They can be assessed using information on how impacts differ for households with different characteristics, as identified in section 4.1.1.

The vertical distribution of impacts refers to the relationship between the impacts on households (or individuals) and their ability to bear these impacts. Vertical impact measures identify whether the costs (or benefits) of road pricing are higher for households with more or less ability to accommodate costs.

Vertical impacts can be assessed by using the household characteristics identified above to categorise households according to their ability to bear financial costs and their ability to respond via behaviour changes. A simple way to assess vertical impacts would be to analyse whether, for each household type, financial and non-financial impacts are larger for households with *lower* or *higher* incomes.

The horizontal distribution of impacts refers to whether households (or individuals) in similar situations experience similar impacts. Horizontal impact measures identify whether the costs (or benefits) of road pricing are similar for similar households located in different places.

Horizontal impact can be assessed by using information on how financial and non-financial impacts vary by location, controlling for household characteristics. It may be possible to assess horizontal impacts even without a full analysis of impacts on different household types, as transport modelling outputs typically enable transport outcomes, including tolls paid, to be summed up by model zone.

4.1.3 Measuring financial and non-financial impacts in the transport market

Road pricing can lead to a number of financial and non-financial impacts on households and individuals. Both financial and non-financial impacts are important, as highlighted by the Treasury's (2018) *Our living standards framework*, which emphasises that economic analysis should take into account a broader conception of wellbeing than simply financial wellbeing

A second key consideration is that the impacts of road pricing can be mitigated (or taken advantage of) by behavioural changes. As a result, these impacts should be assessed taking into account behavioural responses to ensure that the 'first order' and 'second order' effects are counted. As outlined in section 2.4, transport modelling can be used to calculate many financial and non-financial impacts of road pricing and can also account for various behavioural responses that people may use to avoid or mitigate costs.

In principle, the optimal approach would be to model both financial and non-financial impacts and calculate the net effect on households' wellbeing (or utility). However, there are a couple of reasons why this may not be desirable in practice:

- First, different households are likely to have different marginal utility of income or marginal utility of travel time savings. This makes it difficult to accurately calculate wellbeing impacts by combining transport model outputs with separate information on households.

- Second, decision-makers are likely to be interested in understanding financial and non-financial impacts separately.

Table 4.2 therefore summarises four key measures of impacts arising in the transport market that are likely to be relevant for understanding the social and distributional impacts of road pricing. Note all measures are calculated relative to a 'base case' scenario in which road pricing is not applied. In principle, they can *also* be calculated for scenarios that combine road pricing with additional transport investment.

Table 4.2 Transport impact indicators

Impact	Suggested approach to measuring this impact	Rationale for using this measure
Financial (transport) costs	Calculate the change in the monetary cost of travel arising from road pricing. This can be calculated using transport model outputs. This could be measured narrowly by calculating the total tolls users must pay, or more broadly by also adding for changes in vehicle operating costs (including fuel taxes) and public transport fares that users pay. This measure should be reported in two ways: • first, annual (or daily) financial impacts in dollar terms • second, annual financial impacts as a share of household income. In addition, if some users are likely to respond by changing their location choices, then this could be extended to consider financial impacts in other markets, like home delivery, housing markets, or labour markets.	Road pricing involves setting tolls for road use that may vary by location or time of day. Toll payments will therefore be the primary negative impact incurred by most users. Comparing estimated financial costs with household incomes provides information on the relative magnitude of financial impacts for different household types.
Travel time impacts	Calculate the change in the amount of time spent travelling as a result of road pricing. This can be calculated using transport model outputs. There are two ways to calculate impacts on average travel times, which may produce different results and be of interest for different purposes: • First, calculate the average travel time for the journeys that households take with and without road pricing, and compare them. This will provide information on the travel time impacts of road pricing *plus* the impact of behaviour changes to mitigate any financial costs. • Second, calculate the average travel time holding travel behaviours constant. This will provide information on the degree to which road pricing will decongest existing journeys. This measure should be reported in total time impacts on a daily or annual basis. Changes in travel time reliability resulting from road pricing are likely to provide additional benefit to users, above and beyond changes in average travel times. These impacts are generally harder to forecast but should be considered.	As discussed in section 2.2, road pricing can reduce travel time delay by setting a charge for travelling at congested times or in congested locations. Travel time savings will therefore be a potential benefit of road pricing for many users. Calculating travel time impacts provides information on a key non-financial impact for households. As noted, improvements to travel time reliability constitute an additional source of benefits and hence could also be valued subject to the availability of forecasting or data.
Generalised cost impacts	Calculate the change in the generalised cost (GC) of travel, which sums up travel time impacts, impacts on the quality of the travel experience, and financial impacts. This can be calculated using transport model outputs. In order to do so, it is necessary to make assumptions about users' willingness to pay for travel time savings in order to convert time, quality and financial impacts into a common unit of account. If there is sufficient evidence to support it, a separate value of travel time savings parameter could be used	GC provides a summary measure of the net effect of both financial and non-financial impacts on households. It uses a value of travel time savings parameter (or parameters) to convert between time and monetary impacts. Subject to assumptions about the validity of value of travel time

Impact	Suggested approach to measuring this impact	Rationale for using this measure
	for different household types. This measure should be calculated with an adjustment for changes in travel behaviour, to account for non-monetary costs associated with reducing (or increasing) travel. Following the *Economic evaluation manual* (EEM), we suggest applying a 'rule of half' adjustment for consumer surplus to account for these costs. This measure should be reported on a daily or annual basis. The value of travel time savings parameter, which reflects people's willingness to pay for reductions in travel times, can be used to convert this into an equivalent amount of either money or time.	savings parameters, this measure provides an indication of whether road pricing is likely to produce net benefits or disbenefits for households.
Transport accessibility impacts	Calculate the change in the number of jobs (or other destinations) that are accessible to households by car or public transport within a certain amount of travel time, or a certain level of overall transport cost, including financial costs. This can be calculated using transport model outputs at an origin-destination zone level. In order to do so, it is necessary to set a threshold for the maximum travel time (or financial cost) for a destination to be considered accessible. Commonly used thresholds are: • within a 30-minute car journey during the AM peak period • within a 45-minute public transport journey during the AM period, including time spent walking to stops, waiting for services, and transferring between services as well as in-vehicle time. This measure should be reported as the change in the number of jobs accessible within selected travel time thresholds. The definition of accessibility could be broadened to address other destinations that may provide other social or economic benefits to households. This could include, but is not necessarily limited to, education, retail, recreation or social connections such as friends and family. We note the Transport Agency is currently undertaking work to develop a package of accessibility indicators and as a result we recommend using the broader set of indicators that may be identified through that work. In addition, analysis could incorporate financial stress into accessibility measures. Some households may face financial constraints that prevent them from taking advantage of reduced travel times resulting from road pricing. Consequently, it would be possible to measure financial costs as a determinant of accessibility, eg by calculating: • accessibility based on generalised costs (ie time + money), rather than travel time alone • an alternative accessibility measure based on financial costs only. Different financial cut-offs could be set for different households, reflecting their different levels of financial constraints.	Accessibility measures reflect the total amount of opportunities that are available to households via the transport system. All else equal, increasing accessibility will increase the amount of choices available to people. Road pricing is expected to reduce travel time delay and thus increase accessibility to jobs. It may influence accessibility by cars and public transport, if public transport services are subject to traffic congestion. Accessibility measures were used in the Auckland Transport Alignment Project to assist in prioritising interventions.

In addition to impacts that arise primarily in the transport market, we note there are a range of potential external impacts, both positive and negative, that may arise as a result of road pricing. These include other social, economic and environmental impacts. In principle, these impacts could also be valued and ascribed to households, although in practice this may add significant complexity to the analysis.

The NZ Transport Agency's (2018) *Economic evaluation manual*, and other sources of transport evaluation guidance, identify a range of externalities that may arise as 'second order' effects of transport policies. These may include:

- Wider economic benefits associated with increased agglomeration economies (ie the productivity gains arising from better connections between firms and workers), increased labour force participation and increased competitiveness of markets.
- Social impacts of changes to accessibility and transport choice. For instance, increases in the financial cost of travel may cause some households to forgo non-work trips (eg family gatherings, sports, cultural events, recreation, etc), leading to increased social isolation and potential reductions in mental and physical health.
- Health benefits of increased use of walking and cycling for transport, which may arise from policies that result in a shift away from vehicular modes.
- Environmental impacts of changes to travel behaviours, such as reduced air pollution (and hence improved health) from reduced vehicle travel or improved water quality from a reduction in runoff from roads.

When considering these impacts, it is important to note they often go in the same direction as impacts that arise in the transport market. For instance, increases in the financial or time cost of travel will tend to reduce the potential for wider economic benefits and increase the potential for additional social disbenefits as a result of increased social isolation.

4.2 Principles for reporting impacts

A review of the literature and interviews with practitioners suggests there are two important principles for reporting the impacts of road pricing.

First, analysis of the social and distributional impacts of road pricing should be descriptive, rather than normative. The aim of the framework should be to provide information about these impacts – 'let the data talk' – rather than making a judgement about whether these impacts are 'good' or 'bad'.

This reflects the fact that:

- There are alternative views on what constitutes a 'fair' or 'equitable' outcome, as discussed in section 2.3, that are difficult to resolve within an analytical framework of this nature.
- Road pricing will have both financial and non-financial impacts, which may have offsetting effects that are challenging to value for some groups.
- Policymakers are likely to be interested in the *details* of impacts on different people in different places, rather than a summary measure of the overall distributional impacts.

This principle suggests it is important to present information in a 'relatively disaggregated' form, eg by presenting impacts on each individual category of households included in the analysis. It may also be necessary to present some summary statistics, such as a summary measure of vertical impacts, that aggregate up across household categories.

Second, outputs from the framework should be presented in a way that is relevant to policy objectives and which can inform policy design. As noted in section 2.1, there are several different reasons for implementing:

- To manage travel demands and abate the negative consequences of road travel
- To encourage allocation of scarce road capacity for higher valued trips
- To charge transport users to fund improvements to the transport system
- To raise tax revenue for other purposes.

Depending upon the objective, different measures of impacts may be chosen. For instance, if the aim is to raise revenue, then it may be most relevant to consider financial impacts on different households. But if the aim is to manage travel demands and moderate congestion, then non-financial outcomes are also likely to be important.

As noted in section 2.5, there are various options for designing road pricing schemes, ranging from cordon tolls to variable distance-based pricing, and various options for using any resulting revenues, ranging from spending it on transport improvements to redistributing it through tax and transfer policy. Analysis of social and distributional impacts may be used to inform these policy choices.

Outputs from analysis should therefore be reported in a way that is relevant to the policy choices at hand.

For instance, if a key policy question is whether to spend revenues on additional transport services or transport infrastructure, then it will be important to report on the location of disproportionately affected households to understand where negative impacts can be mitigated via additional investment. On the other hand, if changes to income tax rates or benefits are considered as a mitigation option, then it may be more important to understand impacts on employed and unemployed people with varying levels of income.

4.3 Summary

This section outlines a general framework for analysing the social and distributional impacts of road pricing. To conclude, it brings together these principles to outline how these impacts can be reported. In chapters 5 and 6 we demonstrate how this framework can be applied to real-world case studies and highlight practical issues that must be addressed in the process.

Table 4.3 illustrates an example matrix for reporting social and distributional impacts. On the vertical axis of the matrix, the first three columns identify a number of distinct types of households. In the example matrix, the categorisation is limited to the three factors identified in table 4.3 (household composition, income level and location), but these categories could also be extended to include additional household characteristics such as employment status or age.

The horizontal axis of the matrix lists the impact measures described in table 4.4: financial impacts (in $/year and as a share of household income), travel time impacts (in hours per day), impacts on the generalised cost of travel, and impacts on the number of jobs that are accessible by car or public transport. The blank cells in the last six columns would be populated with measures of these impacts.

This matrix can be used to identify different types of impacts on different types of households. It can also be sorted by household composition, income level, or location to investigate both the vertical and horizontal distribution of impacts.

Finally, with respect to the principles for reporting impacts, this matrix is primarily descriptive, rather than normative. It provides data that can be used to inform decision makers about the impacts of different policy options, including any disproportionate impacts on specific groups that may require mitigation through policy design.

Table 4.3 An example matrix for reporting the social and distributional impacts of road pricing

Household categorisation			Impact measures					
Household composition	**Income level**	**Location**	**Financial impacts ($)**	**Financial impacts (% of income)**	**Travel time impacts**	**General-ised cost of travel ($)**	**Access to jobs by car (#)**	**Access to jobs by public transport (#)**
Based on SNZ household classification, level 1	Broken into bands using equivalised household income	Broad geographic location, eg north, south, east, west	Financial costs in dollars per annum	Financial costs as a percent of household income	Travel time impacts in hours per day	GC is measured in monetary equivalents eg dollars per annum	Change in the number of jobs accessible within a 30-minute drive	Change in the number of jobs accessible within a 45-minute PT trip
Single person living alone	Low	North						
Single person living alone	Medium	North						
Single person living alone	High	North						
Single person living alone	Low	Central						
Single person living alone	Medium	Central						
Single person living alone	High	Central						
...	...	...						

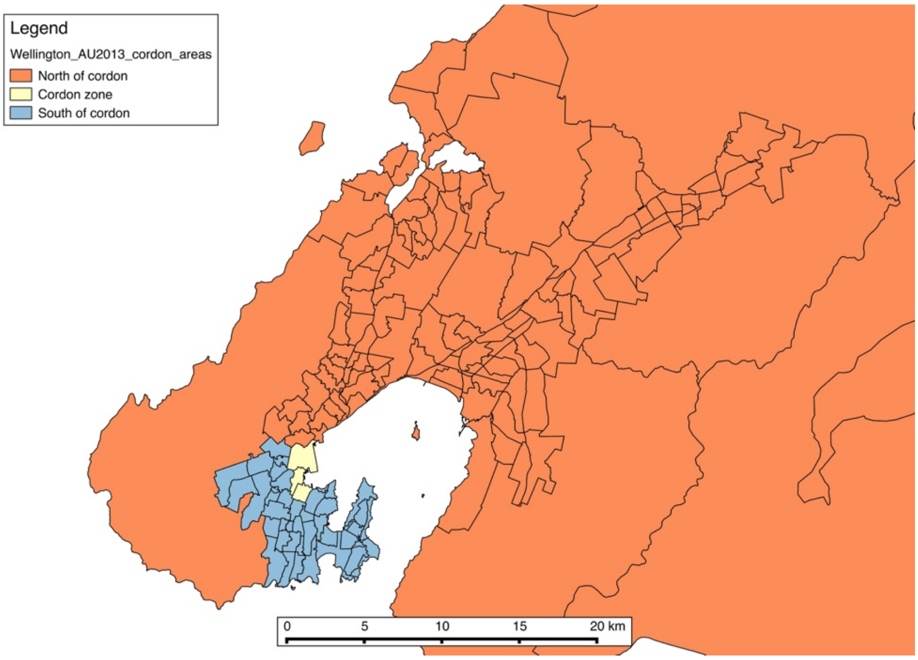
5 Case study 1: Wellington cordon charge

This section describes a case study of a hypothetical cordon charging scheme for Wellington. This consists of a high-level analysis of potential social and distributional impacts that can be implemented without transport modelling or highly detailed analysis of demographic data. It is intended to highlight the *qualitative* impacts of the cordon charging scheme on different types of households, rather than quantify effects.

The hypothetical cordon charging scheme would consist of a $5 charge for vehicles entering (or passing through) inner-city Wellington at any time during weekdays. The indicative $5 charge is roughly in line with the daily cost of a two-zone return journey via public transport ($5.46 via Snapper in 2018), while being considerably lower than the cost of inner-city parking ($16–23 per day, according to *parkopedia.co.nz*).

As shown in figure 5.1 we define the cordon area to consist of three census area units (Thorndon–Tinakori Road, Lambton and Willis Street–Cambridge Terrace) that comprise some of the densest and most congested areas of Wellington. This figure also identifies area units to the north and south of the cordon. Most north-to-south trips must pass through the cordon.

Figure 5.1 Hypothetical Wellington cordon charging area



5.1 Transport impacts of the cordon charge

The purpose of this case study is to demonstrate how the general principles outlined in chapter 4 can be applied even without detailed modelling. As a result, we describe the potential transport impacts of this hypothetical cordon charging scheme in qualitative terms.

The direct effect of a cordon charge will be to raise the cost of driving to or through inner-city Wellington. Assuming that some drivers respond by avoiding travel in the cordon area or changing their travel mode for trips in this area, this is likely to lead to reduced traffic congestion both in the cordon area and on the regional strategic road network feeding into central Wellington.

Many of the costs and benefits of this hypothetical charging scheme are therefore likely to accrue to people who usually drive to or through the cordon area. These people are expected to experience:

- higher financial costs of travel, due to the need to pay the toll
- faster journey times due to reduced road congestion, which they may value to different degrees depending upon their willingness to pay for travel time savings.

Drivers may be able to mitigate financial costs by switching modes or avoiding trips, but this may increase journey times or lead to other welfare losses.

Bus users are also likely to experience faster travel times in the cordon area. Due to the structure of Wellington's public transport network, these benefits are likely to principally accrue to public transport users in Wellington city. People commuting to the CBD from other parts of the region via public transport are more likely to use the rail network, which is not subject to traffic congestion. However, these benefits may be offset by increased crowding on peak-time services, if those services are at capacity at the moment and if there are constraints to increasing services, eg due to a lack of space for terminating services in the CBD.

People who are affected by the charge may be able to mitigate costs by changing their home location or their choice of destination for commuting trips or other household travel. We explore whether these are practical responses below.

Lastly, by mitigating traffic congestion in central Wellington, the cordon charge is likely to improve accessibility to jobs and other destinations via car and bus.

5.2 Estimating 'first order' effects on households

In the absence of transport modelling, it is difficult to make detailed predictions about how users will respond to a charge. However, most studies of the actual or predicted impact of road pricing schemes find that most people choose to bear the charge, rather than change behaviours to avoid it. Therefore, we can obtain a good 'first order' estimate of the impacts of the scheme by looking at current travel patterns. We then consider how these impacts may be distributed among:

- households in different locations within the Wellington region
- households with different income levels
- different types of households (household composition).

This analysis is based on publicly available data from the 2013 Census. To begin, we consider data on commuting journeys on census day, which can be accessed online at Statistics New Zealand's website and which provides information on:[17]

- the origin of commuting journeys (coded to census area units)
- the destination (coded to census area units)
- transport mode for commuting journeys.

[17] Commuter View is available online at www.stats.govt.nz/tools/commuter-view. Full data can be obtained via a custom data request.

In doing so, we note that most household travel is not related to commuting and hence census journey to work data may not be sufficient to assess all road pricing schemes. However, in this specific case, non-commuting journeys are less likely to be affected than commuting journeys. This reflects the fact that school and shopping trips tend to be localised in home suburbs, rather than requiring trips into or through the CBD. Furthermore, commuting trips happen daily, whereas non-commuting trips to or through the CBD are likely to be less frequent.

However, a logical extension to this analysis would be to use a trip matrix from Wellington's regional transport model, rather than the census journey-to-work data, to capture all types of journeys.

We aggregated commuting origins and destinations into the three broad zones shown in figure 5.1. The following table summarises this data. This shows that, out of the approximately 205,700 people in the Wellington region who reported being employed on census day, approximately 38,100 (or 19%) commuted by car to or through the cordon area. The other four-fifths either did not travel through the cordon zone, used non-car modes, worked from home, or did not travel to work on census day.

Out of the 38,100 commute trips that are likely to be affected by the charge, 28,100 (74%) were destined for the cordon zone, which is a relatively high-wage area. The remaining 10,000 trips (26%) represent travel to the northern or southern areas, where wages tend to be lower. These figures suggest that most commuters in the Wellington region will not be directly affected by the cordon charge.

Table 5.1 2013 commuting journeys to or through the cordon zone, Wellington region

Origin area	Destination area	Total commuting journeys	Car commuting journeys	Car mode share	Exposed to charge?
North of cordon	North of cordon	94,000	60,700	65%	No
	Cordon zone	40,800	18,800	46%	Yes
	South of cordon	7,700	5,600	73%	Yes
Cordon zone	North of cordon	800	400	50%	Yes
	Cordon zone	7,900	500	6%	No
	South of cordon	1,100	300	27%	Yes
South of cordon	North of cordon	5,100	3,700	73%	Yes
	Cordon zone	28,800	9,300	32%	Yes
	South of cordon	19,500	8,500	44%	No

While this analysis focuses on a cordon charge that is likely to principally affect commuters, we note that census commuting data or transport model trip matrices can also be used to estimate exposure to other pricing schemes, like the distance-based charge modelled for Auckland in chapter 6.

5.2.1 Impacts on households in different locations

In order to understand 'horizontal' impacts on similar households in different locations, we grouped commuting data by territorial authority (excluding a small number of commuters from the Wairarapa). Table 5.2 summarises how the expected impacts are broken down among commuters from different places.

In short, commuters from Wellington city and Porirua city are most likely to commute to or through the cordon area by car, while people from Kapiti Coast were least likely to do so. This highlights that the cordon charging scheme is likely to have a relatively larger impact on households in these two territorial authorities. In the case of Wellington, this is likely to be accentuated by the fact that many non-commuting car trips are also likely to pass through the cordon area.

In addition, commuters from Porirua and Upper Hutt who commuted across the cordon were more likely to travel by car, indicating that non-car modes may be a less viable option from these locations. This will tend to exacerbate the impact of road pricing for households in Porirua and Upper Hutt.

Table 5.2 Impacts of a cordon charge on commuting journeys from Wellington territorial authorities, 2013

Territorial authority	Total commuting journeys		Commuting journeys that cross the cordon		Share of journeys exposed to charge	Car mode share for journeys across cordon
	Car mode	All modes[a]	Car mode	All modes(1)		
Wellington city	41,000	94,700	24,100	54,600	25%	44%
Lower Hutt city	24,000	40,500	5,900	13,000	15%	45%
Upper Hutt city	10,700	16,800	2,100	4,200	13%	50%
Porirua city	12,600	19,600	4,000	7,100	20%	56%
Kapiti Coast district	10,000	17,500	1,800	4,000	10%	45%

[a] Including people who did not report a mode or who did not travel to work on census day

5.2.2 Impacts on households with different income levels

In order to understand 'vertical' impacts on households with different ability to pay a toll, we examined the relationship between the share of commuters who currently drive across the cordon and median household incomes at a census area unit level.[18] Figure 5.2 displays this relationship. There is a strong *positive* correlation between car commuting across the cordon and high household incomes. This reflects two features of Wellington's labour market and transport system:

- People who work in the cordon area tend to have higher-than-average incomes.
- The price of CBD parking is in the $16–23 range, which will tend to discourage people on lower incomes from commuting by car to the cordon area.

The trendline indicates that an area unit where 10% of commuters drive across the cordon is likely to have a median household income of $65,400, while an area unit where 20% of commuters drive across the cordon is likely to have a median household income of $82,700. This difference in incomes is larger than the annual cost of the toll ($1,250, assuming 250 working days a year and a daily toll of $5). Hence the average financial cost of the toll may be larger in absolute terms, but lower relative to income, for households in higher-income areas. This reflects the fact that estimated exposure to the toll does not rise as fast as median incomes.

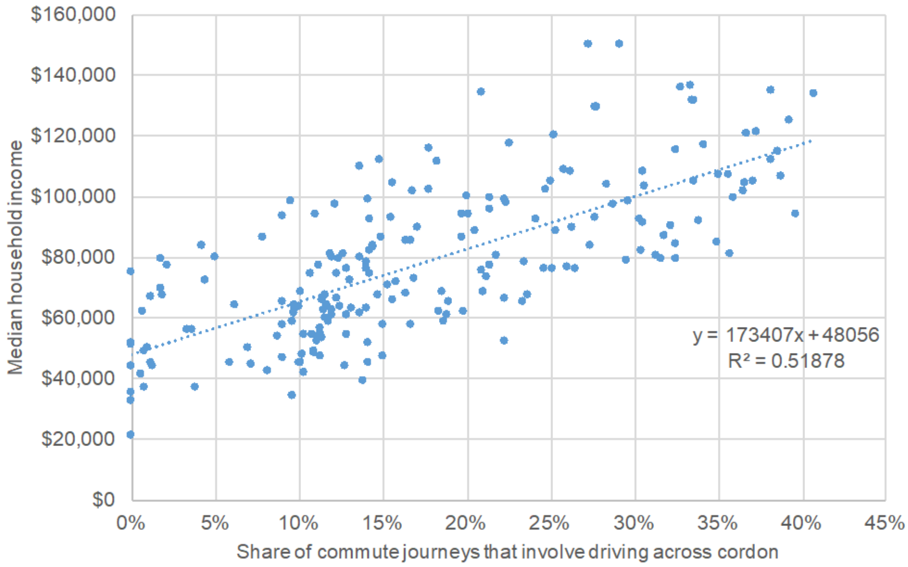
This analysis assumes the travel patterns and modes are distributed evenly across households within each area unit, and hence the average impact of a toll will be experienced by the average household. This assumption is necessary as there is no direct link between the journey to work data and household characteristics. In reality, impacts are likely to be concentrated in a sub-set of the households in each area unit, which may have higher or lower incomes than the average.

As a result, this analysis does not conclusively demonstrate that higher-income households are likely to experience higher financial costs as a result of a cordon charge. Most area units include households with a

[18] Available online at http://nzdotstat.stats.govt.nz/wbos/Index.aspx?DataSetCode=TABLECODE8135

range of incomes. In addition, there are some low income areas with a relatively high rate of car commuting across the cordon, and vice versa.

Figure 5.2 Car commuting across the cordon and median household incomes at an area unit level



5.2.3 Impacts on different types of households

Lastly, we consider potential impacts on different types of households. Discussed further in the Auckland road pricing case study, different types of households travel at a different rate. Smaller households tend to travel less, as do households with fewer employed people. However, in Auckland at least, household incomes do not have a material impact on trip generation rates after controlling for household composition and size.

As a result, household types that generate more trips, and in particular more commuting trips, are likely to bear higher costs as a result of a road pricing scheme. For context, table 5.3 summarises average trip generation rates for different household types in the Auckland region (see section 6.2.3 for a description of this data).

While Wellington trip generation rates are likely to differ somewhat, this suggests that single parent families and one person households are likely to make fewer commuting journeys than average. These households are likely to experience a lower level of financial costs, but as they also tend to have lower incomes, these costs may be proportionately larger as a share of household incomes. By contrast, larger households, including multi-family households and households of unrelated people, tend to generate more commuting journeys and thus may bear higher total costs.

Table 5.3 Average daily trip generation rates for different household types, Auckland 2003–2014

Household type	Daily person trip generation rate by trip purpose	
	Commuting	Other
Couple only	2.0	4.3
Couple with dependent child(ren) only	2.4	10.6
All other couples with non-dependent child(ren) or other people	2.9	5.4
One parent with dependent child(ren) only	1.2	7.9

Household type	Daily person trip generation rate by trip purpose	
	Commuting	Other
All other one parent households (including children aged 18+ or other people)	2.9	5.4
Multi-family household	2.8	4.6
Household of unrelated people	2.8	4.6
One person household	0.9	2.5
Other household composition	3.1	5.9

Source: Analysis of Household Travel Survey data for Auckland, 2003–2014

If different types of households are disproportionately distributed throughout the region, they may experience different impacts as a result. We therefore used census data on household composition at a territorial authority level to investigate whether certain types of households are disproportionately likely to cluster in certain locations.[19] The key differences are as follows:

- One parent households were less concentrated in Wellington city, and more common in Lower Hutt and Porirua city. As commuters from Porirua city are slightly more likely than average to drive through the cordon, this may exacerbate impacts on single-parent households.
- Households of unrelated people (ie people in flatting arrangements) were much more common in Wellington city than elsewhere in the region. Many of these households are likely to be students and young workers, who may be more likely to use non-car modes and hence may be less affected by the charge.

5.3 Estimating 'second order' effects

The above analysis is focused on 'first order' effects, without considering how people's behaviour may change in response to a cordon charge. As outlined in section 2.4, people whose trips are affected by tolls have the option to:

- Do nothing and pay the toll
- Change their transport behaviour, by:
  - changing routes
  - changing modes
  - travelling at a different time
  - avoiding making trips (or combining trips).
- Change their location, by:
  - changing origins, ie moving to a different residence
  - changing destinations, eg by shifting jobs.

Unlike in the following case study of Auckland, which uses transport modelling to evaluate how various changes to transport behaviour may affect the impacts experienced by households, it is necessary to

[19] This data is available online at http://nzdotstat.stats.govt.nz/wbos/Index.aspx?DataSetCode=TABLECODE8165

consider each of these potential responses in a qualitative fashion. We therefore briefly discuss these behavioural responses and how they may allow households to mitigate the financial impacts identified above or take advantage of the benefits of the scheme.

5.3.1 Changing routes

In this hypothetical example, it would be difficult to avoid the cordon charge by changing routes. This reflects the fact that the cordon is defined to intercept all trips to the Wellington CBD. In the process, it also captures the main route between the southern and northern areas defined in figure 5.1.

5.3.2 Changing modes

Wellington has a low car mode share relative to other parts of New Zealand. Non-car transport options are abundant, especially for travel to the CBD. As a result, people travelling to the cordon area may be able to avoid the charge by switching modes. Moreover, people who switched to buses for CBD-bound trips are likely to experience faster travel times due to lower congestion on inner city streets.

However, CBD-bound users' ability to shift to public transport during peak times may be limited by crowding and capacity constraints on public transport services. If cordon pricing increases peak-period demand for public transport, it may exacerbate user inconvenience from crowding and may have adverse effects on service reliability, eg due to people being passed by full buses. As a result, shifting to public transport may be a more viable option for off-peak trips, whereas shifting to walking or cycling may be relatively more attractive for shorter peak trips to the CBD.

Changing modes to public transport is likely to be a less attractive option for people travelling through the cordon area to other parts of the region, eg between the southern parts of Wellington city and the Hutt Valley. First, public transport fares for these journeys are likely to be higher than the cost of the toll. For instance, a five-zone fare (eg between central Wellington and Porirua central) currently costs $4.98, or twice as much as the $5 toll for a return commute. Second, as most public transport routes terminate in the CBD, it is often necessary to transfer between services, adding time to journeys. Carpooling may still be an attractive option for these trips.

As shown below, people employed in the Wellington CBD tend to have higher incomes than people employed elsewhere in the region. Consequently, changing modes may be a more viable option for higher-income CBD workers than for lower-income workers employed in other locations.

5.3.3 Travelling at a different time

In this hypothetical example, it would be difficult to avoid the cordon charge by travelling at a different time. This reflects the fact that the cordon is assumed to apply on all weekdays, with no variation between peak and off-peak times. However, for some trips, travelling on the weekend may allow people to avoid the charge, albeit with an adverse effect on weekend congestion. This is most likely to be relevant for non-commuting trips, such as shopping trips or visits to regional destinations like Te Papa.

5.3.4 Avoiding trips or combining trips

Evidence from other cities suggests people may combine multiple trips into the cordon area to avoid paying multiple tolls. This is also likely to be a feasible option for many non-commute trips in Wellington and may allow individual households to mitigate financial costs. However, as noted in section 2.4.1, it is difficult to model or predict these responses.

5.3.5 Changing residential locations

Households may be able to avoid the cordon charge by moving to another part of the Wellington region. For instance, somebody who lives in Newtown and commutes to Petone could move to Lower Hutt in order to avoid paying the toll. In order to understand whether this is likely to be a financially viable option for households, we analysed census data on dwelling rents at an area unit level.[20]

In doing so, we note that choices about where to live reflects more than simply the financial cost of housing and transport. Households' location choices reflect a wide range of factors in addition to commuting costs, including proximity to natural and man-made amenities such as beaches, sunlight, school zones, restaurants and retail. Switching locations means more than just paying more or less in housing costs – it also means experiencing a different level of residential amenity.

Subject to that caveat, table 5.4 summarises average weekly rents for two and three bedroom dwellings in the three areas defined in figure 5.1. We compare differences in average rents between these areas with the weekly cost of the cordon charge ($25) to understand whether households could save money by changing their home location while holding their work location fixed. This shows:

- For similarly-sized dwellings, average rents in the cordon zone are considerably higher than rents in the other two areas. This means households will not be able to reduce total costs by moving inside the cordon.
- Rents north of the cordon are lower than rents south of the cordon. This means households that travel south to north across the cordon may be able to reduce their total costs by moving north towards their job location.

While this analysis is highly indicative, it suggests some households may be able to avoid the toll by changing their home location. The most likely direction of movement is south to north. This may be a more relevant option for newly formed households, eg people migrating to Wellington from other regions, than already established households.

Table 5.4 Average weekly rents in different parts of the Wellington region, 2013

Area	Two bedrooms	Three bedrooms
North of cordon	$230	$300
Cordon zone	$450	$610
South of cordon	$340	$460

5.3.6 Changing destination locations

Conversely, some people may be able to avoid the cordon charge by changing their destination locations while holding their home location fixed. In particular, people may change their work location by shifting to a job that does not require them to cross the cordon. For instance, the hypothetical Newtown to Petone commuter above may shift to a job at the Wellington Airport to avoid crossing the cordon.

In order to understand whether this is likely to be a financially viable option for households, we analysed census data on average pre-tax incomes for people employed in different industries at an area unit level.[21] Table 5.5 summarises this data for the three areas defined in figure 5.1, focusing on retail employees (a

[20] Available online at http://nzdotstat.stats.govt.nz/wbos/Index.aspx?DataSetCode=TABLECODE8095

[21] This data is not available online but can be obtained via a custom data request to Statistics New Zealand.

low-income industry) and professional services employees (a high-income industry). We compare differences in average incomes with the annual cost of the cordon charge ($1,250) to understand whether households could save money by changing work locations.

In both industries, the pre-tax income difference between the cordon area and the other parts of the city is larger than the cost of the cordon charge.[22] This suggests that shifting to jobs outside the cordon area is not likely to be an attractive option for individual employees.

However, average incomes for employed people are similar to the north and south of the cordon. People who currently live north of the cordon and commute to jobs south of the cordon (or vice versa) may be able to gain from changing their job location to a location that is closer to home. Alternatively, they may choose to seek employment in the cordon area, where incomes are generally higher.

We note this analysis does not explicitly consider the relative *availability* of different types of jobs in different locations, and hence it may over-state the ability of people to find an appropriate job in another part of the region.

Table 5.5 Average incomes for people employed in different parts of the Wellington region, 2013

Area	G Retail trade	M Professional, scientific and technical services
North of cordon	$31,200	$69,100
Cordon zone	$37,500	$90,600
South of cordon	$31,900	$70,800

5.4 Summary of findings

Based on the above analysis, we undertake a qualitative assessment of the social and distributional impacts of a hypothetical cordon charge scheme for Wellington. We then highlight what this case study demonstrates about the feasibility of implementing this framework with incomplete data or modelling capability.

Table 5.6 describes the expected financial impacts on households living in different locations, with different income levels and with different household composition. This highlights some potential differences between different groups of households. On the whole, these results suggest high-income households, which are concentrated in Wellington city, are most likely to be exposed to the cordon charge. However, they are also likely to face lower costs relative to household incomes. Similarly, larger households are likely to face higher total costs, but potentially lower costs relative to incomes.

This analysis also highlights some potential interactions between location and household composition, reflecting the fact that some types of households are disproportionately located in certain places.

[22] In this particular case, the difference is large enough so income taxes will not narrow the gap to a sufficient degree.

Table 5.6 Expected financial impacts on different types of households

Grouping	Level of financial cost	Financial cost relative to incomes
Household location	• Households in Wellington and Porirua cities are more likely to incur the charge based on current commuting patterns. • Households in Kapiti Coast district are least likely to incur the charge.	• Household incomes are highest in Wellington city, followed by Porirua city (controlling for household composition). • Areas where commuters are more likely to be exposed to the toll also tend to have higher median household incomes, meaning that financial costs may be smaller relative to incomes in these areas.
Household income	• Higher-income households are more likely to incur financial costs as a result of the charge, as they are more likely to work in the cordon area. • People crossing the cordon area between the north and south of the region are likely to have lower incomes and may have fewer options for switching modes.	• At an area unit level, median household incomes rise faster than exposure to the charge. • Higher-income households may therefore face lower costs as a share of income.
Household composition	• Smaller households, including one parent households, make fewer trips including fewer commute trips, and hence may face lower financial costs (in dollar terms) as a result. • Households that make more non-work trips, eg for school or retail, that pass through the cordon. • One parent households are slightly more common in Porirua city and Lower Hutt, which may lead to higher costs for one parent households in these particular locations.	• Smaller households and one parent households tend to have lower incomes, meaning that financial impacts may be larger relative to incomes than for larger households.

We have also qualitatively assessed potential transport and land use responses that could be used to mitigate the financial costs of the toll or take advantage of its benefits. Table 5.7 briefly summarises these responses, and identifies which types of households are most likely to be affected by each option. This highlights the fact that some people may be able to mitigate the costs they face by changing their transport or location choices, but these options will not necessarily be available to all households.

Table 5.7 Potential transport and land use responses to a Wellington cordon charge

Response	Likely impact	Who will it affect
Do nothing and pay the toll	• People who choose this option would experience higher financial costs while experiencing faster journey times.	• Table 5.6 describes which groups are most likely to be significantly affected based on current commuting behaviours.
Change routes	• This option is unlikely to be relevant due to the structure of the cordon area.	N/A
Change modes	• People who choose this option will avoid the toll and avoid vehicle operating costs and parking charges, but they must pay public transport fares. • Bus users travelling to or through inner-city Wellington are likely to experience faster journey times.	• This option is most likely to be practical for people commuting to the CBD, as opposed to people commuting between the north and south areas. • This reflects the structure of Wellington’s public transport system and its fare zone system.

Response	Likely impact	Who will it affect
	• Peak-period crowding may limit the practicality of shifting to public transport during this time period, but not necessarily for off-peak trips.	
Travel at a different time	• This option is unlikely to be relevant as the charge is assumed to be fixed on weekdays. • Some people may shift discretionary trips to the weekends, eg for shopping or visiting regional attractions, albeit at the cost of increased weekend congestion.	N/A
Avoid making trips/combine trips	• This option will reduce financial costs for people who can combine multiple trips across the cordon, eg shopping and commuting trips.	• It is difficult to predict who may be most likely to choose this option as it will depend upon their circumstances and other constraints.
Change residential location	• On average, this option will only reduce financial costs for people moving from the southern Wellington suburbs to the area north of the cordon. • Moving inside the cordon is unlikely to save households money unless they also downsize their residence.	• This option may be feasible for some people who currently travel from the southern Wellington suburbs to jobs north of the cordon.
Change employment destination	• The average wage gap between the cordon area and areas outside the cordon is larger than the annual financial cost of the toll, suggesting that commuters are unlikely to gain from seeking employment elsewhere. • Wages to the north and south of the cordon area are similar, which suggests people who commute between these areas may gain from seeking employment closer to home.	• This option may be feasible for some people who currently commute across the cordon to jobs in the north or south areas

5.5 Lessons from this case study

This case study demonstrates that it is possible to consider the social and distributional impacts of a hypothetical road pricing scheme in *qualitative* terms without transport modelling or highly detailed quantitative analysis. This analysis is based on readily available Statistics New Zealand data. If available, transport model outputs could be used to extend this analysis. Even if a specific road pricing scheme was not modelled, outputs for trip generation and distribution under a base case scenario could be used to estimate potential impacts on non-commute journeys.

However, the data used here has several limitations. It does not allow us to 'cross-tabulate' impacts by household location, income and composition, which limits our ability to draw conclusions about detailed impacts. In addition, we note the method we used to identify trips travelling across a single cordon may not be applicable for other pricing structures (eg distance-based pricing) or for transport networks with more alternative routes than Wellington.

A second lesson relates to our findings about the social and distributional impacts of this particular scheme, and how any perceived adverse effects may be mitigated.

In contrast to the case study in chapter 6 of distance-based road pricing for the entire Auckland road network, this scheme principally affects CBD-bound commuters. As a result, the charge is more likely to affect high-income households relative to low-income households. However, people driving across the cordon between north and south areas are likely to have lower incomes and face more limited alternatives for switching modes to avoid the toll.

It may be possible to mitigate some of these impacts by improving the speed of public transport journeys and reducing waiting times for journeys that must transfer in the CBD, or by making complementary changes to the structure or level of public transport fares.

Due to its design, the cordon scheme may have smaller impacts (in dollar terms) on households that make few commuting trips, including one-parent households and families that make more school or retail trips. It may therefore be less important to consider mitigation targeted towards these household types. However, this tentative conclusion bears further investigation.

6 Case study 2: Distance-based road pricing in Auckland

This chapter presents a case study of a hypothetical distance-based, time-varying road pricing scheme that would apply to the entire Auckland road network. This case study is considerably more detailed than the Wellington case study. It draws on detailed data from a travel demand model, census and household travel surveys to create a robust and quantitative evaluation of the social and distributional impacts of road pricing.

This case study is based on the road pricing scenario defined in the ATAP. As shown in table 6.1, this scheme consists of a whole network pricing system with a pricing structure that targeted highest prices to the most congested locations and where travel alternatives were most likely to be available. These prices would replace existing fuel excise and road user charges, which average approximately 6c/km. Off-peak charges would be lower than peak charges, reflecting the fact that peak congestion is considerably higher than off-peak congestion.

It is recognised that Auckland Council and central government are currently investigating different pricing structures, and hence the ATAP road pricing proposal is unlikely to be put in practice as is. However, it has been analysed as a recognised benchmark.

Table 6.1 ATAP road pricing scenario: indicative pricing structure

Round 2 hypothetical price levels used for testing (c/km)				
Area	Network	Peak	Inter-Peak	Off-Peak
Inner Urban (isthmus)	Motorways	40	30	3
	Other Roads	30	20	3
Outer Urban	Motorways	30	20	3
	Other Roads	20	10	3
Rural	All Roads	3	3	3

6.1 Overview of approach

In this case study, we link together data from the Auckland MSM, the 2013 Census of Population and Dwellings, and the Household Travel Survey to implement the general framework described in chapter 4. This analysis demonstrates how these data sources can be used to estimate the full set of impact indicators we identified, ie impacts on financial costs, travel time, generalised costs of travel and accessibility to jobs via car or public transport, for different groups of households, differentiated by location, household type and income.

This case study responds to the need to demonstrate this framework can be implemented in the context of a specific transport modelling environment, without developing entirely new transport models. As such, it is effectively a ‘two stage’ analytical process that maps from transport model outputs to the social/distributional metrics that are of interest. This approach is conceptually similar to the Market Economics’ methodology discussed in section 2.5.2, but it employs more detailed transport model outputs and different data on households.

In the first stage, strategic transport models are used to estimate the impacts of congestion pricing on transport demands and the financial and time cost of transport. This ensures the results of an assessment of the social and distributional impacts of road pricing are consistent with other analysis of its impacts on the overall efficiency of the transport system.

In the second stage, transport model outputs at the transport model zone level are combined with demographic information on households living in those zones in order to identify how the impacts of a road pricing scheme will be distributed between different groups. Implementing this stage requires data on household demographics, eg from the census, as well as data on trip generation rates for different types of households to link together transport model outputs and households. The results from the second stage of analysis can then be reported in a variety of ways.

6.2 Description of data sources

The four road pricing impact indicators detailed in table 4.2 have been evaluated for the Auckland context through the use of three different data sources, these being the MSM, 2013 Census population data and the Household Travel Survey.

6.2.1 Transport model outputs

We begin by discussing key aspects of strategic transport models to highlight which behavioural responses they address and how they model these impacts. Broadly speaking, strategic transport models like Auckland's MSM model journeys between a range of origins and destinations, by multiple transport modes and in multiple time periods. They tend to be regional in scale and hence are well suited for evaluating interventions that potentially affect large parts of a city's transport network. In principle, strategic transport models can be extended to allow changes to the transport system to affect the location of residents and businesses, but this functionality is not commonly applied.

Table 6.2 briefly summarises the types of behavioural responses that are modelled, or partly modelled, within most strategic transport models. It highlights how strategic transport models are able to model the effects of people who do nothing, as well as those who either change route and/or mode. They are also able to capture some types of avoided trips, such as trips that are 'priced off' the network entirely due to tolls, and changes to trip distribution due to the changing cost of reaching different destinations. However, they are less able to capture trip chaining, which allows people to combine multiple trips to avoid multiple tolls, or substitution of trips through home delivery. Lastly, they do not allow home locations to change in response to tolls or other aspects of transport networks, unless the full land use-transport interaction module is run.[23]

Strategic transport models do not tend to capture several important sources of efficiency from road pricing. First, they focus on the impact of road pricing on average travel times, rather than modelling impacts on the reliability (or variability) of travel times.[24] Second, they do not model the monetisation of delays that is predicted by the bottleneck model. Instead, they tend to be purely focused on efficiencies

[23] We note that freight trips are modelled using a 'fixed matrix' approach in which origins and destinations are fixed but which allows freight trips to take different routes between them. This will influence the modelled impact of tolls (or other transport interventions) on freight users.

[24] Impacts on travel time reliability can be assessed using external/post-model procedures, but these procedures do not capture second-order effects on trip distribution, mode choice and assignment.

arising from reduced deadweight losses of congestion. They will therefore tend to underestimate the benefits of road pricing.[25] (See section 2.2 for a discussion of the difference between these frameworks.)

Table 6.2 Linking behavioural response to road pricing to strategic transport models

Type of response	User response	Modelled?
Do nothing	*Do nothing:* Same mode, same route and pay associated toll.	Yes
Transport response	*Change route:* Same mode, different route and pay associated toll.	Yes
	Change mode: To reduce (in the case of car-pooling) or avoid the toll.	Yes
	Change departure times: To travel at times when tolls are lower.	Partially
	Avoid making trips: Whether by removing trips entirely or linking them with other trips.	Partially
Location response	*Change destinations:* To locations that are subject to a lower toll.	Partially
	Change origin: To locations that are subject to a lower toll.	No

As an aside, we note that a review of outputs from Auckland's MSM suggests the total number of motorised trips and the number of motorised trips by time period appear to vary between scenarios. This suggests Auckland's strategic transport model may enable some responses in terms of reducing the number of modelled vehicular trips during periods with higher prices and increasing vehicular trips during periods where prices are reduced. In section 2.4.1, we noted trip suppression has been an important behavioural response to some road pricing schemes. If this is not fully modelled by strategic transport models, then we may under-estimate the impacts (both positive and negative) of this margin of adjustment.

The preceding discussion highlights some important aspects of the underlying economic structure of strategic transport models. Formally, we can represent the economic model in strategic transport models as follows:

Equation 6.1 Economic model of utility maximising behaviour in strategic transport models

$$\max_{m,r} \bar{U} - C\left(m, r; o, d, h, \beta_{h,m,o,d}\right) \qquad \text{(Equation 6.1)}$$

Where:

- $\bar{U}$ denotes the fixed utility the individual derives from completing the trip.
- m and r denote the mode and route chosen for the trip.
- $C(\cdot)$ denotes the generalised transport costs incurred in making the trip.
- $o, d, and\ h$ denote the origin, destination and household type of the trip, which are given.
- $\beta_{h,m,o,d}$ denotes a vector of preference and calibration parameters associated with household type h, mode m, and origin/destination o and d respectively, which is estimated outside the model.

If we assume the utility of the trip always exceeds the costs of the trip, that is $\bar{U} > C\left(m, r; o, d, h, \beta_{h,m,o,d}\right)$, then trips are always undertaken, and total demands are fixed. By extension, utility is maximised when costs are minimised. Formally, this implies that the above economic model reduces to:

[25] We note further that because strategic transport models use deterministic demands, they are not able to capture changes in travel-time reliability, which will typically improve due to reduced congestion. We highlight that the omission of changes to travel-time reliability will also tend to underestimate benefits of road pricing.

Equation 6.2 Economic model of cost minimising behaviour in strategic transport models

$$\min_{m,r} C(m, r; o, d, h, \beta_{h,m,o,d}) \quad \text{(Equation 6.2)}$$

In such models, individual trips are assumed to deliver a fixed level of utility, which exceeds the transport costs incurred in undertaking the trip, so utility maximisation is equivalent to *transport cost minimisation*. Moreover, transport cost minimisation is achieved by the user minimising the cost of individual trips from a choice set defined by available modes and routes, which are in turn associated with outcomes such as travel time, travel distance and monetary costs, including fares and tolls. Under this framework, the primary benefit of transport policy is to affect people's choice of modes and routes to reduce transport costs for individual trips. Hence, strategic transport models are often called 'trip-based models'.

By formulating travel demand decisions in this way, however, strategic transport models generally assume total demand for travel is fixed, and that departure times, origins and destinations are immutable, while technological substitution of travel demands does not generally occur. Hence they do not typically model land use responses to changing transport costs, unless a land use–transport interaction model is incorporated.

Second, we note that strategic transport models model choices about whether and how to take individual *journeys*, rather than modelling households' overall transport choices. This means, in order to use transport model outputs to assess the social and distributional impacts of road pricing, it is necessary to conduct additional out-of-model analysis to link impacts on specific types of *journeys* to impacts on *households*.

Following the above discussion of strategic transport model workings, we note these models can provide estimates of:

- the modelled number of journeys between specific origins and destinations
- the overall generalised cost of these journeys
- individual cost components of these journeys, which can be broken down into financial and non-financial costs.

Auckland's MSM is able to report these outputs by model zone, income level of the agent making the trip, transport mode, trip purpose and time period. Table 6.3 summarises the categories used for reporting MSM outputs. For this case study, we began with data on modelled numbers of journeys, generalised costs, financial costs and travel time disaggregated based on these five categories. We obtained (2016) transport model outputs for two scenarios:

1 Base case: the ATAP base case transport network and land use assumptions without road pricing applied

2 Road pricing scenario: the ATAP base case transport network and land use assumptions with distance-based, time-varying road pricing applied.

Table 6.3 Categorisation of transport model impact groups

Model zone	Income level	Mode	Purpose	Time period
1 2 596	Low Medium High	Car Public transport	EB (employment based) HBW (home-based work) Other	AM (AM peak 2hr) IP (inter peak 6hr) SP (school peak 1hr) PM (PM peak 2hr) OP (off peak 13hr)

6.2.2 Census data

2013 Census household data at an area unit level was used to connect the spatial impacts of road pricing at a zonal level with different types of households. Following the discussion in section 4.1.1, we categorised households by:

- location (census area unit, which we spatially matched to transport model zones)
- household type, based on a modified version of Statistics New Zealand's household composition framework (level 2)
- household income, divided into three bands to match the income band categories in the MSM.

A custom data request was used to obtain information on the number of households, and their median annual pre-tax income, in each of these different categories for each 2013 Census area unit in Auckland.[26] We also obtained a further breakdown of the number of people employed in the household, but further analysis showed this resulted in excessive cell suppression due to Statistics New Zealand's rules about suppressing personally identifiable information. See appendix D for a discussion of this issue. We note this highlights a key technical limit to grouping households into extremely finely grained categories in order to apply the method outlined in this case study.

Table 6.4 shows how household groups are aggregated in this analysis, noting the final categorisation of the number of people employed has not been used in the analysis reported in this section.

Table 6.4 Categorisation of household groups in census

Area unit code (2013 areas)	Tertile – income band	Household composition	Number of people employed in the household
505300 505400 ... 617903	Tertile 1 Tertile 2 Tertile 3 Based on Jensen equivalised household income to adjust for differences in household size	Couple only Couple with dependent child(ren) only All other couples with non-dependent child(ren) or other people[(a)] One parent with dependent child(ren) only All other one parent households (including children aged 18+ or other people) Multi-family household[(b)] Household of unrelated people One person household Other household composition[(c)]	0 no one in paid work 1 person in paid work 2 people in paid work 3 or more people in paid work

[(a)] Aggregates three household composition categories: Couple only and other person(s); couple with child(ren) [only including children aged 18+]; couple with child(ren) and other person(s)

[(b)] Aggregates seven household composition categories: Two 2-parent families; one 2-parent family and a 1-parent family; two 1-parent families; other 2-family household; three or more family household (with or without other people); other multi-person household nfd; household of related people; household of related and unrelated people.

[(c)] Aggregates three household composition categories: One-family household nfd; two-family household nfd; household composition unidentifiable.

[26] It was not possible to estimate post-tax income, as this would require further information on incomes of individuals within those households. While this could in principle be estimated based on Census data, it would not be possible to release due to confidentiality concerns.

Note that the income bands we have used are not identical to the income bands in publicly available Census tables, which break down households into income bands (eg income of $20,000 or less; income of $20,001 –$30,000). A significant shortcoming of this default approach to classification is that it does not control for differences in household size. For instance, a one-person household with an income of $60,000 is unlikely to be materially deprived, while a five-person household with an income of $60,000 may face material hardship due to higher living expenses.

As a result, we group households according to equivalised household income, which standardises for household composition. Statistics New Zealand calculates equivalised household income using the Jensen method, which is set out below.

Equation 6.3 Jensen equivalised income

$$Jensen\ income = \frac{Total\ household\ income}{[a + (c * x) + (t * y)]^z / 2z} \qquad \text{(Equation 6.3)}$$

Where:

- a is the number of adults in household
- c is the number of children in household
- t is the sum of individual ages of children in household
- x, y, z are constants that standardise between children of different ages and households of different sizes.[27]

6.2.3 Household Travel Survey

Finally, in order to link household data from the census with transport behaviour outputs from the MSM, we estimate trip generation rates broken down by different household types and trip purposes. The Ministry of Transport provided us with access to Household Travel Survey microdata for Auckland from the 2003–2014 surveys, which we have used to estimate custom trip generation rates for specific household types.

An alternative would be to use default trip generation rates used as an input to the MSM. We expect these to be generally consistent as the Household Travel Survey is a key source for MSM inputs.

The Household Travel Survey summarises daily trip generation rates for different household types and number of occupants employed. The different groups for which trip generation rates are reported in the Household Travel Survey are shown in table 6.5.

Appendix B summarises exploratory analysis that was conducted to understand which factors affect household trip generation rates, and which have smaller impacts.

[27] For a discussion of alternative household income equivalence scales in New Zealand and choices of parameter values for these scales, see www.eastonbh.ac.nz/2002/11/household_equivalence_scales/.

Table 6.5 Categorisation of trip generation rates in Household Travel Survey

Household composition	Number of people employed in the household	Trip purpose
Family with children < 18 Family with adult children Family with children < 18 and flatmates / boarders Married/de facto couple only Other *Other adults only* *Person living alone* *Single adult living with children < 18* *Single adult with other adult*	0 workers 1 worker 2 workers 3+ workers Total	EB (employment based) HBE (home-based education) HBO (home-based other) HBSH (home-based shopping) HBW (home-based work) Home Other

6.3 Calculating the impacts of road pricing for household groups

The process for evaluating the four road pricing impact indicators through use of the three different data sources is discussed in this section. The following broad steps were undertaken to evaluate the spatial and distributional impacts of road pricing:

3 Two scenarios were evaluated and compared using the transport model, one with and one without road pricing. The predicted number of trips undertaken from each origin zone, average trip travel time, average generalised cost and average financial cost between the two scenarios were determined. Resulting changes in accessibility, financial cost, travel time and generalised cost were given for each group.

4 Assumptions around the value of travel time savings, which were allowed to vary between different income levels and trip purposes, were applied to generalised costs to convert them from minutes to 2016 New Zealand dollar values.

5 The spatial distribution of different household groups, as determined via the census, was aligned with the spatial distribution of road pricing impacts, which were estimated by the transport model.

6 Household Travel Survey data and data on the number of households in each group were used to proportionally allocate impacts from the transport model between household groups.

7 Results were aggregated to investigate patterns in road pricing impacts. They were aggregated according to household type, income band and location within the city.

These steps are discussed in more detail below.

6.3.1 Evaluation of road pricing impacts via the transport model

The four key measures of transport impacts discussed previously were calculated through use of the transport model. A rule of half was applied to changes in average travel time and generalised cost to account for new and existing users. No rule of half was applied to financial costs, as we were interested in the total change in financial cost.

Changes in generalised cost, travel time and financial cost were calculated for each MSM origin zone, trip type (EB, HBW or Other), time period and income level (low, medium, high) as follows. In all cases, a negative number indicates that time, generalised cost, or financial cost decreases as a result of road pricing, while a positive number indicates an increase.

Equation 6.4 Calculation of travel time, generalised cost and financial cost impacts

$$\Delta T_i = \sum_j \frac{1}{2}\left(D_{i,j}^{Pricing} + D_{i,j}^{Base}\right) \times \left(T_{i,j}^{Pricing} - T_{i,j}^{Base}\right)$$
$$\Delta GC_i = \sum_j \frac{1}{2}\left(D_{i,j}^{Pricing} + D_{i,j}^{Base}\right) \times \left(GC_{i,j}^{Pricing} - GC_{i,j}^{Base}\right)$$
$$\Delta F_i = \sum_j \left(D_{i,j}^{Pricing} \times F_{i,j}^{Pricing}\right) - \left(D_{i,j}^{Base} \times F_{i,j}^{Base}\right)$$

(Equation 6.4)

Where:

- ΔT_i is the (rule of half adjusted) change in travel time from origin zone i (subscripts for mode, time period, trip purpose and income level are omitted)
- ΔGC_i is the (rule of half adjusted) change in generalised cost
- ΔF_i is the total change in financial cost
- $D_{i,j}$ is the modelled number of journeys between origin zone i and destination zone j in either the 'Base' and 'Pricing' scenarios (which are referred to in superscripts)
- $T_{i,j}$ is the modelled travel time for this journey
- $GC_{i,j}$ is the modelled generalised cost for this journey
- $F_{i,j}$ is the modelled financial cost, including vehicle operating costs, tolls, parking costs and public transport fares.

Results for each time period (AM, IP, OP, PM, SP) were aggregated to give a daily change in travel time for each MSM origin zone, trip type (EB, HBW or Other) and income level (low, medium, high). Additionally, as EB trips occur between businesses, these trips and their resulting changes in travel time, financial cost and generalised cost have been excluded from analysis of impacts on households.

Changes in transport accessibility were given for each MSM zone and mode type (public transport or car), based on the number of jobs able to be accessed within a:

- 30-minute car journey during the AM peak period
- 45-minute public transport journey during the AM period, including time spent walking to stops, waiting for services, and transferring between services as well as in-vehicle time.

This is a relatively coarse method of assessing accessibility impacts that does not account for differences in the quality or attractiveness of jobs in different locations, eg due to differences in occupations, industries or incomes. In principle, it would be possible to disaggregate accessibility measures to account for quality differences. This would require more detailed analysis of the characteristics of jobs in different locations than we have used in this analysis.

A further point, which we noted in section 4.1.3, is that accessibility to jobs may be too narrow a measure of impacts. In future work, accessibility measures could in principle be supplemented by analysing accessibility to a broader range of destinations.

Equation 6.5 Calculation of change in accessibility

$$A_i = \sum_j E_j \ if \ T_{i,j} < K$$ (Equation 6.5)

$$\Delta A_i = A_i^{Pricing} - A_i^{Base}$$

Where:

- ΔA_i is the change in accessibility due to road pricing
- A_i is the number of jobs accessible from zone i within a travel time of K in either the 'Base' and 'Pricing' scenarios (which are referred to in superscripts)
- E_j is the number of jobs in destination zone j
- $T_{i,j}$ is the modelled travel time between those zones.

Note that accessible jobs are non-exclusive. That is, accessible jobs within a particular zone with and without road pricing are accessible to all households within that zone, regardless of income level, household type, number of persons employed, etc.

Only changes in AM peak accessibility were evaluated and reported, as congestion pricing is expected to have the largest impact on peak travel.

6.3.2 Conversion of generalised costs from minutes to 2016 New Zealand dollars

Generalised costs were then converted from minutes to dollars based on the following assumed value of travel time, based on transport model assumptions. Note that employer-based trips are excluded from the analysis of impacts on households. These trips are generally assumed to place a higher value on travel time savings due to the fact that they occur 'on the clock'.

Table 6.6 Value of travel time savings parameters (2016 NZ$/hr)

		Willingness to pay band		
		Low	**Medium**	**High**
Trip type	**HBW**	$8.91	$12.19	$18.35
	Other	$7.46	$10.20	$15.36
	EB	$28.38	$38.81	$58.42

6.3.3 Spatially aligning the transport model with census data

Census data gives us information on the spatial distribution of households by income band, household type and number of people employed at the 2013 Census area unit level. As the geographic boundaries of area units and MSM zones differ slightly, it was assumed that households are evenly distributed within AU2013 area units. Households were then allocated to MSM zones based on the overlap of land area between MSM zones and Census area units. Median household incomes for MSM zones were calculated based on the average income of overlapping area units weighted by the number of households in that category.

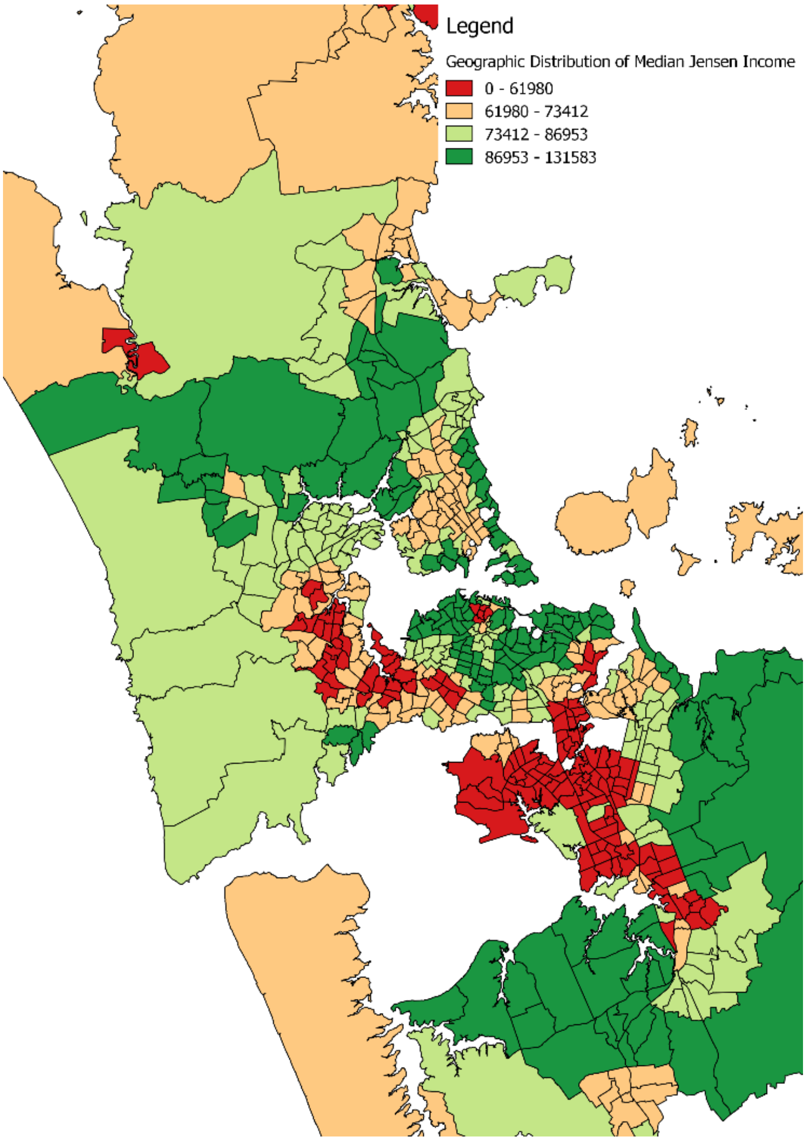
As both census data and the MSM differentiate based on income level, the following concordance between the two data sets was assumed. In effect, we assumed that people in higher income-households were more likely to have a higher willingness to pay for travel time savings, and vice versa. A similar assumption informed the establishment of different bands for willingness to pay for travel time savings in the MSM update, taking into account the fact that willingness to pay for travel time savings tends to rise more slowly than income.

Table 6.7 Concordance between census and transport model classifications

Census Jensen equivalised income bands	Willingness to pay for travel time savings band
Tertile 1	Low
Tertile 2	Medium
Tertile 3	High

Figure 6.1 shows median household incomes for transport model zones. This indicates the spatial distribution of households with different income levels, which can be aligned with spatial differences in road pricing impacts to explain overall results by income band. Higher-income households are clustered in inner suburbs on the Auckland isthmus, along the Waitemata Harbour on the North Shore, and in rural areas in the south and north. Areas in south and west Auckland tend to have lower incomes.

Figure 6.1 Median household income



6.3.4 Allocating impacts from the transport model to household groups

Different household types have different trip generation rates. As such, it is necessary to proportionally allocate the impacts of road pricing from the transport model to different household groups accordingly, based on the number of households within each category and the household types' trip generation characteristics.

Household Travel Survey data for Auckland over the 2003–2014 period gives daily trip generation rates for several different trip types (EB, HBE, HBO, HBSH, HBW, Home and Other) by household type and employment status. We used data for multiple survey waves to increase the sample size and reduce noise in our estimates of trip generation rates. Household Travel Survey trips were aligned with the transport model trip types based on the following assumptions:

1 HBW trip generation rates were calculated by multiplying the HBW trip generation rate by two, to account for the return leg of commuting journeys.

2 Other trip generation rates were calculated by adding HBE, HBO, HBSH, Home and Other trip generation rates together, and subtracting a return leg of commuting journeys (HBW).

As with the transport model, EB trips were not incorporated into this process, as they are between businesses only. Resulting trip generation rates are shown in table 6.8. In addition, we do not vary household trip generation rates by income band, as more in-depth analysis of Household Travel Survey data shows there is little significant variation in trip generation rates between households with different incomes.

Table 6.8 Average daily trip generation rates for different household types, Auckland 2003–2014

Household type	Daily person trip generation rate by trip purpose	
	HBW	Other
Family with children < 18	2.4	10.6
Family with adult children	2.9	5.4
Family with children < 18 and flatmates/ boarders	1.7	11.4
Married/de facto couple only	2.0	4.3
Other	3.1	5.9
Other adults only	2.8	4.6
Person living alone	0.9	2.5
Single adult living with children < 18	1.2	7.9
Single adult with other adult	0.7	2.7

Source: Analysis of Household Travel Survey data for Auckland, 2003–2014

The above household trip generation rates by household type are applied to estimate the total amount of travel that each household category makes from each MSM zone. This is then used to calculate the share of total impacts experienced in each zone (ie changes in generalised cost, financial cost or travel time), by trip purpose, that accrues to household category.

Equation 6.6 Calculating the share of impacts experienced by each household type, in each model zone

$$S_{i,j} = \frac{HH_{i,j} * TR_{i,k}}{\sum_i HH_{i,j} * TR_{i,k}} \qquad \text{(Equation 6.6)}$$

Where:

- $S_{i,j,k}$ is the share of impacts related to trip type k that are experienced by household type i in zone j
- $HH_{i,j}$ is the number of households of type i in model zone j
- $TR_{i,k}$ is the average trips per day taken by a household of type i for trip purpose k.

This equation gives a percentage out of 100% for each specific household group within a transport model zone. Transport model impacts were then multiplied by this number to distribute the impacts between household types. We adopt this approach to ensure the total impacts we estimate and allocate to households sum to the total modelled transport impacts.

An important caveat with this approach is that cell suppression results in higher average impacts per household for each transport measure, as the number of households for which impacts are divided by is reduced. This impact is discussed in detail in appendix D.

As the census and Household Travel Survey differ in their classification of household types, the concordance between these classifications is shown in table 6.9.

Table 6.9 Concordance between census and Household Travel Survey household classifications

Census HH type	Household Travel Survey HH type
Couple only	Married/de facto couple only
Couple with dependent child(ren) only	Family with children < 18
All other couples with non-dependent child(ren) or other people	Family with adult children
One parent with dependent child(ren) only	Single adult living with children < 18
All other one parent households (including children aged 18+ or other people)	Family with adult children
Multi-family household	Other adults only
Household of unrelated people	Other adults only
One person household	Person living alone
Other household composition	Other

It should be noted that the Household Travel Survey classifications of ‘Family with child(ren) plus flatmates /boarders’ and ‘Single adult with other adult only’ did not have an equivalent in the census classification.

6.4 Summary of results

As cell suppression results in higher average impacts per household for each transport measure, employment status was excluded as a disaggregating feature, to reduce the number of cells suppressed. This may be an area for further work, as trip generation rates and incomes vary systematically according to the number of employed people.

To illustrate the impact of changes in financial cost on households, the relative change in financial cost per household as a proportion of annual income was calculated, based on the following equation.

Equation 6.7 Calculating financial costs as a proportion of income

$$RFC_{i,j} = \frac{\Delta F_{i,j} * 250}{I_{i,j}} \qquad \text{(Equation 6.7)}$$

Where:

- $RFC_{i,j}$ is the relative financial cost for household type i in location j
- $\Delta F_{i,j,k}$ is the estimated change in average daily financial cost for household type i in location j (multiplied by 250 to annualise impacts from weekdays to annual impacts)
- $I_{i,j}$ is the average income for household type i in location j.

Broadly speaking, all income bands, household types, and geographic locations experience increases in overall generalised costs of travel. This indicates the modelled travel time savings from this specific road pricing scheme road pricing do not outweigh the additional costs associated with the scheme. This may reflect the fact that modelled tolls are set at a high level relative to people's willingness to pay to avoid delays, or it may reflect the fact that benefits principally accrue to business travellers and freight users.

It should be noted that multiple 'slices' of the data are needed in order to interpret results. For instance, low-income households may experience a relatively greater impact due to their location preferences, which may not be captured through an examination of results by income band only. Analysis of spatial impacts may also highlight opportunities for mitigation through scheme design.

6.5 The spatial impacts of road pricing

Figures 6.2, 6.3 and 6.4 show the average change in transport outcomes per household, ie the total impact per zone divided by number of households in each zone. Impact measures are broken down into quantiles. These figures highlight some important differences from the total transport impacts. Many of the largest positive and negative impacts on households are concentrated around the city centre and along the SH16 and SH1 corridors. There are some important differences on the North Shore, a relatively high-income area where average financial impacts per household are often lower, and in Manukau, where average financial impacts per household appear to be larger.

In effect, these maps indicate that this road pricing scheme will deliver benefits (in terms of reduced travel times) to trips originating from locations that also bear higher costs (in terms of higher financial costs).

Figures 6.5 and 6.6 show the spatial impacts of road pricing in changes in accessibility to jobs by car and public transport. These figures show that car accessibility is expected to increase in the North Shore, the outer areas of West Auckland and the outer areas of South Auckland. Improvements in public transport accessibility, by contrast, tend to be more concentrated in the outer Auckland isthmus and on the North Shore.

These maps display changes in accessibility in percentage terms rather than in absolute numbers of jobs. In doing so, we note that the baseline number of jobs accessible by car is larger than the baseline number of jobs accessible by public transport. As a result, a similar *percentage* change in accessibility for each mode will result in a larger change in the total *number* of jobs accessible by car. This exacerbates the difference between accessibility impacts for each mode; cars experience a larger percentage increase from a larger base in most locations.

Figure 6.2 Average daily change in generalised cost per household ($NZ 2016)

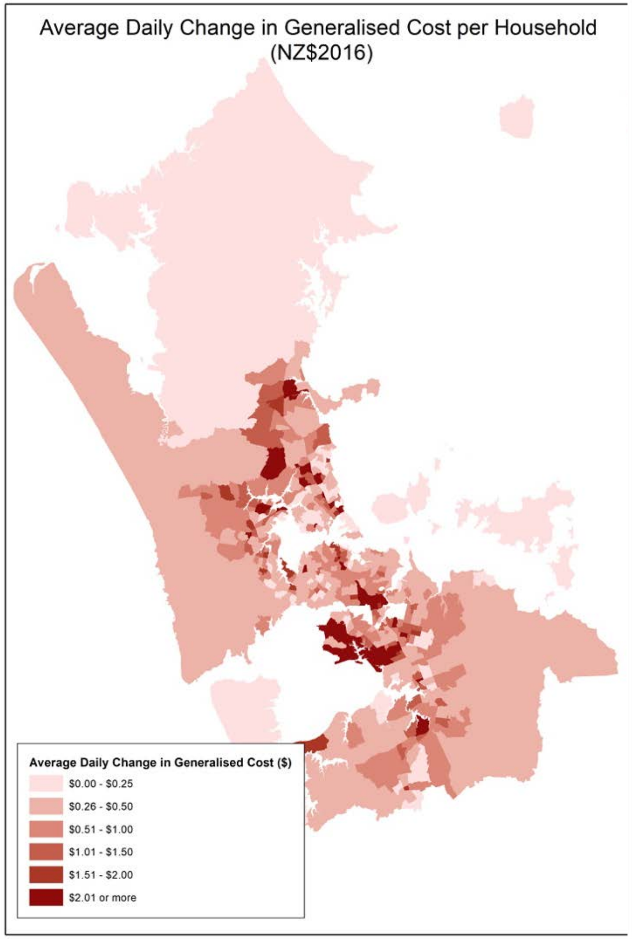


Figure 6.3 Average daily change in financial cost per household ($NZ 2016)

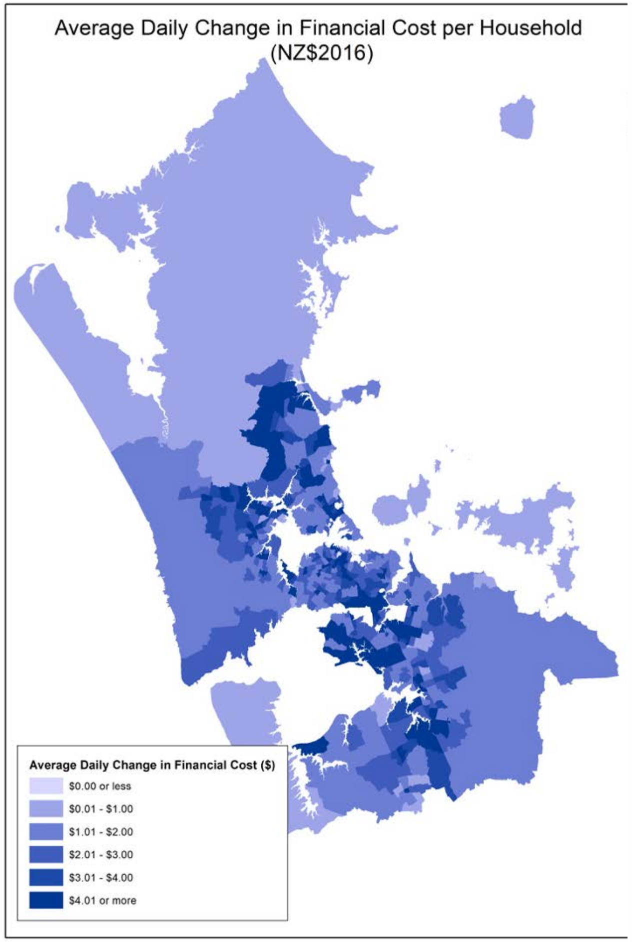


Figure 6.4 Average daily change in travel time per household (min)

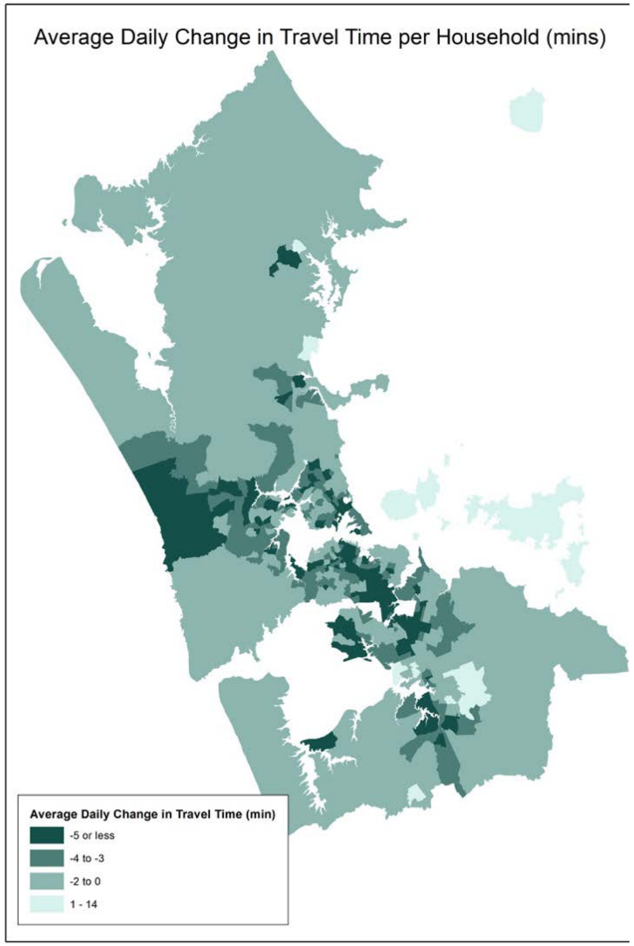


Figure 6.5 Change in accessibility to jobs by car (%)

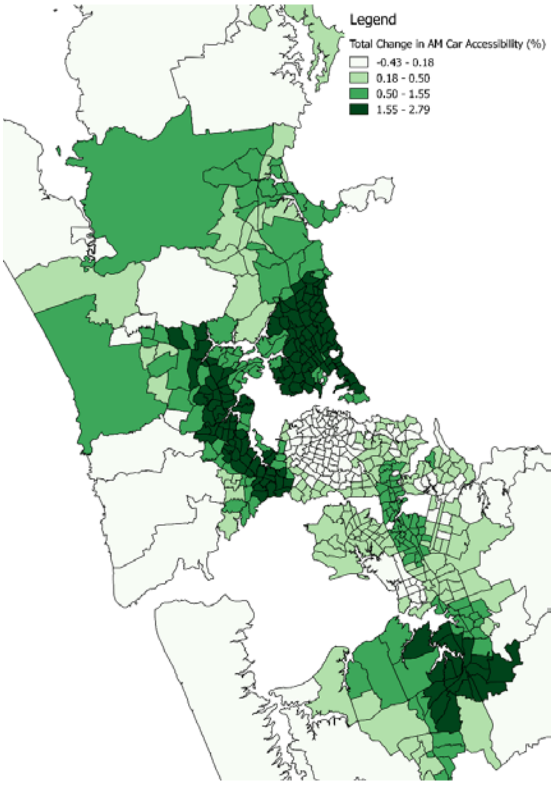
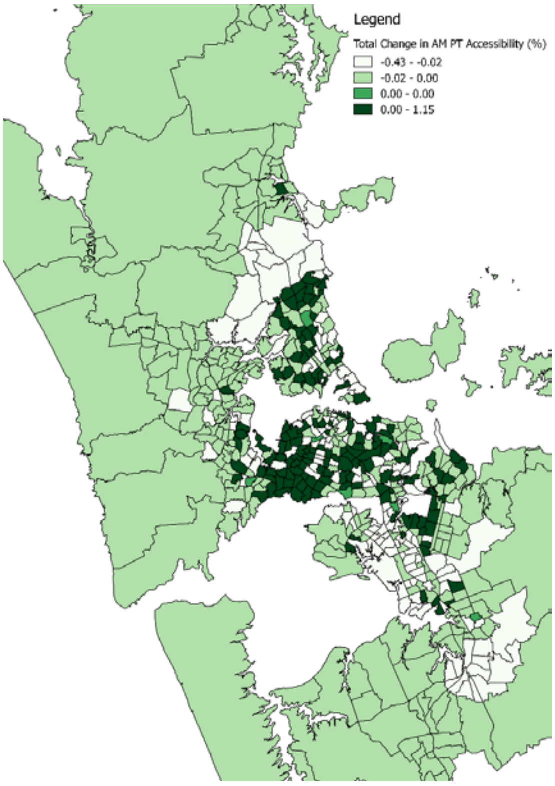


Figure 6.6 Change in accessibility to jobs by PT (%)



6.6 Impacts of road pricing on different household types

The impacts of this road pricing scheme on households are ‘sliced’ in several different ways to enable an analysis of impacts for different types of households. The data allows the results to be shown by income, household composition and location in the region. Detailed impacts of road pricing by income band and household composition are shown in appendix E.

First, table 6.10 shows the impacts of this road pricing scheme by income band alone. Households in Auckland were split into three equal-sized bands – low, medium and high income – based on Jensen equivalised household income.

This analysis shows that:

- Households in the high-income band are expected to experience the largest average daily reduction in travel time. They experience, on average, a larger average daily financial cost than low-income households and a slightly smaller financial impact than middle-income households. Due to the fact that their incomes are higher, these households are expected to experience the smallest increase in financial cost as a share of income.
- Households in the low-income band are expected to experience the smallest absolute change in daily financial and generalised cost per household. They are also expected to experience slightly larger reductions in travel time than middle-income households. However, because these households’ incomes are considerably lower, they are expected to experience the largest increase in financial cost as a share of income.

- Lastly, low- and middle-income households are expected to experience proportionately larger improvements in accessibility to jobs by car than high-income households, reflecting the fact they are more likely to live in areas that experience larger improvements in accessibility.

Overall, this suggests road pricing is likely to lead to different levels of financial and travel time impacts on households with different levels of income. However, financial impacts will be *proportionately* larger for low-income households, as they have lower incomes. As shown in appendix E, this finding is also true for households with similar composition but different income levels: Lower-income households within any category tend to bear proportionately larger financial impacts, even though they pay less in dollar terms.

Second, table 6.11 shows the impacts of this road pricing scheme for eight household types, regardless of incomes. Broadly speaking, the financial and non-financial impacts of road pricing are expected to be higher for larger households, as they tend to travel more.

A key finding from this analysis is that the financial impacts of road pricing are expected to be largest, as a share of household income, for one-parent households with dependent children, followed by other one-parent households (eg people living with adult children or with boarders), and then by couples with dependent children. This reflects the fact that children tend to add to household travel at a similar rate as adults – as shown in the analysis of Household Travel Survey data in appendix B – without contributing to household incomes at a similar rate.

By contrast, couples without children and single people living alone experience smaller financial impacts relative to their income.

This analysis has some potentially important implications for understanding the social and distributional impacts of road pricing and designing mitigation options for undesirable impacts on specific groups. For instance, the finding that single parent families tend to experience larger financial impacts relative to their income may indicate that there is scope to target benefit or tax policies, such as Working for Families, to address some of these impacts.

Third, table 6.12 presents results for aggregated geographic areas. We have opted to aggregate by local board. Appendix C includes a map showing the extent of these areas. The data shows:

- On average, households in Mangere and Manukau/South Auckland, households in the city centre and city fringe, and households in the central isthmus area experience the largest financial impacts relative to their incomes. This reflects a combination of lower incomes (in Mangere and South Auckland) and high exposure to tolls in the most congested parts of the networks in central Auckland and the isthmus).
- On average, households in rural parts of Auckland, particularly in rural north/Warkworth, rural west, rural east and rural south, experience the smallest financial impacts relative to their incomes. This reflects the fact that tolls on rural roads will be low under this hypothetical scheme.

Interestingly, higher-income *areas*, principally on the North Shore are estimated to experience larger percentage changes in accessibility to jobs by car, while lower-income *households* are estimated to experience larger average percentage changes in accessibility. This reflects the fact that people with lower incomes are distributed throughout the city, in different proportions, resulting in some seemingly paradoxical results when aggregating data.

Table 6.10 Impacts of road pricing by income band

Income band	Number of households	Median household income	Average daily change per household			Average annual change in financial cost per household as a proportion of income	Percentage change in jobs accessible	
			Travel time (min)	Financial cost ($NZ 2016)	Generalised cost ($NZ 2016)		By car	By PT
Low	129,246	$31,058	-3.26	$1.92	$2.08	1.54%	52.4%	-0.1%
Medium	129,149	$79,084	-3.40	$2.29	$2.75	0.72%	53.9%	0.0%
High	128,429	$161,392	-3.80	$3.62	$4.06	0.56%	43.1%	0.1%
TOTAL	386,824	$90,365	-3.48	$2.61	$2.96	0.72%	49.5%	0.0%

Note: Positive numbers indicate increases and negative numbers indicate decreases.

Table 6.11 Impacts of road pricing by household composition

Household composition	Number of households	Median household income	Average daily change per household			Average annual change in financial cost per household as a proportion of income	Percentage change in jobs accessible	
			Travel time (min)	Financial cost ($NZ 2016)	Generalised cost ($NZ 2016)		By car	By PT
One person household	76,756	$41,999	-1.72	$1.21	$1.37	0.72%	44.3%	-0.1%
One parent with dependent child(ren) only	17,975	$37,711	-3.13	$2.03	$2.29	1.35%	55.6%	0.0%
Multi-family household	22,698	$125,634	-4.12	$3.03	$3.40	0.60%	52.7%	-0.4%
Household of unrelated people	13,047	$89,953	-5.29	$3.45	$3.86	0.96%	29.1%	-0.4%
Couple with dependent child(ren) only	82,837	$112,108	-4.82	$3.75	$4.35	0.84%	53.3%	0.2%
Couple only	89,862	$93,116	-2.92	$2.24	$2.56	0.60%	49.5%	0.0%
All other one parent households (including children aged 18+ or other people)	23,380	$66,537	-3.89	$2.67	$2.95	1.00%	54.2%	0.0%
All other couples with non-dependent child(ren) or other people	60,269	$129,728	-4.04	$3.16	$3.52	0.61%	53.7%	0.2%
TOTAL	**386,824**	**$90,365**	**-3.48**	**$2.61**	**$2.96**	**0.72%**	**49.5%**	**0.0%**

Note: Positive numbers indicate increases and negative numbers indicate decreases.

Table 6.12 Impacts of road pricing by geographic location (local board)

Geographic location (local board)	Number of households	Median household income	Average daily change per household			Average annual change in financial cost per household as a proportion of income	Percentage change in jobs accessible	
			Travel time (min)	Financial cost ($NZ 2016)	Generalised cost ($NZ 2016)		By car	By PT
Rodney	16,886	$85,455	-2.08	$1.43	$2.19	0.42%	75.3%	-0.1%
Hibiscus and Bays	28,450	$91,563	-1.31	$1.59	$2.34	0.43%	147.5%	4.7%
Devonport - Takapuna	16,717	$102,011	-4.37	$2.62	$2.56	0.64%	207.4%	-4.2%
Kaipatiki	24,986	$89,162	-3.66	$2.18	$2.42	0.61%	181.1%	5.9%
Upper Harbour	14,171	$102,174	-3.65	$4.01	$4.75	0.98%	165.2%	6.5%
Henderson - Massey	27,192	$76,627	-3.02	$2.16	$2.64	0.70%	180.3%	0.2%
Waitakere Ranges	13,720	$89,610	-1.81	$1.97	$2.30	0.55%	58.1%	0.0%
Whau	19,767	$74,351	-3.34	$2.34	$2.52	0.79%	149.3%	1.6%
Waitemata	25,339	$95,720	-6.98	$4.73	$5.40	1.24%	3.8%	-1.8%
Albert - Eden	27,638	$104,641	-4.27	$2.80	$2.88	0.67%	11.5%	2.1%
Puketapapa	13,828	$85,837	-2.45	$2.34	$2.46	0.68%	19.3%	5.2%
Orakei	24,993	$121,803	-2.92	$2.40	$2.54	0.49%	18.3%	1.1%
Maungakiekie - Tamaki	20,491	$83,354	-9.45	$4.82	$4.81	1.44%	31.9%	-1.5%
Great Barrier	3,369	$67,403	-0.01	$0.02	$0.00	0.01%	N/A	N/A
Franklin	19,457	$92,435	-1.20	$1.60	$2.20	0.43%	39.1%	-0.1%
Papakura	11,501	$75,810	-1.67	$2.42	$2.77	0.80%	79.6%	-0.9%
Howick	35,799	$96,313	-3.12	$2.19	$2.37	0.57%	22.9%	-2.5%
Mangere - Otahuhu	11,846	$71,322	-3.35	$3.28	$3.82	1.15%	36.5%	-6.4%
Otara - Papatoetoe	13,831	$70,256	-5.96	$3.67	$4.25	1.30%	51.3%	-4.4%
Manurewa	16,842	$78,655	-0.86	$2.16	$2.48	0.69%	24.2%	-8.7%

Note: Positive numbers indicate increases and negative numbers indicate decreases.

6.7 Impacts of road pricing on businesses

To understand potential impacts on businesses, we also calculated changes in financial cost, travel time, and generalised cost of travel for employment-based (EB) trips, which occur 'on the clock'. We were not able to estimate impacts on freight trips as these are not provided as base outputs from the MSM. However, we would expect the positive impacts of road pricing on travel time to be larger for freight trips, especially time-sensitive freight. There may also be additional non-modelled benefits such as reduced variability of travel time leading and optimised departure times.

Road pricing is expected to lead to reductions in journey times for business trips. Average peak journey times are expected to fall from 17.9 minutes to 15.6 minutes, a 13% reduction. The following table summarises the aggregate modelled impacts on all EB trips, regardless of location, time period, or mode but broken down by their assumed willingness to pay for travel time savings (broken into three bands).

Contrary to expectations, this analysis suggests business trips will also experience overall increases in the generalised cost of travel. In effect, the modelled journey time savings are not 'worth' more than the changes in the financial cost of travel, even at the relatively high value of travel time savings parameters used for business travel. This scenario suggests prices may be set at a level that is too high to provide net benefits for most users.

Table 6.13 Impacts of road pricing on employer-based journeys

Value of travel time savings band	Number of daily trips (Base)	Total change in journey time (minutes)	Total change in generalised cost (2016 NZ$)	Total change in financial cost (2016 NZ$)
Low	117,634	-150,987	$50,884	$109,096
Med	118,455	-156,928	$69,527	$152,616
High	120,167	-159,888	$103,702	$229,577
Total	**356,256**	**-467,803**	**$224,113**	**$491,289**

Note: Positive numbers indicate increases and negative numbers indicate decreases.

6.8 Impacts on representative households

This analysis allows disaggregation of impacts for households by income, composition and location. To illustrate what level of analysis would be feasible we consider the impacts on a hypothetical but representative pair of households in two specific locations: Manurewa and Mt. Roskill. The aim of this analysis is to show how it could be used to explain the potential impacts of road pricing on people in different locations and with different family circumstances.

The following table summarises results for a pair of representative households. This suggests:

- A medium-income couple with dependent children in Manurewa will experience a small (less than one minute) decrease in their daily travel time, while incurring an additional $1.80 in financial cost per day. This will be equal to roughly 0.54% of their annual income. However, road pricing would improve this household's access to jobs via car by 82%.
- A low-income one parent household in Mt. Roskill would experience a 3.65-minute reduction in their daily travel time under the proposed scheme, while incurring additional financial costs of around $1.16 per day. This will be equal to roughly 1.53% of their annual income. This household would

experience improved accessibility to jobs by both car (42% increase) and public transport (27% increase).

A useful supplement, in future work, would be to report summary statistics for the estimated variability in impacts within groups, as well as the average impacts. Appropriate standard deviations may be difficult to calculate given the semi-aggregated nature of these estimates.

Table 6.14 Impacts on representative households

Location	Manurewa (MSM zone 540)	Mt. Roskill (MSM zone 311)
Household composition	Couple with dependent child(ren)	One parent with dependent child(ren)
Income band	Medium	Low
Number of households	108	35
Median income	$83,653	$18,927
Avg. daily change in travel time (mins)	-0.57	-3.65
Avg. daily change in financial costs (NZ$ 2016)	$1.80	$1.16
Avg. daily change in generalised costs (NZ$ 2016)	$2.25	$0.98
Change in financial costs as portion of income	0.54%	1.53%
Percent change in jobs accessible by car	82%	42%
Percent change in jobs accessible by PT	-2%	27%

Note: Positive numbers indicate increases and negative numbers indicate decreases.

6.9 Lessons from this case study

This case study demonstrates it is possible to analyse the social and distributional impacts of a hypothetical road pricing scheme in quantitative terms by analysing transport model outputs and relating them to demographic data on households in different locations. However, this analysis does require custom data from Statistics New Zealand and from the Household Travel Survey, and the creation of algorithms for analysing transport model outputs and linking them to demographic data.

While we only report one case study using this method, we note that this approach, once implemented, is scalable to additional case studies provided that additional transport model outputs are available. Hence we suggest that this approach could be implemented routinely for evaluation of road pricing initiatives (or other major transport projects) in the Auckland region. In principle, it would also be possible to apply this method in other regions, although this would depend to a degree on the availability of appropriate data from strategic transport models.

While this approach is more data intensive than the qualitative method used for the Wellington case study, it offers several important advantages. First, because it uses strategic transport model outputs, it provides a more detailed picture of the transport impacts of road pricing and relates them to household groups. Second, it provides additional insights into how the impacts of road pricing are distributed among different groups of households and between similar households in different locations. The ability to 'cross tabulate' impacts by household location, income and composition enhances our ability to identify specific areas where there may be a need to mitigate perceived adverse impacts. As demonstrated above, it also allows us to identify impacts for 'representative' households in different places.

A final lesson relates to our findings about the social and distributional impacts of this particular scheme and how any perceived adverse effects may be mitigated.

The impacts of this hypothetical road pricing scheme are widely distributed throughout Auckland. Most household types experience increases in the financial costs of travel, which are offset by benefits related to faster or more reliable travel, or improved accessibility, to varying degrees. The estimated scale of these financial impacts is in line with previous research, including previous studies of road pricing in Auckland, ie on the order of 1% of household income, which is in turn roughly comparable to the estimated social cost of traffic congestion in Auckland (Wallis and Lupton 2013; NZIER 2017).

Under this particular set of prices, the generalised cost of travel is expected to rise for all household groups and income groups. This indicates that, in this hypothetical example, toll prices may be set at too high a level to provide net benefits for household travel. Alternatively, it may reflect the fact that some sources of efficiency, such as improvements in travel time reliability and monetisation of bottleneck delays, are not captured by the strategic transport model.

Interestingly, there was no obvious pattern of differing impacts depending upon the level of access to public transport routes. This bears further investigation, as it indicates access to public transport may not allow households to mitigate impacts in the current Auckland context. One potential reason for this is that public transport fares may be high relative to the financial cost of the toll. In addition, we note that the modelled impacts on access to jobs by public transport were small, indicating road pricing alone may not succeed in improving public transport performance to the point where it is competitive with car travel for journeys. This suggests that additional complementary measures, such as improvements to public transport services or reductions in fares, may be required to allow people to mitigate costs via shifting mode.

Lower-income households are likely to experience the largest financial impacts relative to their incomes. This finding holds true for households with varying incomes within each individual household composition category. It principally reflects variations in household incomes, rather than variations in the financial costs of the scheme.

On average, households with children experience larger financial impacts relative to their incomes than other household types. This is particularly acute for single-parent families. This reflects the fact that children contribute to household travel – they need to be transported to school and activities, and they induce retail trips – without contributing to household incomes.

Similarly, the magnitude of impacts on households vary significantly by location.

A key implication of this analysis is that multiple policy responses should be considered to mitigate the perceived negative social and distributional impacts of this road pricing scheme. These policy responses should not be limited to transport investment and transport pricing options but should also consider broader options around tax and benefit policy or even education and labour market policy.

For example, it may be possible to address perceived horizontal equity issues by using road pricing revenue to invest in new transport infrastructure or services. This may consist of providing better transport choices to people in locations where the toll has a relatively high impact.

However, this would not necessarily address the impacts experienced by one-parent households and two-parent households with children, as these households are distributed throughout the city and face relatively large financial impacts due to their household structure and trip-making pattern rather than their location. An alternative approach, such as targeted changes to tax and transfer policies for families with children, may be more successful in mitigating these impacts.

7 Conclusions and recommendations

To conclude, we highlight lessons from this research and identify some recommendations and/or implications for policy development, which address how:

- policymakers should think about the social and distributional impacts of road pricing and identify options to mitigate or respond to them, if they choose to advance a road pricing scheme
- this framework can be incorporated into transport appraisal and policy frameworks to help guide evaluators and decision-makers
- improvements to transport modelling capabilities may assist in improving inputs to this analysis.

7.1 Conclusions

The aim of this research was to outline a general framework that can be used to analyse the social and distributional impacts of road pricing in the New Zealand context and trial it on two hypothetical case studies of road pricing schemes in New Zealand cities. To do so, we reviewed the international literature and interviewed practitioners to understand the likely social and distributional impacts of time and space-based road pricing, developed an assessment framework to identify populations that might be affected by road pricing and to analyse the degree by which they would be affected, and applied this framework to two hypothetical road pricing schemes in Wellington and Auckland.

This research has highlighted several key lessons on how to think about the social and distributional impacts of road pricing in the context of public policy.

First, the social and distributional impacts of road pricing are *multi-dimensional*. No single measure of impacts will tell the whole story. As a result, it is essential to consider:

- How different people or households may be affected, depending upon their location and their personal circumstances, including (but not necessarily limited to) their income and household composition
- What different types of financial and non-financial impacts they will incur. Some of these impacts will be negative, for some households, but others will be positive, and it is important to highlight both to provide a comprehensive picture of the change.

The general framework outlined in this report attempts to bring together multiple dimensions of social and distributional impacts in a relatively accessible way. In doing so, we kept in mind a second key consideration, which is that this information may be used for three somewhat distinct purposes:

- *Design* – the proposed framework may be used by transport planners to inform the iterative development of road pricing schemes 'in the lab'. In such applications, we expect users will want considerable detail on the distributional effects, so they can hone the design of the scheme itself.
- *Mitigation* – the proposed framework may be used to identify how to mitigate the effects of road pricing schemes, whether indirectly (transport investment) or directly (transfers). In such applications, we expect users will want considerable geographic and financial detail, so they can target potential mitigation measures. They may also be interested in using this information to identify how pricing may shape the urban fabric.

- *Communication* – the framework may be used to communicate with non-technical stakeholders, such as elected representatives, about the potential impacts of road pricing schemes. In such applications, we expect users will want to generate charts and maps that are information rich, yet intuitive.

If policymakers are seeking to analyse the social and distributional impacts of road pricing (or other transport interventions) our recommendation would therefore be to provide evaluators with a clear brief that outlines the purpose for which the data will be used in order to ensure they are able to publish information in a relevant form.

Third, we note the social and distributional impacts of road pricing do not arise in a vacuum. They are shaped by the history of political, institutional and individual choices across a range of areas of society, including not just transport but urban planning policy, housing development, labour markets, social welfare and tax policies, education and health.

When evaluating the social and distributional impacts of a road pricing scheme, it is important to be aware of this broader context and ensure it is taken into account in analysis. In the two case studies in this report, we have attempted to do this by incorporating demographic and income data on the characteristics of households that live in different locations, and the transport options facing those households due to existing transport networks. This allows us to describe the impact of road pricing in light of the patterns set by history.

Policymakers must also be aware of this broader context and consider the full range of options for mitigating any perceived adverse social and distributional impacts of road pricing. While it is natural to expect to mitigate adverse impacts of road pricing via other transport policies, such as investment in new infrastructure or services or provision of targeted transport subsidies, these may not be the best way to respond to some impacts.

For instance, in the Auckland case study, we noted that households with children, and especially single-parent families, faced some of the largest financial costs relative to incomes. These households are distributed throughout the Auckland region and may be difficult to reach with location-specific transport investment, but could easily be 'compensated' for any disproportionate costs they incur via targeted tax or transfer policies. However, in saying this, we note this approach may confuse the perceived linkage between implementing road pricing and achieving specific transport improvements. Practitioner interviews highlighted this as an important feature for the success of road pricing schemes.

Fourth and finally, we note this analysis has focused on effects that arise in the transport market, ie financial impacts on travellers and non-financial impacts related to changes in the time and generalised cost of travel and changes in accessibility to jobs. There may also be other external impacts on social, economic and environmental outcomes that arise as a result of road pricing. These impacts may also be relevant to take into account, although modelling how they are likely to affect different households and individuals may be challenging.

7.2 Recommendations

The case studies in this report demonstrate that this framework can be applied in a scalable way to assess social and distributional impacts of projects or policies where different information is available. While these case studies focus on road pricing, the principles and methods we outline could also be applied to major transport projects that may have significant distributional impacts.

A key recommendation arising from this report is therefore to incorporate this framework into the NZ Transport Agency's (2018) *Economic evaluation manual*. At present, appendix A17 contains one page of brief guidance on evaluating the equity impacts of transport projects. The existing EEM guidance is conceptually consistent with the framework we have outlined. It also highlights the need to consider multiple definitions of equity, including egalitarianism (treating everybody the same, regardless of who they are), horizontal equity, vertical equity with respect to income, and vertical equity with regard to mobility needs and abilities, and it identifies (but does not flesh out) similar methods for evaluating impacts.

In our view, the existing EEM section on equity impacts could be replaced by chapter 4 of our report, with appropriate stylistic amendments. To assist practitioners in implementing this approach, some further discussion on how to find and analyse relevant data sources may also be useful. This discussion could draw upon the two case studies we present in this report.

A second recommendation is that additional work is needed to develop models that can better capture the full range of behavioural responses to road pricing. The second case study in this report is based upon outputs from Auckland's MSM, a strategic transport model of the entire Auckland region, combined with additional demographic information from the census. This modelling approach has a number of advantages, including avoiding the need to undertake costly model development processes and ensuring consistency with model-based evaluations of road pricing and other transport policies.

However, the international literature review and our brief review of the characteristics of the MSM suggests that strategic transport models have several important limitations for modelling some aspects of the behavioural response to road pricing, and identifying how specific at-risk individuals may be affected by road pricing. It may be useful to investigate alternative modelling approaches, which may include activity-based models, models that endogenise location choices, models of how people choose their departure time in bottleneck congestion models, models of travel time reliability, and/or targeted analysis to identify individual-level impacts, including impacts on specific at-risk individuals that may not be possible to accurately identify using census demographic data.

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Appendix A: Summary of literature

Appendix A1 - Literature on transport responses

Table A.1 Literature on transport behavioural responses

Study	Methodology	Behavioural responses assessed	Effects on transport behaviour
Arentze et al (2004)	Discrete choice modelling estimated on data from a stated preference survey carried out in the Netherlands. Separate models were estimated for commute trips and non-commute trips.	Options were: 1 No change 2 Eliminate trip by conducting activity at home 3 Eliminate trip by skipping activity 4 Reduce distance of trip by conducting activity closer to home 5 Change transport mode 6 Change departure time 7 Change route. Study focused on short-term responses.	For commute trips currently taken by car, most trips do not change. Route change is the most important adaptation, followed by departure time adjustment. Changing to public transport and working at home to reduce car trips both have a small probability. For non-work trips, the willingness to adapt is smaller probably because a larger share of current non- work trips takes place outside peak hours. Changing route and switching to bike are the main responses among people who do adapt. Socio-economic variables appear to have an impact on the willingness to adapt and choice of adaptation alternatives.
Brownstone et al (2003)	Analysis of revealed preference data from a motorway toll lane demonstration project in San Diego. The demonstration project involved opening up existing high occupancy vehicle lanes for toll users and as a result this study does not have an impact on adaptations.	Study focused on estimating willingness to pay to reduce travel time. It also investigated factors that are associated with a higher likelihood of using the toll lane.	Corridor users have a median willingness to pay of $30 to reduce travel time by one hour. People from households earning more than $100,000 are more likely to use the toll lane, as are women, individuals between 35 and 44 years old, individuals with education beyond a bachelor's degree and homeowners.
Burris and Pendyala (2002) Burris and Stockton (2004) Cain et al (2001) also looks at the same project.	Analysis of long-run responses to a variable pricing scheme on two bridges in Lee County, Florida. This scheme gives users discounted tolls during the shoulder peak periods to encourage switching from the peaks.	The first study examined user responses to the variable toll scheme. The second study focused on estimating the short-run and long-run price elasticity of demand	Toll discounts were not large enough to cause a significant change in the mode of travel, location of housing, or location of employment. User characteristics, such as the availability of flexible working arrangements and being retired, increased the likelihood of users altering their time of travel. Conversely, having a high household income or being on a commute trip decreased the likelihood of altering time of travel. When variable pricing was initially introduced in 1998, drivers responded by

Study	Methodology	Behavioural responses assessed	Effects on transport behaviour
			changing their time of travel to the discount periods. This change in time of travel was higher during the early morning discount period than in the evening discount period. User participation dropped considerably by 2002, suggesting that the share of drivers willing to shift time of travel fell in the long run.
Eliasson (2009)	Cost benefit analysis of the Stockholm congestion charging system based on data before and after the scheme was introduced (2005, 2006). This was a cordon around the city centre. Analysis focused on changes in travel times, travel costs, emissions, and safety.	Study focused on estimating the costs and benefits of congestion pricing, based on conventional transport appraisal methods. Costs for users who stopped travelling as a result of the charge were estimated based on a 'rule of half' adjustment. The details of behavioural responses were not discussed in detail.	The Stockholm scheme was assessed as having benefits that exceeded costs, reflecting the fact that it resulted in faster travel times throughout the city. Overall traffic volumes decreased on the majority of 189 measured road links throughout the city. Traffic crossing the cordon fell by 22%. Congestion pricing was estimated to increase public transport by around 4.5%.
Holguin-Veras et al (2006)	Empirical study of the impact of time-of-day tolling for six bridges and tunnels between New York City and New Jersey on commercial carriers. Study was based on a study of 200 carriers that were current or former users of the toll facilities.	Assessed three responses: Productivity increases (including uptake of transponders to speed up trips through toll booths), cost transfers to customers, and changes in facility usage	20% of the carriers changed behaviour due to time of day pricing. Of the trips that were affected, 43% responded with only productivity increases; 28% responded with changes in facility use and cost transfers; and 19% responded by implementing all three strategies. No firms responded only by changing facility usage. 68% of carriers that did not change their travel behaviour stated that they cannot change their schedule due to customer requirements.
Karlström and Franklin (2009)	Empirical analysis of the impact of the Stockholm congestion pricing scheme on travel behaviour. Also assesses the equity impacts of congestion pricing. Employs data on people who reported undertaking work trips in both of two travel surveys carried out in October 2004 and March 2006.	Study analyses changes in mode choice (car and public transport only) and departure time in response to the cordon charge, including who was more likely to switch and the impacts on travel time. Propensity score matching is used to estimate mode shift, while a multinomial logit model is used to estimate time shifting. Analyses the impacts on welfare on different individuals, setting aside how	Mode choice and departure time choice are highly persistent in this group. Car drivers who crossed the toll cordon in 2004 had a 15 percentage-points higher rate of switching to public transit as compared with those that did not cross the cordon. 65% of people change their departure time by 15 minutes or less. There is some evidence of limited peak spreading in response to the cordon scheme, especially to a later time. Working hour flexibility is positively correlated with household income and consumption level. This may mean that higher-income people have better ability to avoid tolls.

Study	Methodology	Behavioural responses assessed	Effects on transport behaviour
		toll revenues are spent or redistributed.	
Nielsen (2004)	Analysis of a road pricing experiment in Copenhagen that equipped 500 cars with a GPS-based device and tested two alternative zone-based pricing schemes (with per-km charges that varied between zones) and a cordon pricing scheme. Stated preference and revealed preference data was considered.	Study assessed impacts on the number of trips and the number of kilometres travelled per day for participants when they were subjected to different pricing schemes. Results were also used to investigate value of travel time savings for scheme participants.	All three tolling schemes resulted in a reduction in the amount of kilometres travelled, but only the high distance-based toll scheme resulted in a significant reduction in the all-day number of trips. The cordon-based pricing scheme resulted in reductions in morning peak and weekend trips, but only a small reduction across the all-day period. Distance-based tolls appear to have a higher impact on dissuading low-value trips.
Saleh & Farrell (2005)	A departure time choice model was calibrated using data from a stated choice survey of the impact of congestion pricing in Edinburgh, Scotland. The survey was administered to employees in the Edinburgh city centre who currently drive to work in the AM period.	This study estimates choices to travel at earlier or later times to avoid higher peak-period cordon tolls. The study assesses the impact of different off-peak discounts and individuals' characteristics on willingness to switch was analysed.	69% of respondents stated that they currently depart for work between 730am and 829am, indicating concentration of commuting in the peak hour. Almost 70% of respondents expressed a willingness to switch departure times in response to tolls. There is a lower preference for switching to a later departure time rather than an earlier time. Individuals' characteristics, such as income, access to flexible work arrangements, dependent children, and activities before work, influence their propensity to switch. An interesting fact is that 75% of respondents that had fixed working hours stated that they had the ability to start earlier or later than their usual departure time from work.
Santos and Bhakar (2006)	Assesses the impact of the London congestion charging scheme on the generalised cost of travel for car commuters between 2002 and 2003. Uses income and commuting mode data from the Labour Force Survey to assess impacts on Greater London residents who work in the City of London	This study focused on changes in travel times resulting from the cordon charge, and the resulting user benefits, taking into account observed changes in behaviour.	Car commuting to the cordon area fell by 11.6% between 2002 and 2003, which the authors attribute to the effect of the scheme. They estimate that the majority (84%) of mode shifters shift to bus. Increases in car commuting to the City of London are reported from some outer boroughs, which the authors interpret as evidence that some public transport users may be very responsive to reductions in congestion levels.

Study	Methodology	Behavioural responses assessed	Effects on transport behaviour
	.		
Transport for London (2008)	Monitors the impact of the London congestion charging scheme on a range of transport outcomes, including traffic patterns and speeds, public transport outcomes, transport mode, and other social and economic impacts. This monitoring report was written after the Western Extension to the cordon.	TfL reports on surveys on traveller responses to the Western Extension, as well as traffic count and public transport ridership data.	TfL estimates that around 30 percent of those previously driving a car in the western extension zone during charging hours prior to the introduction of charging do not do so any more. The majority of these are likely to have changed mode of transport. The remaining 70 percent continue to make their trip by car and pay the charge. There was evidence that those travelling in the western extension zone had reduced the frequency of trips made by car after the introduction of charging, but that this had not had a significant impact on the overall frequency of trips made by any mode, or on access to shops and services.
Washbrook et al. (2006)	Assesses the impact of road pricing and parking charges on transport mode choice using a stated choice survey of 548 car commuters in Vancouver, Canada.	The study focused on mode choice responses to different road prices and parking charges, looking at carpooling and express bus options. Choices estimated using conditional logit models. Travel time ranges for carpool and bus choices were set slightly lower than for driving alone to reflect priority measures for those modes (e.g. T3 lanes), but this is offset to a degree by time spent picking up carpoolers or waiting for the bus.	Parking and road tolls had the largest effect of the cost attributes on mode choice. Tolls had a nonlinear effect: at higher road charges, the negative impact of an increase in cost declines. The authors suggest that higher-income respondents associate higher road charges with less congested travel routes and are willing to pay for the associated reduction in travel time. A C$1.00 parking charge plus a C$1.00 return road charge are estimated reduce the probability of driving alone from 83 to 75%. A C$9.00 road charge plus a C$9.00 parking charge are estimated to reduce the drive alone market share to 17%. Most of the people switching are estimated to transfer to carpooling rather than bus.

Appendix A2 – Literature on location responses

Table A.2 Literature on land use behavioural responses

Study	Modelling approach	Welfare effects	Impacts on location behaviour
Anas and Xu (1999)	General equilibrium model of a dispersed city where both jobs and residents can be located in multiple places Agglomeration economies are not modelled	Overall long-run gains from congestion pricing are on the order of 3.0% of incomes; around 80% of these gains arise from more efficient road planning (optimising use of land for roads in response to price signals) The gains from congestion pricing in a monocentric city, without a land use response, are smaller – roughly 2/3 as large as gains with a land use response.	Congestion pricing has two effects: 1. Businesses disperse closer to workers and customers, paying lower rents 2. Residents concentrate to save on commuting and shopping travel Overall impact can be for the city to either concentrate or disperse; under Anas and Xu's parameter values the net effect is concentration.
Arnott (2007)	General equilibrium model of commuting to work with two zones and a choice of multiple time periods, with agglomeration economies dependent on the number of workers present at the same time	Paper investigates optimal congestion toll to maximise social welfare, finding that tolls should be below marginal external cost of congestion to account for positive agglomeration economies	Not reported although could be solved from model
Brinkman (2016)	Spatial equilibrium model of urban structure that includes both congestion and agglomeration externalities; calibrated using data from Columbus, Ohio, which is somewhat monocentric	Tolls equal to the marginal external cost of congestion may have net positive or net negative effects on economic welfare, depending upon the magnitude of the agglomeration externality, as tolls may discourage commuting to major employment centres.	Congestion pricing causes workers to move closer to their jobs or jobs to move closer to workers; the relative magnitude of these effects depends upon price elasticities of different agents. In the calibrated model, a congestion toll results in dispersal of employment to the city fringe.
De Lara et al (2013)	General equilibrium model of a monocentric city, which is then extended to a two-centre city; no agglomeration economies are included; model is calibrated to Paris data	This paper does not compare the effects of congestion pricing with and without a land-use response, but does find positive welfare effects from all pricing schemes.	An optimal congestion toll is estimated to reduce the radius of the city by 34% in long-run equilibrium. A cordon toll would have a smaller effect – a 24% reduction in city radius. In the long run the share of land allocated to roads is also estimated to decrease. Results are qualitatively similar for a two-centre city.

Study	Modelling approach	Welfare effects	Impacts on location behaviour
Fridstrøm et al (2000)	Uses a land use-transport interaction model to assess the long-run land use impacts of first-best or second-best congestion pricing.	N/A	Road pricing would result in users centralising towards the city centre, which has the largest concentration of jobs, while jobs decentralise to reduce travel distances. The magnitude and spatial distribution of these effects depends upon the design of the charging scheme (e.g. distance-based or cordon charges), as well as the network structure and price of public transport. First-best pricing appears to result in more dramatic changes relative to second-best charging.
Guo et al (2011)	Analyses data from a pilot VKT fee programme run in Portland, Oregon; comparing the impacts of congestion pricing versus flat mileage fees for households in different locations	N/A	The VKT reduction from congestion pricing is found to be greater in traditional (dense and mixed-use) neighbourhoods than in suburban (single-use, low-density) neighbourhoods, potentially due to the availability of alternative modes.
Gupta et al (2006)	Applies an integrated land use-transport model of Austin, Texas to study the impacts of new toll roads, bridge tolls, and a downtown cordon charge	New toll roads have positive welfare impacts, although these impacts are not sufficient to offset their costs. Bridge tolls have insignificant impacts on citywide welfare. The welfare impacts of a cordon charge are not calculated due to the fact that the model does not accurately pick up impacts of land use responses.	New toll roads cause a positive land use response in areas where accessibility improves as a result. Bridge tolls do not appear to cause any significant land use changes. The land use impacts of a cordon charge are not calculated. However, total daily traffic to downtown is estimated to reduce, with the drop in peak times partly offset by an increase in off-peak times.
Hymel (2009)	Empirical analysis of the impact of congestion on regional employment growth, based on historic data for US metropolitan areas over the 1982-2003 period Results are used for a policy simulation of the first-order impact of congestion pricing on employment growth	N/A	A congestion pricing scheme that reduces travel delay by 50% is estimated to result in a 10-30% increase in employment growth over the 1990-2003 period in ten cities with the highest level of congestion in 1990. This is a partial-equilibrium assessment that assumes that toll revenues will be redistributed in lump-sum fashion.

Study	Modelling approach	Welfare effects	Impacts on location behaviour
Kalmanje and Kockelman (2004)	Models the impact of a congestion pricing scheme that returns all toll revenues to drivers in a uniform fashion on Austin, Texas. Study focused on assessing welfare impacts based on the change in utility from the toll (calculated as the log sum of utilities of all destination choices). The distribution of utilities was also estimated. The impact of congestion pricing on home price was estimated using a regression model that used the accessibility of home locations (measured as the weighted average of destination utilities) as an explanatory variable.	Overall welfare effects and the distribution of welfare effects arising in the transport market are assessed. Congestion pricing is found to generate positive welfare impacts, albeit with a distribution between users. In the absence of revenue redistribution, most users would be worse off.	Home values are predicted to fall slightly in almost all areas when all roads are priced and revenue is not redistributed. Home values are expected to fall by more in southwest Austin than in other locations, including the CBD, reflecting the fact that southwest Austin experiences smaller gains in utility. These estimates do not account for the impact of revenue redistribution, which may result in a net positive impact on property values throughout the city.
Oron et al (1973)	General equilibrium model of a monocentric city; no agglomeration externality.	N/A	Congestion pricing causes cities to be smaller (ie less suburbanised) than they otherwise would be.
Safirova et al (2006)	Integrated land use-transport model used to estimate long-run effects of congestion pricing (drawing on Anas and Xu 1999), while a strategic transport model is used to estimate short-run effects. Models are calibrated to Washington DC and used to estimate the impacts of an AM peak cordon price around the downtown core	Long-run welfare gains from an optimal toll, taking into account land use responses, are approximately five times larger than short-run welfare gains that only take into account transport responses. The distribution of welfare gains is also different in the long run than in the short run. In the short run, a cordon toll is estimated to be progressive, resulting in gains for the bottom quartile of household incomes, small losses for middle-income earners, and ambiguous effects on the top	A cordon charge is estimated to cause an increase in downtown population, and a decrease in population just outside the cordon charge. This is associated with increases in downtown rents and decreases in rents in downtown fringe areas. Employment in the downtown core declines, with jobs dispersing to non-tolled areas. When considering land use effects, welfare maximising tolls are higher than when considering only transportation effects.

Study	Modelling approach	Welfare effects	Impacts on location behaviour
		quartile. In the long run, the same toll will lead to positive impacts on all groups, but the largest positive impacts on the top quartile of household incomes. These results depend on redistribution of revenues to a significant degree.	
Tang (2016)	Empirical analysis of the impact of the western extension zone of the London cordon charge on property values within small distances around the boundary	N/A	Analysis finds that buyers pay 3.68% more for homes in the cordoned area relative to similar homes 1 kilometres from the cordon boundary that also benefit from a discounted congestion charge due to their position in the road network. The author ascribes this as a benefit arising from a 3.58% decrease in traffic within the cordon area.
Thissen et al (2011)	Spatial computable general equilibrium model used to assess the impact of congestion pricing in the presence of agglomeration economies, with redistribution of revenues. Model is estimated for Netherlands regions.	Analysis focuses on the relationship between transport benefits and agglomeration benefits, with land use responses. Reduced agglomeration economies resulting from reduced intra-regional or inter-regional commuting and business linkages may result in lower welfare benefits than transport effects alone would suggest.	Spatial effects vary depending upon which sources of agglomeration economies are stronger. National congestion pricing may lead to offsetting effects for intra-regional and inter-regional travel. The overall effects are harder to assess in a polycentric / multi-region environment than for a monocentric city. Spatial effects also vary depending upon how congestion pricing revenues are redistributed.
Verhoef (2005)	Spatial general equilibrium model for a monocentric city; agglomeration economies not modelled	The welfare effects of first-best congestion pricing (tolls equal marginal cost of congestion) and second-best pricing are compared. Overall utility increases by 0.30% in the first-best pricing case, and 0.27% with a cordon charge or a flat per-km charge	Both first-best and second-best pricing are estimated to result in an increase in residential density throughout the city, and a reduction in the size of the city.
Wheaton (1998)	General equilibrium model of residential location in a monocentric city with commuting costs	N/A	Modelling finds that, in the presence of unpriced congestion, residential densities are too low to maximise social wellbeing. There is a smaller difference between the 'market' and 'optimal' densities when provision of road capacity is allowed to vary depending upon demands on the network.

Appendix A3 – Literature on assessments of road pricing

Table A.3 Literature on assessments of road pricing

Study	Analytical approach	Equity dimensions considered	Key findings on equity
Arnott et al (1994)	Uses a theoretical model of bottleneck congestion on a single link, with endogenous arrival time and a fixed number of users with different values of travel time and costs of schedule delay. An optimal time-varying toll is modelled.	Compares outcomes for user groups with different values of travel time and costs of schedule delay (ie early arrival), which may not correspond exactly to income.	If users are identical, their welfare is unaffected by an optimal time-varying toll. In general, tolls benefit users that place a high value on travel time savings and schedule delay costs, relative to those with low values. Lump-sum redistribution of revenue can leave all groups better off.
Bonsall and Kelly (2005)	Estimates the impact of road pricing policies on different travellers, using a simulated set of individuals with varying incomes and types of social disadvantage. Characteristics of individuals estimated based on joint distribution of various characteristics in the population (age, gender, employment status, occupation, income, car ownership, disability, single parenthood, and ethnicity). Land use and transport responses to charging are not modelled. Model is applied to Leeds, UK. Cordon charges, distance-based charges, and time-based charges are tested, set at levels that produce a similar amount of revenue.	Focuses on the impact of road pricing on social exclusion, ie an inability to participate fully in the life of the community due to low income, ill-health, unemployment, physical isolation, lack of education, lack of confidence, or multiple factors. Identifies the following categories of at-risk users: • people with low incomes • people with disabilities • elderly people • women (eg due to security fears) • ethnic minority groups (if language/ cultural barriers make use of other modes difficult) • people without access to public transport.	Analysis highlights the types of users who are most affected under each scenario, both in terms of the share of people in at-risk groups that are affected and in terms of spatial impacts. As expected, the impact on at-risk groups varies depending upon location and extent of the charging area and on the basis for the charge. The results cannot easily be summed up in a single metric and thus it is not clear which scheme leads to the ‘least’ distributional effects.

Study	Analytical approach	Equity dimensions considered	Key findings on equity
Bureau and Glachant (2008)	Models the effects of nine road pricing scenarios for Paris on commuters, using data from a travel survey carried out in 2001-2002. Uses a random utility model to estimate the 'compensating variation' required to offset the utility losses from tolls for individuals, assuming a nonlinear marginal utility of money. This observes that models that assume a constant utility of income may under-estimate the regressiveness of charging schemes.	Focuses on variations between individuals with different incomes. Income is found to be positively correlated with value of travel time. Analysis is conducted at the individual level using microdata from the travel survey, and aggregated up to five income quintiles.	Distributional patterns across income groups depends upon the level of traffic reduction achieved by road pricing, as well as toll design. All pricing scenarios are regressive, as the disbenefits experienced by lower-income individuals are greater as a proportion of their income. When tolls lead to a lower reduction in traffic, low-income motorists lose more (in absolute terms) than wealthier motorists, but the reverse is true with larger reductions in traffic. This is because the latter scenario involves more low-income commuters switching to PT, which mitigates disbenefits from pricing. Redistributing revenues in a lump-sum fashion makes pricing progressive, as lower-income individuals experience net benefits. Using revenues to reduce PT fares has a similar impact. Under both scenarios for spending revenues, 63% of commuters experience net benefits.
CEDR (2009)	Survey of users, application of causal chain	Discusses in general terms notions related to winners and losers, but does not focus on specific characteristics	Equity impacts are significantly influenced by the scheme's specification and will vary as a result. Equity impacts should be considered throughout the development of the scheme.
De Palma and Lindsey (2004)	General equilibrium model of the impact of congestion pricing on heterogeneous users. Users differ in terms of value of travel time, preferences for when and where to travel, and other socio-economic characteristics. Modelling accounts for multiple modes and routes, as well as fiscal impacts for government (a supplier of public goods)	For simplicity, two user groups are modelled – high and low-income earners with high and low values of time. Two routes are available between a single origin-destination pair. Three tolling scenarios are modelled: tolling one route only, applying the same toll to both routes, and applying different tolls to both routes to provide different level of service. Lump-sum redistribution of revenues is modelled.	The optimal toll is higher if both routes are tolled than if only one route is tolled, which results in more toll revenues to redistribute. All three tolling schemes result in benefits for low-income users and disbenefits for high-income users, although this is driven by redistribution of revenue to a significant degree. Applying differentiated tolls to different routes results in the largest overall welfare gains and is more progressive than tolling both routes equivalently. Toll routes operating in parallel to free routes that offer slower travel times can benefit both high-income and low-income users.
Eliasson and Mattsson (2006)	Undertakes a quantitative assessment of the equity effects of road pricing for a proposed congestion pricing scheme in	Effects of cordon pricing on individuals in the representative sample are estimated. Effects are broken down by gender, individual income (3 income bands), by household type,	Before revenue redistribution, men experience larger disbenefits than women as they make a larger share of trips that would be subject to charging. If revenues are redistributed in lump-sum fashion or spent on public transport improvements, both men and women experience net

Study	Analytical approach	Equity dimensions considered	Key findings on equity
	Stockholm. Method takes into account differences in travel behaviour, preferences (eg value of travel time savings), and mode options. Effects of congestion pricing modelled using a system of logic models applied to a representative sample of individuals from travel surveys. Strategic transport model outputs used as inputs to this model, matched based on value of travel time saving assumptions. Welfare effects are calculated using rule of half measures of consumer surplus, rather than logsum.	by employment status, and by location. Model focuses on short-run effects on mode choice and destination choice, and does not consider responses related to change of departure time or changes in land use. Four types of effects are calculated: (1) higher travel costs for car travellers, (2) changed travel behaviour to avoid charges, (3) shorter travel times to avoid tolls, and (4) revenue generation and distribution.	benefits but benefits are larger for women. If revenues are used to reduce income taxes both men and women experience similar benefits. Before revenue redistribution, lower-income users experience smaller disbenefits than higher-income users. If revenue is redistributed in lump-sum fashion or used to improve PT, lower-income users experience net benefits while higher-income users experience net disbenefits. If revenues are used to cut income taxes the scheme is regressive. Effects of cordon pricing vary significantly between locations, and individuals in some parts of the city are worse off even with revenue redistribution, reflecting existing commuting patterns.
Fridstrøm et al (2000)	Models the impact of 'first best' and 'second best' congestion pricing on economic welfare and equity using transport models for Edinburgh, Helsinki, and Oslo. The Helsinki model assesses land use impacts but not equity impacts. Modelling does not differentiate marginal utility of income between separate groups, which may result in an overestimate of the progressivity of pricing.	Equity impacts are assessed by looking at changes in the Gini coefficient of income after adding in the monetary costs of pricing, plus non-monetary effects related to time savings, plus revenue redistribution. To do so, households are split into discrete income brackets based on average income per household member.	Study found that impacts on equity are moderate. In Oslo, the Gini coefficient increases (indicating less equality) before redistribution, but not to a significant degree. Lump-sum redistribution results in a considerable reduction in the Gini coefficient. In Edinburgh, the Gini coefficient reduces (indicating greater equality) before redistribution.
Safirova et al (2006)	Integrated land use-transport model used to estimate long-run effects of congestion pricing (drawing on Anas and Xu 1999),	Households are separated into five income quintiles and average effects for each quintile are reported.	Long-run welfare gains from an optimal toll, taking into account land use responses, are approximately five times larger than short-run welfare gains that only take into account transport responses. The distribution of welfare gains is also different in the long run than in the

Study	Analytical approach	Equity dimensions considered	Key findings on equity
	while a strategic transport model is used to estimate short-run effects. Models are calibrated to Washington DC and used to estimate the impacts of an AM peak cordon price around the downtown core		short run. In the short run, a cordon toll is estimated to be progressive, resulting in gains for the bottom quartile of household incomes, small losses for middle-income earners, and ambiguous effects on the top quartile. In the long run, the same toll will lead to positive impacts on all groups, but the largest positive impacts on the top quartile of household incomes. These results depend on redistribution of revenues to a significant degree.
Santos & Rojey (2004)	Uses transport models to model the impact of a cordon toll in three English towns, and ascribes costs and benefits to people based on data on commuting mode choice and patterns, occupations and estimated incomes at a fine geographic level.	Analysis considers the equity impacts in terms of the impacts on groups of people with relative low or high incomes. It does not evaluate effects on individuals.	Cordon pricing can be progressive, regressive, or neutral depending on where low-income people live and where and how they travel to work.
McMullen, Zhang, & Nakahara (2010)	Quantitatively evaluates hypothetical distributional impacts of a shift from a gasoline tax to a tax on vehicle-mile travelled in Oregon via a linear regression model. A static model (ie no resultant changes in driving behaviour) and dynamic model (ie changes in driving behaviour) were considered. Data from the 2001 National Household Travel Survey is used.	Analysis is conducted at the individual level using microdata from the travel survey, and aggregated up to six income groups, although household composition is also considered. Zero vehicle households were excluded from analysis. Impacts on urban and rural households are also compared. Focuses on changes in average annual household expenditures.	A tax on vehicle-miles travelled is found to be slightly more regressive than existing fuel taxes. Rural households benefit relative to urban households. Alternative VMT pricing structures that might increase incentives to use more fuel-efficient vehicles are found to be more regressive than a flat VMT tax.
Odeck and Bråthen (2002)	Ex post survey of users	N/A	Study found that there is a need for more public involvement in the planning process prior to the implementation of toll systems, which can improve the real and perceived impacts of pricing.

Study	Analytical approach	Equity dimensions considered	Key findings on equity
Raub et al (2013)	Models the hypothetical effects of four road pricing scenarios for on German households, using 2008 everyday mobility data from the German Mobility Panel. A simple individual welfare measure that takes account of the price increase, compensation measures and users' reactions was applied. Analysis includes trip suppressions but mode choice, vehicle occupancy, route choice or destination choice as well as time savings due to reduced congestion and improved road conditions are not covered.	Focuses on variations between individuals with different incomes. Analysis is conducted at the individual level using microdata from the travel survey, and aggregated up to five income quintiles, although household composition is also considered.	Scenario A (time-based pricing with an annual permit) leads to relative welfare losses (in relation to the EDI) across all income groups but decreasing losses with increasing income can be observed because of a fixed annual permit price. A regressive distributional outcome is clearly identifiable. In Scenario B (time-based pricing with compensation via reductions in energy and motor vehicle taxes) a lower negative welfare effect across the five income groups can be observed but the developed compensation measures can only partly counterbalance the road charges. regressive effects are not avoided. In Scenario C (distance-based pricing on motorways) the relative welfare losses across all income groups are more even distributed in contrast to A and B. In Scenario D (distance-based scenario with compensation measures) the observations of Scenarios A and B are reversed. A distance dependent toll in combination with compensations in the form of tax reductions has nearly a neutral effect.

Appendix B: Econometric analysis of Household Travel Survey data

We analysed Household Travel Survey data from all surveys undertaken between August 2003 and July 2014, focusing on households in the Auckland region. We used this data to (a) identify factors that have a statistically and practically important impact on household trip generation and (b) identify average trip generation rates, by mode, for each household category.

In total, this provided data on around 95,000 journeys taken by almost 8,200 households, although some observations were dropped due to missing data. We transformed this data as follows:

- We grouped trip legs into journeys and coded them according to the purpose of each trip, using the trip purpose categories used in the MSM.
- We categorised households based on data on household type, household size, employment status of household members and vehicle ownership. We also constructed an estimate of equivalised household income.[28]
- We estimated the average number of trips taken by each group.

We calculated the total number of daily trips for each household in the sample, noting that households were typically surveyed on two consecutive days. We then estimated a set of Poisson regression models to 'predict' the number of daily trips per household based on household characteristics.[29]

The following table summarises key results from the preferred regression model, which includes household type, household size, employment, equivalised incomes, and vehicle ownership. To aid with interpretation, we report the marginal impact of a one-unit change in each explanatory variable for the mean observation in the sample.

The key results from this analysis are as follows:

- Household size has a strong impact on trip generation. At the mean, an additional adult adds 2 trips, while an additional child adds 2.3 trips.
- After controlling for household size, household type variables are mostly not statistically significant, although the marginal effects have the expected sign (eg single people living alone make fewer trips).
- Employment is associated with more trips per day. At the mean, every additional full-time employee adds 0.3 trips, while additional part-time or casual employees have a slightly larger impact.
- There is a statistically significant positive correlation between household income and trip generation, although this effect is practically insignificant. After controlling for employment and household composition, each additional $1,000 in equivalised household income only results in an additional 0.015 trips per day.

[28] We used the 1988 Revised Jensen scale to standardise incomes between households of different size and composition. Statistics New Zealand employs this approach in their reporting. As Household Travel Surveys ask people for their personal income in $10,000 bands, we constructed a rough measure of total personal income by assigning individuals incomes in the middle of each band.

[29] Poisson regression models are commonly used to predict 'count' data like trips per day. See https://en.wikipedia.org/wiki/Poisson_regression for a description.

- Finally, vehicle ownership has a strong positive impact on trip generation. At the mean, households with one or more cars take 1.8 more trips per day than households with zero cars.

Table B.1 Poisson regression model of factors that influence household travel behaviour

Outcome variable	**Number of trips per day**		
Explanatory variables	**Marginal effect at the mean**	**Standard error**	**P-value**
Household type (base level: Family with children <18 years)			
Family with adults only	-0.110	0.471	0.816
Family with child(ren) plus flatmates / boarders	-1.215	0.798	0.128
Married/de facto couple only	0.412	0.497	0.407
Other household type	-0.093	0.668	0.889
Other adults only	0.161	0.528	0.760
Person living alone	-1.226	0.488	0.012*
Single adult living with children (<18)	-0.445	0.731	0.543
Single adult with other adult only	-2.993	0.742	0.000***
Household size			
Number of children	2.314	0.350	0.000***
Number of adults	2.038	0.127	0.000***
Number of full-time employees	0.337	0.091	0.000***
Number of part-time employees	0.402	0.120	0.001***
Number of casual employees	0.917	0.328	0.005**
Equivalised household income ($000s)	0.015	0.002	0.000***
Vehicle ownership (base level: 0 cars)			
Owns 1+ vehicles	1.807	0.271	0.000***
Other controls			
Year effects	Y		
Day of week effects	Y		

We tested various permutations of this basic model with different combinations of variables and calculated Akaike's Information Criterion scores to identify the degree to which different models were 'better' or 'worse'. (AIC identifies the trade-off between a model's complexity and explanatory power. A lower AIC score indicates a model with more information content.)

The following table summarises AIC scores for seven models we tested. The key findings of this are as follows:

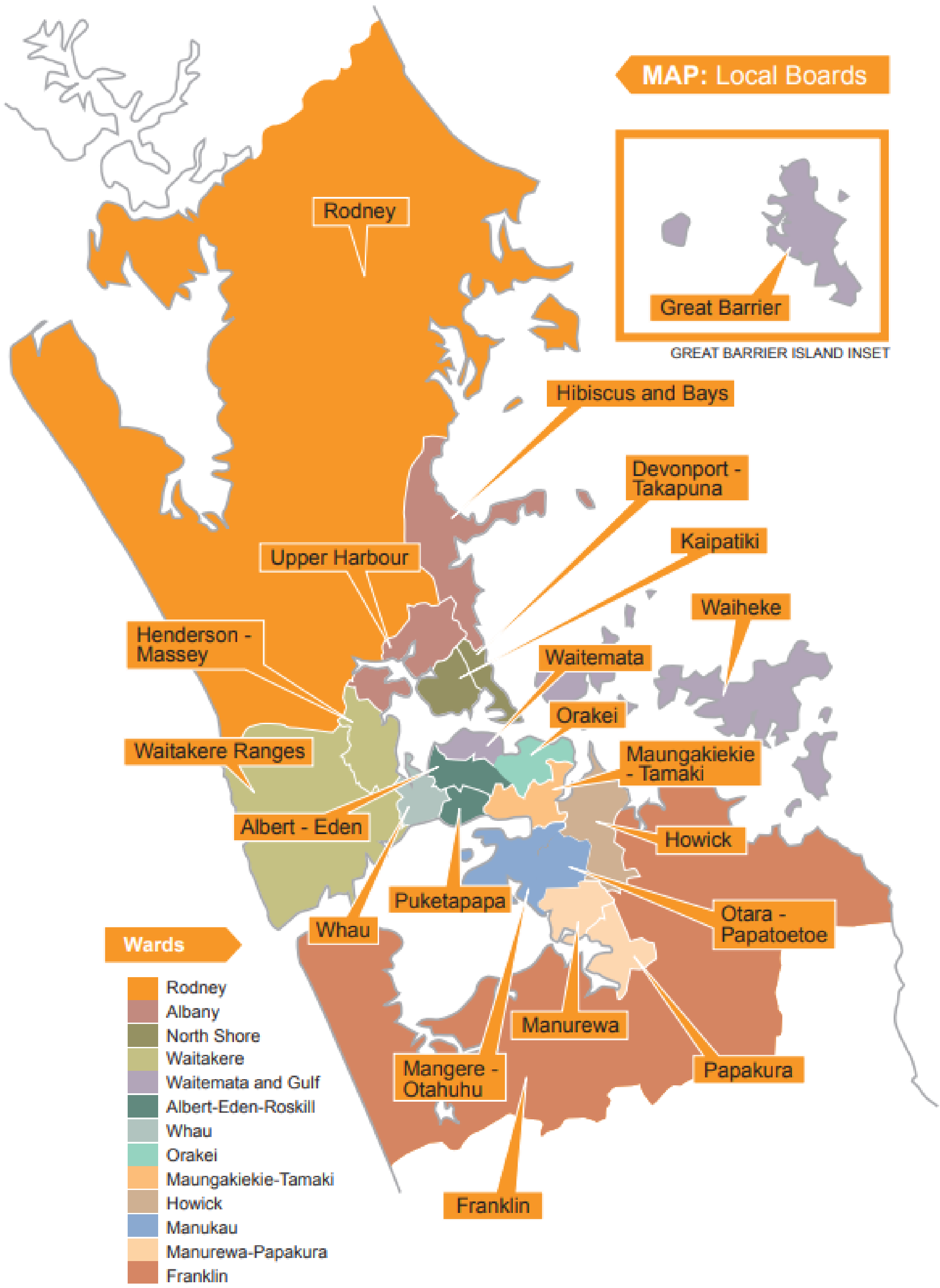
- The base model is the 'best' model, in terms of minimising AIC score.
- Dropping household size variables from the model results in the largest increase in AIC score, indicating that household size is a quite important factor to measure. However, as household size is related to household type, dropping this variable increases the statistical and practical significance of the household type indicators.

- Different specifications for the employment variables have a small impact on the AIC score, indicating that alternative specifications for this variable may be equally valid.
- Dropping the household income variable increases the AIC score to a modest degree.
- The seventh model, which only includes household type and a binary indicator of employment, has a considerably higher AIC score.

Table B.2 Akaike's information criterion score

Model	Description	Df	AIC
1	Model estimated in table above	32	21529.79
2	Drops household type variables	24	21674.88
3	Drops household size variables (number of adults / number of children)	30	22237.52
4	Sums up three employment variables into a single indicator of number of people employed	30	21534.16
5	Drops equivalised household income variable	31	21639.15
6	Summarises employment variables into a single binary indicator of whether there are any employed people in the household	30	21565.55
7	Drops household size variables, drops equivalised household income variable, drops vehicle ownership indicator, and summarises employment variables into a single binary indicator of whether there are any employed people in the household	26	22967.92

Appendix C: Geographic aggregation of impacts in Auckland region



Source: Auckland Council

Appendix D: Impacts of cell suppression

Due to privacy concerns, Statistics New Zealand will not release information on custom groupings that include only a small number of households. This can lead to bias in reported outcomes, as impacts are redistributed from suppressed households to the remaining households in that model zone.

To understand the impact of cell suppression, Table D.1 shows the number of households in specific categories that were suppressed, with and without differentiation by the number of employed people per household. If employment status is included in the household composition classification, then it leads to the loss of around 8% of total households. Classifying households only by income band and household type results in only 1.4% of households being lost to cell suppression. As a result, our analysis does not include employment status in the household classification.

As can be seen from table D.1 cell suppression rates are broadly similar across income band groups, so these results are unlikely to lead to significant bias by income band. However, when household types are considered, one-parent households, households of unrelated people, and multi-family households are more likely to experience cell suppression. This reflects the fact that there are fewer of these households in most area units. The result of this is that the impacts of road pricing for these groups will be understated somewhat, while road pricing impacts for other groups with less cell suppression (eg one-person household) will be overstated somewhat.

Table D.1 Suppression of household census data

Household classification		Households stated in raw census data	Without differentiation by employment status		With differentiation by employment status	
			Households observed	% suppressed	Households observed	% suppressed
Income band	Low	130,716	129,246	-1.1%	120,141	-8%
	Medium	130,716	129,149	-1.2%	120,327	-8%
	High	130,719	128,429	-1.8%	121,436	-7%
Household type	Couple only	90,366	89,862	-0.6%	87,817	-3%
	Couple with dependent child(ren) only	83,181	82,837	-0.4%	79,478	-4%
	All other couples with non-dependent child(ren) or other people	60,570	60,269	-0.5%	56,262	-7%
	All other one parent households (including children aged 18+ or other people)	24,111	23,380	-3.0%	18,812	-22%
	One parent with dependent child(ren) only	18,903	17,975	-4.9%	16,594	-12%
	Household of unrelated people	14,301	13,047	-8.8%	9,082	-36%
	One-person household	77,313	76,756	-0.7%	75,720	-2%
	Multi-family household	23,298	22,698	-2.6%	18,139	-22%
Total Auckland region		**392,151**	**386,824**	**-1.4%**	**361,903**	**-8%**

In order to understand the impact of including employment status, and hence experiencing a higher rate of cell suppression, we ran a version of the analysis with employment status included. Table D.2 compares results with and without employment status included. Note that the aggregate results do not change very much.

Table D.2 Outcomes with and without employment status disaggregation

Census data used	Number of house-holds	Mean house-hold income	Average daily change per household			Average annual change in financial cost per household as a proportion of income	Percentage change in jobs accessible	
			Travel time (min)	Financial cost ($NZ 2016)	Generalised cost ($NZ 2016)		By car	By PT
With employ-ment status	386824	$90,365	3.48	$2.61	-$2.96	0.72%	49.48%	0.03%
Without employ-ment status	361903	$90,670	3.40	$2.62	-$2.96	0.72%	49.48%	0.04%
Difference	**24921**	**-305**	**0.09**	**-$0.01**	**$0.00**	**0.00**	**0.00**	**0.00**

However, table D.3 shows that there can be significant variances for different household types, particularly one-parent households, which are disproportionately likely to be suppressed, and couples with children, which are less likely to be suppressed. This suggests that the additional cell suppression caused by including additional household composition variables is likely to lead to significant bias in results.

Table D.3 Difference in outcomes with and without employment status disaggregation, by household type (ie combined disaggregated)

Household composition	Number of households	Mean house-hold income	Average daily change per household			Average annual change in financial cost per household as a proportion of income	Percentage change in jobs accessible	
			Travel time (min)	Financial cost ($NZ 2016)	Generalised cost ($NZ 2016)		By car	By PT
One person household	1,036	$135	0.07	0.02	-0.04	0.01%	-0.05%	-0.05%
One parent with dependent child(ren) only	1,381	$1,055	0.24	0.17	-0.19	0.08%	0.02%	0.17%
Multi-family household	4,559	-$4,448	-0.58	-0.66	0.69	-0.11%	-0.01%	-0.01%
Household of unrelated people	3,965	-$7,013	-0.41	-0.35	0.39	-0.02%	-0.02%	0.03%
Couple with dependent child(ren) only	3,360	-$560	0.22	0.11	-0.12	0.03%	0.14%	-0.01%
Couple only	2,044	-$523	0.05	0.00	-0.03	0.00%	0.22%	-0.09%

Household composition	**Number of households**	**Mean house-hold income**	**Average daily change per household**			**Average annual change in financial cost per household as a proportion of income**	**Percentage change in jobs accessible**	
			Travel time (min)	**Financial cost ($NZ 2016)**	**Generalised cost ($NZ 2016)**		**By car**	**By PT**
All other one parent households (including children aged 18+ or other people)	4,569	$5,503	1.13	0.80	-0.86	0.24%	-0.02%	0.00%
All other couples with non-dependent child(ren) or other people	4,007	-$3,036	-0.39	-0.45	0.48	-0.07%	-0.01%	-0.02%
TOTAL	**24,921**	**-305**	**0.09**	**-$0.01**	**$0.00**	**0.00**	**0.00**	**0.00**

Appendix E: Breakdown of impacts by household type and income band

Table E.1 Impacts of road pricing by household type and income band

Household composition	Number of households	Mean household income	Average daily change per household			Average annual change in financial cost per household as a proportion of income	Percentage change in jobs accessible	
			Travel time (min)	Financial cost ($NZ 2016)	Generalised cost ($NZ 2016)		By car	By PT
Low income band								
Couple only	24,609	$32,185	2.84	$1.75	-$1.95	1.36%	56.2%	0.0%
Couple with dependent child(ren) only	18,697	$40,816	5.27	$3.07	-$3.32	1.88%	57.8%	0.0%
All other couples with non-dependent child(ren) or other people	13,112	$45,905	4.40	$2.51	-$2.63	1.37%	54.8%	0.2%
All other one parent households (including children aged 18+ or other people)	11,178	$34,422	3.96	$2.37	-$2.50	1.72%	53.4%	-0.3%
One parent with dependent child(ren) only	13,347	$23,732	3.09	$1.90	-$2.09	2.01%	57.8%	-0.3%
Household of unrelated people	4,260	$29,216	5.53	$2.78	-$3.10	2.38%	25.5%	-0.8%

Household composition	Number of households	Mean household income	Average daily change per household			Average annual change in financial cost per household as a proportion of income	Percentage change in jobs accessible	
			Travel time (min)	Financial cost ($NZ 2016)	Generalised cost ($NZ 2016)		By car	By PT
One person household	37,018	$18,558	1.59	$0.95	-$1.03	1.28%	50.4%	-0.1%
Multi-family household	7,025	$48,987	3.84	$2.21	-$2.33	1.13%	50.3%	-0.8%
Medium income band								
Couple only	30,412	$75,215	2.88	$1.91	-$2.33	0.63%	52.9%	0.0%
Couple with dependent child(ren) only	30,547	$87,370	4.57	$3.16	-$3.85	0.90%	61.6%	0.3%
All other couples with non-dependent child(ren) or other people	21,210	$98,198	3.70	$2.52	-$2.94	0.64%	58.5%	0.2%
All other one parent households (including children aged 18+ or other people)	8,926	$78,321	3.63	$2.50	-$2.91	0.80%	57.7%	0.1%
One person household	21,264	$43,480	1.70	$1.09	-$1.34	0.63%	44.9%	-0.2%
One parent with dependent child(ren) only	3,496	$60,674	3.28	$2.18	-$2.64	0.90%	56.5%	0.8%

Household composition	Number of households	Mean household income	Average daily change per household			Average annual change in financial cost per household as a proportion of income	Percentage change in jobs accessible	
			Travel time (min)	Financial cost ($NZ 2016)	Generalised cost ($NZ 2016)		By car	By PT
Multi-family household	8,717	$112,891	3.51	$2.37	-$2.77	0.53%	56.0%	-0.5%
Household of unrelated people	4,578	$77,504	5.07	$2.96	-$3.61	0.95%	35.7%	-0.3%
High income band								
Couple only	34,840	$151,778	3.02	$2.88	-$3.20	0.48%	43.2%	0.1%
Couple with dependent child(ren) only	33,594	$174,280	4.81	$4.67	-$5.38	0.67%	45.2%	0.3%
All other couples with non-dependent child(ren) or other people	25,947	$197,862	4.14	$4.01	-$4.43	0.51%	49.6%	0.3%
One person household	18,474	$87,267	2.01	$1.86	-$2.08	0.53%	34.3%	-0.1%
One parent with dependent child(ren) only	1,131	$131,665	3.14	$3.11	-$3.52	0.59%	37.9%	0.4%
All other one parent households (including children aged 18+ or other people)	3,277	$143,981	4.35	$4.17	-$4.57	0.72%	48.4%	0.3%

Household composition	Number of households	Mean household income	Average daily change per household			Average annual change in financial cost per household as a proportion of income	Percentage change in jobs accessible	
			Travel time (min)	Financial cost ($NZ 2016)	Generalised cost ($NZ 2016)		By car	By PT
Multi-family household	6,956	$219,004	5.18	$4.69	-$5.26	0.53%	51.5%	0.0%
Household of unrelated people	4,210	$164,955	5.28	$4.67	-$4.89	0.71%	26.7%	0.0%