MINISTRY OF TRANSPORT
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Domestic Transport Costs and Charges Study

Synthesis of Road Price Elasticities

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DTCC: Synthesis of Road Price Elasticities

Stage 2 Report

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Report to the New Zealand Ministry of Transport

ITS

Contents

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EXECUTIVE SUMMARY

The overall purpose of this study is to establish from a desktop review, *"a range of credible values for the road price elasticity of demand, along with an assessment of the effect of other factors on this elasticity, to help calibrate Monty"*. The values emanating from the review will be used to confirm, and potentially adjust, parameters of the utility functions in Monty – New Zealand's National Transport Model – to ensure that it reflects more closely the conditions in different parts of the New Zealand road network.

The study was split into two stages. The first stage conducted a review of relevant literature, of use in its own right but also to determine whether a second stage meta-analysis would be sensible.

Stage 1 undertook an extensive review of international road price elasticity evidence based on published studies almost invariably in peer-reviewed journals. The report (ITS Leeds, 2024) covered 52 studies that yielded 397 elasticities relating to changes in prices and charges alongside 48 demand impacts resulting from the introduction or removal of prices/charges. It summarised the evidence in terms of elasticity variation that was apparent both within and across studies according to a number of influential factors; it also discussed a number of previous literature reviews and sets the evidence collected in the context of those reviews. The Stage 1 report recommended proceeding to Stage 2 and the conduct of meta-analysis of the assembled data.

The objective of the research reported in this second stage was to take the evidence assembled as part of Stage 1, supplemented with some further explanatory data, and conduct a meta-analysis in order to quantify how road price elasticities vary with a wide range of factors.

Whilst Bain (2017) reviews 368 toll elasticities drawn from 60 studies, as with our Stage 1 report it does not contain a meta-analysis of the assembled price elasticities. There have been significant meta-analyses of price elasticities in general (Wardman, 2022a), of the demand impacts of the introduction or removal of charges (Bain & Sullivan, 2024), and of toll price elasticities on Japanese expressways (Tsukada & Fukuda, 2013), but in our understanding we here provide the first meta-analysis of international evidence on road pricing elasticities.

Additional data was collected to allow the meta-analysis to provide a better account of variations in elasticities across studies. This covered:

- Estimates of the degree of competition, particularly from other routes but also other modes;
- Measures of income;
- Population density and geographic size, for shorter distance routes;
- Whether there was a significant physical barrier, distinguishing rivers and harbours;
- Whether the context was specifically rural

The meta-model was estimated to 386 observations after removal of 11 non-negative elasticities and 8 elasticities in excess of -1.5 in absolute terms, although this had only a very small impact on the mean elasticity. Two separate models are reported; one based on representing the competition from other routes as a proportionate time variation and the other replacing this time detour with a categorical variable representing whether the alternative route would involve no, slight, moderate or long detour. Otherwise the two models contain the same variables.

The reported models remove what might be regarded to be outlier observations with standardised residuals outside the range ±1.96. These might be regarded to be the 5% of observations that are of poorest quality or most difficult to explain, resulting in the respective models containing 362 and 359 observations. The results obtained from the two models are broadly similar. Although the model containing the categorical specification of route competition provides a slightly better fit, our preference is for the model with the quantified detour since this provides greater granularity of competition and involves less judgement. Moreover, the parameters for categorical detours for freight are not entirely consistent with expectations. The results of Model I are here discussed.

The meta-model contains a number of explanatory factors. All were significant at the customary 5% level. The findings were:

- When elasticities are estimated to changes in Generalised Cost as a result of toll changes they are somewhat larger than when estimated to toll charges or road pricing. This is to be expected since toll and road pricing form a relatively small proportion of Generalised Cost. As expected, elasticities estimated to changes in motoring costs as a result of toll changes are between those estimated to Generalised Cost or specifically to toll.

- Toll variations due to their introduction have a larger impact than variations in existing tolls, which presumably reflects protest behaviour and the pricing-off of the most cost sensitive traffic.

- Elasticities reflecting variations in trip-kilometres are, as would be expected, larger than elasticities relating to variations in trips.

- As incomes increase then elasticities fall slightly but the effect is restricted to passenger travel.

- Elasticities fall as population density in urban contexts increases, with density providing a better explanation than area size. This density effect presumably reflects the different characteristics of urban and shorter distance travellers, particularly more price insensitive business travellers and commuters, whilst increased congestion might make tolled facilities more attractive. Urban areas might also have higher average incomes.

- As expected, elasticities are lower where there is electronic toll collection, with the elasticities being around a third lower than where payment is by cash.

- Inter-urban roads were found to have elasticities somewhat lower than for urban roads, but only for freight. However, toll cordons were found to have very high elasticities and we do not find this credible given they tend to be in a strong competitive position since most traffic will be into the cordon.

- We would expect elasticities to be larger where the time detour involved in using the best alternative route is less, and this was found to be the case. A time detour provided a better explanation of elasticity variation than a distance detour.

- Modal competition was found to impact elasticities but only where there were high quality public transport alternatives and then the elasticities were around 70% larger. As might be expected, this effect was restricted to passenger travel.

- The overall freight elasticities relative to passenger elasticities are influenced by a number of factors. Whilst freight elasticities are somewhat larger than passenger elasticities for urban roads, they are broadly similar for inter-urban roads.

- There were no differences in elasticities between those obtained from econometric analysis of demand, monitoring of demand and choice modelling, except that elasticities that were explicitly long run, representing the outworking of lagged behavioural responses, were found to be somewhat larger.

- Elasticities at weekends were found to be larger, presumably reflecting the greater amount of discretionary travel which has a greater price sensitivity and propensity to switch destinations. The weekend effect relates solely to passenger travel.

The table below provides some illustrative implied elasticities for urban and inter-urban roads. The implied elasticities here are based on toll charge as the monetary instrument, demand variations based on trips, electronic toll collection as the payment instrument, weekday travel and detours that relate to available alternatives, although of course implied elasticities can be provided for combinations of any of the variables in the estimated model.

The income levels used relate to the minimum, 75th percentile and maximum in the analysis data, with the 75th percentile used on the grounds that New Zealand has relatively high incomes. The population densities used are the minimum, median and maximum in the analysis data. The large ranges in income and population density are used to demonstrate the maximum variation in elasticities on account of these variables that would be apparent for the data collected.

Implied Elasticities for Illustrative Scenarios

Facility Type	Barrier	Mode	Income 2015 US$	Density Pop/Km^2	Modal Competition	Detour Factor[1]	Short Run Elasticity	Long Run Elasticity
Urban	No	Car	$3142	1358	None	1.0	-0.26	-0.61
Urban	No	Car	$3142	1358	None	1.5	-0.17	-0.40
Urban	No	Car	$3142	1358	None	2.0	-0.11	-0.26
Urban	No	Car	$3142	1358	None	2.5	-0.07	-0.17
Urban	Yes	Car	$3142	1358	None	1.5	-0.09	-0.22
Urban	No	Car	$3142	325	None	1.5	-0.21	-0.48
Urban	No	Car	$3142	7825	None	1.5	-0.13	-0.31
Urban	No	Car	$355	1358	None	1.5	-0.26	-0.61
Urban	No	Car	$4811	1358	None	1.5	-0.16	-0.36
Urban	No	Car	$3142	1358	Good	1.5	-0.31	-0.71
Urban	No	Freight	N.A	1358	N.A	1.0	-0.46	-1.07
Urban	No	Freight	N.A	1358	N.A	1.5	-0.36	-0.85
Urban	No	Freight	N.A	1358	N.A	2.0	-0.29	-0.67
Inter	No	Car	$3142	N.A	None	1.0	-0.23	-0.53
Inter	No	Car	$3142	N.A	None	1.5	-0.15	-0.35
Inter	No	Car	$3142	N.A	None	2.0	-0.10	-0.22
Inter	No	Car	$3142	N.A	None	2.5	-0.06	-0.15
Inter	Yes	Car	$3142	N.A	None	1.5	-0.08	-0.19
Inter	No	Car	$355	N.A	None	1.5	-0.23	-0.53
Inter	No	Car	$4811	N.A	None	1.5	-0.14	-0.32
Inter	No	Car	$3142	N.A	Good	1.5	-0.27	-0.62
Inter	No	Freight	N.A	N.A	N.A	1.0	-0.20	-0.46
Inter	No	Freight	N.A	N.A	N.A	1.5	-0.16	-0.36
Inter	No	Freight	N.A	N.A	N.A	2.0	-0.12	-0.29
Inter	No	Freight	N.A	N.A	N.A	2.5	-0.10	-0.23

Note: The elasticities for tunnel/bridge, toll cordon and for ERP are the same as for urban road.

We also provide forecasted elasticities for several case studies specified by the New Zealand Ministry of Transport. The short run elasticities were in the range -0.04 to -0.15. These are lower than the conventional wisdom of short run elasticities in the range -0.2 to -0.3 identified in the Stage 1 report,

[1] A Detour factor of 1.5 means that the time on the alternative route is 50% longer.

and contributory factors are the large time detours and relatively high personal incomes. The implied long run elasticities were also generally less than -0.20.

The estimated models have delivered credible results, both in terms of absolute elasticities and variations in them. In our understanding, this is the most extensive meta-analysis undertaken of international elasticity evidence relating to the pricing for the use of roads.

1 INTRODUCTION

1.1 Overall Aims

The overall purpose of this study is to establish from a desktop review, *"a range of credible values for the road price elasticity of demand, along with an assessment of the effect of other factors on this elasticity, to help calibrate Monty"*. The values emanating from the review will be used to confirm, and potentially adjust, parameters of the utility functions in Monty – New Zealand's National Transport Model – to ensure that it reflects more closely the conditions in different parts of the New Zealand road network.

The study was split into two stages. The first stage conducted a review of relevant literature, of use in its own right, but also to determine whether a second stage meta-analysis would be sensible. This is the report of Stage 2, but before proceeding it will be helpful to recap on the scope and findings from Stage 1.

1.2 Stage 1

The first stage undertook an extensive review of road price elasticity evidence based on published studies almost invariably in peer-reviewed journals. The report (ITS Leeds, 2024) covered 52 studies that yielded 397 elasticities relating to changes in prices and charges alongside 48 demand impacts resulting from the introduction or removal of prices/charges. It summarised the evidence in terms of elasticity variation that was apparent both within and across studies according to a number of influential factors; it also discussed a number of previous literature reviews and sets the evidence collected in the context of those reviews.

The recommendations of the Stage 1 study regarding a Stage 2 meta-analysis were as follows:

Our recommendations are as follows with regards to proceeding to a Stage 2 meta-analysis.

- *There is never a guarantee that meta-analysis will be successful, but the data assembled is promising in terms of its size, the potential to increase its size, its quality and its ability, as demonstrated, to provide some credible insights into elasticity variation. These features would indicate that further investigation through meta-analysis would yield important insights.*
- *The dataset assembled undoubtedly contains much useful information but a meta-analysis would be valuable in terms of:*
    - *Exploring and hopefully overcoming the confounding effects that we suspect exist;*
    - *Delivering a model that synthesises the available data into elasticity parameters that are useable by the New Zealand Ministry of Transport.*
- *We therefore feel that it would be beneficial to proceed to a meta-analysis stage with the independent variables in the model covering:*
    - *estimation method;*
    - *the cost numeraire, covering toll, road price and GC;*
    - *time period;*
    - *facility type;*
    - *payment type;*
    - *year;*
    - *whether the charges were an increase or reduction or a mix of the two.*

- *Given that the extent of close substitutes will undoubtedly impact on the elasticities of charged facilities, and is important in the New Zealand context, we would recommend supplementing the current dataset with qualitative indicators of the extent of competition from other routes. Estimating detailed quantitative measures of competition is not feasible given the Stage 2 resources.*

These recommendations for a Stage 2 meta-analysis were accepted by the New Zealand Ministry of Transport, albeit with modification to the measures of route competition to be collected and requests for some additional variables to be covered.

1.3 Objectives of Stage 2

The objective of the research reported here was to take the evidence assembled as part of Stage 1, supplemented with some further data, and conduct a meta-analysis in order to quantify how road price elasticities vary with a wide range of factors.

Whilst an existing study, Bain (2017), reviews 368 toll elasticities drawn from 60 studies, it does not contain a meta-analysis of the assembled price elasticities. There have been significant meta-analyses of price elasticities in general (Wardman, 2022a), of the demand impacts of the introduction or removal of charges (Bain & Sullivan, 2024), and of toll price elasticities on Japanese expressways (Tsukada & Fukuda, 2013), but in our understanding we here provide the first meta-analysis of international evidence on road pricing elasticities.

1.4 Structure of Report

Section 2 discusses the data collection process, with an emphasis on the data collected in this second stage of the study. Section 3 summarises the characteristics of explanatory variables that can be used in the meta-analysis, covering evidence assembled in Stage 1 and the new evidence collected in Stage 2. The meta-analysis is reported in Section 4. Section 5 deals with the application of the meta-models, comparing their variations in elasticities with the variations apparent in the cross-tabulations provided in the Stage 1 report and also delivering implied elasticities for a range of illustrative scenarios. Concluding remarks are the subject of section 6.

2 DATA ASSEMBLY

2.1 Previously Collected Data

In Stage 1 of this study, we collected information on a range of factors which potentially explain variations in price elasticities across contexts. These were:

- Whether the elasticity related to toll, road price or generalised cost (GC);
- Whether the behavioural response underpinning the elasticity covered trips or trip-kilometres;
- Mode, which covers car, light goods vehicles and heavy goods vehicles, and combinations thereof;
- Method of elasticity estimation, distinguishing between formal econometric analysis, before-and-after monitoring and choice modelling;
- Facility type which covered tolled bridges and tunnels, urban toll roads, inter-urban toll roads, toll cordons and road pricing schemes;
- Time period, covering peak versus off-peak and also weekday versus weekend;
- Payment type, distinguishing electronic and cash payment and combinations of the two;
- The year of data collection;
- Increases or reductions in charges or a mix of the two;
- Choice context, which indicated the likely behavioural responses, distance and journey purpose.

The specification of choice context, distance and purpose often involved judgement since the secondary data used in analysis provides little detail on these variables and charged facilities are used for a variety of purposes and journey durations.

2.2 Additionally Collected Data

Notably absent from the variables listed in section 2.1 is any measure of the degree of competition from other routes or indeed modes that was experienced by a charged facility. We would expect price elasticities to be larger, perhaps very much larger, where there are more, better and cheaper alternatives that road users can use in the event of price increases on the charged facility. And it is a requirement in New Zealand that any charged roads have a free alternative so the competition characteristics of the identified elasticity evidence are particularly relevant.

Stage 1 did not collect detailed data on the competitive environment given it was a non-trivial task and was sensibly left to the Stage 2 meta-analysis should that go ahead[2].

[2] However, section 4.4 of the Stage 1 report discusses the 'qualitative' competitive insights provided in nine studies, noting that the literature contains very little explicit analysis of how this key variable impacts on elasticities. The Tsukada & Fukuda (2013) meta-analysis is an exception in that it does include some variables that represent competitive effects but they are very much proxies.

In this second stage of the study, the following additional data was collected for each road price elasticity observation in our dataset:

- Estimates of the degree of competition, particularly from other routes but also other modes;
- Measures of income;
- Population density and geographic size;
- Whether there was a significant physical barrier, distinguishing rivers and harbours;
- Whether the elasticity was estimated to the introduction or removal of tolls and whether the introduction of tolls was linked to a new or existing facility;
- We further identified that some elasticities had been estimated to variations in a composite motoring cost variable, as opposed to toll variations or as part of variations in GC;
- Whether the context was specifically rural.

We now discuss each of these in turn.

2.2.1 Route Competition Measures

As we discussed in our Stage 1 Report, a change of route is the most likely way to avoid an increase or introduction of a toll; changing mode of travel or destination are possible but less likely responses. We have used Google maps to determine journey time and distance differentials between the charged route and the best alternative. These differentials are expressed separately as ratios of journey times and distances for the alternative route relative to the route for which the elasticity was estimated. The best alternative was almost always an untolled route.

The measurement of the time and distance differentials between the charged and best alternative routes was not an exact science and often involved reasonable judgement.

For bridge and tunnel facilities, we took the journey times and distances for the charged route and the best alternative for 'sensible' locations at each side of the crossing.

For urban and inter-urban toll roads, we again used sensible points at each end. In some cases, this corresponded with the actual start and end of the charged facility.

Where it was difficult to determine sensible beginning and end points, a few different locations were used and the time and distance differentials were based on these.

The two remaining facilities relate to toll cordons and electronic road pricing (ERP). Here we recognised that the vast majority of trips would be into the charged area. Using measures of journey time and distance for trips across and around the charged area would not be a sensible measure of the 'monopolistic' nature of the charged facility. Therefore, we here coded the continuous time and distance differentials as 'no alternative'. Nonetheless, we are in a position to specify dummy variables for toll cordons and ERP to allow for the extent to which the absence of an alternative is not strictly true.

There were also other instances where we coded the competition as 'not identified'. A few related to being unable to identify the specific route in question but more often it was because the elasticity in question involved the analysis of a wide range of routes as occurs, for instance, with panel data econometric models.

At the outset, we must recognise that the current degree of competition between routes as indicated by Google maps will not necessarily be the same as when the elasticity was estimated. Moreover, any quantified differentials between the charged route and the best alternative can depend upon the specific journey being made; for example, on inter-urban routes the proportionate time and distance variations can depend quite strongly on journey length and/or time of day.

Given uncertainties and approximations surrounding the metrics of competition expressed as ratios of journey time and distance, we also specified two further variables which were categorical in nature although admittedly to some extent based on our professional judgements.

We specified what we regarded to be the number of alternative routes, defined as:

- None;
- Really just one;
- Several;
- Many.

We also specified a route competition variable along the lines of Bain & Sullivan (2024) which identified between:

- No alternative route;
- Best alternative is quicker or no detour;
- Best alternative involves a slight detour;
- Best alternative involves a moderate detour;
- Best alternative involves a long detour.

The categorical definition of competition made use of statements in the reviewed documents such as "there were no real alternatives to the tolled route" or that "the tolled route was paralleled by free routes"[3]. But in general we observed Google maps and took a view that we believed would be "reasonable" or "common sense" for a professional seeking to estimate an elasticity from the meta-model.

Whilst the categorical specification of route competition can be queried given the element of judgment involved, it has the following attractions:

- Some studies cover a number of different routes, as is the case with panel data econometric analysis. Hence arriving at a single estimate of time or distance detours is not straightforward yet it remains reasonable to summarise the route competition along the lines of the qualitative categories set out above.

- In some cases, it is not clear how to calculate relative journey times and distances, since the facility covers many different O-D movements. Nonetheless, a judgment can be made on the qualitative degree of competition from other routes.

- We recognise that the time differentials between routes that now apply might be somewhat different to those that were relevant when the elasticity was estimated as congestion or the advent of new facilities may have changed. However, the categorical judgement of the degree of competition might be more transferable over time.

- It provides an alternative measure.

[3] Where authors stated that the route in question had no alternatives, this coding was used for the time and distance differentials as well as the categorical definitions.

2.2.2 Mode Competition Measures

If there are good public transport alternatives then motorists can switch to them in the event of a toll increase and elasticities will be larger than otherwise.

There are many aspects of public transport services that contribute to their attractiveness, and we are clearly not in a position to specify generalised cost measures for the current situation let alone relevant to when the elasticities were estimated. We therefore followed the approach used by Bain & Sullivan (2024) and specified the following categories:

- No public transport;
- Poor infrequent public transport service;
- Good/higher frequency public transport service;
- MRT system or high-quality competing rail service.

Whilst these are judgmental, it tends to be clear which category is relevant to the context in question.

2.2.3 Income Measures

We have used two measures of income in our models. One is the national GDP per capita; it has the attraction of being measured across countries and over time on a consistent basis, although it lacks spatial detail. This data was sourced from the World Bank for the year of data collection and is expressed in US dollars at 2015 market prices. It is assigned to each elasticity observation in the dataset.

However, national GDP per capita will not generally be relevant to specific charged facilities, not least because such facilities tend to exist in more prosperous areas of the relevant country.

As far as more location specific income data is concerned, we took the following approach:

- In the few cases where a study reported income levels relevant to the travellers, this was used.

- We aimed to identify measures of locally relevant income, either as income per capita or salaries. This might be at city level where available and appropriate but was much more usually at state/regional level.

- The fall-back position was to use national income per head or mean salary figures.

These income measures were converted to 2015 prices in US dollars for consistency with the World Bank GDP per capita data. Where the income measure available was not for the year in which the elasticity was estimated, income was adjusted using the variations in the World Bank GDP per capita between the relevant years. The figures relate to pre-tax income per person.

2.2.4 Population Density and Area Size

Population density might act as a proxy for congestion in high-income countries; higher population density can be expected to reduce elasticities for charged facilities which avoid congestion. Moreover, locations with higher population density will tend to have higher incomes which will also tend to reduce price elasticities. In any event, the inclusion of population density effects might also support transferability of results to the New Zealand context given that population density is relatively low.

We made a judgement on the area to be taken as representative for the estimated elasticity. Most of the time this is the area and population of the “metropolitan area”. Moreover, we did not think it sensible to collect such data for inter-urban routes, since population density will often vary considerably along the route. This is though not a serious issue since population density and area are taken to proxy for urban congestion and other urban differentials.

In the vast majority of cases, the population density figure obtained relates to the representative year of data collection for the reported elasticity estimate or to a few years either side of it.

2.2.5 Barriers

Barriers such as harbours and major rivers could proxy for the competitive situation given that the alternatives to the charged facility will tend to be relatively unattractive. Barriers may also add a subjective sense of separation that the alternative journey time may not fully capture. Moreover, we have already stated that it is sometimes unclear what the start and end points of a journey are when estimating representative time and distance differentials of alternative routes. Hence the inclusion of a variable denoting barriers might detect an impact on elasticities over and above any attributed to the other measures of competition we have collected.

2.2.6 Introduction or Removal of Tolls

Some of the elasticities related to the introduction or removal of tolls, such as with toll cordons. Even though the before or after toll is zero, these can be estimated as part of GC or motoring cost measures or because arc elasticity estimates are used which are based on averages of the before and after tolls. These elasticities might be different; in particular, the introduction of tolls might be met with some opposition in principle and will have a greater impact on those who are more sensitive to relatively large cost variations.

2.2.7 Rural

Some evidence relates to elasticities for roads in very sparsely populated areas, such as some remote parts of Norway, where not only are there no alternative routes but the characteristics of travellers and their journeys might well be somewhat different. It therefore makes sense to identify these contexts with a view to determining whether they impact on the estimated elasticities.

3 SUMMARY OF DATA

We do not here provide summary statistics relating to the variations in price elasticities according to a range of influential variables since that was the purpose of the Stage 1 report. Instead, we summarise the variables that can be used in the meta-analysis to investigate and explain variations in elasticities across studies.

The dataset covers 405 elasticity observations. However, we remove from further consideration elasticity observations that we regard to be implausible. These are the 11 non-negative elasticities and the 8 elasticities in excess of -1.5 in absolute terms. This reduces the dataset by just 4.7% and the mean elasticity is only very slightly impacted, increasing from -0.45 to -0.47. The figures reported below are for the dataset of 386 observations.

The 386 elasticity observations are drawn from 46 studies, and these were summarised in the Appendix of the Stage 1 report. The countries covered are listed in Table 3.1. The USA provides by far the most evidence although there is also a large amount from Japan and Norway.

Table 3.1: Elasticity Observations and Studies by Country

	Elasticities	Studies
Australia	3	1
Chile	10	2
Great Britain	3	2
Hong Kong	8	1
Italy	3	1
Japan	95	3
Mexico	4	2
Norway	50	6
Portugal	5	1
Singapore	24	2
Slovenia	2	1
Spain	8	4
Sweden	22	2
USA	149	18

The number of elasticities per study is listed in Table 3.2. The 22 studies that provide 3 or fewer elasticities form 48% of the studies but only 10% of the elasticities whereas the 5 studies each containing over 25 elasticities provide 185 observations which is almost half (48%) of the total.

Table 3.2: Elasticities per Study

Elasticities per Study	Studies
1	9
2	9
3	4
4-5	7
6-10	7
11-25	5
26 and over	5

Taking the midpoint of time series data to indicate the year of data collection, 70 (18%) elasticities covered the period up to 1990, with 118 (31%), 138 (36%) and 60 (15%) respectively covering the periods 1991 to 2000, 2001 to 2010 and after 2010. Of the 386 elasticities, 40 (10%) represented variations in trip-kilometres as opposed to trips, whilst 61 (16%) related to generalised cost (GC), 22 (6%) to motoring cost, and 25 (6%) to road price with the remaining 278 (72%) relating to toll charges.

The elasticities cover introductions in 48 (12%) cases, removals in 30 (8%) cases, with the remaining 308 (80%) being variations in existing toll charges. Overall, there are 223 (58%) increases in tolls, 111 (29%) reductions in tolls with 52 (13%) covering a mixture of the two or where it was not clear. New facilities represent only 14 (4%) cases[4].

The types of facility covered are indicated in Table 3.3. The largest category is inter-urban roads, followed by tunnel/bridge crossings and urban tolled roads. Of course, urban roads can be used as part of a longer distance journey and short journeys can be made on inter-urban roads.

Table 3.3: Facility Type

Tunnel/Bridge	79 (20%)
Urban Road	78 (20%)
Inter-Urban Road	162 (42%)
Urban and Inter-Urban Road	9 (2%)
Toll Cordon	33 (9%)
ERP	25 (7%)

The modes covered are listed in Table 3.4. Given that secondary demand data generally provides the basis for elasticity estimation, there are instances where all modes are covered without distinction. The largest category though relates solely to car travel.

Table 3.4: Modes

Car	172 (45%)
Freight	103 (27%)
All Vehicles	90 (23%)
Car and Light Goods	21 (5%)

Table 3.5 sets out the estimation methods used. The largest category is based upon econometric analysis of demand (55%), distinguishing between dynamic models that estimate short run (SR) and long run (LR) impacts as well as 'static' models with no such distinction. The 'before and after' monitoring of demand response to price changes provides 38% of the elasticities. The remaining evidence is derived from choice models estimated to either Revealed Preference (RP) or Stated Preference (SP) data.

Table 3.5: Estimation Method

Demand SR	70 (18%)	Monitoring	146 (38%)
Demand LR	77 (20%)	Choice Models	29 (7%)
Demand Static	64 (17%)		

[4] Whether the toll was an introduction or removal and whether a new facility was involved were collected in the second stage of the study.

Most (72%) of the elasticities represent the entire day, as indicated in Table 3.6. However, the number of observations for peak travel and the various periods combined outside of the peak might be sufficient to detect variations in elasticities by time period.

Table 3.6: Time Period

All Day	278 (72%)
Peak	50 (13%)
Inter Peak	19 (5%)
Off Peak	27 (7%)
Weekend	12 (3%)

The studies do not always make it clear what the payment instrument was and hence the number for both cash and ETC might be an overstatement. The ‘not relevant’ category relates to contexts which could not be taken to indicate actual behavioural differentials between cash and ETC instruments, such as when SP methods are used.

Table 3.7: Payment Instrument

Cash	95 (25%)
ETC	95 (25%)
Cash and ETC	173 (44%)
Not Relevant	23 (6%)

Turning now to the additional data collected in Stage 2, and discussed in section 2, these relate to:

- Population density and geographic size;
- Measures of income;
- Estimates of the degree of competition, particularly from other routes but also other modes;
- Whether there was a significant physical barrier, distinguishing rivers and harbours;
- Whether the context was specifically rural.

The population density, in terms of population per square kilometre, and area, in terms of square kilometres, were collected where it was sensible to do so[5]. This was the case for 231 (60%) of the 386 elasticity observations. The mean population density was 3013 pop/km^2 with a standard deviation of 2916. The corresponding figures for area were 1219 and 3053 km^2. Further details of the distribution of the population density and size data are given in Table 3.8. The amount of variation in the data is encouraging with regards to being able to support the analysis of effects that exist from these variables on the price elasticities.

Table 3.8: Population Density and Area

	Min	10%	25%	Median	75%	90%	Max
Density (Pop/km^2)	38	325	795	1358	5000	7825	9568
Area (km^2)	4	19	238	641	778	1572	10400

Two measures of income were collected. One was, where possible, a local measure based on monthly individual pre-tax income and converted to 2015 prices and US dollars. The other was World Bank

[5] These were for the metropolitan area in which the urban road, toll cordon or ERP scheme lay.

national GDP per capita for the year of data collection and also expressed in 2015 prices and US dollars. The mean monthly income was $2570 with a standard deviation of $984. The mean GDP per capita was $41421 with a standard deviation of $15067. The GDP per capita figure is, on average, around 30% larger than the individual income when converted to an annual amount. The correlation between the two measures was 0.52.

Table 3.9 provides more detail on the distribution of the income measures, indicating a wide range which supports the analysis of possible effects of income on price elasticities.

Table 3.9: Income Distributions (US$ 2015 prices)

	Min	10%	25%	Median	75%	90%	Max
Monthly Income	$355	$1510	$1847	$2301	$3142	$4136	$4811
GDP per Capita	$9162	$24107	$30795	$34918	$52650	$55818	$76374

With regards to the proportionate time and distance detours[6] of the best alternative, 100 (26%) elasticity observations were deemed to relate to facilities where there was no credible alternative whilst in 42 (11%) cases it was not sensible to estimate a figure since the elasticity covered different routes with varying competitive features.

Of the remaining 244 cases, the mean journey time detour was 1.33 with a standard deviation of 0.37. The respective figures for the distance detour were 1.20 and 0.39. Table 3.10 provides more detail about the distributions of these detour variables, indicating a wide range which is useful for investigating the effect of these key variables on price elasticities.

Table 3.10: Proportionate Time and Distance Detours

	Min	10%	25%	Median	75%	90%	Max
Time	0.65	0.97	1.12	1.20	1.60	1.78	2.90
Distance	0.64	0.86	1.00	1.10	1.31	1.50	3.50

As discussed in section 2.2.1, we also made judgments about the degree of road competition experienced by the route in question and the number of alternative routes. Table 3.11 reports the distribution of competitive categories assigned, indicating a good spread of route competition levels. A few elasticity observations covered several routes where it was not possible to estimate a detour but it was deemed possible to estimate the number of competing routes.

Table 3.11: Route Choice Judgements

ROUTE CHOICE		NUMBER OF ROUTES	
Not Identified	16 (4%)	Not Identified	7 (2%)
No Alternative	100 (26%)	No Alternative	100 (26%)
Best Alternative Quicker or no Detour	74 (19%)	Just One	69 (18%)
Best Alternative Slight Detour	78 (20%)	Several	172 (44%)
Best Alternative Moderate Detour	66 (17%)	Many	38 (10%)
Best Alternative Long Detour	52 (14%)		

[6] A detour deemed to represent a 20% longer journey than the tolled route is specified as 1.20

Table 3.12 reports the degree of categorical modal competition assigned to each elasticity observation. The two most common categories are the extremes of non-existent public transport alternatives and high quality public transport provision.

Table 3.12: Modal Competition

No Public Transport	136 (35%)
Poor/Infrequent Services	40 (10%)
Good/Higher Frequency Services	49 (13%)
MRT/Strong Competing Rail Service	161 (42%)

101 (26%) elasticities were for facilities that crossed a major river with a further 3 covering harbours and 43 (11%) were identified as relating to specifically rural contexts.

4 META-ANALYSIS

4.1 Approach

The meta-analysis reported here is regression based, seeking to explain variations in elasticities across studies. The dependent variable is the absolute value of the elasticity. We have specified a multiplicative model since we have found this to be statistically superior to an additive model in several previous studies, and it provides estimates that indicate the proportionate variation in elasticities, which are readily interpretable, and has the attraction that the estimated model cannot imply wrong sign elasticities.

The multiplicative model takes the form:

$$\eta_i = X_i^{\alpha} e^{\mu + \beta X_i + \gamma Z_i} \qquad (1)$$

η_i is an **absolute** price elasticity in study i, μ is a constant term, X denotes continuous variables for study i and Z_i represents a set of categorical variables relating to study i.

In this formulation, α is an elasticity, denoting the proportionate change in η after a proportionate change in some continuous variable X. In the analysis reported below, the only variable that enters in this form is income. The continuous variables X need not enter in this constant elasticity form and this is the purpose of the βX_i term. Here the exponential of β reflects the proportionate change in the elasticity after a unit change in the continuous variable X; in other words, β is a semi-elasticity This is the form that population density and time detour enter the models reported below.

The remaining variables Z are categorical in nature, represented by dummy variables, and the exponential of γ indicates the proportionate effect of some level of a categorical variable relative to the arbitrary base category. As an example, the price elasticities can relate to trip variations or trip-kilometre variations and a coefficient on a dummy variable representing trip-kilometre variations would be expected to be positive to denote that behavioural responses in trip-kilometres are larger than the behavioural responses of trips which serves as the base category.

Logarithmic transformation of equation (1) allows the estimation of α, β and γ by ordinary least squares:

$$ln(\eta_i) = \mu + \alpha \ln(X_i) + \beta X_i + \gamma Z_i \qquad (2)$$

This is the model form reported in Table 4.1 which provides the coefficient estimates and t-ratios for each included variable along with the proportionate effect on the price elasticity where a variable is categorical.

As for the summary statistics reported in section 3, we removed 11 non-negative elasticities and the 8 elasticities in excess of -1.5 in absolute terms. The meta-analysis is therefore initially based on a dataset of 386 observations. However, we also removed what we term outlier observations. These are defined as observations with standardised residuals outside the range of -1.96 and 1.96. These can be taken to represent the 5% of observations that are of lowest quality or hardest to explain. The general effect of removing these observations is to increase the t-ratios of the coefficient estimates, a desirable feature given that we are here dealing with a relatively small sample size with diverse properties.

Two models are reported in Table 4.1. They have the same explanatory variables except that Model I bases the route competition variable on the time detour whereas Model II uses the categorical route competition variables.

There is not a lot of difference between the coefficient estimates of the two models. Model I is our preferred model, since it is based on quantification of the detour involved in using the competing route. Model II demonstrates that route competition effects can also be obtained when using the categorical definitions, but the relative effects for freight are not entirely consistent with what would be expected. Discussion of the results is therefore based on Model I except for when the route competition effects are discussed and then the results of Model II are also considered.

4.2 Results

4.2.1 Cost Units

The cost units could be GC, car motoring costs, toll charge or road price for which dummy variables were specified. Although we are primarily interested in toll and road price elasticities, the inclusion of GC and motoring cost elasticity evidence based on toll charge variations expressed within a GC or motoring cost framework provides a worthwhile amount of additional data that is beneficial to our meta-analysis so long as the effect of using the GC and motoring cost approaches is isolated.

The base cost unit was specified to be toll. The effect estimated to GC units was highly significant. The toll elasticity implied by a GC elasticity will depend upon the proportion that it forms of GC. We find that the GC elasticities are 181% larger than the base of toll elasticities, which is in line with tolls forming a small proportion of GC. The motoring cost unit elasticity is also, as expected, larger than the base toll elasticity and the effect, at 80% relative to tolls, is smaller than for GC since a motoring cost elasticity will be less than a GC elasticity. The other cost unit is ERP but a dummy variable denoting ERP was far from significant.

4.2.2 Toll Introductions and Removals

Some of the evidence related to the introduction or removal of tolls through the use of composite elasticities such as GC and motoring costs as well as arc elasticities based on an average of before and after prices. Dummy variables were specified for instances where a toll was introduced and where the toll charge varied around an existing level. A significant effect was obtained for the introduction of tolls, where the elasticity is 36% larger, presumably due to pricing off the most cost sensitive users as well as protest response that may fade over time.

No significant effects were detected for toll increases or a mix of increases and reductions compared to a base of toll reductions. Nor was there any effect from a toll introduction coinciding with new infrastructure.

4.2.3 Demand Units

As indicated in section 3, a small amount of elasticity evidence covers trip-kilometres rather than trips. As with GC based elasticities, it is sensible to make use of this evidence in our meta-analysis, to inform understanding of how elasticities vary with other influential factors and isolate any effects specific to demand units. Kilometrage elasticities are found to be around 28% larger, which seems credible.

4.2.4 Payment Instrument

There is a widely held view that the sensitivity to toll will depend upon whether cash is paid at a toll booth or whether the payment is made electronically, on the grounds that in the latter case there will be less awareness of what the toll is and there might also be convenience effects. This is an important segmentation since if there is an effect it is the elasticity relevant to ETC that will be most appropriate to the appraisal of toll roads in the New Zealand context.

The price elasticity is found to be around a quarter smaller under ETC than cash only, and the estimated effect is reasonably precise. The impact of a combined cash and ETC payment is consistent with these findings in having a lesser impact than the pure ETC effect.

Table 4.1: Meta Models

		Model I		Model II	
		Coeff (t)	%Effect	Coeff (t)	%Effect
	Constant	2.320 (3.35)		0.728 (1.20)	
Travel cost & distance	Base = Toll Charge				
	Generalised Cost	1.034 (8.68)	+181.2%	0.996 (8.88)	+170.7%
	Motoring Cost	0.588 (2.70)	+80.0%	0.924 (5.37)	+152.0%
	Base = Trips				
	Trip-Km	0.247 (2.26)	+28.1%	0.210 (2.09)	+23.4%
Toll variation	Base = Toll Removed				
	Toll Introduced	0.308 (2.45)	+36.1%	n.s.	
Socio-economic-demographic	log Income Passenger	-0.198 (2.41)		-0.182 (2.24)	
	Spatial Not Exist	-1.152 (4.24)	-68.4%	-0.622 (2.27)	-46.3%
	log Pop^n Density Exists	-0.141 (3.87)		-0.073 (1.98)	
Payment instrument	Base = Cash Payment				
	ETC	-0.319 (3.28)	-27.3%	-0.360 (3.78)	-30.2%
	Cash_ETC_Unknown	-0.169 (2.00)	-15.5%	-0.125 (1.59)	-11.8%
Facility type	Base = Urban Road				
	Inter-Urban Road Freight	-0.706 (4.97)	-50.6%	-0.775 (5.62)	-53.9%
	Base = No Barrier				
	Major River/Harbour	-0.610 (6.40)	-45.7%	-0.641 (7.17)	-47.3%
Competition	Detour No Alternative	-1.072 (5.44)	-65.8%	Base	
	Detour Not Identifiable	-0.775 (4.37)	-53.9%	-0.356 (1.78)	-29.9%
	Detour Time Pass	-0.869 (7.40)		n.a.	
	Detour Time Freight	-0.466 (3.35)		n.a.	
	No Detour Pass	n.a.		0.346 (2.74)	+41.3%
	Slight Detour Pass	n.a.		0.152 (1.16)	+16.5%
	Moderate Detour Pass	n.a.		-0.380 (2.92)	-31.6%
	Long Detour Pass	n.a.		-0.656 (4.89)	-48.1%
	No Detour Freight	n.a.		1.645 (5.14)	+418.0%
	Slight Detour Freight	n.a.		1.027 (3.23)	+179.2%
	Moderate Detour Freight	n.a.		0.866 (2.70)	+137.8%
	Long Detour Freight	n.a.		1.346 (4.06)	+284.4%
	Base = No PT				
	Mode High Qual Pass	0.588 (6.75)	+80.1%	0.552 (6.07)	+73.6%
Other miscellaneous	Base = Car Passenger				
	Freight	-1.441 (2.22)	-76.3%	-2.074 (3.00)	-87.4%
	Base = Monitoring/SR				
	Demand Long Run	0.846 (8.74)	+133.0%	0.761 (8.21)	+114.1%
	Base = Weekday				
	Weekend	0.639 (3.47)	+89.4%	0.547 (3.21)	+72.9%
	Mean Square Error	0.284		0.245	
	Adjusted R^2	0.606		0.648	
	Observations	363		363	

Note: The "Effect" index relates to categorical variables and can be interpreted as follows. If the Effect is -29.1% for ETC it shows that the resulting elasticity is 29.1% lower than it would be if the payment is made with Cash which is the arbitrary base category. The discussions below provide illustrations of how changes in population density and time detour impact upon price elasticities.

Whilst we find the ETC effects reported in Table 4.1 to be credible, they contrast somewhat with the findings of Bain (2017) which were discussed in the Stage 1 report. For 228 observations that related to a specific network in the United States and multiple price changes over an 8-year period, Bain found that the average elasticity for cash payment was -0.41 but for ETC was only -0.05. An ETC elasticity 27% lower than that for cash payment is in line with common practice, in the experience of one of the authors of this report. One explanation for the large difference between Bain's figures may be the presence of Managed Lanes in his dataset. Managed Lanes are well known to display very low demand elasticities to tariff changes, relative to those for cash payment on other toll roads.

4.2.5 Mode

There might be an expectation that the sensitivity to charges is less for freight since the company pays, somewhat akin to the situation for car journeys where business travellers are regarded to be less price sensitive than others. But as Bain (2017) points out, owner driver operators might have relatively high price sensitivity whilst there is little point in paying a charge to save time if no productive use can be made of the saved time. In addition, the impact of various influential variables might differ between passenger and freight travel.

On balance, a lower elasticity for freight seems likely, although the Stage 1 segmentations did not find strong support for elasticity variation by mode. However, it turned out in this meta-analysis that the relationship between freight and passenger elasticities depended upon a number of factors. We tested whether the passenger and freight elasticities were different for population density, payment type, facility type, competition type, income and estimation method. Differential effects were obtained for facility type, route and modal competition and income as well as a dummy variable relating to freight in general.

The freight specific variable was negative and significant, indicating somewhat lower elasticities for freight all else equal. However, this effect is moderated by different competition effects for freight, as discussed in sections 4.2.10 and 4.2.11, different facility type effects for freight, as discussed in section 4.2.7, and different income effects, as discussed in section 4.2.9. The net effect requires application of the meta-model to the relevant circumstances, and Table 5.1 provides illustrative freight elasticities that can be both larger and smaller than passenger elasticities.

4.2.6 Estimation Method

Table 3.5 set out the different estimation methods used in the reviewed studies. Monitoring involves comparing demand levels before and after a price change and is widely used. Econometric demand models are also common, distinguishing between whether a dynamic model is estimated, which provides an instantaneous (short run) effect and an effect when the behavioural adjustment has fully worked through (long run), or where a static model is specified which yields a single elasticity estimate that does not differentiate the short and long run. The other method used was choice modelling based on Revealed or Stated Preference choice data, elasticities from which are somewhat different because they omit the income effects of price changes and focus upon substitution effects.

The base estimation method was specified to be monitoring. Compared to this, elasticities from econometric demand models covering the short run or static in nature had far from significant effects. Certainly the effect for short run demand responses can be expected to be in line with the elasticities obtained from before and after monitoring, although the static elasticities might be larger. Nor was there any effect from choice model based elasticities, although there are few such observations.

The one significant effect related to long run demand effects where the elasticity is found to be 133% larger. Although we would expect the long run elasticity to be larger than the instantaneous effect, this is a large incremental effect, larger than the 60% effect apparent in a meta-analysis of UK price elasticity evidence (Wardman 2022a), but actually very much in line with that obtained in a meta-analysis of UK time related elasticity evidence (Wardman, 2022b). We would note that the models that yielded the long run elasticity were almost always partial adjustment models, and shortcomings of these models are that the inevitable correlation between demand and lagged demand can lead to long run effects differing from short run effects even where none exist and the lag effect is constrained to be the same for all independent variables contained in the demand model.

4.2.7 Facility Type and Barrier

Whilst we have measures of route competition, there are (as discussed elsewhere in this report) approximations involved in such calculations and hence specifying facility specific dummy variables might account for these. But in any event, the types of journeys being made on different facilities and indeed the types of motorist may differ. Given that we do not have comprehensive data on journey purpose and journey length, the best we can do is to approximate these effects with facility specific dummy variables.

The base category was specified to be tolled bridges and tunnels. Two significant incremental effects were obtained relating to inter-urban roads and toll cordons.

The dummy variable for inter-urban routes indicated the elasticity to be 51% lower but only for freight trips. This effect could be because of the fewer alternative routes for inter-urban roads. No significant effect from inter-urban routes was apparent for passenger trips. These routes will have a greater dominance of longer distance trips and whilst there might be a greater attractiveness of, and hence willingness to pay for, higher quality charged roads for longer duration passenger trips, this could be offset by the greater proportion of higher elasticity discretionary trips.

Note though that population density, discussed in section 4.2.12 below, was not specified for inter-urban routes and hence the variable denoting the absence of population density (Spatial Not Exist) is relevant in deriving implied elasticities for inter-urban routes. Moreover, the income effect relates only to passenger travel. These additional factors will impact the relationship between passenger and freight elasticities as will become apparent in Table 5.1.

If there was a significant barrier, defined in terms of a major river or harbour, the elasticities were found to be 46% lower. We expect elasticities to be lower in circumstances where there will be fewer alternatives and generally congested conditions, and presumably this effect overcomes the approximations inevitably involved in specifying time detours for alternative routes in these contexts.

4.2.8 Time Period

The only time period effect discerned related to weekend travel where price elasticities are found to be 89% larger. This is credible, given that weekend travel will be dominated by relatively price sensitive discretionary travel and less constrained by destination and mode than journeys to work. Note that all weekend travel related to passenger trips.

4.2.9 Income

The income variables for both the GDP per capita and the income per person measures were specified in logarithmic form and hence parameters estimated to these measures themselves reflect elasticities (i.e. elasticity of the price elasticity with respect to income).

The World Bank GDP per capita income measure was not significant but the elasticity to personal income was significant and of the correct negative sign. However, when segmented by passenger or freight trips, we found that the income elasticity for freight was far from significant and hence was not retained. The income elasticity for passengers indicates that the sensitivity to charges diminishes as incomes increase; the directionality of this effect is credible, as is the magnitude of the elasticity itself. This is an important finding with regards to the transferability of the results to New Zealand, which is a relatively high-income country. We would generally not expect the freight elasticity to fall as income increases; if anything, the elasticity should increase with income to the extent that higher driver wages will incentivise the purchase of time savings. But a possible exception to this hypothesis would be where freight drivers are owner driver operators.

In the absence of income measures in the estimated models, significant regional effects for Europe, Asia and South America relative to a base of North America could be detected. These will presumably reflect differences in incomes and perhaps lower car dependency. Our preference is to allow for income differences across regions using the income elasticity estimated rather than regional dummy variables.

4.2.10 Route Competition

This is where Models I and II differ in terms of the specification of the explanatory variables.

In Model I there are elasticity observations where the route in question was specified as having no realistic alternative or where it was not sensible or possible to specify a journey time or distance detour. For the remainder, there is a measure of the time and distance detour as the ratio of the time or distance on the alternative route relative to the route for which we have the price elasticity. Table 3.10 illustrated the distribution of the time and distance detours.

The meta-model was therefore specified as follows in Model I:

$$ln(\eta_i) = \gamma_1 d_{1i} + \gamma_2 d_{2i} + \beta_1(1 - d_{1i} - d_{2i})D_i + \cdots. \quad (3)$$

The dummy variable d_{1i} indicates that there is no alternative route for elasticity observation i and dummy variable d_{2i} denotes that it was not sensible to specify a time or distance detour for elasticity observation i. D_i represents the proportionate detour, either time or distance, for elasticity observation i where it is measured.

The exponential of γ_1 denotes the proportionate effect on an elasticity of there being no alternative route, the exponential of γ_2 denotes the proportionate effect on an elasticity of there being no sensible measure of competition and the exponential of $\beta_1 D_i$ would indicate the proportionate effect on an elasticity of a level of the detour variable D_i.

We found, not surprisingly, that a better fit was obtained when D_i was taken to be the time detour rather than the distance detour. As expected, a larger time detour on the alternative route reduces the sensitivity to the charge.

As part of exploring differing impacts from influential variables between passenger and freight travel, equation (3) was specified separately for the two modes. It was found that β_1 differed between passenger (-0.869) and freight (-0.466). We might expect a lesser effect for freight on the grounds that there is less freedom over route choice, and indeed less awareness of changes, than is the case for passenger travel.

Where there is no time detour, the detour effect multiplies the passenger elasticity by 0.42. This falls to 0.27 and 0.18 respectively as the time detour increases to 1.5 and 2.0. The respective figures for freight are 0.63, 0.50 and 0.39. These seem reasonable variations in the price elasticity.

Where there is deemed to be no alternative, the scaling on the elasticity is 0.34. This is equivalent to a time detour of 1.25 for passenger and 2.3 for freight. However, we would very much expect the absence of an alternative to have an effect somewhat larger than the passenger detour of 1.25 and most likely greater than the 2.3 detour for freight. Other factors would seem to be at work here, such as routes deemed to have no real alternatives being common in very rural areas where trip suppression or redistribution might be relatively strong and hence increase the elasticity whilst the large effect attributable to barriers could well also have a bearing.

The scaling where we deemed it not sensible to estimate a detour effect would be 0.46 which would imply a high degree of competition which is unlikely to be the case. However, these routes would be forecast to have larger elasticities than where there are no alternatives which is what would be expected.

This pattern of results is not entirely what we would have wanted, but we note that in the New Zealand context there would primarily be interest in the detour effect itself since alternatives to a charged route would be required.

As for Model II, the measure of competition is categorical and all observations are in one of six categories as set out in Table 3.11. As for Model I, separate parameters have been estimated for passenger and freight. The base category represents routes where there is no real alternative and hence the parameter estimates for all the other categories should in principle indicate higher elasticities. This is not however the case in practice, a similar issue to that apparent in Model I, but the implied elasticities for passenger do increase, as required, as we move from a long detour through to no detour. The same relationship is not however exhibited by freight, where the long detour coefficient implies a larger elasticity than for both slight and moderate detours.

We also have information on the number of alternative routes. When this was added, in both Model I and II, the estimated effects of increasing the number of alternative routes were wrong sign, with some insignificant, and therefore they were not retained.

4.2.11 Modal Competition

There were four categories of modal competition specified, as set out in Table 3.12. The base category was specified to be no public transport provision. We specified separate terms for passenger and freight. There were no significant effects apparent for freight, which is hardly surprising. There was only one significant effect for passenger travel relating to the best level of public transport provision, covering the existence of a mass rapid transit system or high quality competing rail services, where price elasticities were found to be 80% larger.

We do not find it surprising that it is only the best level of public transport provision that had a discernible effect, given that cross-elasticities of car demand with respect to public transport characteristics tend to be very low. But by the same token, an 80% effect does seem large and other metropolitan or cosmopolitan factors may be at work. Nonetheless, this variable does not apply in the New Zealand context since high-speed rail alternatives and Mass Rapid Transit systems in urban areas are very limited or non-existent.

4.2.12 Spatial Definition

The specification of the spatial variables was similar in nature to the specification of the detour variables in equation (3) given that it was not sensible to specify population density for routes that covered longer distances where population density can vary drastically across the length of route. As such, population density and area size were very much local constructs.

The meta-models were therefore specified with regards to the spatial dimension as follows:

$$ln(\eta_i) = \gamma_3 d_{3i} + \beta_2(1 - d_{3i})S_i + \cdots \quad (4)$$

The dummy variable d_{3i} indicates that no spatial variable was collected for elasticity observation i and S_i represents the spatial variable for elasticity observation i where it is measured.

The exponential of γ_3 denotes the proportionate effect on an elasticity of there being no spatial data, and hence it is relevant to the characterisation of inter-urban routes. The exponential of $\beta_2 S_i$ would indicate the proportionate effect on an elasticity of a level of the spatial variable S_i.

It turned out that population density provided a better fit than area size and that a better fit was achieved when population density was entered in logarithmic form. Hence the S_i term is in fact specified as $ln(S_i)$. When we specified different population density terms to for passenger and freight, we found their coefficient estimates to be very similar.

The population density term indicates that the elasticity falls as density increases. This might be detecting the different characteristics of urban and shorter distance trips and travellers in more densely populated areas. For example, there will be more price insensitive business and commuting trips in more densely populated areas whilst increased congestion will make the toll facility more attractive which can also be expected to lower its elasticity. It might also be discerning higher average incomes in more populated areas in already high-income countries.

Table 4.2 demonstrates the impact of population density on the elasticity. It takes the 10th, 25th, 50th, 75th and 90th percentiles of population density reported in Table 3.8 and provides the weight to be attached to the elasticity. This shows that the price elasticity is quite sensitive to the level of population density. And it is reassuring that the weight relating to elasticities where there is no spatial detail, which are the inter-urban trips, lies within the range of the range of weights by population density and is indeed similar to the median value.

Table 4.2: Weights on Price Elasticity by Population Density

Density Pop/km^2	Weight
325	0.44
795	0.39
1358	0.36
5000	0.30
7825	0.28
None	0.32

5 APPLICATION OF MODEL

5.1 Summary of Findings Compared to Stage 1 Study

The Stage 1 study, when comparing results across studies, as is done by the meta-analysis reported here, found only a limited number of effects. These were for long run demand impacts, weekend travel, facility, kilometrage, cost unit and region, although there were also within study variations in elasticities denoting effects from time period and mode.

The meta-analysis has added to understanding of across study variation by providing insights into variations according to ETC, mode, major barriers, the introduction of tolls, route competition, modal competition and population density, albeit with the latter three insights based on data that had not been collected in Stage 1. The meta-model also detects variations in the impacts of influential variables between passenger and freight travel. The effects estimated in the Stage 2 meta-model seem to be more consistent with theoretical expectations, thereby confirming our belief in the ability of meta-analysis to overcome the confounding effects that seemed to be apparent in Stage 1's cross-tabulations. Moreover, the various effects have been quantified and the estimated model is able to provide implied elasticities for a range of situations and it to these we now turn.

5.2 Implied Elasticities

Whilst meta-analysis provides important insights into how relevant explanatory factors impact on a behavioural variable of interest, which is here pricing elasticities relating to charged facilities, its key attraction is being able to provide estimates of the behavioural variable in question for a range of relevant scenarios. And indeed that was the main purpose of this study; to inform the New Zealand Ministry of Transport of appropriate price elasticities in its modelling of charged facilities.

Implied elasticities are not only useful for application to policy and scheme appraisals, but they are important in determining the credibility of the meta-models in terms of the absolute elasticities implied. Even though the elasticity variations in the models reported in Table 4.1 are credible, this is no guarantee that the absolute elasticities implied by the model will be acceptable.

Table 5.1 provides implied price elasticities for a range of illustrative scenarios using Model I of Table 4.1. By way of example, the implied short run elasticity in scenario 1 of Table 5.1 (η_{SR1}) is derived as:

$$\eta_{SR1} = e^{2.462-0.319ETC-0.869Detour-0.141ln(Density)+(0.0*Urban)+(0.0*Car)-0.610Barrier+0.588Modal}Income^{-0.198}$$

$$\eta_{SR1} = e^{2.462-(0.319*1)-(0.869*1)-0.141ln(1358)+(0.0*1)+(0.0*1)-(0.610*0)+(0.588*0)}3142^{-0.198} = 0.26$$

Given the estimated model, of equation (2), is a logarithmic transformation, the unbiased predictor involves adding half of the mean square error of 0.284 to the constant term to yield a revised constant of 2.462 (Miller, 1984).

All the implied elasticities here are based on toll charge as the monetary instrument, demand variations based on trips, ETC as the payment instrument, weekday travel and detours that relate to available alternatives, although of course implied elasticities can be provided for combinations of any of the variables in the estimated model.

The income levels used relate to the minimum, 75th percentile and maximum in the analysis data, as reported in Table 3.9, with the 75th percentile used on the grounds that New Zealand has relatively high incomes. The population densities used are the minimum, median and maximum in the analysis data, as reported in Table 3.8. The large ranges in income and population density are used to demonstrate the maximum variation in elasticities on account of these variables that would be apparent for the data collected.

Table 5.1: Implied Elasticities for Illustrative Scenarios

	Facility Type	Barrier	Mode	Income 2015 US$	Density Pop.Km^2	Modal Competition	Detour Factor	Short Run Elasticity	Long Run Elasticity
1	Urban	No	Car	$3142	1358	None	1.0	-0.26	-0.61
2	Urban	No	Car	$3142	1358	None	1.5	-0.17	-0.40
3	Urban	No	Car	$3142	1358	None	2.0	-0.11	-0.26
4	Urban	No	Car	$3142	1358	None	2.5	-0.07	-0.17
5	Urban	Yes	Car	$3142	1358	None	1.5	-0.09	-0.22
6	Urban	No	Car	$3142	325	None	1.5	-0.21	-0.48
7	Urban	No	Car	$3142	7825	None	1.5	-0.13	-0.31
8	Urban	No	Car	$355	1358	None	1.5	-0.26	-0.61
9	Urban	No	Car	$4811	1358	None	1.5	-0.16	-0.36
10	Urban	No	Car	$3142	1358	Good	1.5	-0.31	-0.71
11	Urban	No	Freight	N.A	1358	N.A	1.0	-0.46	-1.07
12	Urban	No	Freight	N.A	1358	N.A	1.5	-0.36	-0.85
13	Urban	No	Freight	N.A	1358	N.A	2.0	-0.29	-0.67
14	Inter	No	Car	$3142	N.A	None	1.0	-0.23	-0.53
15	Inter	No	Car	$3142	N.A	None	1.5	-0.15	-0.35
16	Inter	No	Car	$3142	N.A	None	2.0	-0.10	-0.22
17	Inter	No	Car	$3142	N.A	None	2.5	-0.06	-0.15
18	Inter	Yes	Car	$3142	N.A	None	1.5	-0.08	-0.19
19	Inter	No	Car	$355	N.A	None	1.5	-0.23	-0.53
20	Inter	No	Car	$4811	N.A	None	1.5	-0.14	-0.32
21	Inter	No	Car	$3142	N.A	Good	1.5	-0.27	-0.62
22	Inter	No	Freight	N.A	N.A	N.A	1.0	-0.20	-0.46
23	Inter	No	Freight	N.A	N.A	N.A	1.5	-0.16	-0.36
24	Inter	No	Freight	N.A	N.A	N.A	2.0	-0.12	-0.29
25	Inter	No	Freight	N.A	N.A	N.A	2.5	-0.10	-0.23

Note 1: The elasticities for tunnel/bridge, toll cordon and for ERP are the same as for urban road.

Note 2: Elasticities above 1 in absolute terms, as in case 11, are very large and also unusual; they no longer maximise revenues; such tolls may be justified to manage traffic congestion or when introducing Road User Charges.

Implied elasticities are provided for urban roads, toll cordons and inter-urban roads. Both short run (SR) and long run (LR) elasticities are provided, although the uplift from the SR to the LR is the same proportion throughout.

As for urban roads, scenarios 1 to 4 demonstrate the impact of variations in the time detour, with what seem like sensible reductions in the elasticity as the detour increases. The SR elasticities tend to be less than the conventional wisdom stated in the Stage 1 report of around -0.2 to -0.3. The remaining urban road scenarios maintain the detour at 1.5 as in Scenario 2 but vary the other variables one at a time.

Scenario 5 shows a large impact from the presence of a major barrier, with the implied elasticities somewhat lower. Scenarios 6 and 7 indicate modest variations in elasticities as population density varies. There are relatively large variations in elasticities according to the income variations represented in Scenarios 8 and 9 although it should be noted these do represent large variations in incomes. The modal competition impact in Scenario 10 is large, although these would not apply to the New Zealand context since the MRT systems apparent in locations such as New York City, Hong Kong, Singapore and London do not exist in New Zealand.

Scenarios 11 to 13 cover freight travel. Here the income levels and modal competition are not relevant. We can observe that in this urban context the freight elasticities are somewhat larger than for passenger for equivalent levels of detour.

Scenarios 14-25 relate to inter-urban trips. The pattern of results for car is the same as for urban trips with the difference being that the elasticities are slightly lower and therefore again tend to be lower than the conventional wisdom values of -0.2 to -0.3. Freight is more relevant to inter-urban trips, and scenarios 22 to 25 yield figures for freight which are only slightly different to car for the income level of $3142 and seem reasonable. As incomes increase, there will be more divergence between the passenger and freight elasticities. What is clearly apparent is the very much lower freight elasticities for inter-urban than urban roads.

We have also produced implied elasticities for a range of scenarios provided by the New Zealand Ministry of Transport. These are reported in Table 5.2 and relate to variations in trips, toll charge, electronic toll collection and passenger travel on a weekday. There is no high-quality modal competition and the population density term is not relevant since the facilities are inter-urban roads.

These case study elasticities tend to be low, reflecting the generally large detours and high monthly incomes. Indeed, the short run elasticities are somewhat lower than the 'conventional wisdom' of -0.2 to -0.3 identified in the Stage 1 report, and the long run elasticities are generally lower.

Table 5.2: Implied Elasticities for Case Study Scenarios

Location	Time	Detour Factor	Income 2015 US$	Facility	SR Elas	LR Elas
Auckland: Northern Gateway	6	2.83	$3816	Inter-Urban	-0.04	-0.10
Auckland: Northern Gateway to Warkworth	16	2.13	$3816	Inter-Urban	-0.08	-0.19
Wellington: Otaki to North of Levin	14.5	1.45	$3885	Inter-Urban	-0.15	-0.35
Christchurch: Belfast to Pegasus motorway/bypass	6	2.17	$3379	Inter-Urban	-0.08	-0.19

Note: Income is monthly personal income.

6 CONCLUSIONS

This second stage of the study has delivered a meta-analysis of the price elasticities assembled in Stage 1 of the study. Additional information was obtained regarding population density, area size, income levels, the degree of competition from other routes and modes, and the presence of major barriers with a view to contributing an improved understanding of price elasticities across studies.

The estimated models have delivered credible results, both in terms of absolute elasticities and variations in them. In our understanding, this is the most extensive meta-analysis undertaken of international elasticity evidence relating to the pricing for the use of roads. The implied elasticities for urban and inter-urban roads tend to be lower than the conventional wisdom of short run elasticities around -0.2 to -0.3 cited in the Stage 1 report. The case study elasticities covering the New Zealand context would indicate that the relevant elasticities are lower than the conventional wisdom, with contributory factors being the large detours and high personal incomes.

The estimated meta-model can provide implied elasticities for urban and inter-urban roads, bridge/tunnel crossings, toll cordons and road pricing schemes which depend upon:

- Whether the elasticity to be used is generalised cost, motoring cost or toll, although toll is the most likely candidate;
- Whether demand relates to trips or trip-kilometres, with the former likely being the default;
- Payment instrument, with ETC being typical;
- Car passenger or freight;
- Short run or long run behavioural responses;
- Facility type, covering urban road, inter-urban road, toll cordon and electronic road pricing;
- The presence or not of a barrier in the form of major river or harbour;
- Weekend as opposed to weekday travel;
- Income levels relevant to the area in which the charged facility lies;
- The extent of the time detour on the best alternative route, with the option of using quantified amounts of time or discrete categories;
- The population density for urban roads;
- The impact of very high quality public transport provision.

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